Balancing Mixed-Model Assembly line in Electronic Industries Company

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Received on: 29/9/2015 & Accepted on: 12/11/2015

ABSTRACT

In this work, an approach to solve mixed-model assembly line balancing Problem has been suggested which consists of six stages. In the fourth stage of this approach, a heuristic method is suggested for solving the combined model. This method is programmed using C# language. This program is called "Assembly line balancing-Method of Merging Shortest and Longest Operation" symbol by (MMSLO), which is based on merging two heuristic methods "Shortest Operation time" (SOT) and "Longest Operation Time" (LOT). This approach has been applied in the actual industrial environment at Electronic Industries Company (EIC) in assembly plant for assemble three models of automatic changeover (ACH). The results of the suggested method in (MMSLO) program compared with the results of the basic method (SOT) and (LOT) that existed in "production and operations management, quantitative methods" software that symbol by (POM-QM). It has been proved the ability of the suggested method to give a better solution than the traditional methods, in which the efficiency increased from **92.75%** for (LOT) method and **86.98%** for (SOT) method to **93.53%** for the suggested method.

Keywords: mixed-model assembly line balancing, heuristic methods, combined model.

موازنة لخط تجميع مختلط النموذج في شركة الصناعات ألالكترونية

الخلاصة

في هذا العمل أُقترح أسلوب لحل مشكلة موازنة خطوط التجميع المختلطة النموذج والتي تتكون من ست مراحل. المرحلة الرابعة من هذا الاسلوب أُقترحت طريقة توجيهية لموازنة النموذج المركب (combined model). بُرمجت هذه الطريقة باستخدام لغة C# وسمي البرنامج "موازنة خط التجميع- طريقة دمج أقصر وأطول عملية" ويرمز له (MMSLO)، تعتمد هذه الطريقة على دمج طريقتين من الطرق التوجيهية " اقصر وقت تشغيل" (SOT) و"اطول وقت تشغيل" (LOT). طُبق الاسلوب في بيئة صناعية لشركة الصناعات الالكترونية في معمل التجميع لتجميع ثلاثة انواع من المغير الاوتوماتيكي. قورنت النتائج المأخوذة من برنامج (MMSLO) مع طريقتي (SOT) و(LOT) الموجودة ضمن البرامجية الجاهزة "الانتاج وأدارة العمليات، الاساليب الكمية"ويرمز له (POM-QM). أُثبتت قابلية الطريقة المقترحة على إعطاء حل أفضل من الطرق التقليدية، والتي أدت الى زيادة الكفاءة من ٩٢.٧٥% لطريقة (LOT) و ٨٦.٩٨% لطريقة (SOT) الى ٩٣.٥٣% للطريقة المقترحة.

https://doi.org/10.30684/etj.34.2A.4
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INTRODUCTION:

The main objective when it comes to the balancing of an assembly line is the distribution of tasks among the stations to equalize the workload between stations along the line. It is more complicated to balance a mixed-model line than a single-model line because of the difference in time between models [1]. The most important difference between single-model and mixed-model assembly line balancing is in the precedence diagram and setup cost. In single-model assembly line balancing (SMALB), there is just one model and precedence diagram. But, in mixed-model assembly line balancing (MMALB), each model has its precedence diagram. The (MMALB) assume that both changeover times and changeover costs are negligible. This assumption allows transforming the problem into single-model assembly line balancing problem. There are mainly two methods used in this transformation**:** Combined precedence diagram and Adjusted task times [2]. For the other hand, the mixed-model and multi-model line balancing problem differs in the lot sizes and objectives. For a mixed-model line the lot sizes can be equal to one. Because of the set-up costs and times on a multi-model assembly line balancing (MuMALB), these lot sizes are more than one. The objective of the (MuMALB) is to minimize the costs of production. These costs include (cost from the set-up of the line from one model to another). This objective differs from the objective of the (MMALB), which takes (in most cases) only the idle time of the station into account [3].

Related Literature Review:

In the literature, different studies published in the last years which start from the oldest to the current years in ascending order that utilize different approaches for solve mixed-model assembly line balancing problem.

Zhang et al (2011) [4]: they convert the mixed-model assembly line balancing problem into a single-model assembly line balancing. At first, mathematical modeling is set up with the given cycle time, the least number of stations and the highest assembly line balancing rate as optimization objective. Then they used an ant colony optimization algorithm for solving the mixed-model assembly line balancing problem.

Elia and Choudhary (2014) [5]: they optimized (MMALB) for the best performance. Four models with different demand are computed for assembly line optimization. At first, the average of task times of all the models is calculated in order to allocate and distribute the tasks among stations. And optimized the total number of stations required for allocation. Then they computed the load balancing for every station, for each model and for all the station models. The idle time is reduced for every station model by an iterative algorithm by incrementing the quantity of the appropriate model.

Li (2015) [6]: he considered in this paper the mixed-model and multi-model of assembly lines balancing problems with bi-objective. At first, two efficient mathematical programming models, (MMALB) and (MuMALB) Problem with bi-objective, are constructed. The first one is to minimize the cycle time with a known number of stations, and the second is related to horizontal balancing. Two examples are selected for the comparisons of these two models. The computational results of total cycle time minimization indicate that (MMALB) model is superior to (MuMALB) Problem.

The Suggested Approach

In this section, an approach based on a heuristic method (These methods are simple that are used to solve complicated problems. Heuristic methods provide most likely but not optimal solutions, which are good enough from a practical point of view) is suggested for solving the mixed-model assembly line balancing problem. This approach aimed to increase the efficiency by getting minimum shift time (the max. work time of all models units allowed for station) for a given number of stations.

At first the suggested approach is applied to get a feasible solution with a predefined fixed shift time then it is getting a minimum shift time with the desired number of stations. This approach consists of six stages and based on a heuristic method that applied at the fourth stage of this approach, this method based on merging two heuristic methods "Shortest Operation Time" (SOT) and "Longest Operation Time" (LOT). This method programmed using C# language and it is named "Assembly Line Balancing – Method of Merging Shortest and Longest Operation" symbolized by *(MMSLO)*. Figure (1) shows the stages of the suggested approach.

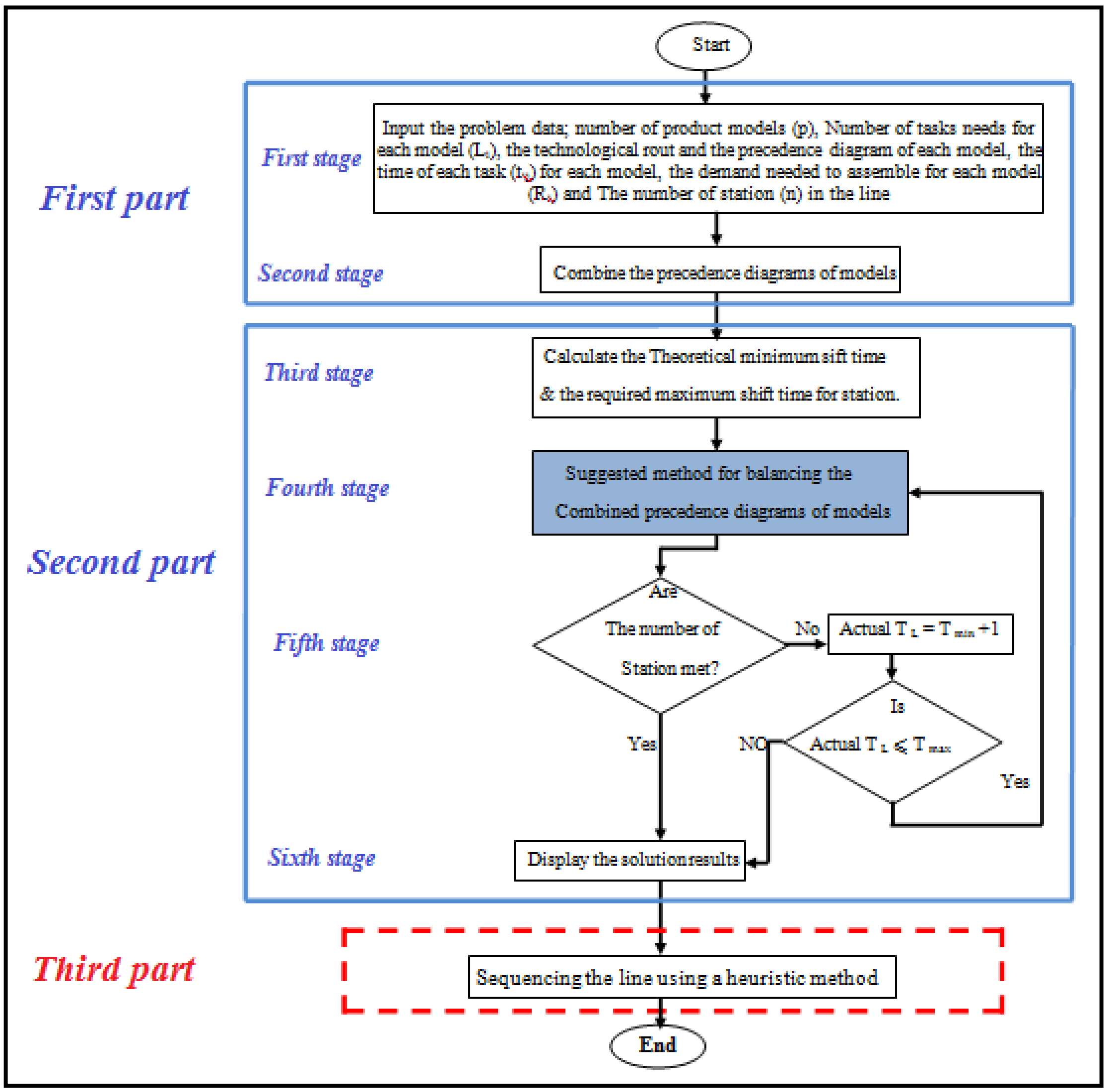


Figure (1) Stages of the suggested approach

Problem Description:
The work problems has been applied in the assembly plant of the Electronic Industries Company (EIC) for assemble different models of automatic changeover *(ACH)*. There are three models of Automatic Changeover *(ACH)*. All of these models are assembled manually.

a. Automatic Changeover (80 A) With Timer (model A)
b. Automatic Changeover (30 A) Without Timer (model B)
c. Automatic Changeover (30 A) With Timer (model C)

These models differ from each other in design and in the tasks number and their times, figure (2) shown the models of Automatic Changeover.

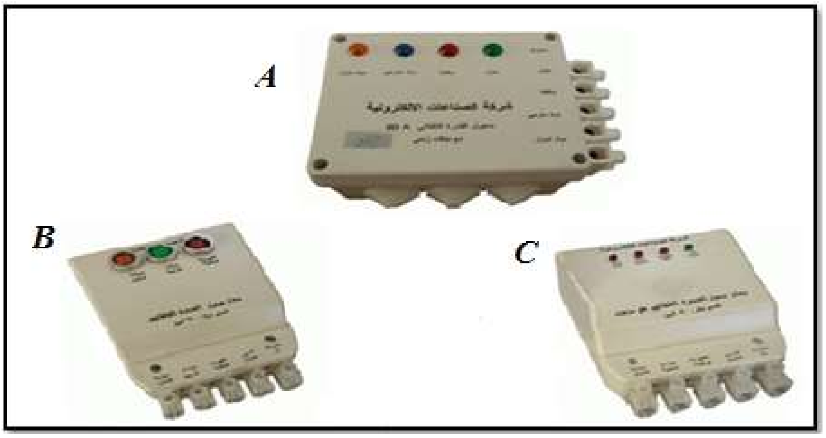


Figure (2) Models of (ACH) [7]

Implementation of Suggested Approach on (ACH) Models Assembly Line
As it was mentioned, the suggested approach is consists of (6) main stages, these stages will explain in details for this practical case as the following**:**

First stage: (Data Collection)
The first stage contains all the problem data which contain (the description of models, technological rout of each model, task time and demand of models). The three model of changeover has the following basic items: (Printed circuit board, diodes, resistors, thermal resistors, transistors, source wires, neon lamp wires, capacitor, ceramic capacitor, relay (30A), relay (10A), relay (120A), Upper & lower part of plastic box, terminal block (100A), terminal block (60A), closure wires, and screws). The total number of tasks for all models is 21 tasks. The descriptions of these tasks are shown in table (1). The models are differ from each other in the number of items for the same task and in the tasks required by having or not some items. Therefore, their assembly times will be different from each other

Table (1) Total assembly tasks required in (ACH) assembly line

Task. No	*Description of task*	T_{Aj} *(min)*	T_{Bj} *(min)*	T_{Cj} *(min)*
1	*Soldering the pieces of diode to the printed circuit board*	*1.86*	*1.86*	*1.86*
2	*Soldering the pieces of resistor to the printed circuit board*	*1.33*	*0.26*	*1.33*
3	*Soldering the pieces of thermal resistor to the printed circuit board*	*0.33*	*0.33*	*0.33*
4	*Soldering the pieces of transistor to the printed circuit board*	*0.73*	______	*0.73*
5	*Soldering the pieces of wire (red, blue, red, black, red) to the printed circuit board (that connect between the house and the other sources)*	*0.83*	*0.83*	*0.83*
6	*Soldering the neon lamp wires or (LED) wires to the printed circuit board*	*2.26*	*1.7*	*1.41*
7	*Soldering the pieces of elect. Capacitor to the printed circuit board*	*0.46*	*0.35*	*0.58*
8	*Preparing & soldering (LED) to the wires*	______	______	*0.83*
9	*Soldering the pieces of ceramic capacitor to the printed circuit board*	*0.66*	*0.66*	*0.66*
10	*Soldering the pieces of relay (30A) to the printed circuit board*	*0.9*	*0.6*	*1.2*
11	*Soldering the pieces of relay (10A) to the printed circuit board*	*0.26*	*0.3*	*0.26*
12	*Connecting the neon lamps wires to the upper cover of plastic box*	*1.33*	*1*	*1*
13	*Soldering the relay (120A) to the printed circuit board*	*16*	______	______
14	*Soldering 2 pieces of wire to the printed circuit board (that connect to the relay that used for closure)*	______	*0.33*	*0.33*
15	*Making the printed circuit board stronger in the relay (120A) area by making welding lines in that area from the other face of the printed circuit board using solder wire*	*4*	______	______
16	*Fixing the printed circuit board to the base part of plastic box using 4 screws & nuts*	*3.33*	*0.25*	*0.25*
17	*Connecting the terminal block (100A) to the plastic box using 2 screws & nuts*	*1.66*	*0.05*	*0.05*
18	*Fixing the terminal block (60A) to the lower plastic box*	______	*0.05*	*0.05*
19	*Connecting the 5 wires (red, blue, red, black, red) of to the terminal block (100A)*	*1.33*	*1.16*	*1.16*
20	*Connecting the 2 welded wires of relay (10A) to the terminal block (60A) for closure*	______	*0.5*	*0.5*
21	*Connecting the upper and lower plastic box by 4 screws without nuts*	*1*	*0.5*	*0.5*

The following sections explain the similarity and differences of the technological rout for each model.

Automatic Changeover with Timer (80 A) Model A

This model is the biggest one and it has more additional parts than other models so the total time to assembled it are more than other models. Figure (3) presents the precedence diagram with the times these tasks (minute) of this model.

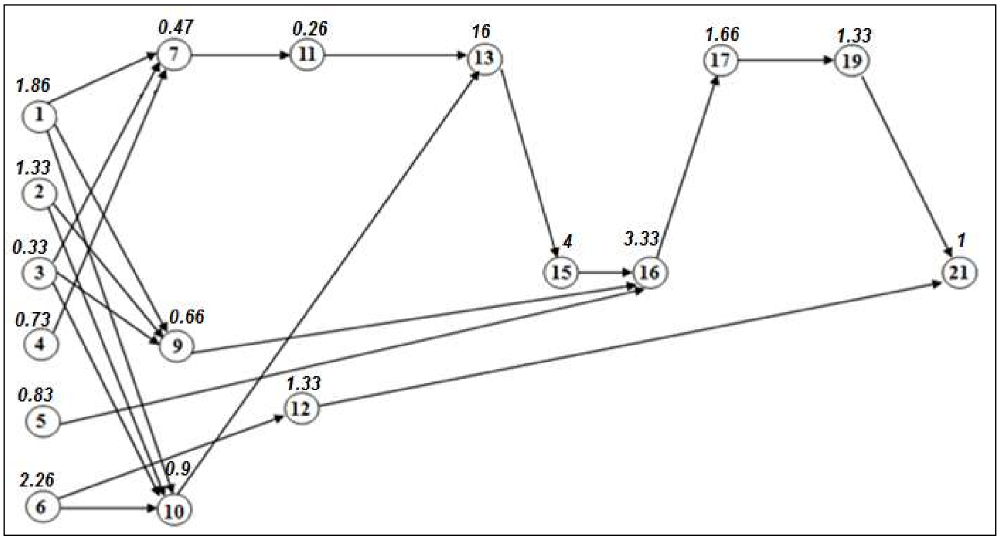


Figure (3) Precedence diagram of model A

Automatic Changeover without Timer (30 A) Model B

In this model, the biggest differ from the first one, that this type doesn't have relay (120A), and resistors, and it has 2 pieces of wire for closure that connect with terminal block 60A, the other different related to the number of items. Figure (4) presents the precedence diagram of this model.

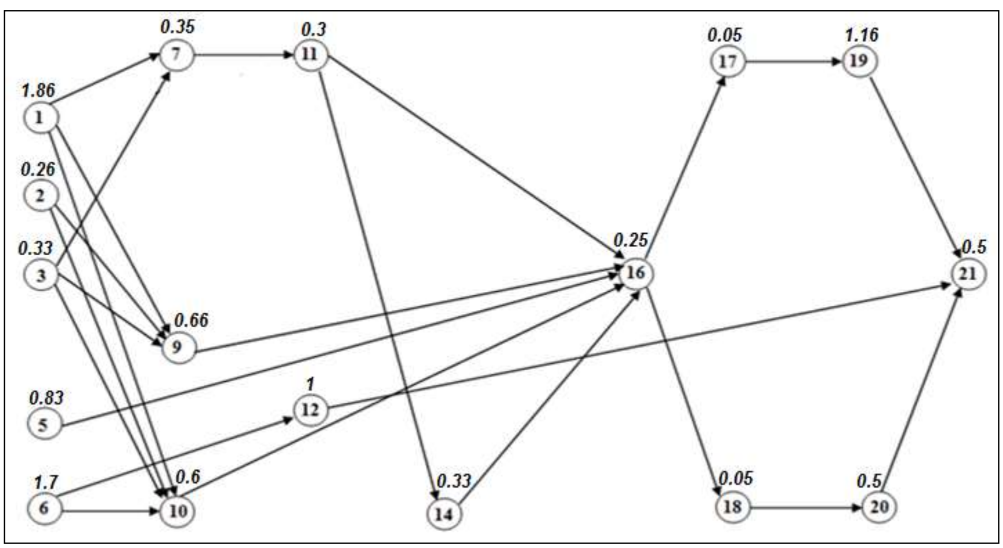


Figure (4) Precedence diagram of model B

Automatic Changeover with Timer (30A) Model C

This model similar to the second one (model B) in the design but they have some differences such as this model has resister (cause it's with timer), and it has LED instead of neon lamp, the other different related to the number of items. Figure (5) present the precedence diagram with the relationship between these tasks.

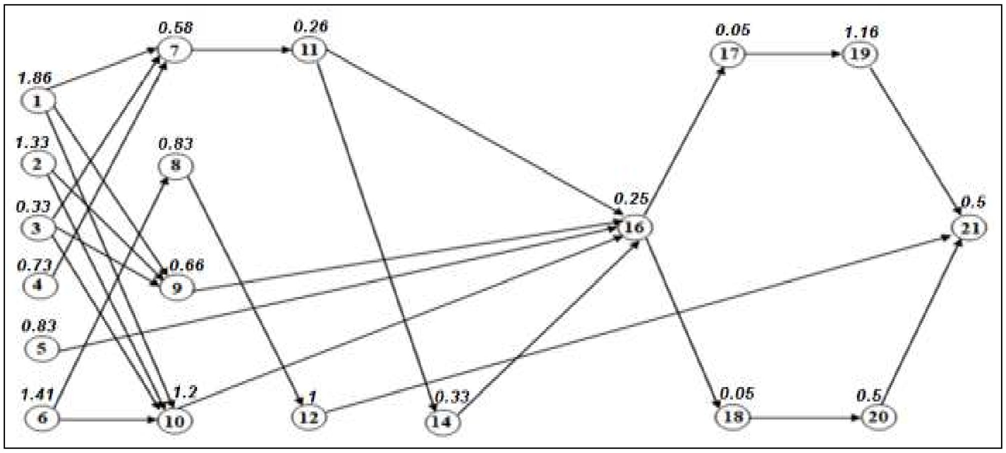


Figure (5) Precedence diagram of model C

Recording the task time and demand of models

The demand required by customer for each model has been recorded which is (2 of A), (7 of B) and (13 of C) every 80 min, and the tasks time for each model has been record using (tasks time) matrix as it shown bellow.

Table (2) Tasks time matrix for ACH models

(R)	(i)	Tasks (j)																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2	A	1.86	1.33	.33	.73	.83	2.26	.46	_	.66	.9	.26	1.33	16	_	4	3.33	1.66	__	1.33	__	1
7	B	1.86	.26	.33	__	.83	1.7	.35	_	.66	.6	.3	1	_	.33	_	.25	.05	.05	1.16	.5	.5
13	C	1.86	1.33	.33	.73	.83	1.41	.58	.83	.66	1.2	.26	1	_	.33	_	.25	.05	.05	1.16	.5	.5

Second Stage: (Combining precedence diagrams)

In this stage all models are combined in to single model using the following equation:

$$TT_j = \sum_{i=1}^{p} R_i \, t_{ij} \qquad \text{............................} \quad (1)$$

Where; $\boldsymbol{TT_j}$: represents the total time required for task j to accomplish all models that represents the time of the combined model. Table (3) presents the combined model matrix. Figure (6) shows the combined model diagram of all models

Table (3) Combined model matrix for ACH models

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A	3.72	2.66	.66	1.46	1.66	4.52	.92	-	1.32	1.8	.52	2.66	32	-	8
B	13.02	1.82	2.31	—	5.81	11.9	2.45	-	4.62	4.2	2.1	7	-	2.31	-
C	24.18	17.29	4.29	9.49	10.79	18.33	7.54	10.79	8.58	15.6	3.38	13	-	4.29	-
TT	40.92	21.77	7.26	10.95	18.26	34.75	10.91	10.79	14.52	21.6	6	22.66	32	6.6	8

i \ j	16	17	18	19	20	21
A	6.66	3.32	—	2.66	—	2
B	1.75	.35	.35	8.12	3.5	3.5
C	3.25	.65	.65	15.08	6.5	6.5
TT	11.66	4.32	1	25.86	10	12

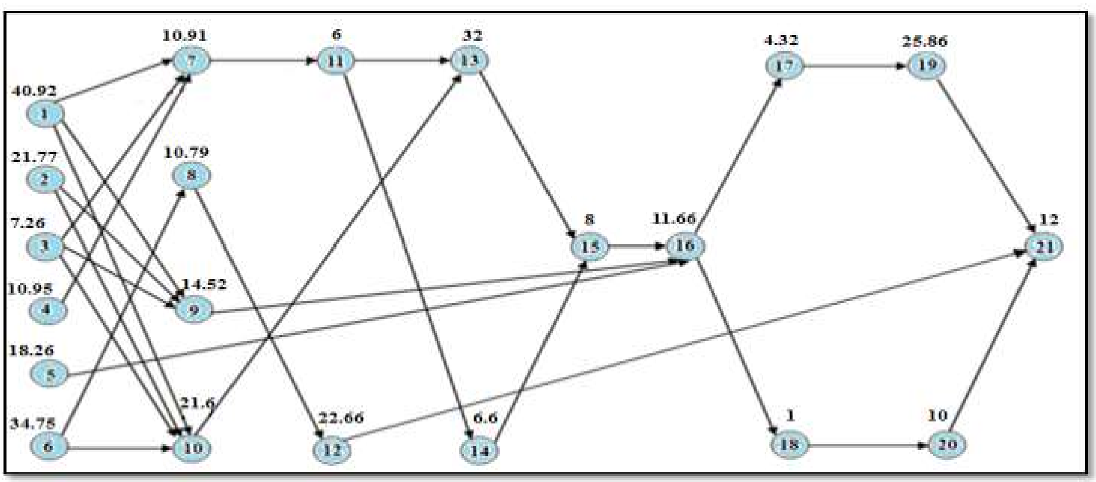


Figure (6) Precedence diagram of combined model

Third Stage: (calculating the balancing shift time)

This stage starts with calculating the theoretical minimum shift time for this line that has (6) fixed stations and one worker for each station

$$Theoretical\ (T_{min}) = max\ [\frac{1}{n}\sum_{j=1}^{L} TT_j\ ,\ max\ TT_j\ ] \qquad \cdots\cdots\cdots\cdots\ (2)\ [8]$$

T_{min} = 55 min, lower limit, without exceeding the maximum shift time for balancing the line. *The required available time* (Required AT) which is the time to deliver the next batch of models in (MMAL) which is specify by the customer, contain both maximum shift time and idle time that occur between pieces due to variability of time between models (assume the idle time between items in station could be reach to max t_{ij}).

$$T_{max} = required\ AT - max\ t_{ij} \qquad \cdots\cdots\cdots\cdots\cdots\cdots \qquad (3)$$

$T_{max} = 80 - 16 = 64$, As a result, the maximum shift time **T_{max} = 64 min**, that consider the upper limit.

Fourth, Fifth and sixth stages:

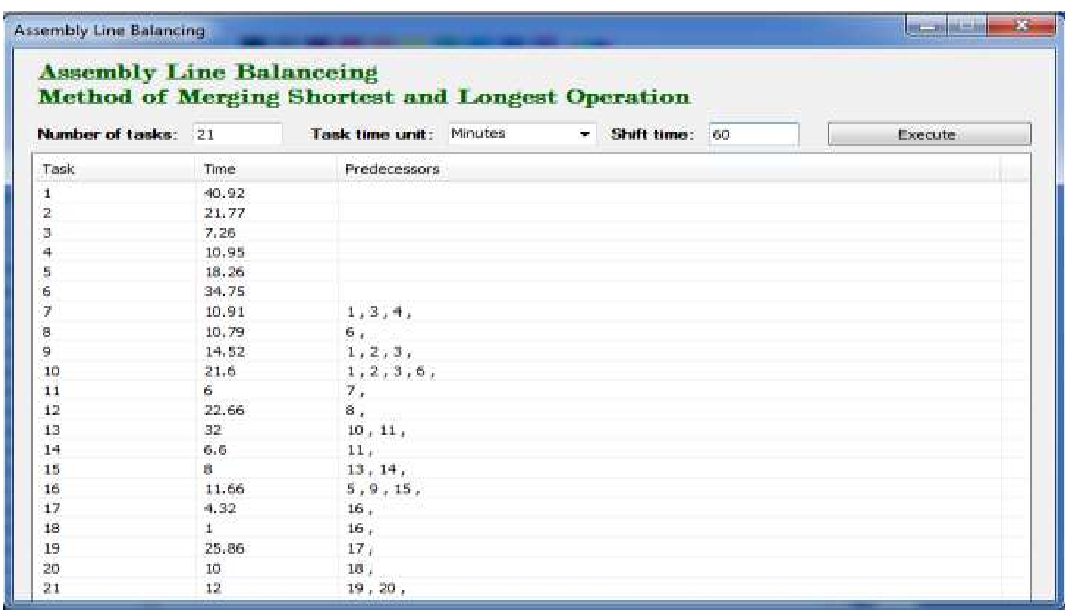
This stages began by applied the suggested method for balancing the combined diagram to get minimum number of station then checked one of the results of the fourth stage which is the number of stations (n). If the minimum number of stations obtained from the solution is more than the given number of stations, then (T_{min}) is made larger to generate the actual shift time (T_L) that achieves the required number of stations, but the increasing in (T_{min}) should not be more than the (T_{max}) that allowed for station. *Actual T_L* can by calculated by:

$$(Actual\ T_L = Theoretical\ (T_{min}) + 1) \qquad \cdots\cdots\cdots\cdots \qquad (4)\ \text{for first iteration}$$

Or

$$(Actual\ T_L = Actual\ T_L + 1) \qquad \cdots\cdots\cdots\cdots \qquad (5)\ \text{for next iteration}$$

- The method began with **T_{min} = 55min**.
- The given number of station (6) is achieved when the actual **T_L = 60 min**.
  Figure (7) shows the input data window of *(MMSLO)* program



Task	Time	Predecessors
1	40.92	
2	21.77	
3	7.26	
4	10.95	
5	18.26	
6	34.75	
7	10.91	1 , 3 , 4 ,
8	10.79	6 ,
9	14.52	1 , 2 , 3 ,
10	21.6	1 , 2 , 3 , 6 ,
11	6	7 ,
12	22.66	8 ,
13	32	10 , 11 ,
14	6.6	11 ,
15	8	13 , 14 ,
16	11.66	5 , 9 , 15 ,
17	4.32	16 ,
18	1	16 ,
19	25.86	17 ,
20	10	18 ,
21	12	19 , 20 ,

Figure (7) Input data screen with fully data of (MMLSO) program

The distributing of tasks among the station in the line and the quality measures of the suggested method solution are shown in figure (8)

Report

Station	Task	Time
1	3	7.26
1	1	40.92
1	4	10.95
2	6	34.75
2	8	10.79
2	7	10.91
3	11	6
3	12	22.66
3	14	6.6
3	2	21.77
4	9	14.52
4	10	21.6
4	5	18.26
5	13	32
5	15	8
5	16	11.66
5	18	1
5	17	4.32
6	20	10
6	19	25.86
6	21	12

Summary Statistics

Max station work Time	59.13
Number of Stations	6
Time allocated (Stations * Cycle Time)	354.78
Time Needed (Sum of Tasks Time)	331.83
Idle Time (Time allocated - needed)	22.9499999999999
Efficiency (Time needed / allocated) * 100%	93.531202435312
Balance Delay (100-Efficiency)	6.46879756468796

Figure (8) Report of result screen for balancing (ACH) assembly line using (MMLSO) program

Implementation of Traditional Methods on (ACH) Models Assembly Line:

In this section the balancing problem solved using (LOT) and (SOT) methods that was the basic of the suggested method. These methods exist in (POM-QM) software. After select the data limitation of the problem such as number of tasks, time unit for tasks, the solution is began with T_{min}=55 min and select the method. After selecting the type of method inter solve to show the result windows of that method, at first select the *(Longest Operation Time)* heuristic method, the result of this method could not obtain the required 6 station with 55 min, so the time is increased until its get 6 stations with 60 min, Then solve the problem with (shortest operation time) heuristic method that obtained the 6 stations with 64 min, table (4) shows the comparison between the balancing results of (LOT) and (SOT) methods in *(POM-QM)* software and the suggested method in *(MMSLO)* program. That shows the last one is better than others.

Table (4) Comparison between the suggested method and the traditional methods (SOT & LOT)

Balancing Result Measures	*The Suggested Method*	*L O T Method*	*S O T Method*
Shift time (min)	*60*	*60*	*64*
Max. station work time (min)	*59.13*	*59.63*	*63.58*
Min. number of stations	*6*	*6*	*6*
Time allocated (min)	*354.78*	*357.78*	*381.48*
Idle time (min)	*22.95*	*25.95*	*49.65*
Efficiency	*93.53 %*	*92.75 %*	*86.98 %*
Balance delay	*6.47 %*	*7.25 %*	*13.02 %*

Conclusions and Recommendations:

From the results, none of stations had idle time equal to zero which means none of stations is uploaded with 100% working time (shift time). Based on that, the shift time value is changed to maximum station work time. In this case the maximum station work time equal to the shift time value and maximum station work time different than the shift time value are considered without mistakes. The obtained results from implementing the suggested approach show improvement in the efficiency (when the efficiency increased from **92.75%** for (LOT) method and **86.98%** for (SOT) method to **93.53%** for the suggested method) and reduction in the maximum Station work time (when the max. station work time decreased from **59.63(min)** for (LOT) method and **63.56(min)** for (SOT) method to **59.13(min)**) for the suggested method).

As a further future work the following recommendation are important:

1. Study the balancing and its related sequencing and scheduling problems as an integrated problem
2. Study the balancing problem on more complex mixed-model assembly line, such as robotic or automated line …etc.
3. Extending the practical case to large number of cases with different size and criteria of case problem.

REFERENCES:

[1] Hellman, F., Lindahl, B., and Malmberg, J., "*Mixed-Model Assembly Line at Volvo Construction Equipment*", MSc. Thesis, Technology Management and Economics, Chalmers University OF Technology (2011)

[2] GÜden, H., "*An Adaptive Simulated Annealing Method for Assembly Line Balancing and a Case Study*", MSc. Thesis, Industrial Engineering, Middle East Technical University, (2006).

[3] Zante, J. I. V., Fokkert, and Kok, A. G., "*The Mixed and Multi Model Line Balancing Problem: A Comparison*", Operations Planning and Control, Eindhoven University of Technology, TUE/BDK/LBS/95-07, June, (1995).

[4] Zhang, Y., Tao, L. F., and Ju, F., "*Balancing of Mixed-Model Assembly Line Based on Ant Colony Optimization Algorithm*", IEEE, 978-1-61284-449, (2011).

[5] Elia, A. K., and Choudhary, D., "*Optimization of Balancing for a Mixed Multi Model Assembly Line*", International Journal of Scientific & Engineering Research, Vol. 5, Iss. 4, ISSN 2229-5518, (2014)

[6] Li, M., L., "*Construction and Comparison of Multi-Model and Mixed-Model Assembly Lines Balancing Problems with bi-Objective*", Journal of Industrial and Production Engineering, Vol. 31, No. 8, 483–490, (2015).

[7] Website of Electronic Industries Company (EIC) http://www.eiciq.com/index.php?product_section=25

[8] Grzechca, W., "*Assembly Line-Theory and Practice*", InTech, Croatia, (2011).