



Study The Effect of Machine Efficiency In Production Lines Balancing

Rasha J. Marzoog^{a,*}, Sawsan S. Al-Zubaidy^b, Ahmed A. Alduroobi^c

^a Production and Metallurgy, Engineering department, University of Technology, Baghdad, Iraq, 70075@uotechnology.edu.iq

^b Production and Metallurgy, Engineering department, University of Technology, Baghdad, Iraq, sawsanaa2006@gmail.com

^c Prosthetics and Orthotics Engineering department, Al-Nahrain University, Baghdad, Iraq, ahmed-abdulsamii7@yahoo.co.uk

*Corresponding author.

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ABSTRACT

Production Line Balancing (PLB) is the technique of assigning the operations to workstations in such a way that the assignment minimizes the idle time between workstations. PLB aims to equator the workload in each workstation to assure maximum production flow. By adding machine in specific configurations is one treatment which leads to this leveling in workload. This research studies the different efficiencies of the added machine and the effect of these efficiencies on line balancing to select the machine with suitable efficiency. This will be led to reduce the idle time between workstations and increasing production flow. The work time considered as the efficiency criterion for this case study. The study has been implemented on a dumb truck production line and resulted in increasing the line efficiency to 81.7%.

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1. Introduction

In the production line, if the machines and workers are not utilized effectively then it results in low efficiency. Also, the big variety in tasks times resulted in Work In Process (WIP) in some workstations and idle time in another [1]. Line balancing is a systematic technique or approach had been introduced to achieve the objectives of specifying the bottleneck workstation and thereby maximizing the smooth functioning, increasing productivity, minimizing the production times, and increasing line efficiency [2]. In this research, a study of machine efficiency and their effects on line balancing has been introduced. The task time on the specific machine has been taken as an efficiency criterion. Machines are varied in accomplish the time of specific tasks for many reasons. Supposing the management has limited resources of different efficiencies, it is not necessary to select the highest machine efficiency as the best solution. In some situations, this will lead to aggravating the idle time in some workstations and increasing (WIP) for others. The aim is to

select the machine with suitable efficiency to reduce the idle time between workstations and increasing production flow. A case study has been taken to demonstrate the aim of this research.

2. Production Line expressions

A production line is a progression of tasks in which the product is transferred from one workstation to the next. In each workstation, the materials are fabricated and joined together to create a product [3]. Figure 1 depicts a representation of the production line elements.

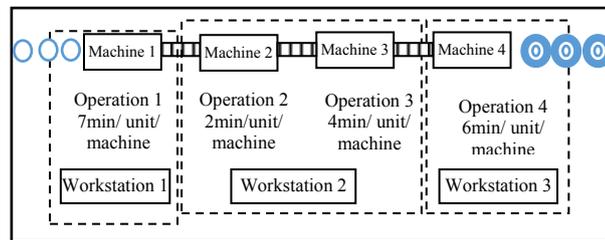


Figure 1: production line elements [4]

A brief definition of the production line basic terminologies are as follows [5]:

I. Task (i)

The job is divided into work elements called tasks so that the work may be spread along the line. The task is a part of the total job content in the line. (t_i) is the time that needed to complete a specific task, where ($i=1, 2, 3, \dots, n$) and (n) is the No. of work elements (tasks) in a workstation.

II. Work Stations (WSs):

It is a location on the production line where one or a combination of work elements is performed. WS time (t_j) is the summation of all tasks (n) on WS and ($j=1, 2, \dots, m$), where (m) is the No. of WSs in the line.

III. Cycle Time (c):

Cycle time is the duration of time required to finish a single unit part or to finish the job or task from beginning to end. It can be bigger than or equal to the maximum of all task times. If,

$$\text{cycle time}_{(\text{actual})} (c) \geq \text{Max } t_i (\text{time unit}) \quad (1)$$

Then there will be ideal time at all WSs having WS timeless than the cycle time.

The theoretical cycle time can be determined by utilizing the following formula.

$$\text{cycle time}_{(\text{theoretical})} = \frac{\text{production time available(per day)}}{\text{quantity of units required (per.day)}} (\text{time unit}) \quad (2)$$

IV. Precedence Diagram:

The precedence diagram is a graph representation wherein the work elements (tasks) are appeared according to sequenced relations. The activity can't be performed except if its antecedent is completed. In the precedence diagram, the tasks are referred by nodes, and the relations between tasks are referred by arrows from the predecessor to the successor work element. Figure 2 depicts a precedence diagram for a production line of seven WSs. In this graph, the numbers inside nodes refer to task number while numbers outside nodes refer to task time.

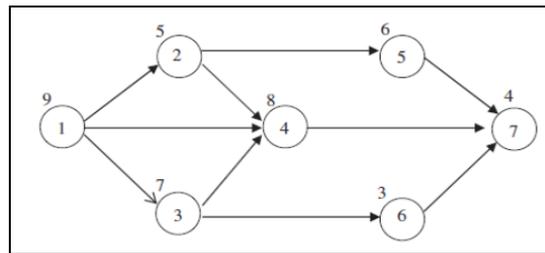


Figure 2: Precedence Diagram showing seven WSs [5]

V. Smoothness Index (SI):

Smoothing index describes the relative smoothness of the production or assembly line balancing. Perfect balance is indicated by SI = 0. This index is calculated in the following manner:

$$SI = \sqrt{\sum_{j=1}^m (t_{max} - t_j)^2} \tag{3}$$

Where (t_{max}) is the maximum WS time (in most cases cycle time) and (t_j) is the time of WS j [6].

VI. Balance Delay time (D):

Balance delay is a measure of inactive time on production or assembly lines caused by the uneven division of work among operators or WSs. determined utilizing the accompanying formula:

$$D = \frac{m * t_{max} - \sum_{j=1}^m t_j}{m * t_{max}} \times 100\% \tag{4}$$

Where t_{max} is Max WS time (in most cases cycle time), t_j is the time of WS j, and m is the number of WSs [7].

VII. Efficiency (E):

Efficiency is a measure of effectiveness for machines and workers' time that determine the efficiency of WS and hence line efficiency [5].

3. Work efficiency

The efficiency of production or assembly lines is urgent as it results in product improvement and utilization of available resources. Many Factors contribute to production line efficiency; which is manpower utilization and machine efficiency [8].

I. Machine or workstation efficiency:

Machines are intended to work efficiently, but in some conditions, machines are less productive due to improper preventive maintenance and long age. Many works of literature discussed various indicators in evaluating the effectiveness of machines production lines, the common are Plant and Machine Control coefficient (PAMCO) [9] or Overall Equipment Effectiveness (OEE) [10] Mean Time Between Failure (MTBF) & Mean Time To Repair (MTTR) [11].

II. Worker efficiency:

Worker efficiency refers to the productive capacity of a worker to do more or better work or both during a specified period of time.

$$E_{(worker)} = \frac{\text{standard hours for output}}{\text{actual hours}} \times 100\% \tag{5}$$

Work-study utilizes both method study and works measurement to deal with the potential overall human work regarding time spent on completing an operation or job. These procedures help to identify ways to make the task simpler and easy, which consequently increases productivity and efficiency [12].

III. Machine or workstation efficiency:

It is mean the percentage of the overall station time and the cycle time multiplied by the No. of WSs.

$$E_{(line)} = \frac{\sum_{j=1}^m t_j}{m \times t_{max}} \times 100\% \tag{6}$$

4. The performance of the production line

A significant proportion of performance for a production line is the system throughputs (the number of parts produced per time unit). The line performance depends on the production rate as well as the configuration of each WS.

I. The production rate for each WS (per unit time) can be determined using the following formula:

$$\text{production rate for WS (j)} pr_j = \frac{1}{t_j} \tag{7}$$

Where (j=1, 2, ..., m) number of WSs in the line, tj: workstation time.

II. The workstations arrangement in the production line affects line productivity. The three basic production line configurations are:

1) Serial line: the stations are arranged in series [13], as shown in Figure 3.

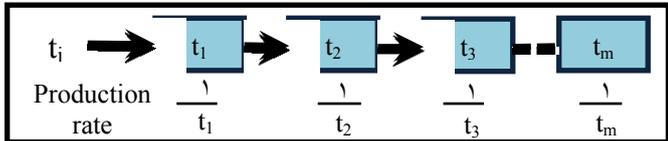
$$\text{production rate for serial WSs} = \frac{1}{Max t_j} \tag{8}$$


Figure 3: serial production line configuration [14]

2) The parallel line where a set of workstations or machines configured in parallel [13] as shown in Figure 4. the the production rate for parallel WSs or machines can be calculated using the following equation:

$$\text{production rate for parallel WSs} = \sum_{k=1}^s \frac{1}{t_k} \dots = \frac{s}{t_k} \tag{9}$$

Where k=1,2,...s, and (s) is the number of tasks in parallel configuration for the WS.

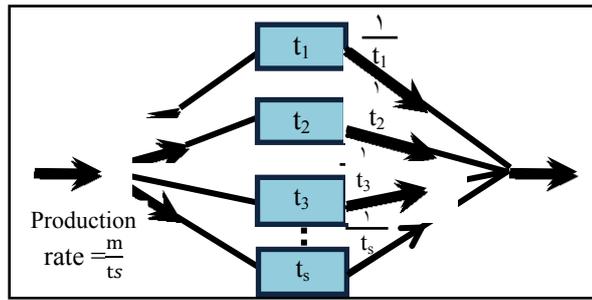


Figure 4: parallel production line configuration [13]

3) Parallel-serial line. The combined arrangement (parallel and series), Figure 5, shows the combined arrangement, the cycle time can be decreased by arranging some stations in parallel in tasks that require a long time to implement with keeping on the tasks sequence and constraining in precedence conditions. The production rate of this arrangement founded by using Eq. (9) first and then Eq. (8) [14].

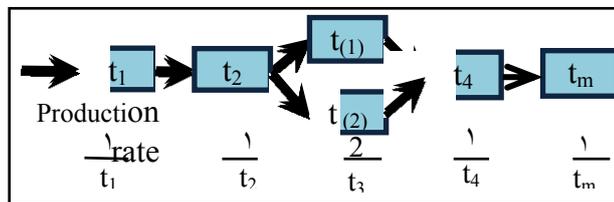


Figure 5: parallel-serial production line configuration [14]

5. The Proposed Methodology

By adding machine(s) in parallel with the critical task machine or workstation is one solution of line balancing to level the workload according to the following formula:

$$pr(WS_1) \square \square \square \dots \quad (10)$$

Where $pr(WS)$ is the production rate for the WS, and $m =$ the number of WSs in the serial production line.

The added machine to the WS should be able to accomplish the job in the required quality. If the added machine (machines) has the same efficiency and working conditions, the task time in both machines will be equal, and the machines are identical. Figure 6.a depicts an example of a simple production line consists of three WSs with tasks time of t_1, t_2 & t_3 respectively. The critical task is the task with Max time which is t_2 . To reduce WIP in this WS, machine of the same type of the original machine could be configured in parallel. as shown in Figure 6.b.

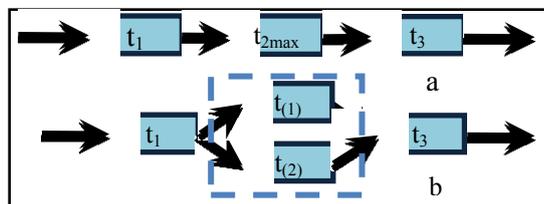


Figure 6: adding machine in parallel

It is rare to accomplish the operation on two machines at the exactly equal time. There are many reasons for machine differences to accomplish the tasks:

1. The machine is old and not modern but can do the task but in a longer time.
2. The variety in setup time.
3. The variety in handling time.

4. The variety of skilled operators.

For these reasons the added machine (s) in parallel may require longer/lesser time than the original machine and refer to as (non-identical machine(s)). Time study principles have been used to calculate the duration of the task (k) on the available machines ($t_{(k)}$) (where $k=1, 2, 3 \dots s$, and s = the number of parallel machines). The machine with Max production rate is assumed the Max efficiency machine and it is the reference machine. Task duration on the reference machine considered as standard ($t_{(k)}$ (standard)). The production rate for the standard task is denoted as ($Pr_{(k)}$ (standard)); while the production rate for other machines in the parallel configuration is referred to as ($Pr_{(k)}$). The efficiency for standard (assumption) machine is referred to as $E_{(k)(\text{standard})}$; while the efficiency for other machines in the parallel configuration is ($E_{(k)}$)

$$E_{(k)(\text{standard})} = \text{Max } E_{(k)} \quad (11)$$

The efficiency of other machines will be considered as a percentage of standard efficiency machines. The efficiency should be calculated for the available machines according to the following formula:

$$E_{(k)} = \frac{Pr_{(k)}}{Pr_{(k)(\text{standard})}} \quad (12)$$

The production rate for the critical workstation that is configured in parallel is the summation of efficiencies of parallel machines and can be calculated using the following formula:

$$Pr_{j(\text{critical workstation})} = Pr_{(1)} + Pr_{(2)} + \dots + Pr_{(s)} = \sum_{k=1}^s Pr_{(s)} \quad (13)$$

From Eq. (12) $Pr_{(k)}$ for any machine in the parallel configuration is:

$$Pr_{(k)} = Pr_{(k)(\text{standard})} \times E_{(k)}$$

Then:

$$Pr_{j(\text{critical workstation})} = Pr_{(s \text{ standard})} \times E_{(1)} + Pr_{(s \text{ standard})} \times E_{(2)} + \dots + Pr_{(s \text{ standard})} \times E_{(s)} \quad (14)$$

$$Pr_{j(\text{critical workstation})} = Pr_{(s \text{ standard})} \sum_{k=1}^s E_{(s)} \quad (15)$$

The equivalent time for the parallel machines $t_{j(\text{equivalent})}$ is the time required to produce one part from the parallel workstation and can be derived using the formula:

$$Pr_{j(\text{critical workstation})} = \frac{1}{t_{j(\text{equivalent})}} \quad (16)$$

$$t_{j(\text{equivalent})} = \frac{1}{Pr_{j(\text{critical workstation})}} \quad (17)$$

For each available alternative, the Eq. (15) & Eq. (17) are used to calculate production rate for critical workstation then equivalent time. The equivalent time is then considered as (j) workstation time (t_j) in serial line and once more the cycle time should be specified.

Line Efficiency, Balancing Delay, and Smoothing Index have been used in this research as the measurement criteria for selecting a suitable alternative machine using the Eq. (6), Eq. (3) & Eq. (4).

Recurring to Eq. (10), the goal is to select suitable machine efficiency which accommodates the production rate of the critical workstation with other workstations.

6. Implementing the methodology

The proposed methodology will be implemented on a production line of the dump truck. The data had been taken from (Syahputri et al.) who developed the original line that its precedence diagram is shown in Figure 7 and consist of 30 work elements and (7) workstations (metal cutting, forming, installed assay, welding body, painting, installed hydraulic and finishing) with the details shown in Table 1.

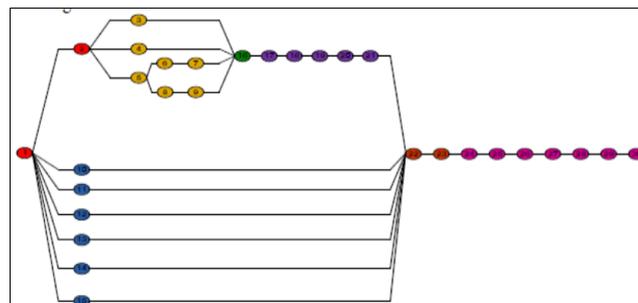


Figure 7: Actual Precedence Diagram [7]

Table1: Allocation of actual work elements [7]

workstations	Work Elements	Total time (min)
I metal cutting	1, 2	35
II forming	3,4,5,6,7,8,9	336
III installed assay	10,11,12,13,14,15	458
IV welding body	16	1254
V painting	17,18,19,20,21	1109
VI installed hydraulic	22,23	5994
VII finishing	24,25,26,27,28,29,30	268
Total		4054

The development approach used Moodie Young Method in its two phases in order to minimize the workstation to (4) WSs by grouping (metal cutting, forming & installed assay) into one workstation and the (installed hydraulic & finishing) into one workstation. The reduction resulted in an increase in line efficiency and a reduction in SI and D. The developed line workstations are shown in Figure 8 and the details are shown in Table 2

Table2: workstations forming using Moodie Young Method [7]

workstations	Work Elements	Total time (min)
I metal cutting, forming, installed assay	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	825
II welding body	16	1254
III painting	17,18,19,20,21	1109
IV installed hydraulic, finishing	22,23,24,25,26,27,28,29,30	862
Total		4054

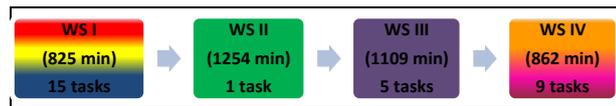


Figure 8: line workstations after reduction

This research aims to maximize line smoothness and workflow. This can be achieved by adding a supplementary machine in parallel to the critical workstation. In the presented case the critical workstation is (III welding WS) with Max time of 1254 min. The existent or original welding machine requires (1254) min to finish the task for one piece. Supposing the company has five additional welding machines with efficiencies of (similar to the reference machine 100%, 90%, 80%, 70%, 60%, & 50%). These percentages are resulted from using Eq. (12). The management should decide which machine to adopt as an attempt to equate the production flow between workstations by making use of the available machines. The following calculations are achieved

- 1- The standard machine is the original machine with E=100% and time of 1254 min. calculate the production rate $pr_{k(standard)}$ using Eq. (7)
- 2- Calculate the production rate for the welding WS (parallel machines) using Eq. (15)
- 3- The equivalent time for welding WS is calculated using the Eq. (17).
- 4- The efficiency (E) of the line is calculated using the Eq. (5).
- 5- The smoothness index (SI) is calculated using the Eq. (3)
- 6- The balancing delay (D) using the Eq. (4)

Figure 9 clarifies the line WSs with the proposed solution and the equivalent time for the parallel WS and Table 3 shows the results of the calculations. The results show that the machine with efficiency 50% is the best choice to balance and smooth the production line.

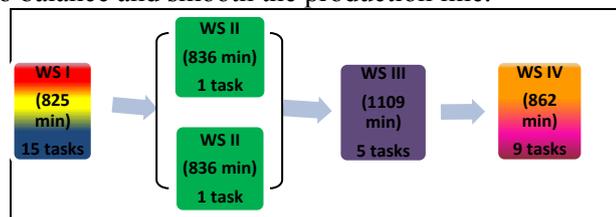


Figure 9: The line WSs with the proposed solution

Table 3: The calculations for different machines efficiencies

	WS 1	WS 2	W 3	WS 4	E (%)	SI	D
100% typical to original	825	627	1112	863	77%	616.1	23
90%	825	660	1112	863	77.7%	590.48	22.3
80%	825	696.4	1112	863	78.6%	563.1	21.5
70%	825	737.6	1112	863	79.5%	533.4	20.5
60%	825	783.7	1112	863	80.5%	502.11	19.5
50%	825	836	1112	863	81.7%	469.62	18.2

7. Results and conclusions:

By adding a machine in parallel to the original machine in the critical workstation resulted in increasing the line flow, decreasing Work in Process WIP, and thereby increasing the line efficiency. Machines are different in their efficiencies and accomplishing the time of a specific task. The machine with appropriate efficiency should be selected. The highest efficiency is not always

necessary to be the best solution. For example, for the selected case study the machine with the lowest efficiency is the best solution because it is compliant with line smoothness. The results parallel machine addition is increasing in Line Efficiency of dump trucks industry to (81.7%). Also, the Smoothness Index has been decreased to (469.62) by decreasing of (21.4%) from Syahputri et al. as well as a reduction in Balance Delay to (18.2%). Figure 10 illustrates a comparison between the original line, developed line by Syahputri et al and the proposed line respectively. Figure 11 shows a comparison of workstation time and idle time for the developed and the proposed method.

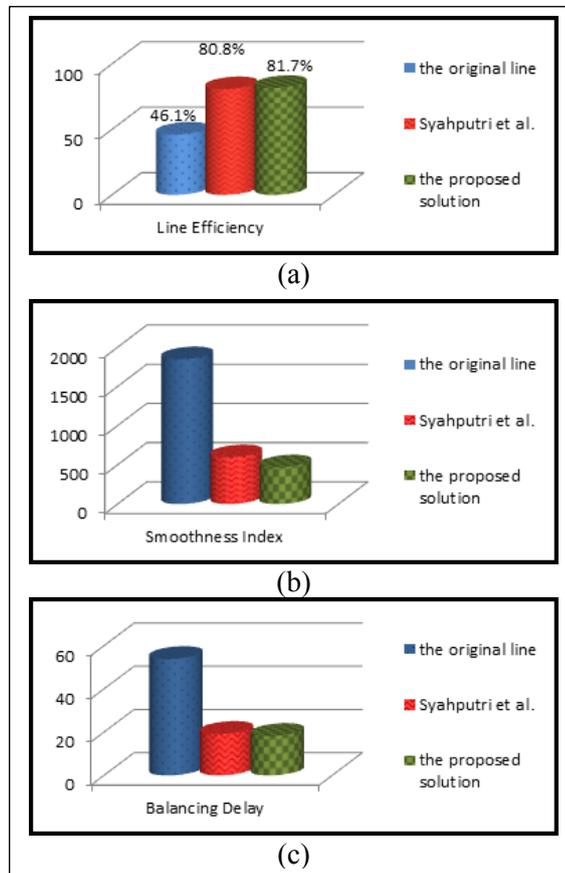


Figure 10: A comparison between the original line, developed line (by K., Syahputri et al.) and the proposed line by (a) line efficiency (b) smoothness index & (c) balancing delay.

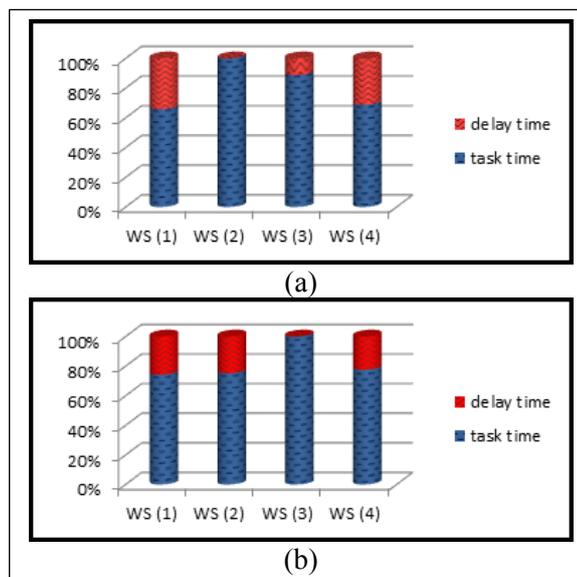


Figure 11: A comparison of the task and idle time for (a) the developed line (by K., Syahputri et al.) (b) the proposed method.

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