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The Heuristic Methods for Assembly Line Balancing Problem: A Case of Vietnam Garment Industry

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Abstract: The problem of balancing line in garment industry is a big problem and it is difficult to find the optimal solution. Setting up the industrial sewing line by manual method, based on the experience of the line manager takes a long time while the line efficiency could not be highly achieved. This study has adopted three different heuristic methods to build a solution for the sewing line balancing and applied these methods for a typical case of Vietnam garment firm. The results show that applying heuristic methods to balancing industrial sewing line saves time, improves the line efficiency and improves productivity for the whole industrial garment firm.
Keywords: Assembly Line Balancing Problem, Heuristic Method, Ranked Positional Weight, Largest Candidate Rule, Kilbridge and Wester.

I. INTRODUCTION

Vietnam has a long tradition and history from hundreds of years ago in textile and garment sector. Nowadays, Vietnam turned to be an emerging player in the global textile and garment industry. The garment sector has seen speedy and sustainable development over more than a decade. In 2016, Vietnam has ranked after China and Bangladesh to be the third top garment exporters in the world. Presently, the garment industry played a crucial role in national socio-economic development and became the major contributor to the total export earnings of Vietnam, accounting for 16% of the country's total exports (2017) [1]. This industrial sector also creates a huge job opportunity for the country. With the population of 90 million, 2.5 million people are now working in nearly 6,000 textile and apparel manufacturing companies.

The major market for Vietnam textile and garment products are U.S., Europe, Japan and South Korea [1]. However, under the high pressure of a huge global demand, this industry in Vietnam has been facing the challenges in finding investment and changing equipment and technology to meet the world market requirement as well as to improve its world competiveness. Productivity in the garment industry of Vietnam is still lower than ones of the other players in the same region such as China, Thailand, Philippines and Indonesia [2].

How to improve productivity and the quality of the garment products are the major concerns of the managers and policy makers of this industry. There are many ways for productivity improvement that helps garment factories to boost up current labor productivity. Among those, higher productivity driven by improving assembly line balancing of the garment production is one of the critical approaches.

The typical problem facing with garment assembly line is the situation that while there is a set of workstations through a sub-assembly process is laying idle, bottlenecks and excess capacity happen in the others. The purpose of balancing a line is to reduce operator's idle time or maximize operator utilization. In a balanced line, work will flow smoothly and no time will be lost in waiting for work. Line balancing is an effective tool for greater efficiency by distributing the task over each work station in proper balance of the resources, thus increasing the productivity.

Many advanced information systems that are equipped with techniques and algorithms for solving line balancing issue have been used in the garment factories in many developed countries. However, in Vietnam, balancing sewing lines is still one of the very new issues.

Currently, the balancing line arrangement is mainly based on the experiences of the shop floor supervisors to transfer workers from one workstation to other when there is any congestion or idle status. Yet this manual method is impossible for big-sized garment factories. As a result, the productivity of the sewing lines as well as productivity of the whole factory is always at low and medium level compared to others of countries in the same region and in the world. This emerges the urgency of the research about the application of computer algorithms to solve the problem of balancing sewing lines for garment factories in Vietnam. This study is an attempt to propose the solution of the assembly line balancing for garment factories in Vietnam by applying the heuristic methods. The next parts of the paper will be structured as follows: Section 2 reviews related literature. Section 3 defines the line balancing problem and related technical terms. Subsequently, the scales and parameters for evaluating the effectiveness of the production line balancing solution will be presented. Section 4 describes the heuristic methods for solving line balancing. Section 5 presents the testing and results. Finally, some discussion will be drawn for future work directions.

II. LITERATURE REVIEW

In the industrial factories, products are produced in line according to the flow of patterns to compile to finished products. A line includes multiple workstations that specialize a given work tasks with the high expertise in labor and machinery. In other words, one to several tasks are grouped into one workstation. The process of deciding how to arrange these workstations in the production line and which tasks are assigned to a specific workstation to ensure that no workstation is overloaded while these others are idle, is so-called assembly balancing line in industrial factories. The main goal is to create the solution for assigning various tasks to workstations so that all workstations have the relatively equal length of time to complete all work contents at that station (i.e. the total length of time spent performing all the work tasks). By maintaining well balanced, the line could maximize uses of man power and machine capacity, as well as minimize the process time, thus increase production efficiency.

Balancing industrial sewing line is one of the specific applications of the line balancing problem. In the world, the garment industry in particular and the manufacturing industry in general have a long history, but it was not until the early 1950s that the balance of production lines began one of the research topics in the field of Industrial Engineering Management. There are many different approaches to line balancing problem which are used to optimize the allocation of resources and improve the efficiency of the production line. One of the typical studies in this area is that of Anthony A. Mastor. In his studies, Mastor [3] classifies the balancing problem into two types. The first type is designed for the production lines with a given specific cycle time, the solution aims to minimizes the number of workstations in the line. The second type is the form of the existing production lines with a fixed number of workstations. The goal of line balancing is to build up the plan for production line so that the process output is as high as possible, or in short, the cycle time of the line is minimal.

In general, the line balancing problem is a big and complex problem requiring suitable models and algorithms. There are many different techniques to solve this problem that have been studied in this field. These solutions can be divided into four main groups as follows [4]: The first group is composed of optimum seeking methods include branch and bound technique, dynamic programming, linear and integer programing [5]. The second group of solutions is the heuristic method, including constructive procedure, genetic algorithms, Tabu search, simulated annealing and ant colony optimization. The third is the group of machine learning solutions that includes the theory of constraints, knowledge-based approach and expert systems. The fourth group is the solutions using simulation models.

There are numerous studies in the group of optimum seeking methods, typical ones are those from Bowman. Bowman has adopted linear programming and integer programming to solve the equilibrium problem. Patterson and Albracht [6] presented the zero-one programming with Fibonacci search to solve assembly line balancing which requires about 50% - 60% of the variables to be expressed in the form of 0 and 1. By his method, the equation for balancing problem is solved by examining a sequence of variables 0-1 to find the final solution. In another way, Held et al [7] has proposed dynamic programming method with precedence constraints. However, the limitation of this study is that it is only suitable for small-sized production lines. Bautista and Pereira [8] have also used dynamic programming, yet based on the approximate solution for task allocation which satisfies the problem of large-scale assembly line. For the group of heuristic solutions, Suresh and his colleagues [9] has developed two algorithms that are Genetic-1 and Genetic-2 to provide the approximate solutions. Suresh and his team [10] have also constructed stochastic assembly line balancing solution using simulated annealing. This is an algorithm that is based on the probability distribution of real-time tasks in the assembly line. Helgeson and Birnie [11] have developed ranked positional weight technique to arrange the tasks on the workstations of the line based on their execution times. Kilbridge and Wester [12] constructed a weighted ranking algorithm based on the order of execution. Bautista and Pereira [13] use Ant algorithm to solve the constraints on the time and capacity of the production line. The third group of solutions can be represented by the typical researches of Eliyahu M. Goldratt's research [14] on the theory of constraints in production lines, Malakooti and Kumar [15] have adopted knowledge-based approach to solve the problem of balancing production lines with multiple objectives. Keytack H. Oh [16] presents an expert system for balancing sewing line. Finally, the simulation model has been applied in the study of J. Driscoll & AA Abdel-shafi [17]. There are also studies by Pablo Cortés, Luis Onieva & José Guadix [18] on optimizing and simulating production line to solve the balancing issue in motorcycle manufacturers.

In summary, there are many methods to solve the line balancing problem for the production line, but most of these approaches provide asymptotically optimal solutions and each of them comes up with a distinct solution about the layout design and arrangement for the production line. No less important is that no solution is considered as the best one for all various cases of line balancing problems.

III. ASSEMBLY LINE BALANCING

A. *Problem Definition*

An assembly line is a manufacturing system in which components are consecutively assembled by a set of tasks to produce an unfinished product. The unfinished product is then transferred from one workstation to its successive workstation along a line until they reach to the end of the line to complete a final product. Each and every station is assigned with a finite set of different tasks that link together by the precedence relationship among them. In other words, some tasks can only be started after other tasks have been finished. For each task, it is performed in a certain time called as the task time. For a given workstation, the sum of the task time of all tasks performed at this station should not exceed the maximum amount of time a product is allowed to spend at each station. That is called the cycle time. Under two constraints of precedence relations and cycle time restrictions, how to equalize the amount of tasks at each workstation such that each workstation has the same work load/time for processing a unit is known as the assembly line balancing problem. If each workstation on the assembly line takes the same amount of time to perform the work elements that have been assigned, then products will move smoothly from workstation to workstation with no need for a product to wait or a worker to be idle. By this way, balancing a line can help reduce operator's idle time or maximize operator utilization, thus increasing the productivity of the whole manufacturing system.

B. *Technical Terms*

To reach to a completed product, the work is divided into series of elementary tasks with short duration so-called task. If $\boldsymbol{V}$ is a set of tasks to finish a single product, then $\boldsymbol{V}$ is represented as $\boldsymbol{V = \{1, \ldots, n\}}$, whereas $\boldsymbol{i}$ is the index of task and $\boldsymbol{i = 1, 2, \ldots, n}$, and $\boldsymbol{i}$ is the total number of tasks to produce a completed product. To perform a given task $\boldsymbol{i}$, it requires a period of time $\boldsymbol{t_i}$. It is so-called a standard processing time of task $\boldsymbol{i}$.

A production line includes a set of workstations located along the production line or raw material processing line that are numbered as $\boldsymbol{1, 2, \ldots, m}$. Each workstation will be allocated to perform one single task or a set of tasks. If $\boldsymbol{S_k}$ is a set of tasks assigned to workstation $\boldsymbol{k}$, hence $\boldsymbol{t_{S_k}} = \sum_{j \in S_k} \boldsymbol{t_j}$ is the total length of time for that workstation to perform all the assigned tasks, so-called in short as workstation time In the garment production, the process is continuously carried out in the sewing line and the work results of this workstation will be transferred to the workstation. However, the transition between tasks will depend on the constraints between them. This constraint is the requirements of precedence order among these tasks. For example, in the sewing line of T-shirt products, there are the task such as: sewing the collar, sewing the shirt body, sewing the sleeves. These tasks must be performed separately before moving to the task of assembly of the collar and sleeve to the body of the shirt. Balancing in sewing line is to assign a given set of tasks to an ordered set of work stations and ensures that the precedence constraints of tasks are satisfied while some general objectives such as line performance measure, machine/labor utilization or production cost are optimized.

The order constraint of task to produce a complete product, along with the time taken to perform each task are represented by a diagram so-called precedence diagram. The precedence diagram is a type of network representation that consist of nodes and edges. For representing the tasks of a given production line, two decisions need to be made: What constitutes a node and what forms a link? On the precedence diagram, each node represents a task, indexed by the task code along with its processing time in parentheses. The links navigate between two given nodes to show the order relationship between them.

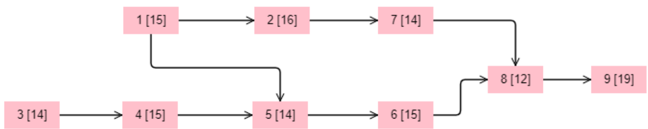

Figure 1. Precedence Diagram

Figure 1 is the precedence diagram of an example of production line. There are 9 tasks with the task's processing time in the parentheses correspondingly. For example, node 1 (task 1) has the processing time of 15 seconds, node 2 (task 2) has the processing time of 16 seconds. The link directed from node 1 to node 2 and 5 show that task 1 must be completed before turning to task 2 and task 5. If we allocate these nine tasks of this production line in five workstations with the following arrangement in details:

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$\boldsymbol{S_1} = \{\mathbf{1}, \mathbf{3}\}$, i.e. workstation 1 will be responsible for task 1 and task 3; $\boldsymbol{S_2} = \{\mathbf{2}, \mathbf{4}\}$, i.e. workstation 2 will perform task 2 and task 4, $\boldsymbol{S_3} = \{\mathbf{5}, \mathbf{6}\}$, i.e. workstation 3 will perform tasks 5 and 6, $\boldsymbol{S_4} = \{\mathbf{7}, \mathbf{8}\}$, i.e. workstation 4 will perform tasks 7 and 8, and $\boldsymbol{S_5} = \{\mathbf{9}\}$, that is, workstation 5 will perform task 9. With this "task to workstation" allocation, the cycle time will be $\boldsymbol{c} = \mathbf{31}$ which is also the time taken at workstation 2 to complete all of its tasks. This is the longest time length among the workstation times along the production line. Therefore, we can count the free time of the workstations 1, 2, 3, 4, 5 are: 2, 0, 2, 5, 12 correspondingly. In summary, there are many different plans to layout the workstations along the production line. As the results, the efficiency, the amount of wasted time, as well as productivity of these alternative arrangements will also vary. Therefore, the next part of the study will present the well-known parameters to assess the effectiveness of a specific line balancing solution.

C. Scales to Evaluate the Balance of the Production Line

In order to assess the balance of production lines, one draws up scales to evaluate the balance of different algorithms. This study uses four scales in Scholl's study [19], [20], [21] to measure the balance of the line as following:

1) *Line Efficiency:* Line efficiency ($\boldsymbol{LE}$) is an indicator of the effective use of time in the assembly line. $\boldsymbol{LE}$ is expressed as the ratio of time at work stations $\boldsymbol{t_{S_k}}$ to the product of the cycle time $\boldsymbol{c}$ and workstation number $\boldsymbol{m}$. Therefore, $\boldsymbol{LE}$ is mathematically represented as follows:

$$LE = \frac{\sum_{k=1}^{m} t_{S_k}}{c.m}$$

where:

m is the number of work stations of the production line
c is the cycle time
t_{S_k} is the total time of performing the steps at the station k

2) *Balance Delay:* Balance delay ($\boldsymbol{BD}$) is the amount of idle time on production assembly line caused by the uneven division of work among workstations [22]. Therefore, $\boldsymbol{BD}$ is mathematically represented as follows:

$$BD = \frac{c.m - \sum_{k=1}^{m} t_{Sk}}{c.m}$$

where:

m is the number of work stations of the production line
c is the cycle time
t_{S_k} is the total time of performing the steps at the station k

3) *Smoothness Index:* Smoothness index (SI) is used to measure the distribution of working time between the working hours in the assembly line. At the same time, it is also an important indicator to reflect the working time of each station. The smaller the smoothness index number, the smaller the working time fluctuation between the workstations of the assembly line, hence, the better the balance of the assembly line. Its formula is as follows:

$$\boldsymbol{SI} = \sqrt{\sum_{k=1}^{m} (c - t_{Sk})^2}$$

where:

$\boldsymbol{m}$ is the number of work stations of the production line
$\boldsymbol{c}$ is the cycle time
$\boldsymbol{t_{S_k}}$ is the total time of performing the steps at the station $\boldsymbol{k}$

4) *Production Rate:* With the assumption that the number of working hours of the production is 8 hours per day, production rate ($\boldsymbol{PR}$) is the total working time a day by second divided to the cycle time and the number of workstations, as follows:

$$\boldsymbol{PR} = \frac{\mathbf{8 * 60 * 60}}{\boldsymbol{c * m}}$$

where:

$\boldsymbol{m}$ is the number of work stations of the production line
$\boldsymbol{c}$ is the cycle time

IV. HEURISTIC METHODS

A heuristic method is a procedure to discover a fairly feasible solution, yet not necessarily an optimal solution, for the specific line balancing problem. There is no guarantee about the quality of the solution obtained, but a well-designed heuristic method usually can provide a solution that is at least nearly optimal (or with the conclusion that no such better solutions exist). The heuristic method also should be sufficiently efficient to deal with very large line balancing problems. This is an iterative algorithm, where each iteration searching for a new solution that might be better than the one found previously. After a given time running the iterative algorithm, the final solution it finds out is can be seen as the best one. In this research, we use three heuristic approaches, namely Largest Candidate Rule (LCR), Kilbridge and Wester's method (K&W), Ranked Positional Weight method (RPW). These are heuristic procedures which selects the tasks to assign to each workstation according to their processing time and their relationship order in the precedence diagram.

A. The Largest Candidate Rule (LCR)

This is the method that aim to achieve the line balance by distributing the total workload on the assembly line as evenly as possible, despite the reality in which it is impossible to obtain a perfect line balance among the workstations. It is then the role of line balance efficiency which is related to the differences in minimum rational processing time and the precedence constraints between the tasks. The LCR accounts for work tasks to be arranged in a descending order of the task time to allocate it to workstation, so that each workstation time Tek should not exceed the cycle time c.

B. Kilbridge and Wester (K&W)

Kilbridge and Wester method is a heuristic procedure that selects work task to assign to workstations according to their positions in the precedence diagram. This method known for its reliability in overcoming the difficulties facing in LCR method where a given task could be selected based on it processing time. Yet it fails to comply with the order relationship among the tasks in the precedence diagram [4].

C. Ranked Positional Weight (RPW)

RPW was introduced by Helgeson and Birnie in 1961 [5]. It is a combination of LCR and K&W methods. The RPW takes account of both the processing time of the task and its position in the precedence diagram. Therefore, the tasks are assigned to workstations based on their RPW weight.

D. Steps of Algorithm Procedure

1) *Step 1:* Set up the precedence diagram for the assembly line
2) *Step 2:* Compute the weight for each task
3) *Step 3:* Iterative running

a) *Step 3.1*. The task that satisfies the assignment condition will be stacked in the queue

b) *Step 3.2*. Re-arrange tasks based on their weight
   a. in descending order of the task time (for LCR case)
   b. in ascending order of a given task's positions in the precedence diagram and in a descending order of its task time (for K&W case)
   c. in descending order of RPW weight (RPW case)

c) *Step 3.3*. The tasks in the queue will be respectively assigned to workstations. For each allocation of task, it is necessary to check the constraint that the workstation time should not exceed the cycle time. If the workstation time exceeds the cycle time, the allocation will be for the next task. If all the tasks fail to comply with this constraint, the allocation will be for the next workstation.

d) *Step 3.4*. Repeat step 3.1

4) *Step4*. Loop until the final task in the precedence diagram.

V. EMPIRICAL TESTING

A. Data Description

To test and tocompare these assembly line balancing methods, this study has used the dataset gathered from a sewing line of a garment company in Vietnam. For a finished product, the technical department in the garment factory will divide the process of sewing into 73 tasks. The longest task time is for task 56 and task 59 with the processing time of 200 seconds. Task 70 has the shortest processing time of 7 seconds. Task code, task name and respective processing time are listed in details in Table 1.

Table 1. List of tasks and its processing time

Task ID	Processing Time	Precedence relation	Task ID	Processing Time	Precedence relation
1	16	-	37	118	-
2	104	3;1;4	38	10	40
3	19	-	39	14	-
4	16	-	40	25	39
5	19	9	41	95	54
6	20	10	42	44	58
7	10	6	43	18	47
8	16	7	44	25	11;5;38;37;18;36
9	31	8	45	57	50
10	48	2	46	28	45
11	45	12	47	26	46
12	22	13	48	17	44
13	28	-	49	14	48
14	36	-	50	18	49
15	22	-	51	35	43
16	117	-	52	28	42
17	56	19	53	48	56
18	96	20	54	21	52
19	46	15	55	40	57
20	36	23	56	200	51
21	50	14;17;16	57	63	41
22	93	21	58	89	53
23	79	22	59	200	66
24	53	25;28	60	143	55
25	22	-	61	43	59
26	35	29	62	174	60
27	38	26	63	81	61
28	50	-	64	60	62
29	50	-	65	30	61
30	28	27	66	25	64
31	81	35	67	30	65
32	111	31	68	14	61
33	15	24	69	102	65
34	78	33	70	9	69
35	26	34;30	71	90	63
36	59	32	72	18	68
			73	120	70;71;72;67

In this testing scheme, we apply three different heuristic methods to discover a fairly feasible solution of the wing line balancing. The first step is to build the precedence diagram as shown in Figure 2. Each node of the diagram is numbered by the code of the task, along with the processing time. Based on this precedence diagram, the order relationship between the tasks is clearly shown by the links between the nodes.

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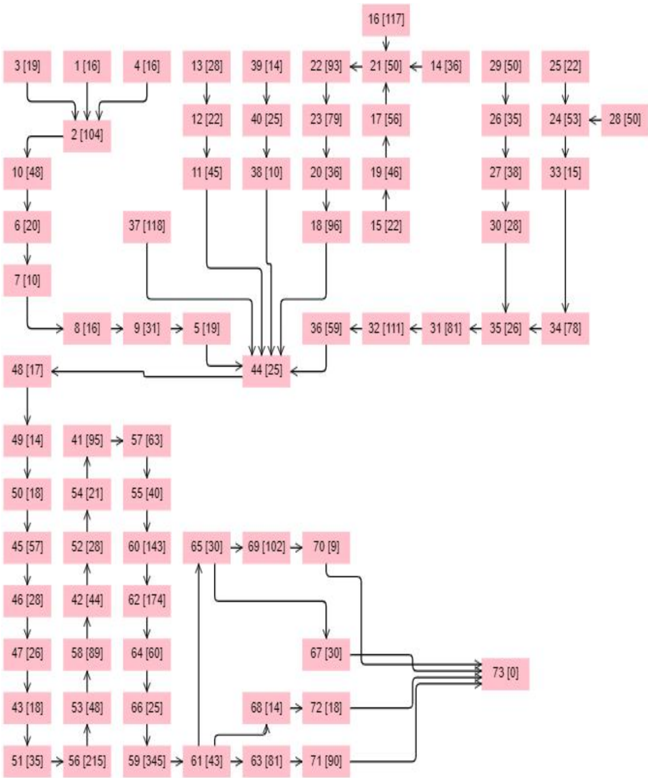

Figure 2. The precedence diagrams

B. Results and Discussions

For Large Candidate Rule, the weight allocated for each node (i.e. task) is its processing time, sorting by descending order.

For Kilbridge and Wester, the weight allocated for each node (i.e. task) is the combination of task's positions in the precedence diagram, sorting by ascending order and, task's processing time sorting by descending order.

For Ranked Positional Weight method, the weight allocated for each node (i.e. task) is the total time to go through this node to the final node of the precedence diagram. The node is sorted by descending order of node's RPW weight.

The results of weight calculations based on these three methods are listed in the Table 2.

In order to assess the balance of production line by applying the three heuristic methods, we make the comparison among them based on the four scales: Line Efficiency, Balance Delay, Smoothness Index, Production Rate. For all the four scales, it is interesting to find that LCR is seen to be the most effective method as compared with others.

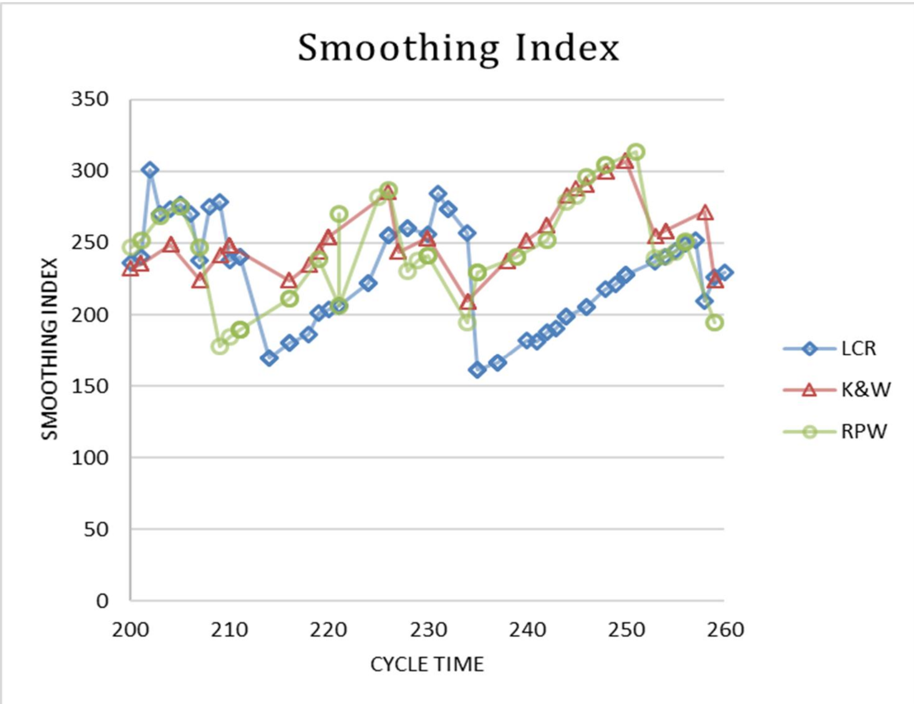

Figure 3. Comparision among heuristic methods on three scales LE, BD and SI

However, when we consider about the number of workstations in the assembly line and the number of products that can be finished per day by the line (table 3), we can see that if the numbers of workstations are 19, 22, 23, the maximum number of products will be 123, 139 and 144 respectively for all the three heuristic methods. In case of 21 workstations, RPW provides the best assignment solution for the production line of 138 products per day. In case of 17 or 18 workstations, LCR can achieve the highest number of finished products per day of 112 and 123 respectively.

Table 2. Weight calculation based on heuristic methods

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Large Candidate Rule		Kilbridge and Wester		Ranked Posional Weights		Large Candidate Rule		Kilbridge and Wester		Ranked Posional Weights	
Task ID	LCR Weight	Task ID	K&W Weight	Task ID	RPW Weight	Task ID	LCR Weight	Task ID	K&W Weight	Task ID	RPW Weight
59	200	1	1	15	2483	20	36	32	7	11	2050
56	200	3	1	28	2478	14	36	18	8	40	2040
62	174	4	1	16	2476	51	35	36	8	5	2024
60	143	16	1, 3	19	2461	26	35	5	8	38	2015
73	120	14	1, 3	25	2450	9	31	44	9	44	2005
37	118	37	1, 8	29	2433	65	30	48	10	48	1980
16	117	29	1	24	2428	67	30	49	11	49	1963
32	111	28	1	17	2415	30	28	50	12	50	1949
2	104	39	1	14	2395	46	28	45	13	45	1931
69	102	13	1	26	2383	52	28	46	14	46	1874
18	96	25	1	33	2375	13	28	47	15	47	1846
41	95	15	1	34	2360	47	26	43	16	43	1820
22	93	12	2	21	2359	35	26	51	17	51	1802
71	90	26	2	27	2348	44	25	56	18	56	1767
58	89	24	2	30	2310	66	25	53	19	53	1567
63	81	2	2	22	2309	40	25	58	20	58	1519
31	81	40	2	35	2282	15	22	42	21	42	1430
23	79	19	2	3	2272	12	22	52	22	52	1386
34	78	11	3, 8	4	2269	25	22	54	23	54	1358
57	63	38	3, 8	1	2269	54	21	41	24	41	1337
64	60	17	3	31	2256	6	20	57	25	57	1242
36	59	10	3	2	2253	5	19	55	26	55	1179
45	57	27	3	23	2216	3	19	60	27	60	1139
17	56	33	3	32	2175	50	18	62	28	62	996
24	53	34	4	10	2149	72	18	64	29	64	822
21	50	21	4	20	2137	43	18	66	30	66	762
29	50	6	4	37	2123	48	17	59	31	59	737
28	50	30	4	18	2101	8	16	61	32	61	537
10	48	35	5	6	2101	1	16	65	33	65	291
53	48	7	5	13	2100	4	16	63	33	63	291
19	46	22	5	7	2081	33	15	68	33	69	231
11	45	31	6	12	2072	49	14	72	34, 35	71	210
42	44	23	6	8	2071	39	14	67	34, 35	68	152
61	43	8	6	36	2064	68	14	69	34	67	150
55	40	20	7	9	2055	7	10	71	34, 35	72	138
27	38	9	7	39	2054	38	10	70	35	70	129
						70	9	73	36	73	120

Table 3. Number of products based on

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number of workstations

	Maximum number of products finished per day		
Number of Workstations	LCR	K&W	RPW
17	112	111	111
18	123	113	114
19	123	123	123
20	135	126	130
21	137	133	138
22	139	139	139
23	144	144	144
24	143	-	-

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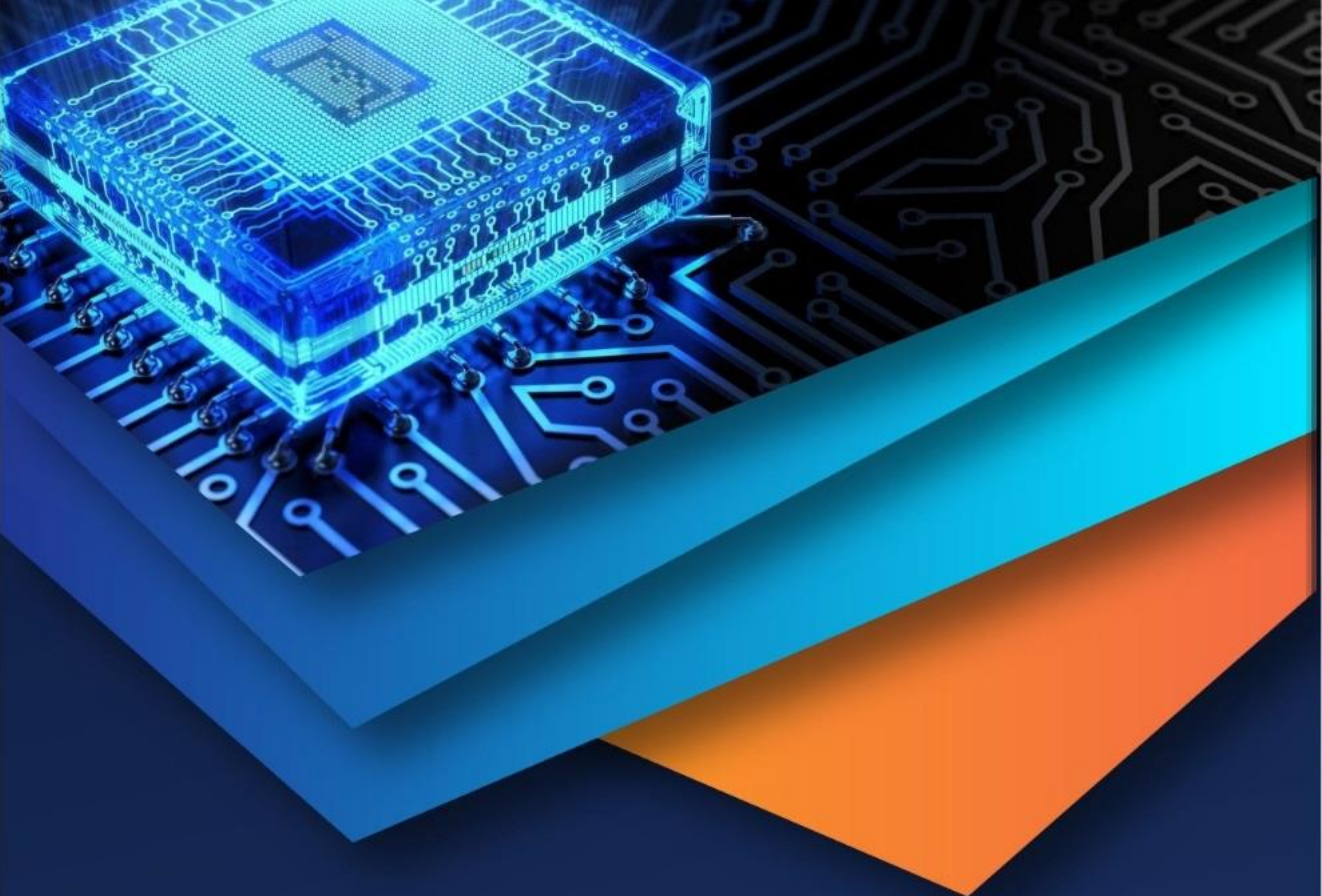

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