OPTIMUM EFFICIENCY OF THE PRODUCTION LINE AT THE AUTOMOTIVE INDUSTRY

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ABSTRACT

Production Line Balancing Problem (PLBP) is one of the most important stages in automobile manufacturing. It is a critical problem in continuous Production Line (PL), and it is one of the difficult optimization problems. PLBP includes many stations concerned with the allocation of tasks to work, where each station contains a number of operations that cooperate to achieve the task work. The main PLBP are: queuing, idling time among stations during the task achievement, and unregulated number of workers among a station, which is an obstacle to the efficient PL. In this paper, the technical constraint was carried out to minimize the queuing problem and regulate the workers by applying hybrid models; Multi-Objectives Model and Genetic Algorithm. The outcome of the mixed models assists to reduce the queuing and the idling time through harmonizing the tasks in each workstation. In addition to balance the distribution of the new workers in order to get the optimal solutions as well as improving the ability of PL with the high production rate.

***Keyword**:* Production line balancing, Multi-objectives model, Genetic algorithm, Automobile manufacturing system, production plan.

INTRODUCTION

Since 1955 the PLBP is appearance a historical utilized management technique in a manufacturing industry. The earlier research of line balancing was studied by (Bowman, 1960; Held et al., 1963). The researchers during these years developed many approaches for finding best and heuristic solutions to the simplified of the line balancing problem. (Salveson, 1996; Yasuhiro et al., 1996) was first isolated of the line balancing problem and offered an analytical approach to PLBP solution later.

PLBP is the practice of distributing work into work stations in order to achieve the tasks. However, line-balancing problems attempt to assign workers in such a way that the total number of workers required is minimized, given a specified cycle time (Sury, 1997). The assembly of a product is divided into a number of tasks where each workstation in the line carries out some tasks. The consecutive execution of these tasks completes the product sequence, in which the work stations are passed through is the same for every product. The workstations of the PL are an efficient method of manufacturing high-volume products. In fact, it is a common practice to balance the line so that a more identical flow is maintained, given that the tasks are restricted by a set of precedence restrictions. The PLBP method seeks to reduce the queuing by combining and assigning a number of tasks to workstations in such a way that each workstation requires an identical amount of time to perform the required tasks (Sury, 1997; Amir et al., 2006).

The PLBP is difficult to solve with conventional methods when its scale is very large. Therefore, it is necessary to develop an efficient algorithm for solving this problem. The GA has powerful performances for such combinatorial optimization problems, especially for sequencing process problem such as PL problems (Gnoni 2003).

The PL system is like many problem in operations research, in generally there are many solutions to the PL. Moreover, there is still a need to develop an efficient algorithm that can identify the solution and preferably optimum solutions if they exist. The PL consists of a number of workstations arranged in a line. Any point on the PL in which a task is performed considered as station. The cycle time of a PL is predetermined by a desired production rate. This production rate is set so that the desired amount of end product is produced within a certain time period.

The mathematical optimization using linear programming, and Multi Objectives Model (MOM) have been attempted. (Rita, 2006) Recently, an approach of using Genetic Algorithms (GA) was investigated to develop the technique of optimization, which is an important tool to improve the production line. Today, many researchers seem to consider line-balancing as mostly an important and relevant research area. The case study will be composing new Hybrid Models (HM) between MOM and GA to get the optimum solution for PLBP at automobile manufacture system.

PRODUCTION LINE PROBLEMS

The problem in PL is a queuing; the system consists of many servers, an arrival process, and a service process, along with some additional assumptions about how the system works. The word "queue" is sometimes used to describe the whole system, but mostly it has been used for just that part of the system that holds the excess customers who cannot gain immediate access to a server (Subba et al., 1998). The PL problem is shown in Figure 1, which contain 12 stations and each station includes many tasks. The maximum number of tasks is 20, while the minimum number of tasks is 16. Each task needs a time to be process that needs different processing time. The problem of PLBP can perceived clearly in Figure 1, where the number of tasks in all stations is not equal, which is the reason behind the queuing in PLBP.

Tasks

20	t_{20}										t_{20}	
19	t_{19}			t_{19}							t_{19}	
18	t_{18}	t_{18}		t_{18}		t_{18}		t_{18}			t_{18}	
17	t_{17}	t_{17}	t_{17}	t_{17}	t_{17}	t_{17}	t_{17}	t_{17}	t_{17}		t_{17}	t_{17}
16	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}	t_{16}
15	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}	t_{15}
14	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}	t_{14}
13	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}	t_{13}
12	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}	t_{12}
11	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}	t_{11}
10	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}	t_{10}
9	t_9	t_9	t_9	t_9	t_9	t_9	t_9	t_9	t_9	t_9	t_9	t_9
8	t_8	t_8	t_8	t_8	t_8	t_8	t_8	t_8	t_8	t_8	t_8	t_8
7	t_7	t_7	t_7	t_7	t_7	t_7	t_7	t_7	t_7	t_7	t_7	t_7
6	t_6	t_6	t_6	t_6	t_6	t_6	t_6	t_6	t_6	t_6	t_6	t_6
5	t_5	t_5	t_5	t_5	t_5	t_5	t_5	t_5	t_5	t_5	t_5	t_5
4	t_4	t_4	t_4	t_4	t_4	t_4	t_4	t_4	t_4	t_4	t_4	t_4
3	t_3	t_3	t_3	t_3	t_3	t_3	t_3	t_3	t_3	t_3	t_3	t_3
2	t_2	t_2	t_2	t_2	t_2	t_2	t_2	t_2	t_2	t_2	t_2	t_2
1	t_1	t_1	t_1	t_1	t_1	t_1	t_1	t_1	t_1	t_1	t_1	t_1
	1	2	3	4	5	6	7	8	9	10	11	12

Stations

Fig. 1: Number of tasks in each station

On the other hand, the queuing and idling times are present in Figure 2. In the figure, the yellow color indicates the idling time among the stations while the blue color indicates the queuing time. This delay causes a problem in continuous production that leads to waste time and affect the efficiency of PL in addition to reducing the production rate.

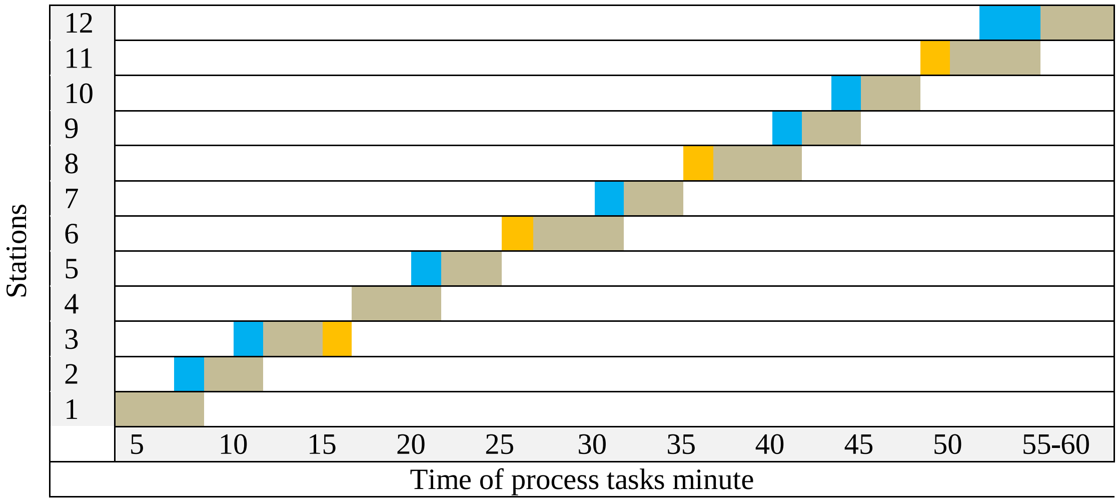

Fig. 2: Queuing and ideal time in PL

Consequently, the number of worker in each station of PL is not equal. It is depending on processing time and number of tasks, which is not sufficient to achieve the task in the workstation. Figure 3 shows the number of workers in each station.

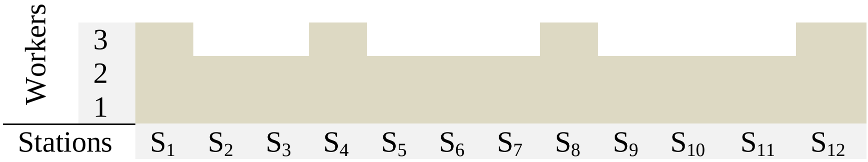

Fig 3: Number of workers in each station

THEORY AND MODELLING

The study of this problem remains of a continuous interest (Salverson, 1955; Scholl, 1999; Razman et al., 2010). Since its first mathematical formulation, until the last researchers, this problem was both intensively and extensively considered to find more efficient solving methods and to extend the model for handling new constraints.

A lot of real-world search and optimization problems are naturally posed as linear programming problems having multiple objectives. Due to lack of suitable solution techniques, such as problems are artificially converted into a multi-objective problem and solved (Coello et al., 2002; Amir, 2006; Ali A.J 2009).

In this case study, the authors tried to increase the productions (output) and reduce wastage of production capacity, through a decrease the queuing time and ideal time, therefore, The HM between the (MOM & GA) has been recognized as an efficient and useful procedure for solving large and hard combinatorial problems. However, the HM assisted PLBP to get the optimum solution through applications three objectives, which are:

- The first objective present is reducing the queuing and idle time at PL.
- The second objective is calculating the cost of the move any tasks among stations.

- Third objective is increasing the number of workers according to the assigning task. Section 4.1 and 4.2 present the objectives and subjective of the model. Appendix A shows the definition of the entire variable.

OBJECTIVES

$$\mathrm{Min\ Q} = \ \max \sum_{l=1}^{s} \ \sum_{i=1}^{n} \ \sum_{j=1}^{m} \ |(t_l - t_{l-1})|x_{ij} -------------- (1)$$

$$\mathrm{Max\ W} = \ \min_{1\le nw\le d} \sum_{l=1}^{s} \sum_{i=1}^{n} \sum_{j=1}^{m} w_l \, x_{ij} ------------------(2)$$

$$\mathrm{Min\ C} = \sum_{i=1}^{n} \sum_{j=1}^{m} C(co_{ij}) ----------------------------(3)$$

SUBJECTS

$$\sum_{i=1}^{n} \ \sum_{j=1}^{m} x_{ij} = 1 \ ------------------------------(4)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} t_{ij}x_{ij} = t_i ----------------------------- (5)$$

$$\sum_{l=1}^{s} \sum_{i=1}^{n} \sum_{j=1}^{m} s_l \, t_{ij} = \ s_l -------------------------(6)$$

$$\sum_{l=1}^{s} \sum_{u=1}^{nw} s_l nws_u = tnw \quad -------------------------(7)$$

$$x_{ij} \in \{0,1\} \forall_{i,j}$$

ALGORITHM

The procedure of the proposed method for solving PLBP problem is shown as follows:
Step 1: Computational processing time of each station and cycle time in PL.
Step 2: Select the station is consist of the Maximum Processing Time (MaPT) and Minimum Processing Time (MiPT).
Step 3: Calculate the queuing process time among the stations by applying ($\sum_{i=1}^{n} D_i = \quad \sum_{i=1}^{n-1} qs_i - qs_{i+1}$).
Step 4: Calculate the idle time, which make delay in PL ($\sum_{i=1}^{n} D_i = \ \sum_{i=1}^{n-1} ds_i - ds_{i+1}$)
Step 5: move some tasks from MaPT stations to MiPT stations.
Step 6: If the result as the best solution. Go to step 10
Step 7: If the managers no need the optimum solution, go to step 10.
Step 8: To get optimum solution appended worker to PL.
Step 8: Divided the rate of job new worker to MaPT stations.
Step 9: Print the optimum solution.
Step 10: Print the final schedule of the tasks, number of the workers and cycle time in PL.

FLOWCHART

Figure 4 shows the flowchart of HM stages of the PLB which is containing many operations. Appendix B is illustrating the sequences operations in this flowchart.

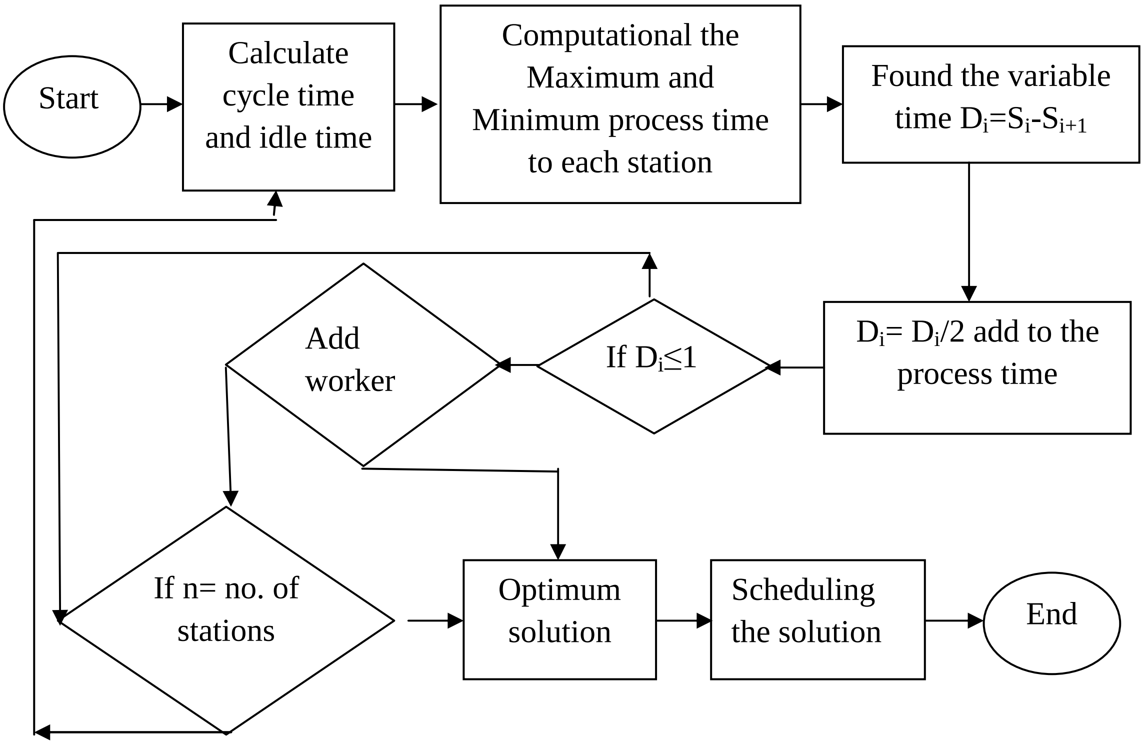

Fig. 4: Mathematical operations stages flowchart

DATA COLLOCATION

The case study applied the HM to 12 stations in the body shop at PL of automobile manufacturing. Table 1 shows the total tasks, process time, number of worker, queuing, and idle time of each station. From the Table, the total queuing time is (231.8 sec), and the idle time is (196.2 sec). In fact the queuing consider as the longest period of the PL that reduce the efficiency and produce. Table 1 shows the data collocations in PL.

Table 1: Tasks, time and worker in each station

stations	No. task	Time Sec	Worker	Queuing	Idle Time
1	20	338.4	3		
2	18	316	2	22.4	
3	17	301	2	15	
4	19	312	3		11
5	17	305	2	7	
6	18	343	2		38
7	17	291	2	52	
8	18	349	3		58
9	17	296	2	53	
10	16	270.6	2	25.4	
11	20	359	2		89.2
12	17	302	2	57	
				231.8	196.2

Table 2 contains process time of each task in stations, and total tasks process time of each station.

Table 2: Process time of the tasks

Stations

Time of tasks sec.	1	2	3	4	5	6	7	8	9	10	11	12
1	21.6	19	18	17	18	18	18	19	17	20.4	21	17
2	21.6	19	18	17	18	18	18	19	17	20.4	21	17
3	18	18	17	17	17	19	15	20	18	19.2	18	19
4	18	18	17	17	17	19	15	20	18	19.2	18	19
5	14.4	17	18	14	18	17	18	17	18	14.4	16	16
6	14.4	17	18	14	18	17	18	17	18	14.4	16	16
7	18	16	17	17	17	20	18	19	15	18	19	20
8	18	16	17	17	18	19	18	17	18	18	19	18
9	16.8	18	18	17	19	19	18	22	20	16.8	20	17
10	16.8	18	18	17	20	19	19	22	19	16.8	20	17
11	14.4	19	17	16	19	22	17	19	19	16.8	20	17
12	14.4	19	17	16	19	22	17	19	17	14.4	16	17
13	16.2	18	20	17	18	19	16	21	17	15	16	16
14	16.2	18	20	17	18	20	16	21	17	15	16	16
15	16.8	17	17	16	18	20	17	22	17	16.8	17	21
16	15	17	17	16	16	19	17	22	16	15	17	21
17	15	16	17	17	17	18	16	15	15		16	18
18	18	16		16		18		18			18	
19	18			17							18	
20	16.8										17	
	338.4	316	301	312	305	343	291	349	296	270.6	359	302

Figure 5 shows the idea among the station and total process time of tasks. It shows that each station has to process time that is not equal compare to next stations.

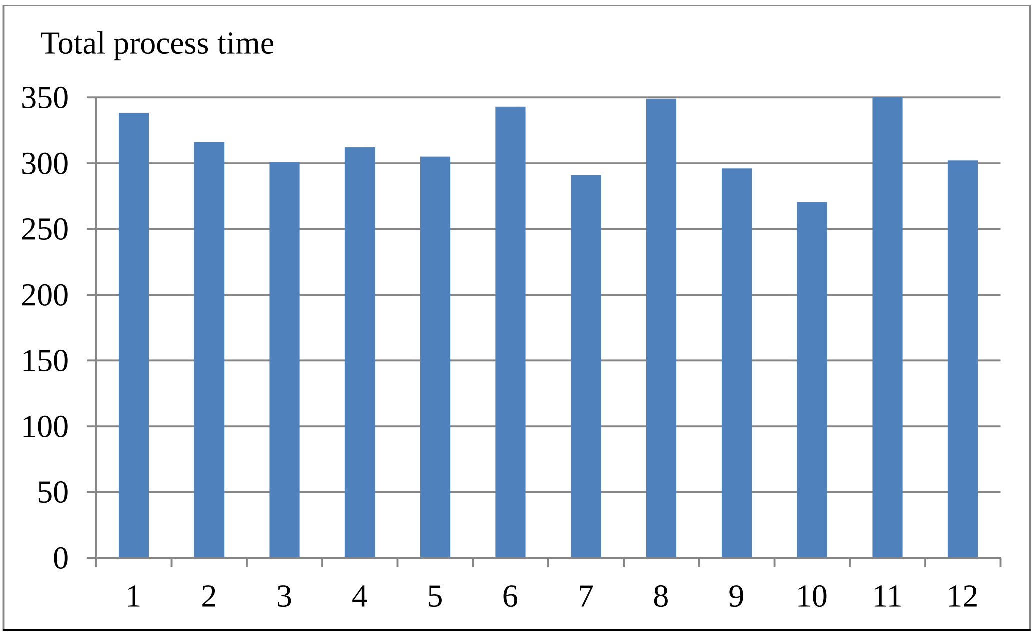

Fig 5: The relation of station with total process time

RESULTS

The results after applied The HM will be discusses in below through three sections, each section will be explain one objective.

TIME BALANCING

The model modified the operation through moving some tasks from station to another. Besides, the model follows the condition of moving the tasks among stations. The movement of the tasks should be in sequence among the stations similar to moving the tasks from, i station to i+1station, where i is numbered of station.

The best balance in PL to reduce the queuing is shown in Table 3. The moving of the tasks among stations takes place with two directions; first moving the tasks in sequence from first station to the last station and second moving follows the first one immediately starting from the last station to first station according to the order of the tasks.

From the Table 3, the red colors indicate the first moving, and the blue colors indicate the second moving. As a result, the total processing time of all stations seems to be close to each other.

Table 3: The best balancing time in PL

	Stations											
Tasks	1	2	3	4	5	6	7	8	9	10	11	12
1	21.6	19	18	17	18	18	18	19	17	20.4		17
2	21.6	19	18	17	18	18	18	19	17	20.4	21	17
3	18	18	17	17	17	19	15	20	18	19.2	18	19
4	18	18	17	17	17	19	15	20	18	19.2	18	19
5	14.4	17	18	14	18	17	18	🟥	🟥	14.4	16	16
6	🟥	17	18	14	18	17	18	🟥	🟥	14.4	16	16
7	18	16	17	17	17	20	18	19	15	18	19	20
8	18	16	17	17	18	19	18	17	18	18	19	18
9	16.8	18	18	17	19	19	18	22	20	16.8	20	17
10	16.8	18	18	17	20	19	19	22	19	16.8	20	17
11	14.4	19	17	16	19	🟥	17	19	19	16.8	20	17
12	14.4	19	17	16	19	22	17	19	17	14.4	🟥	17
13	16.2	18	20	17	18	19	16	21	17	15	16	16
14	16.2	18	20	17	18	20	16	21	17	15	16	🟥
15	16.8	17	17	16	18	20	17	22	17	16.8	17	21
16	15	17	17	16	16	19	17	22	16	15	17	21
17	15	16	17	17	17	18	16		15	18	16	18
18	18	🟥	16	16		18	22	18	17	18	18	21
19	18	14.4		17					17	16	18	16
20	16.8								15		17	
	324	314.4	317	312	305	321	313	300	309	322.6	322	323

Further, the relation between the stations and total process tasks` time is shown in Figure 6, it can be observed that the queuing and the idling time was reduced through harmonizing the tasks in each workstation. Further, clearly that the balance has high efficiency, that does not provide the optimum solution, but it gives the best solution to PLBP.

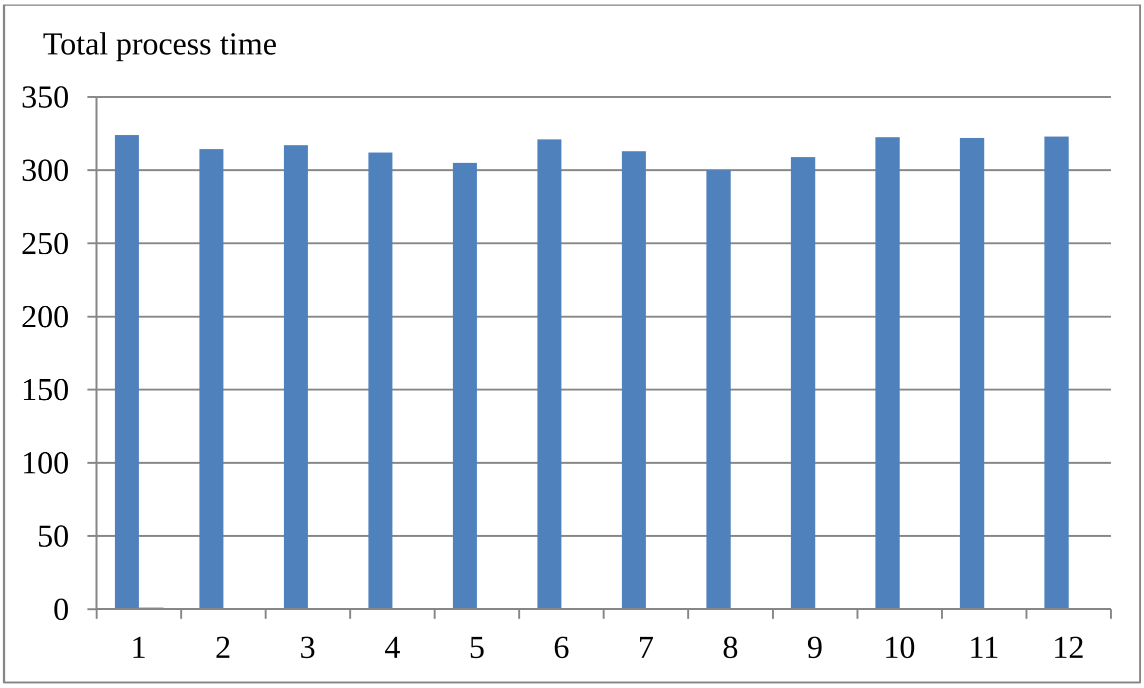

Fig 6: The relation station with total process time

Figure 7 shows the number of tasks moved from stations to be other. It is present the two type of moving where the blue color shows the first movement of the tasks from left side to right side, and the red color shows the second movement of the tasks form right side to left side. The arrows on the top and down of the Figure presents the direction of the moved tasks.

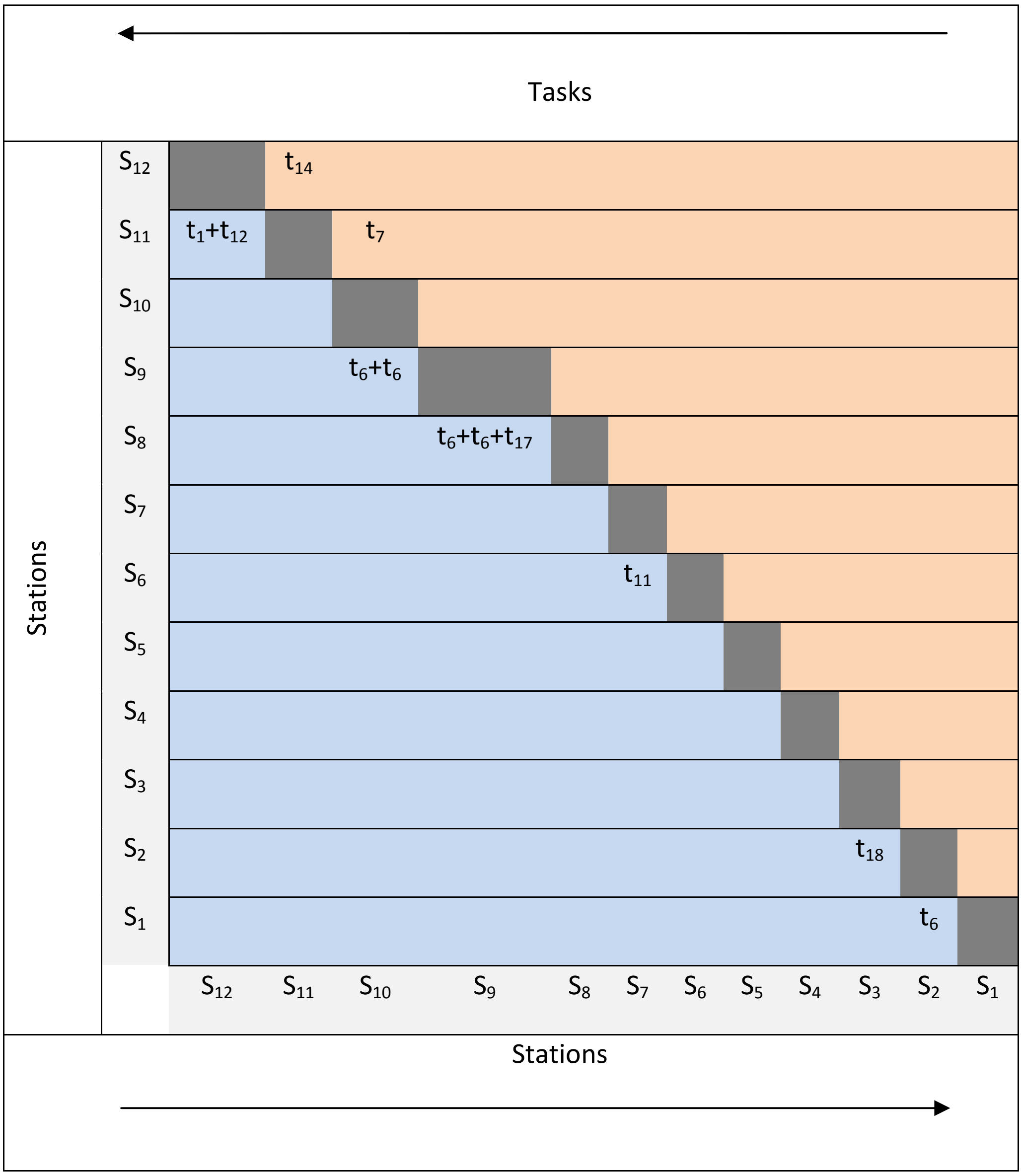

Fig. 7: Sides of moved tasks among stations

Figure 8 illustrate the PL in which the stations have been queuing or idling time. It shows the moving of the tasks among stations while the arrows describe the directions of the sequence moving of tasks among stations.

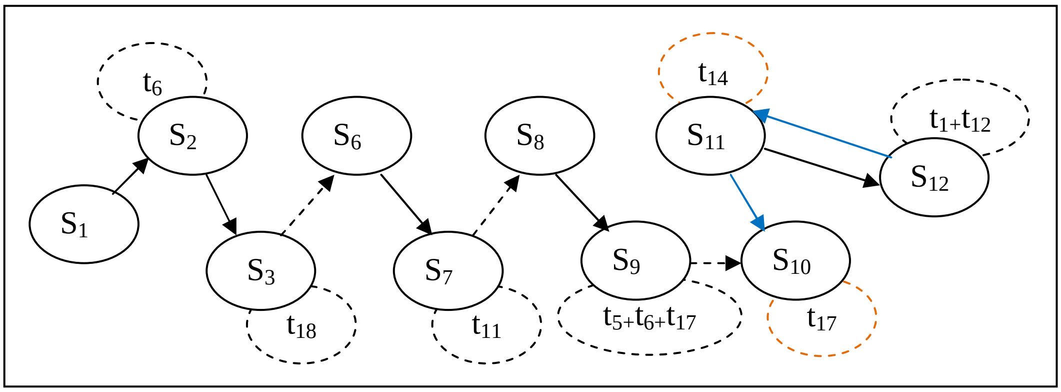

Fig. 8: Direction of tasks moving between stations

WORKERS

The second objective application by the HM if couldn’t get the optimum solution from the first objective, it is finding the optimum solution where the number of workers should be increased. The increasing in the number is limited according to the objective 2 into formula (2) variable (d), which gives the conditional number to add a worker. After getting the optimum solution, the model did not increase the number of workers because it leads to make the high cost as well as the limitation of an efficient system. Figure 9 shows the work of the worker in which station.

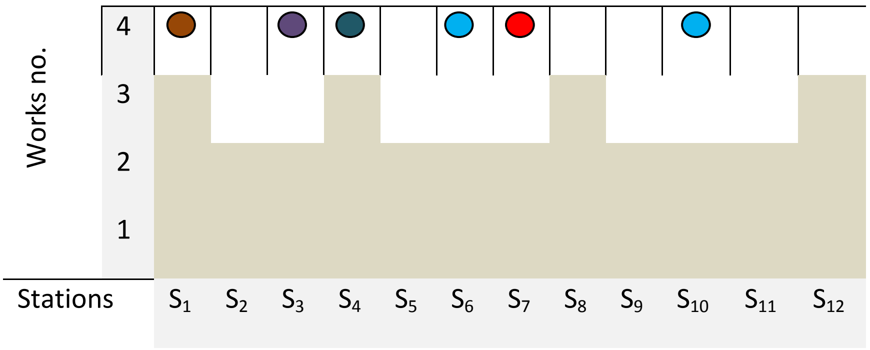

Fig 9: The work of the worker in the station.

Figure 10 illustrate the rate works of the appended worker in each station. According to the model, there is only one worker was appended to reach the optimum solution. Table 4 shows the rate work of the appended worker in each station. It can be seen there is a verity rate work among stations (1, 3, 4, 6, 7, and 10) where the rate work of each station depended on the queuing.

Rate	23%		11%	15%		18%	31%			16%		
work	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}

Fig. 10: the rate work of the worker in each station.

Table 4 present the summary of the results, it contains the number of tasks, total time to process all tasks, rate works of a worker, and queuing time (waiting and idling time) of each station. Compare with Table 1(before applying the model) it can be observed that the queuing time is reduced, in addition, the difference between waiting time and queuing time is just 1 min. As well, the number of tasks and the tasks processing time are closed to each other.

Table 4: Summary result

stations	No. task	Time sec	Worker	Waiting time	Idle Time
1	19	324	3+23%		
2	18	314	2	9.6	
3	18	317	2+11%		2.6
4	19	312	3+15%	5	
5	17	305	2	7	
6	17	321	2+18%		16
7	18	313	2+31%	8	
8	15	300	3	13	
9	15	309	2		9
10	19	322.6	2+0.16%		13.6
11	18	322	2	0.6	
12	19	323	2		1
				43.2	42.2

TASKS MOVEMENT COSTS

The third objective is managed to calculate the cost of moved tasks among the stations, to make balance in PL. Some tasks need high cost to change the position from station to another. The objective assists the managers to obtain the decision for each task in PL of moving or not, which depend on the rate cost. Table 5 shows the cost of each task.

Table 5: The cost of each tasks that is move among stations

	Tasks							Cost
S_{12}						t_1+t_{12}		0
S_{11}					t_{17}		t_{14}	0
S_9				$t_6+t_6+t_{17}$				0
S_7			t_{11}					0
S_3		t_{18}						0
S_2	t_6							0
Stations	S_1	S_2	S_6	S_8	S_{10}	S_{11}	S_{12}	

In many cases, if the task moved among the sequence station, the cost is zero. Else the tasks moved among the station do not follow the sequence of moved that raises the cost. In this case the costs are zero, because they transferred follow the sequences movement and the GM assist to follow transferred the tasks by sequence

CONCLUSION

The HM between the MOM & GA assists to get the optimization solution to PLBP in the automobile manufacture system, through the objectives. It is formulated three important objectives to make balance for all variables in PL as (tasks, processing time and number of workers). The first objectives to minimize the queuing among a station and to reduce the cycle time in PL to get the best solution. The second objective achieved the optimum solution

through to append the worker in PL. The third objective calculated the cost of transferred tasks among the stations. Therefore, the MOM and GA were solved those objectives with best an optimum solution. In this study, the model presented the GA procedure using the PL efficiency based on realized cycle time. The model could give a good result through solving the PLBP using the values showed in data collection table. The results indicate to increase the productions through saving the time and reduce the queuing and ideal time.

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Appendix A

Q	Total queuing time in PL
Tl	Total process time in station l
|tl-tl-1|	Abs queuing time among stations
Wl	Number of worker in station l
L	No of station
S	Total number of stations
n, m	Total number of tasks in each station
Tl	total process time in each station
i, j	Sequences No of task in PL
Xij	Process time to task no i, j
W	No of worker
Nw	Total number of worker in each station
D	Number of worker can extend
Si	Number of station
Nws	Number of worker in each station
Tnw	Total number of worker in PL
C	Total cost to move tasks among stations
Coij	Cost to move any tasks no. i, j
PT	Process time
CT	Cycle time

Appendix B

```
Procedure: Hybrid model MOM& GA
Input: Data of PL (tasks, workers, processing time)
Output: the best solution, optimum solution
Begin
    t ← 0;
    Calculate the CT
    Initialize calculate the max and min processing time in PL
    Evaluate different the time process among stations;
            While (queuing ≥ min) do
                    Move task from MaPT station to MaPT station
                    Calculate the PT in each station
           end
            If the solution not optimum
               Increase the worker
               Distribution rate work of the new worker to stations
            End if
   t ← t +1
Print the result (number of tasks, processing time and number od workers)
Output the best solution or optimum solution
end
```