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Application of Two Sided Assembly Line Balancing for Lean operations - A Case Study

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Abstract: ***The present study aims to solve the Two-Sided Assembly Line Balancing Problem (TLBP) by spread sheet model employing Enumerative Heuristic Algorithm (EHA). The problem source was identified based on the need for TI cycles of India to manufacture 24000cycles/month in exports bay. The existing assembly line was found infeasible from time study. A multi-objective optimization of a two-sided assembly line is considered, which is minimising number of workstations thereby reduce number of workers, minimise idle time, uniform distribution of load and matching supply with demand. Takt time calculations were made after thorough investigation of existing assembly line and time study performed elucidates each task's standard processing time, direction and precedence relation. A two sided assembly line processing layout was eventually developed from an optimal assignment foraged from a solution space by Pareto analysis. The results of final assembly line for the cycle time of 57.6 sec indicates line efficiency of 85.25%, smoothness index 46.05 and increased production rate of 500 units/shift with reduction in number of workstations.***

Keywords: Two sided assembly line, Line balancing, Pareto analysis, Enumerative Heuristic Algorithm

Nomenclature

Symbol	*Description*
CT	Cycle Time
W/S	Workstation
K	Total No. of W/S
ST_{max}	Max W/S time
T_K	Standard time of last W/S
ST_{maxF}	Max of duration of Front Allocated Stations
ST_{iF}	Duration of i^{th} Front Allocated Station
ST_{maxR}	Max of duration of Rear allocated W/S
ST_{iR}	Duration of i^{th} Rear allocated W/S
LE	Line Efficiency
LL	Line Length

1. Introduction

The idea of interchangeability led to the introduction of assembly line and development of interchangeable parts of high accuracy and close tolerance. Division of total work into a number of tasks and assigning to a worker makes him proficient of that particular task. In an assembly line the smallest portion of total work that can be sub divided is called Task and the time taken to complete each task is called Task time. One or more different set of tasks are performed by each work station on each unit. These set of tasks are assigned into workstations based on the given "Precedence Relation" and are performed within a definite time called "Cycle Time". If the tasks assigned into workstations are not well balanced then some workstations will have high work load and subsequently others face more idleness. Thus Assembly line balancing Problem (ALBP) is a prerequisite in assigning the tasks into workstations thereby optimizing the objectives without any violation to imposed line restrictions.

Assembly lines are classified into three categories: one-sided assembly lines or two-sided assembly lines and U line assembly. In one-sided assembly line either left-side or right-side of the line is used whereas in a two-sided assembly line both left-side (L) and right-side (R) of the line are simultaneously used. The tasks in the two-sided assembly lines are grouped into categories as; L (left), R (right) and E (either).The first two-sided assembly line balancing problem study in literature was made by Bartholdi [3] that two sided assembly line possess numerous advantages like reduction in number of workers, throughput time, tools and fixtures cost, material handling costs and line length on comparison with conventional one-sided straight assembly line. A general overview of simulated annealing algorithm as global optimum and its application in graph problems was discussed by Fleischer [4]. The balancing of Two-sided assembly line differs from the traditional one-sided assembly line balancing, often called simple assembly line balancing problem, in which tasks have restrictions on the operation directions was studied by Simaria and Vilarinho [10] using ant colony optimization algorithm. Similarly two-sided assembly line balancing using ant-colony-based heuristic was also done by AdilBaykasoglu and Türkay Dereli [1]. Keun Kim, Yeongho Kim & Yong Ju Kim [8] used genetic algorithm for two-sided assembly line balancing to solve the problem, and its applicability and extensibility were discussed. At the same time, Almanza and Ovalle [2]developed a Memetic Algorithm to solve deterministic TLBP. Mixed integer programming and simulated annealing for solving stochastic TLBP was proposed by Ozcan [9]. Jawahar, Ponnambalam, Sivakumar and Thangadurai [6 & 7] used a multi-objective optimization line balancing problem of a more general category two-side assembly, solved by two approaches namely Enumerative Heuristic Algorithm and Simulated Annealing Algorithm. An enumerative heuristic and reduction method was developed by Hindi and Fleszar

[5] to solve assembly line balancing problem. In the present paper, Enumerative Heuristic Algorithm (EHA) suitable for small and medium sized problems is used to develop a two sided assembly line for the product. Hence, this case study attempts to venture into the TLBP and suggest an optimal solution foraged from a solution space.

2. Case Study

Tubes Investments of India Ltd Cycles is apioneer in the Cycles market since 1949. It exports over 365,000 units to different countries, encompassing a 45 per cent share of overall Indian exports in the industry. The research work was conducted at one of its plant at Ambattur, Chennai. The present production rate of an exports bay is unable to cater the high demand for the product and thus they want to increase its rate to 500 units per shift.

2.1 Product Specification and takt time calculations

- Product Type : Export Model
- Production Type : Two Sided Assembly

ASSUMPTIONS:

- Demand : 1000 Units/Day
- No. of Shifts/Day : 2
- Production Rate : 500 units/shift
- Working Hours : 8 hours/shift
- Throughput Rate $= \frac{\text{Demand}}{\text{Working Hours}}$ = 0.01736 units/sec
- Takt time = 1/Throughput Rate =57.6

2.2 Existing Assembly line of Export Model

The schematic representation of the existing assembly line for an Export model is shown in figure 1. Here, W/S stands for workstation and numbers inside the rectangle represents tasks assigned to respective workstations. The existing assembly line has 24 workstations employing one operator for each workstation except W/S 23 employs two operators. It also has three sets of workstations ("W/S 5 W/S 6", "W/S 9 W/S 10" and "W/S 14 W/S 15") assigned with same tasks such that W/S 6 operator on completion of his work has to walk across W/S 5 operator to fetch a new job swapping their position. This swapping process is cyclic disrupting line flow and affects the basic definition of assembly line. Thus emphasising need for a novel and well balanced two sided assembly line without any disruption in line flow for better production.

3. Design of Two sided assembly line for Export Model

After thorough investigation of present assembly line as discussed in section 2, the development of two sided assembly line for a particular model involves time study of all tasks in terms of standard processing time, direction (front, rear or either) and precedence relation. From time study, Standard processing time of each task is calculated considering rating factor and allowances. The pace rate of the worker is taken 110% (10% above average) then the Rating factor is 1.10. Then normal time which is the product of averaged observed time and rating factor is found. Allowances equal to 10% are added to normal time in order to arrive at standard time by taking psychological and physiological effects into account. Chronologically, an input data table is formulated and succeeded by Precedence diagram are depicted in table 1 and figure 2 respectively.

Table 1: Input Data Table

Task No.	Standard Time (sec)	Direction Code	No. of Precedence	Immediate Predecessors
1	18.45	3	0	--
2	27.83	2	0	--
3	26.32	2	0	--
4	31.46	1	0	--
5	31.46	1	0	--
6	17.24	3	1	1
7	55.66	2	2	2,3
8	18.45	1	1	4
9	24.20	1	1	4
10	43.56	1	1	5
11	22.08	3	1	6
12	26.02	2	1	7
13	49.61	1	1	9
14	25.11	1	2	8,10
15	36.60	2	1	12
16	40.54	1	2	13,14
17	49.61	2	2	8,15
18	29.65	1	1	16
19	55.36	2	1	17
20	38.12	1	1	18
21	22.39	1	2	18,19
22	47.80	1	1	20
23	53.24	2	2	11,21
24	47.49	1	1	23
25	55.66	1	1	23
26	48.70	2	2	22,23
27	49.91	1	1	26
28	38.72	1	3	24,25,27

3.1 Spread sheet model for Two sided Assembly line balancing (TLB)

Enumerative Heuristic Algorithm (EHA) using spread sheet is employed for allocation of tasks into respective workstations based on direction constraint, precedence relation and cycle time. The tasks 1, 6 and 11 are either type tasks and should be constrained to either front or rear before the commencement of line balancing. Since there are 3 (n=3) either type tasks then **2^n=8** Assignments is attained. For each Assignment, assembly line balancing is done by changing its values in cells E6, E11 and E16 say 111, 121, 222, 212 etc., respectively. Spread sheet model for two sided assembly line balancing follows an iterative procedure for assignment of tasks into workstation. The algorithm executes the following steps for allocation of tasks into workstations for each of its iterations.

Step 1: The number of feasible tasks is determined. These are tasks that are not scheduled, have their precedences met with processing time less than the time available in work station and have direction of the previous task allocated to the same workstation.

Step 2: In case of unavailability of feasible task a new work station is added and allocated with a complete cycle time.

Step 3: If there is more than one feasible task then the one that satisfies longest operation time is taken.
Step 5: Steps 1 to 3 are repeated until all the tasks are assigned to respective workstations.
Step 6: Find number of workstations and maximum idle time based on the allocations made to the either type assignments.

It is evident that one task is allocated to a work station for each iteration. Thus, number of iterations equals the number of tasks. The iteration part is divided into two sections. The number of unmet precedences is tracked first by the number of precedences existing for each task and then subtracting 1 each time when one of the precedences for this task is met. Task code for each task is specified. Thus allocation of tasks into workstations from time study is achieved using spread sheet model given in figure 3.Furthermore, table 2 provide data on Cell formulae and its respective functions of Spread sheet model for TLBP.

Thus for each assignment the number of workstations and maximum idle time shown in table 3 is calculated. **Pareto Analysis** is then followed by plotting number of workstations along **X** axis and maximum idle time along **Y** axis of all the possible 8 assignments. The graph thus formulated is called Pareto Front Diagram depicted in figure 4. The one with minimum number of workstations and idle time is the **Optimal Pareto Front**. In this case it is the assignment221.

Table 3: No. of workstations and maximum idle time for each Assignment

S. No	Assignment	Total No. of W/S	Max idle time
1	111	22	35.52
2	121	22	32.49
3	212	22	35.52
4	112	22	35.52
5	221	21	19.48
6	122	22	35.52
7	211	22	35.52
8	222	22	35.52

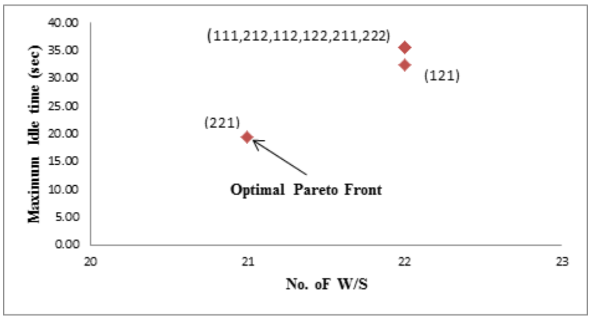

Figure 4: Pareto Front diagram

4. Results and Discussion

Table 4: Measures of final results of proposed final assembly line (CT=57.6)

S. No	Measures	EHA
1.	$LE = \frac{\sum_{i=1}^{K} ST_i}{CT.K} * 100\%$	85.25%
2.	$SI = \sqrt{\sum_{i=1}^{K}(ST_{max} - ST_i)^2}$	46.05
3.	$LT = CT * (K-1) + T_K$	1190.72
4.	$SI_L = \sqrt{\sum_{i=1}^{K}(ST_{maxF} - ST_{iF})^2}$	24.82
5.	$SI_R = \sqrt{\sum_{i=1}^{K}(ST_{maxR} - ST_{iR})^2}$	20.37
6.	$BD = (100\text{-}LE)\%$	14.75%
7.	*LL = One W/S Length*(Total No. of W/S)*	25.2 meters
8.	No. of Workstations	21
9.	No. of Operators	21
10.	Maximum Idle time	14.50 sec

It is envisaged from the table 4 that configuration layout drawn for the Optimal Pareto front (Assignment 221) has commendable Line efficiency (LE) of 85.25%, Time of the line (TL) 1190.72 sec, smoothness index (SI) 46.05, smoothness index of the front (SI_F)and rear side (SI_R) of Two-sided assembly line is 24.82 and 20.37 respectively proves to be an optimal one on comparison with the existing model. Moreover, figure 5 elucidates the reduction in number of workstations from 24 to 21, line length from 28.8 to 25.2 metre and operators from 25 to 21(one operator for each workstation).

5. Conclusion

The proposed final assembly line has no two workstations assigned with same tasks and thus disruption in line flow due to movement of workers across one other has been eradicated. Optimal assignment of tasks to workstation was met along with minimum idle time, number of work stations, operators and targeted cycle time.

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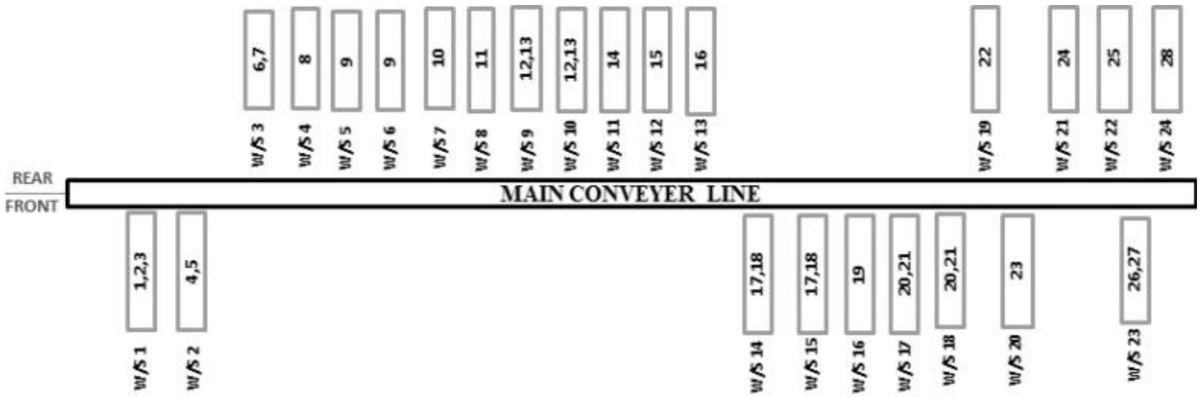

Figure 1: Layout for Existing Assembly line

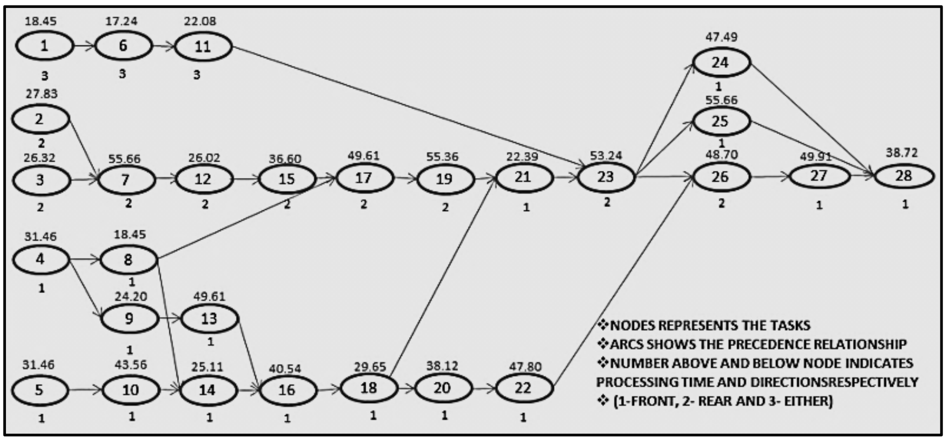

Figure 2: Precedence Diagram

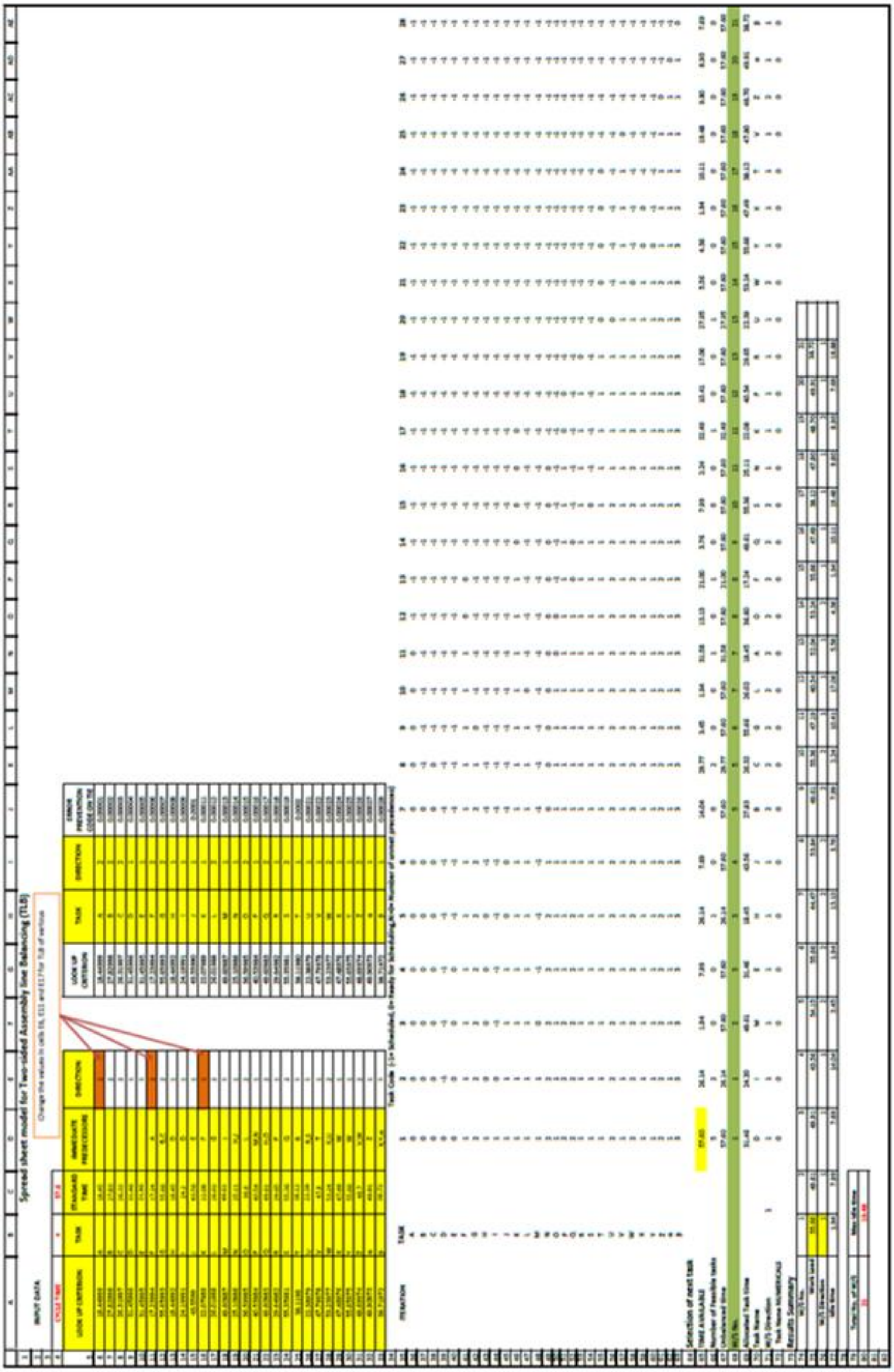

Figure 3: Spread sheet model for TSLB

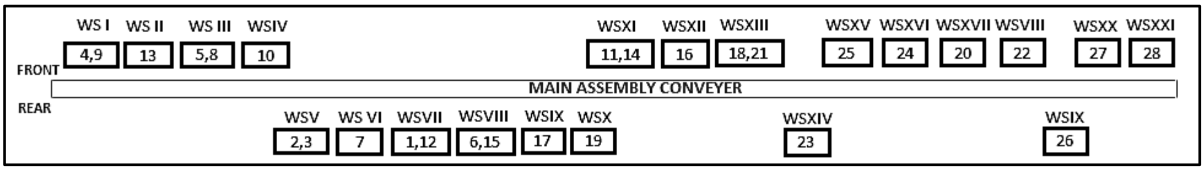

Figure 5: Configuration layout for proposed final assembly line

Table 2: Cell formulae and its respective functions of Spread sheet model for TLBP

Cell No.	Formulae	Function	Copied To
A6	=(C6-J6)	To avoid Tie error	A6:A33
D36	=SUM(IF(ISERR(SEARCH($B$36:$B$63,$D6)),0,1)) {Ctrl + Shift + Enter}	To find the number of immediate predecessors Task Code (-1= Scheduled, 0= Ready for Scheduling, N>0= Number of unmet precedences)	D36:D63
E36	=IF(ISERR(SEARCH(D$70,$D6&$B6)),D36,D36-1)	To reduce the number of immediate predecessors for a task if it is allocated in previous iteration	E36:AE63
E65	=D67-D69	Time available for allocation of tasks into workstation	E65:AE65
D66	=SUM(IF($A$6:$A$33<=D65,1,0)*IF(D36:D63=0,1,0) *(IF(D65=$C$4,1,0)+IF(D65<$C$4,IF($I$6:$I$33=C71,1,0))))	Number of feasible tasks with respect to all constraints	D66:AE66
D67	=IF(D66>=1,D65,$C$4)	Unbalance Time after allocation of task if there are feasible tasks else the cycle time is displayed	D67:AE67
E68	=IF(E66>=1,D68,D68+1)	To add new workstation	D68:AE68
D69	=MAX(IF($A$6:$A$33<=D67,1,0)*IF(D36:D63=0,$A$6:$A$33,0)*(IF(D67=$C$4,1,0)+IF(D67<$C$4,IF($I$6:$I$33=C71,1,0))))	Allocation of suitable one among feasible tasks based on largest candidate rule	D69:AE69
D70	=VLOOKUP(D69,$A$6:$B$33,2,FALSE)	Name of task allocated	D70:AE70
D71	=VLOOKUP(D69,$G$6:$I$33,3,FALSE)	Workstation direction	D71:AE71
D72	=VLOOKUP(D70,$H$6:$K$33,4,FALSE)	Task name in numerical	D72:AE72
B75	=SUM(IF($D$68:$AH$68=B74,$D$69:$AH$69))	Workload at each workstation	B75:V75
B76	=HLOOKUP(B74,$D$68:AH71,4,0)	Workstation direction	B76:V76
B77	=$C$4-B75	Idle time at each Workstation	B77:V77
A80	=MAX(68:68)	Total number of workstation for an assignment	-
B80	=MAX(77:77)	Maximum idle time for an workstation	-