Proceedings of The National Conference
On Undergraduate Research (NCUR) 2014
University of Kentucky, Lexington, KY
April 3-5, 2014

Systematic Pedagogy to Line Balancing with EXCEL

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Abstract

Over the past ten years, simple and inexpensive operations research software that is user friendly to the mentor, student, and instructor is becoming difficult to obtain. This is especially true since Emmons, Flowers, Khot, and Mathur's STORM 4.0 for Windows is obsolete for current operating systems and no longer in print. After a diligent product and literature search, it appears there is no adequate inexpensive software that is easily available. Assembly line balancing algorithms are heuristic methods used for balancing an operations or production line. However, most methods employ complex calculations that are challenging to the mentor and mentee. This paper presents pedagogy from a systems approach using Microsoft EXCEL. The object is to prepare a spreadsheet file with four separate worksheets that are linked to the first worksheet. The step-by-step systematic approach allows the entry on the main worksheet of data such as an annual demand, annual time available, and process time for each operating or production area. When the user changes these data entry points, the efficiencies of each operating or production line are automatically re-computed for all three shifts. The sheet uses one of the several available heuristics to compute cycle times (required time between process activities) and transfers it to one, two, or three shifts (worksheets two, three, or four). Once the spreadsheet and accompanying worksheets were completed, the results were compared to several different heuristic algorithms. Once the author was satisfied that the results were accurate and not significantly different from other examined algorithms, the final step was to develop a working pedagogy to efficiently describe the process. The results of this project were satisfactorily tested in a production operations class. The major advantage to the practitioner, engineer, instructor, and student is that EXCEL is readily available on all personal computers, easily understood, and is very practical. Students with very little exposure to line balancing were able to master the method within the first hour of exposure.

Keywords: Line Balancing, Cycle Time, EXCEL

1. Introduction

Line balancing is the process of assignment of work to stations based upon the demand. Line balancing is an essential tool that assists the engineer, operations research specialist, consultant, and operations manager in optimizing a facility layout. Its value is to the user to optimize the procurement of equipment required for each task, the efficient use of available floor space, hiring of skilled workers, and determining the amount of annual time required to meet demand. For years, a palfrey variation of software has been available to assist in performing this analysis. Emmons, Flowers, Khot, and Mathur's STORM 4.0 for Windows (2001) was adequate, user-friendly, and affordable. However, since STORM 4.0 (16 bit) is now obsolete for current 32 or 64 bit operating systems, no inexpensive, user-friendly, easily explained pedagogy software is available. This project presents pedagogy for line balancing using Microsoft EXCEL (2013). There are several different applications offered on-line that promote a systematic approach: however, the authors have found these to be relatively clumsy and difficult to explain to novices. In today's economic environment, demands over small time periods are becoming more common. The value of EXCEL is that it is a software package that is compatible with most computers, very user-friendly, easily adapted to an instructor's teaching style and pedagogy, and internationally accepted. In the workplace an easily defined EXCEL algorithm can be readily available to the engineer or operations manager.

To perform a line balance, the cycle time must be calculated. The cycle time is the maximum amount of time that can be allowed to perform any specific task on any one workstation. It is not the time required to complete a task, but is the time required between units in a typical operation. If the time required to perform a specific task on any one workstation exceeds the cycle time, the work period demand will not be met. Thus, cycle time is expressed in time per unit as illustrated in Equation 1. Thus, cycle time is time between units, not time it takes to complete a task. Figure 1 illustrates Cycle Time.

Equation: ***Cycle Time = Total Time Available/Demand for that Period*** **(1)**

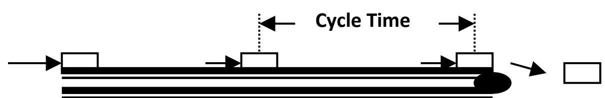

Figure 1: Cycle Time Illustrated

Once the cycle time is computed and a sequence of tasks is completed, a precedence diagram is constructed (Figure 2). Then the cycle time is compared to the longest task time. If the time required to perform any one specific task exceeds the cycle time, then additional component must be added to the workstation. There are many different algorithms that compute cycle time for any given operation. Computer-based techniques tend to give good, although not necessarily optimal results. Human judgment and pattern recognition often allow us to improve on computer-generated solutions. Thus manual methods are still the most prevalent in practice. The authors chose the *'Longest Work-Element Time Rule'* for the basic solution (Krajewski and Ritzman, 2009). The challenge was to create a system algorithm and pedagogy that requires the user to enter inputs on a main worksheet (annual demand, workdays, hours worked per day, and task time in minutes or seconds) with the end goal of completing a working, functional line balancing model using EXCEL.

2. Methodology

This step-by-step procedure will address each cell that is contained in the four different spreadsheets. The interactive EXCEL file's first spreadsheet will be the first worksheet and is to be named *Main.* Succeeding tabbed worksheets will be named as follows: Second worksheet is named *1 Shift*, third worksheet *2 Shifts*, and fourth worksheet *3 Shifts.* Comments in this paper will be addressed in the typical spreadsheet matrix where numeric values represent rows within the spreadsheet, while alphabetic characters represent columns.

2.1 Phase 1 Algorithm Development

This project required four interlinking worksheets using standard EXCEL functions. A worksheet was completed for a main sheet and three different scenarios (1 shift per day, 2 shifts per day, and 3 shifts per day). Cycle time is calculated for a period demand and associated task times for an operation. Each of the three worksheets were then linked to the main worksheet, where inputs must be entered in order for the spreadsheets to work. Two scenarios will be examined; that of which process time is greater than cycle time, and vice versa.

2.1.1 main tab data entry

The user must enter task times, demand, workweeks per year, and hours worked per day on the main worksheet (Table 1). This allows the user to manually change any of the inputs on the main worksheet, resulting in the automatic re-calculation of the other worksheets. The first tab, entitled *Main*, is to be set-up as follows:

Table 1: Data Entry for Cycle Time Computations (Main Tab)

	A	B	C
1	Demand/Year =	5,000,000	
2	Number Of Weeks =	50	
3	Number of Days/Week =	5	
4			
5	Demand/Day =	20,000	
6	Meal Time on Employer (Yes (1) or No (0))	1	
7	Maintenance (%)	0.1	
8	Set-Up Times (%)	0.2	
9			
10	Work Station	Task Time (Minutes)	Task Time (Seconds)
11	A	1.200	72.000
12	B	0.350	21.000
13	C	1.100	66.000
14	D	0.750	45.000
15	E	0.800	48.000
16	F	1.400	84.000
17	G	0.900	54.000
18	H	0.490	29.400
19	I	0.780	46.800

B1. Enter demand per year
B2. Enter number of operating weeks per year
B3. Enter number of operating days per week
B5. Enter =SUM(B1)/(B2*B3)
B6: Enter 1 for set-up (1=Meal On Employer, 0=Meal On Employee)
B7. Enter maintenance times as a percent
B8. Enter set-up times as a percent
B11: Enter task time in minutes for each individual workstation. Repeat for B12 through B19.
C11: Enter =SUM(B11*60). Repeat for C12 through C19 (multiplying task times in min *60)

2.1.2 shift 1 data entry and cycle time computations

Once the Main tab has been completed, data entry can begin on the next tab (worksheet 2), which is to be named *1 Shift*. This tab will include all cycle time calculations for 1 shift per day. To set-up the worksheet, see Table 2. Spreadsheet cells are as follows:

B2. Enter =SUM(Main!B5)
D4. Enter number of breaks per workday
E4. Enter allotted minutes per break (15 minutes)
F4. Enter =SUM(D4*E4)
D5: Enter =IF(Main!B6=1,1,0)
E5: Enter allotted minutes per meal break (30 minutes)
F5: Enter =SUM(D5*E5)
G4: Enter =SUM(F4+F5)
D7. Enter =SUM(Main!B7)
E7. Enter =SUM(Main!B8)
F7. Enter =SUM(D7+E7)
B10. Enter number of operating hours per shift
B11. Enter =SUM(B10*60)
B12. Enter =SUM(B11*60)
C11. Enter =SUM(G4)
C12. Enter =SUM(G4)*(60)
D11. Enter =SUM(B11-C11)
D12. Enter =SUM(B12-C12)
E11. Enter desired efficiency expressed as a percent
E12. Enter desired efficiency expressed as a percent
F11. Enter =SUM(D11*E11)
F12. Enter =SUM(D12*E12)
B15. Enter =SUM(F11/$B$2)
B16. Enter =SUM(F12/$B$2)

Table 2: Data Entry For 1 Shift

	A	B	C	D	E	F	G
1	1 Shift/Day						
2	Demand/Shift =	20000					
3			**Break Type**	**# Of Breaks**	**Min/Break**	**Break Time**	**Total Breaks**
4			**Breaks**	2	15	30	60
5			**Meal**	1	30	30	
6				**Maintenance**	**Set-Up**	**Total**	
7			**Efficiency**	0.1	0.2	0.3	
8							
9		**Total Time**	**Break Time**	**Time w/ Break**	**Efficiency**	**Available Time**	
10	Hours/Day =	8					
11	Min/Day =	480	60	420	0.9	378	
12	Sec/Day =	28800	3600	25200	0.9	22680	
13							
14	**Cycle Time**						
15	**Minutes**	**0.0189**	**Min/Unit**				
16	**Seconds**	**1.134**	**Sec/Unit**				

2.1.3 shift 1 assembly line balance

Once the cycle time calculations are complete, the assembly/production line needs to be balanced. In order for this to be accomplished, see Table 4. Note that Table 3 is a continuation of Table 2. Start construction of Table 3 in row 18.

Table 3: Assembly Line Balance (Continuation of Table 2)

	A	B	C	D	E	F	G
17							
18	**Work Station**	**Task Time (Min)**	**# Of O/M**	**Assigned**	**Idle Time**	**% Efficiency**	**% Idle**
19	A	1.200	63.492	64	0.010	99.206	0.794
20	B	0.350	18.519	19	0.009	97.466	2.534
21	C	1.100	58.201	59	0.015	98.646	1.354
22	D	0.750	39.683	40	0.006	99.206	0.794
23	E	0.800	42.328	43	0.013	98.437	1.563
24	F	1.400	74.074	75	0.018	98.765	1.235
25	G	0.900	47.619	48	0.007	99.206	0.794
26	H	0.490	25.926	26	0.001	99.715	0.285
27	I	0.780	41.270	42	0.014	98.262	1.738
28							
29		**7.770**	**411.111**	**416**			
30							
31	**% Efficiency**	**98.825**		**% Inefficiency**	**1.175**		

B19. Enter =SUM(Main!B11)
B20. Enter =SUM(Main!B12)
B21. Enter =SUM(Main!B13)
B22. Enter =SUM(Main!B14)
B23. Enter =SUM(Main!B15)
B24. Enter =SUM(Main!B16)
B25. Enter =SUM(Main!B17)
B26. Enter =SUM(Main!B18)
B27. Enter =SUM(Main!B19)
B29. Enter =SUM(B19:B27)
C19. Enter =SUM(B19/$B$15). Drag down to C27.
C29. Enter =SUM(C19:C27)
D19. Enter =ROUNDUP(C19,0). Drag down to D27
D29. Enter =SUM(D19:D27)
E19. Enter =SUM(D19*$B$15)-(B19). Drag down to E27
F19. Enter =SUM((B19)/(D19*$B$15))*(100). Drag down through F27
G19. Enter =SUM(100-F19). Drag down to G27
B31. Enter =SUM(B29/(D29*B15))*(100)
E31. Enter =SUM(100-B31)

2.1.4 main worksheet results

The idea behind the results summary is to connect all results from worksheets 2, 3, and 4 to the Main tab so that all results are displayed on the Main tab. Included in the detailed results are total employees, efficiencies and inefficiencies of each assembly/production line, and cycle time dependent on number of shifts. Additionally, the detailed results display the number of machines for each workstation, again dependent on number of shifts per day. It is important to note that only worksheet 2 has been completed at this point (worksheet 3 and 4 have yet to be set-up). For this reason, only copy over results from the *1 Shift* tab. To begin, navigate back to the *Main* tab, and begin construction in row 21 (Table 4).

Table 4: Detailed Results Summary Construction (*Main Tab)*

Row/Column	**A**	**B**	**C**	**D**	**E**	**F**
21	Number of Shifts	Total Employees	Number Workstations	Efficiency	Inefficiency	Cycle Time (Min)
22	1 Shift	416	310	98.825	1.175	0.019
23	2 Shifts					
24	3 Shifts					

B22: Enter =SUM(1Shift!D29)
C22: Enter =SUM(1Shift!D20:D26)
D22: Enter =SUM(1Shift!B31)
E22: Enter =SUM(1Shift!E31)
F22: Enter =SUM(1Shift!B15)

2.1.5 worksheet 3 & 4 development (2 shifts & 3 shifts)

Worksheets 3 and 4 are to be set up almost identically to that of worksheet 2. Open worksheet 2 (*1 Shift)* and copy the entire page (Table 2 and Table 3), to create Table 5, and paste in cell A1 on worksheet 3 (*2 Shifts).* Most of the formulas will remain the same with certain exceptions. Then make appropriate changes to the cells in Table 5, which are indicated in red. Necessary formula changes will be listed below the Table, as in previous sections.

A1: Label Worksheet 3: 2 Shifts Per Day
B2: Enter =SUM(Main!B5)*0.50
B10: Change total time from 8 to 16 hours
D4: Change number of breaks from 2 to 4
D5: Enter =IF(Main!B6=1,2,0)

Table 5: Changes To Worksheet 3 and 4 (Highlighted in Red)

	A	B	C	D	E	F	G
1	2 Shift/Day						
2	Demand/Shift =	10000					
3				**# Of Breaks**	**Min/Break**	**Total Break Time**	**Total Breaks**
4			**Breaks**	4	15	60	120
5			**Meals**	2	30	60	
6				**Maintenance**	**Set-Up**	**Total**	
7			**Efficiency**	0.1	0.2	0.3	
8							
9		**Total Time**	**Break Time**	**Time w/ Break And Meal**	**Efficiency**	**Available Time**	
10	Hours/Day =	16					
11	Min/Day =	960	120	840	0.9	756	
12	Sec/Day =	57600	7200	50400	0.9	45360	
13							
14	**Cycle Time**						
15	**Minutes**	**0.0756**	**Min/Unit**				
16	**Seconds**	**4.536**	**Sec/Unit**				
17							
18	**Work Station**	**Task Time (Min)**	**# Of O/M**	**Assigned**	**Idle Time**	**% Efficiency**	**% Idle**
19	A	1.200	15.873	16	0.010	99.206	0.794
20	B	0.350	4.630	5	0.028	92.593	7.407
21	C	1.100	14.550	15	0.034	97.002	2.998
22	D	0.750	9.921	10	0.006	99.206	0.794
23	E	0.800	10.582	11	0.032	96.200	3.800
24	F	1.400	18.519	19	0.036	97.466	2.534
25	G	0.900	11.905	12	0.007	99.206	0.794
26	H	0.490	6.481	7	0.039	92.593	7.407
27	I	0.780	10.317	11	0.052	93.795	6.205
28							
29		**7.770**	**102.778**	**106**			
30							
31	**% Efficiency**	**96.960**		**% Inefficiency**	**3.040**		

*Numbers in Table 5 reflect a successfully completed worksheet 3 (2 Shifts).

Making these simple and quick changes will make the entire assembly line balance change. Note how numbers in Table 5 are different from that of Table 3. The above five changes will automatically re-compute all calculations on the page. Once those changes have been successfully completed, repeat the process with worksheet 4 (*3 Shifts).* To do this, copy worksheet 3 (*2 Shifts)* in its entirety, and paste it to cell A1 on worksheet 4 (*3 Shifts).* Again, certain changes will need to be made. The changes are listed below.

A1: Label Worksheet 4 : 3 Shifts Per Day
B2: Enter =SUM(Main!B5)*(0.333333333333)
B10: Change total time from 16 to 24 hours
D4: Change number of breaks from 4 to 6
D5: Enter =IF(Main!B6=1,3,0)

2.1.6 main worksheet final results

Navigate back to the *Main* tab, and find the detailed result summary that began construction in part 2.1.4 of this paper. Since worksheets 3 and 4 (*2 Shifts & 3 Shifts)* are now complete, results can be copied over to complete our detailed results chart. Table 4 Continued is the complete table with the required entry for shifts 2 and 3. Required entries are in red.

Table 4 (Continued): Detailed Results Summary Completion (*Main Tab)*

Row/Column	**A**	**B**	**C**	**D**	**E**	**F**
21	Number of Shifts	Total Employees	Number Workstations	Efficiency	Inefficiency	Cycle Time (Min)
22	1 Shift	416	310	98.825	1.175	0.019
23	2 Shifts	212	79	96.960	3.040	0.076
24	3 Shifts	153	38	89.567	10.433	0.170

B23: Enter =SUM(2Shifts!D29)
B24: Enter =SUM((3Shifts!D29)
C23: Enter =SUM(2Shifts!D20:D26)
C24: Enter =SUM(3Shifts!D20:D26)
D23: Enter =SUM(2Shifts!B31)
D24: Enter =SUM(3Shifts!B31)
E23: Enter =SUM(2Shifts!E31)
E24: Enter =SUM(3Shifts!E31)
F23: Enter =SUM(2Shifts!B15)
F24: Enter =SUM(3Shifts!B15)

3. Examples

Listed below are two example scenarios, the first of which is a scenario that include cycle time being greater than process time. This example can be seen in section 3.1 (manual entry), where work elements have been grouped into stations. The manual entry calculations are listed in Table 6. After the calculations were completed, they were tested against the spreadsheet developed in this paper. Both models resulted in identical efficiencies and balance delays.

3.1 Manual Entry (process time < cycle time)

Table 6: Manual Calculations

Station	**Work Element Assigned**	**Time (seconds)**	**Station Slack**
S1	1,2	51	9
S2	3,4,5	47	13
S3	6	52	8
S4	7,8,9	48	12
	Total	**198 (t)**	**42**
# Workstations	**Efficiency**	**82.5%**	
9 (n)	**Inefficiency**	**17.5%**	

T = 198, N = 9, C = 60 (60 sec = 1 min)

Efficiency = ((t)/(n*c))*100 = ((198/9*60))*100 = 82.50%
Inefficiency = 100 – Efficiency = 100 – 82.50 = 17.50%

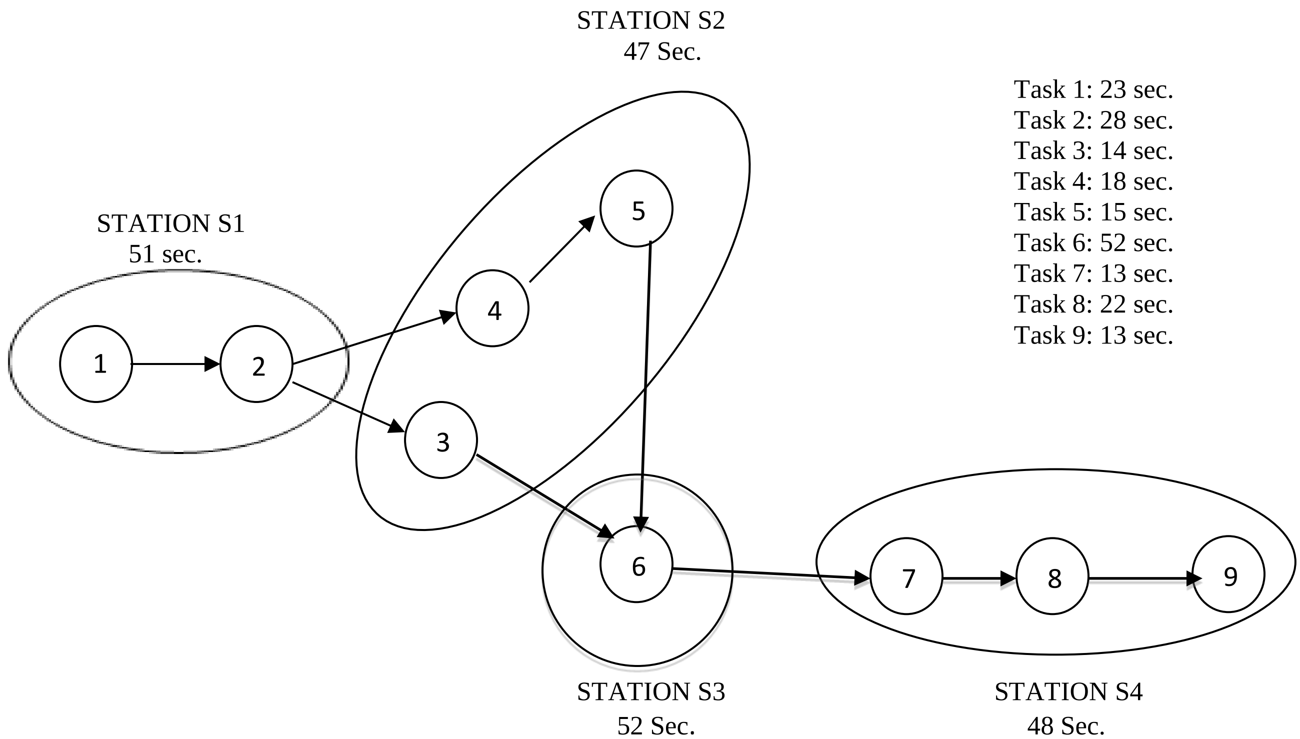

Figure 2. Process Within Four Stations (Nine Work Elements)

Table 7: Spreadsheet Results For Manual Entry

Station	Task Time (sec)	# of O/M	Assigned	Idle Time	% Efficiency	% Idle
S1	51.000	0.850	1	9.0000	85.000	15.000
B	47.000	0.783	1	13.0000	78.333	21.667
C	52.000	0.867	1	8.0000	86.667	13.333
D	48.000	0.800	1	12.0000	80.000	20.000
	Efficiency	**82.500**			**Inefficiency**	**17.500**

3.2 Spreadsheet (process time > cycle time)

When Process Time exceeds Cycle Time, the basic assembly line balancing algorithm must be modified. To modify the model the analyst must make one of two decisions as follows.

a. Add one or two shifts, which will increase the amount of total time available. Adding a shift will effectively increase the Cycle Time to a point where it exceeds Process Time.
b. Within a workstation, the analyst would increase the number of operators or machines in each workstation. For example, see Figure 2 below.

Cycle Time = 1 Minute
Process Time = 1.5 Minutes

- At 1.5 Minutes: Machine A has been in process for 1 minute.
- At 1.5 Minutes: A part leaves Machine B.
- At 2 Minutes: A new part arrives at Machine B.

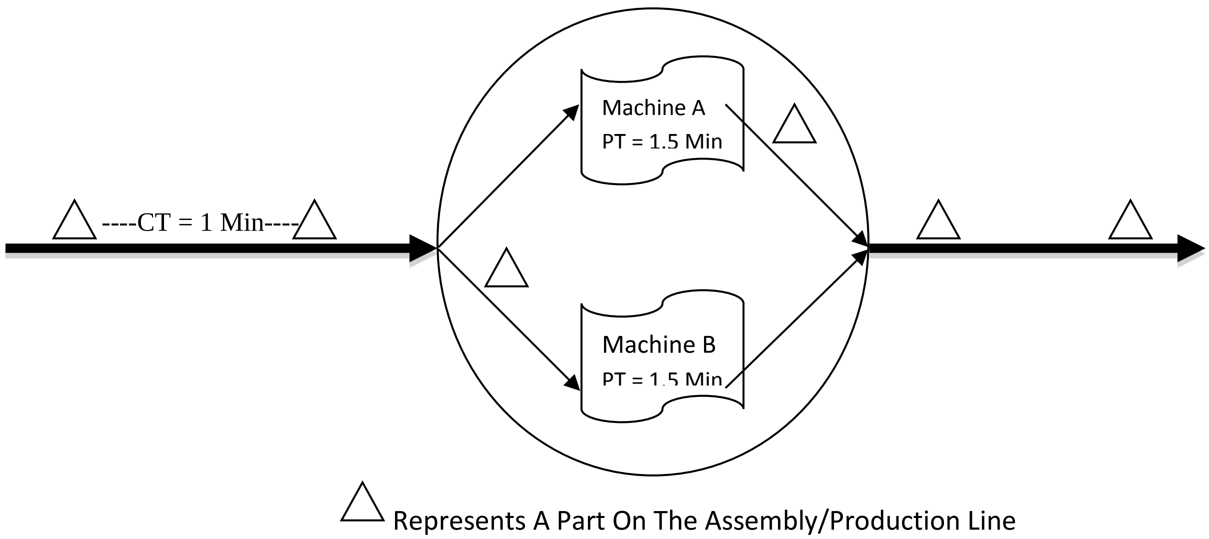

Figure 3: Adding Machine To Work Element 6 in Station 3 (See Figure 2)

Table 8: Spreadsheet Entry (Process Time > Cycle Time)

Station	Task Time (sec)	# of O/M	Assigned	Idle Time	% Efficiency	% Idle
S1	51.000	0.850	1	9.0000	85.000	15.000
S2 (3)	90.000	1.500	2	30.0000	75.000	25.000
S2 (4)	18.000	0.300	1	42.0000	30.000	70.000
S2 (5)	100.000	1.667	2	20.0000	83.333	16.667
S3	52.000	0.867	1	8.0000	86.667	13.333
S4	48.000	0.800	1	12.0000	80.000	20.000

Cycle Time		
Min	***1***	***Min/Unit***
Sec	***60***	***Sec/Unit***

As seen in the above spreadsheet entry, the cycle time in seconds for this process is 60 seconds/unit. Looking at the Task Time (sec) column of Table 8, the process time of activity S2 (3) and S2 (5) are both greater than the cycle time. For this reason, in the Assigned column of Table 8, the spreadsheet automatically added another assigned operator/machine to each workstation that process time exceeded the cycle time.

4. Discussion

Calculating cycle time can be a long, arduous process. However, as this pedagogy details, EXCEL is more than capable of completing these complex calculations, with a small amount of help from the user. As seen in Section

3.1 (Manual Entry: CT > PT), calculating the efficiencies and inefficiencies (balance delay) of an assembly/production line can be calculated manually. When the results of the manual entry were compared against the results of the spreadsheet model developed in this paper, the results were identical. Both models depicted an 82.5% efficiency rating, while assuming a balance delay of 17.5%.

When process time exceeds the cycle time (Section 3.2: PT > CT), modifications must be made to the model. As detailed in Section 3.2, one of two things must be done; either add another shift, or increase the number of operators/machines in each workstation. One major advantage of increasing the number of shifts is that no more machines are needed, thusly saving money. However, increasing the number of shifts will also inevitably increase labor costs. On the other hand, increasing the number of operators/machines within a workstation will require money for the machine purchases. Doing this will eliminate the need for additional shifts, which will keep labor costs low. Each option has its own advantages and disadvantages. It is up to management to decide which decision to make. Often times, the individual circumstance of the business itself helps to dictate which decision will be selected.

It is important to note the significance of choke points within a process layout. Looking at Figure 2, notice Station 3. Located in Station 3 is work element 6, with two work elements preceding (work elements 3 and 5). Choke points are the points within a process layout where the layout is most sensitive. Essentially speaking, there are two work elements within a process layout sending a part to one proceeding work element, which can cause problems in the long run. These points have the potential to slow down the entire system or force it to a complete halt if not handled correctly. It is incredibly important to have a process time significantly lower than the cycle time within choke points.

5. Conclusion

Line balancing is a tool used by operations manager, industrial engineers, and instructors across the world. With user-friendly, affordable line balancing software becoming obsolete for current operating systems, demand exists for a reliable alternative. Microsoft EXCEL proves to be fully capable of these calculations. The major advantage to the practitioner, engineer, instructor, and student is that EXCEL is readily available on all personal computers, easily understood, and is very practical. Students with very little exposure to line balancing were able to master the method within the first hour of exposure.

Once the EXCEL spreadsheet and accompanying worksheets were completed, the results were compared to several different heuristic algorithms. Once the author was satisfied that the results were accurate and not significantly different from other examined algorithms, the final step was to develop a working pedagogy to efficiently describe the process. The results of this project were satisfactorily tested in a production operations class.

6. References

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