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Research Article

Online Distribution and Load Balancing Optimization Using the Robin Hood and Johnson Hybrid Algorithm

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Abstract

Proper planning of assembly lines is one of the concerns of production managers at the tactical level so that it will be possible to use the machine capacity, reduce operation costs and deliver customer orders on time. Lack of an efficient method in balancing assembly lines can create serious problems for manufacturing organizations. The use of ordinary methods of balancing cannot balance the load distribution on the assembly line which can cause higher depreciation of machinery in the assembly line. In the present paper combined Robin Hood and Johnson algorithm approach is used for the problem of load distribution and optimized online load balance, based on the optimized order of works on the assembly line for polymer cover print in Iran Plot Company. The results are analyzed in terms of creating load balance in the assembly line. The results obtained in the present study include the uniform load distribution of orders to the machines and the presence of reservations and the backup machine that cause the production process to continue with a proper sequence and the priorities without any interruption.

Keywords: Line Balancing; Online load balancing; Robin Hood algorithm; Assembly line balancing; Load balancing

1. Introduction

Competitive conditions force the production systems to search for efficient designs and planning for their assembly line (Baudin.M, 2002). Flexibility is among the most modern and effective methods in order-based production systems and proper management of costs. Assembly lines should be planned such that they respond to different levels of production strategies (Levi et al., 2003). In tactical level, short and medium-term decisions about planning are important (Mula et al., 2010). One of the most important problems at the tactical level is the mass production and ordering products. The assembly line consists of several workstations and machines that are connected in production sequence where the input of one is the output of another. In this case, each machine and the process performed on the product face the process and technology limitations in terms of time, volume and weight of each action. In many cases, by observing a process, it can be noticed that a number of machines are not working, but some other equipment work continuously and there are many workpieces in front of them, in order to be loaded on the machines to start new operations; and also some workers are extremely busy with a considerable amount of unfinished job in fron of them. The existence of downtime or too much job means the lack of balance in the production process that is among the factors causing problems for system management. To resolve these problems the manager has to provide solutions to improve the existing conditions. An activity is the smallest part of a process which can not be divided into smaller parts, and a station is a part of an assembly line in which some activities are performed (Yolmeh and Salehi, 2015).

One of the ways to increase the effectiveness and efficiency of an assembly line is balancing (Boysen, 2007). The balance of the assembly line in terms of timing and distribution of the load on the machine can optimize two important indices of timely delivery and timely production that enhances customer satisfaction and competitive advantages, reduces the costs caused by unbalanced machines and stagnation of semi-finished products in assembly lines (Yano and Bolat, 1989) (Bart et al, 1992) (Scholl et al, 1998).

In this paper, we investigate the assembly line both in terms of time and load distribution on the printing line of polymer covers used in the food packaging industry which consists of Heliogravure Printing, laminating, cutting and packaging machines. To balance the mentioned assembly lines, considering the restrictions in balancing algorithms and negligible workload of themachines, a modified Robin Hood algorithm that performs online workload balancing in the assembly lines is utilized. Johnson algorithm is used to determine the sequence of orders to allocate the job order to the Robin Hood algorithm. The Robin Hood algorithm for real condition production has not been used in scientific

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researches so far; and combining it with Johnson algorithm can increase the efficiency of the algorithm, which is the aim this research seeks to accomplish alongside the other aforementioned goals. The rest of the paper is as follows: literature review in section 2, the proposed method in section 3, experimental setting in section 4, numerical calculations in section 5, and conclusion in section 6.

2. Literature Review

This section is divided into three parts: models of balancing the assembly line, Robin Hood online load balancing algorithms. Johnson algorithm

2.1. Models of balancing the assembly line:

In general, assembly line balancing includes logical classification of operations and action elements in the form of workstations in compliance with the prerequisite limits, job time cycles and other special restrictions to optimize the target(s) (Salveson, 1955). Simple Assembly Line Balancing Problem (SALBP) was initially formulated by Salson and its classification was performed by Baybars (1986). He explained assembly line balancing in the simplest form in which the priority limitations are related to assembly operations, time cycle limitation and operation allocation to the downtime of the machine. In practice these simple assumptions caused limitations in solving the problem using SALBP and motivated more realistic modeling and problem-solving methods in later studies (Becker and Scholl, 2006). SALBP explains that considering the list of activities and the time required to perform processes on each activity and prioritized restrictions between the activities, the job distance, boundaries, and workstations are as below:

- In a certain time cycle, the purpose is to minimize workstation. SALBP-1
- In certain workstations, the purpose is to minimize the time cycle. SALBP-2
- Workstation and time cycle are minimized together SALBP-E
- In certain workstation and time cycle, the real job allocation to the station is obtained SALBP-F

SALBP has the following features:

- Homogeneous mass production
- Specific manufacturing process
- Monilithic production line (without buffer between workstations)
- Job cycle time a an integer and specific number
- Not relating some restrictions to the others

Another classification has been proposed in assembly line balancing issues considering the positioning of machinery in which straight line and U-shaped layouts are called SALP and SULP (Alavidoost, Fazel, 2015). Gutjahr and Nemhauser discussed the assembly line balancing problem as Hard N-P problem(Gutjar and Nemhauser, 1964).

The proposed assembly line methods include Ranked Positional Weighting Technique (RPWT), COMSOAL technique (ARCUS,1966), MALB technique (Dar-El,1973), MUST technique (Dar-El , Rubinovitch.1979), LBHA method (Baybars , 1983), Critical Path Method (CPM) (Avikal et al, 2013), the meta-heuristic genetic algorithm (GA) (Falkenauer and Delchambre, 1992), Simulated Annealing (SA) (Baykasoğlu, 2006), Tabu Search (TS) (Peterson, 1993; Lapierre et al, 2003) Particle Swarm Optimization (PSO) (Jian-sha et al, 2009), Ant Colony Optimization (ACO) (Sabuncuoglu et al, 2009) A multi-objective GA for solving the U-shaped Assembly Line problem (Hwang et al, 2008).

Between 2008 and 2014 genetic algorithm was utilized to optimize assembly line in different aspects (Kucukkoc and Zhang, 2014). Most conducted studies have focused on primary and secondary balance problems. In the primary problems, the assembly line period is known as the problem input, and the purpose is to reduce the number of workstations. In the secondory problem, the number of assembly stations is known as the problem input, and the objective to is to minimize the time cycle (Paksoy et al., 2006; Scholl and Becker, 2012). All these models do not consider the weight distribution on the machines and their implementation is not simply possible due to the complexity of the production systems with automatic and semi-automatic machines on their assembly lines (Caramia and Dell'Olmo, 2006).In the product lines in which combination of machinery in different categories work to manufacture the final product and the production system is order based, the optimized scheduling of production is always one of the problems in the field of operation of this type of production plants (Boysen et al, 2007).

2.2.Online balance of load in the production line

Without proper planning and resource allocation, long queues are formed in each processing and operation leading to disturbance in system balance and the presence of huge workloads on some machines and the downtime of other ones. This problem originates from the lack of job balance on the assembly line. To resolve this problem, the On-Line Load Balancing algorithms are provided for assembly lines that lead to a balanced distribution of workload on the machines (Caramia & Dell'Olmo, 2006).

2.3.Modified Robin Hood algorithm

This algorithm is simple and definitive. It allocates orders online and makes decision about new order allocation not only based on the load of the current job but also by considering the allocation of the previous work. Based on the state of the current problem any order can be assigned to more than one specific machine and each job order has a certain weight.

In this method for allocation of the first order to the desired machine L (1) the following equation holds (where the order j is allocated at time t with the load w_j):

$$L(t) = \max \{L(t-1), w_j, \mu(t)\} \quad (1)$$

The value of $\mu(t)$ is obtained from:

$$\mu(t) = \frac{1}{n}\left(w_j + \sum_{i=1}^{n} l\, i(\text{t-1})\right) \quad (2)$$

Here the loadable and unloadable machines are determined and this process will continue until the balanced order is allocated. To determine the loadable and unloadable machines the following equation is applied:

$$L_{i(t)} < \sqrt{n} \times L_{(t)} \quad (3)$$

- Direct layout plan
- The proportionate existence of machine and worker at the workstations (Scholl and Becker 2006; Paksoy et al., 2012)

If the above relation holds the machine is load-able, otherwise it is not (Caramia and Dell'Olmo, 2006).

2.4.Johnson algorithm

Sequencing the operations in the timing of manufacturing activities is mainly performed after defining the manufacturing process and determining the required machines. In a shop production system, the problem of sequencing N works on two machines, which is performed on the assumption that each job has two stages, the first stage of which should be done on the first machine and the second stage on the second machine, is known as "Johnson" problem. Johnson implementation steps are as follows:

1) The shortest time to finish the jobs are determined by machine 2.

2) If the shortest time was associated with machine 1, this job is performed at the beginning of the sequence of the remaining works and then step 3 is performed. If the shortest time was associated with machine 2, this job is performed at the end of the sequence. Between the similar conditions, one is selected arbitrarily.

3) Remove the scheduled works from the list and if there is an unfinished job, go to step 1, otherwise stop (Jin Deng et al, 2015).

3. Research Methodology

3.1. Overview

In each assembly line formed of Heliogravure printing machines and the printing machines used in food packaging, the orders are delivered online into the production line. Due to the competitive price of these businesses, reducing the operating costs and the use of assembly line and human resource capacity is important, because in such production lines the time imbalance between the production flow and the machines increases the time to implement the required processing and increases the inventory time and delay in the production process. Also, the mere attention to the balance of the sequence of operations leads to neglecting the proper load distribution on different machines of the production plant; therefore, in some machined we are faced with an overload that causes an increase in the rate of depreciation. In such lines, these machines cannot be replaced; this leads to the production process stall and the resulting losses and maintenance costs and even the reduced rate capacity of the machines after the application of repair. These types of production systems are fully machine-based and are not efficient using meta-heuristic algorithms such as genetic and heuristic algorithms since these algorithms are not able to perform simultaneous balancing of production time and load distribution. There is a need for the algorithms that have the ability to use methodes that perform simultaneous balancing of production time and load distribution. Therefore the On-Line Load Balancing algorithms are used here (Caramia and Dell ' Olmo, 2006).

For the online balancing of the assembly lines, the problem of job order allocation to the *n* machines is defiend, and job allocation will be performed immediately after the entry of finalized orders which leads to the work loading on the machine during the operation process in that machine. In this case, the orders should be allocated in balanced mode with the correct sequence of the production process to the machines for online balancing (Caramia and Dell'Olmo, 2001). It should be noted that in this case two types of works are loaded on the machines:

1) Temporary works: These works have limited process time. They are discussed in the field of reworks caused by problems of quality control errors and customer complaints.
2) Permanent works: these works are considered as the value-added operations in the production process and affect the main load on the machines and the time for production per machine and capacity (Caramia and Dell ' Olmo, 2004)

3.2. Generation of a solution and Fundamental steps

In a case study of the study, there is a printing plant on BOPP and Polyester and PVC films and the final product should be passed through printing, lamination and sealing, cutting and packaging stages. The schematic view of the production process is shown in Figure 1:

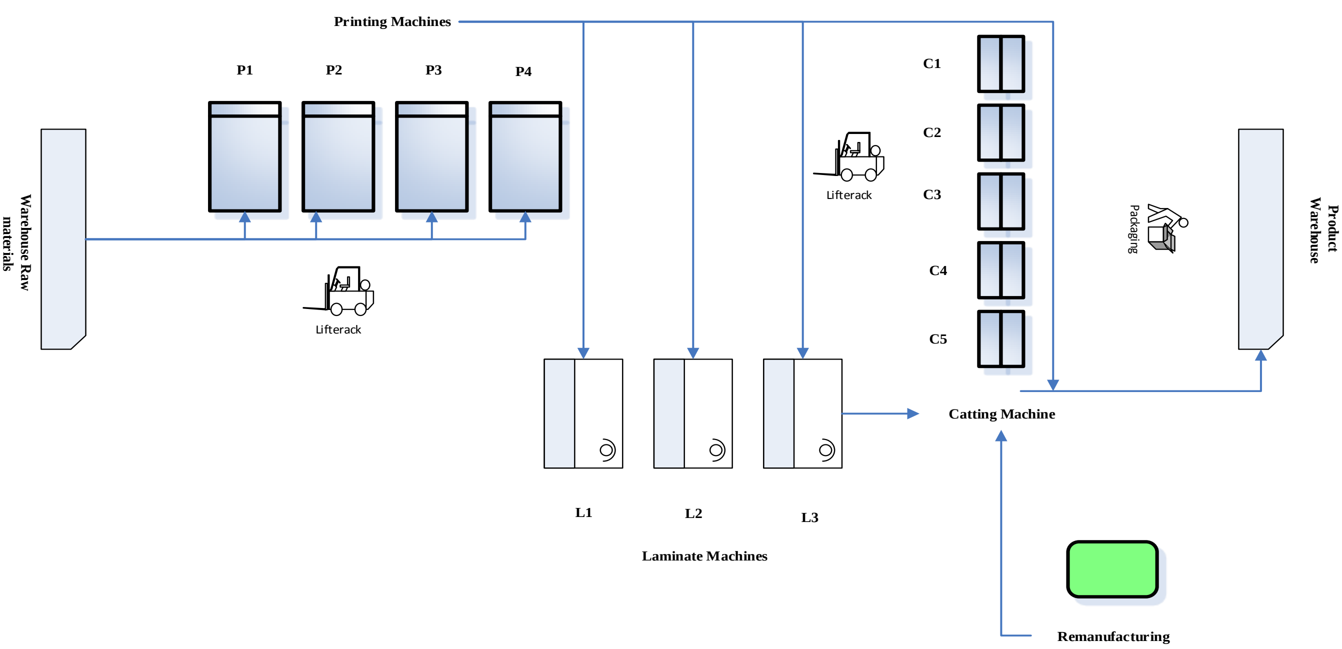

Fig. 1. Schematic of the production line

In the initial review, the forklifts and trucks to transport raw materials and materials used in the process will be added to the above machines. The aim is to minimize the maximum load by minimizing the sum of the value of the difference between the loads on each machine and the average value.

Load happens when the job *j* is done on the machine, the vector of which is as below:

$$P_j = \{P_{1j}.P_{2j}.\dots.P_{nj}\}$$

Whrer P_{ij} is the load increase on the machine *I* when the job *j* is allocated to it and this load increase happens in d_j.

In the above-mentioned assembly line, there is an order restriction on each machine according to the capacity of each machine in performing the details of each order as well as considering the production sequence. In such a case, the job order *j* with weight W_j should be allocated to machine *i*. One thing that is very important in this case is that the temporary job caused by rework (Plotski, 2015), if it exists, enters the online balancing problem as a restriction along with the permanent works a machine is allocated to, so that the necessary process is applied to it. About the weight of each order, an efficient algorithm called Robin Hood or RH algorithm is used in the online balancing of the production lines. From the schematic it is obvious that RH algorithm should solve the allocation problem in five modes. In the manufacturing (permanent work) mode where the order is allocated to one of the machines, it is either allocated to one of the laminate lines or the cutting lines and the laminated products are allocated to the cutting lines. In reworking (temporary work) only the products which need to be improved are allocated to the cutting line directly and allocation problem is done on cutting machines.

$[P_1.P_2.P_3.P_4]$ Printing machines

$[L_1.L_2.L_3]$ Laminating machines

$[C_1.C_2.C_3.C_4.C_5]$ Cutting Machine

In this study, based on the orders of each work day including 10 manufacturing and 2 reworks, the job allocation by Johnson’s algorithm is done given that the manufacturing process is sequential where the sequence of *n* orders has three production process (Jin Deng et al, 2015); and its balancing is performed by Robin Hood algorithm which minimizes the maximum load and the total difference between load on each machine and the average load on the system. Then the real improvements in the assembly line are analyzed in terms of optimum use of capacity, reducing costs in this area and reviewing the completion of the orders allocated by Robin Hood algorithm.

$$X: Min \sum |(\mu(t) - L_i(t)| \qquad (4)$$

We performed the comparison for new solutions based on the available data and the actual conditions of the assembly line and determine online balancing in the production system. Also, using the simulation, we analyzed other combinations of the order of the later 10 days in normal and optimum conditions and studied the results obtained about the performance and improvement of the algorithm.

3.3. Proposed algorithms

The proposed algorithm is shown in the Figure 2.

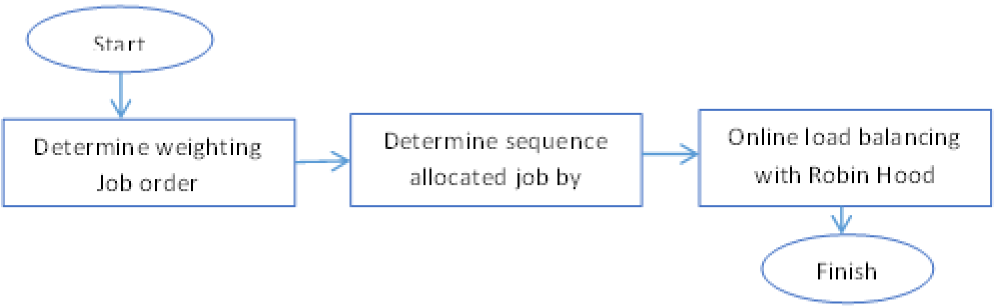

Fig. 2. Proposed algorithm

4. Experiment Setting

At the beginning of each work cycle, the machines are unemployed and empty and 12 orders pass the course of production depending on the nature of the required process. The time period for each job is extracted by step watch technique. Neglecting the workshop transportation limits, the numerical calculations are performed by the actual state of the job at the beginning of the period.

4.1. Use of algorithms on the assembly line (numerical calculations)

When implementing the Robin Hood algorithm on the assembly line the lines should be empty and inactive, which is the beginning of the job period (Caramia and Dell'Olmo, 2006). Tables 1 and 2 present the order of works and the passage of each order through the machines and the time of each order in each process.

Table 1
The combination of orders and numbers in each process

Machine / Job type		Printing Machine	Lamination Machine	Cutting Machine	Total
Manufacturing	Print - cutting	3	0	3	12
Manufacturing	Print-Laminate - cutting	7	7	7	
Re-manufacturing				2	

Table 2
The duration of working on each order in each machine

	Job	Print duration	Laminate duration	Cutting Duration
Manufacture	J1	120	60	80
	J2	160	70	90
	J3	140	65	85
	J4	130	62	82
	J5	150	68	88
	J6	120	60	80
	J7	160	70	90
	J8	160	0	80
	J9	140	0	75
	J10	120	0	70
Remanufacture	J11	0	0	70
	J12	0	0	75

Cnsidering the number of operators, the amount of raw material, time duration of the order, and their locating coefficient using the SAW method of simple weighting (Harsanyi, 1955), the weight of each job order on each machine is extracted. Using the adjustment factor determined by the experts the weight of orders are as Equation 4.

$$A^* = A_i \left| Max \frac{\sum_j w_j . r_{ij}}{\sum_j w_j} \right. \quad (4)$$

Table 3
job loads on each group of machines

Job	Weighting on printing machine	Weighting on cutting machine	Weighting on laminating machine
J1	4.72841357	4.268184243	3.201138182
J2	5.772269458	4.801707274	3.627956607
J3	5.263739693	4.534945758	3.467899698
J4	4.978232427	4.374888849	3.307842789
J5	5.549246958	4.695002668	3.627956607
J6	4.839864716	4.534945758	3.201138182
J7	5.799065815	4.801707274	3.734661213
J8	4.638291003	4.268184243	
J9	4.169955774	4.001422728	
J10	3.723257655	3.734661213	
J11	1.560316054	3.734661213	
J12	1.333807576	4.001422728	

In the first step, the works should be allocated to printing machines. To determine the priority of order entry in the Robin Hood algorithm, the Johnson method is used. The entrance order is presented in Table 4.

Table 4
Determining the order entry by Johnson method in Robin Hood algorithm for printing machines

J7	J2	J5	J3	J6	J4	J1	J8	J9	J10

Order allocation of printing machines:

		Stage t = 1 Allocated according to Johnson J7
Load vector {5.8,0,0,0} all machines at this stage are poor and printing machine 1 is selected randomly	μ(t)	0.48
	L (1)	5.80
	L (i)< sqrt (n)*L(1)	20.09
		Stage t = 2 Allocated according to Johnson J2
Load vector {5.8,5.8,0,0} all machines at this stage are poor and printing machine 2 is selected randomly	μ(t)	0.97
	L(t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Stage 3= t Allocated according to Johnson J5
Load vector {5.8,11.3,0,0} all machines at this stage are poor and printing machine 2 is selected randomly	μ(t)	1.43
	L (t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Stage 4 =t Allocated according to Johnson J3

Load vector {5.8; 16.6, 0,0} all machines at this stage are poor and printing machine 2 is selected randomly	μ(t)	1.87
	L (t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Stage t = 5 Allocated according to Johnson J3
If J6 is allocated to MP2, the machine weigh will be 21.5 which is greater than 20.9 and this machine becomes rich, thus the allocation is made on machine 1 and load vector {10.6, 16.6, 0,0}	μ(t)	2.27
	L (t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Stage t = 6Allocated according to Johnson J4
Load vector {15.6, 16.6, 0,0} all machines at this stage are poor and printing machine 1 is selected randomly	μ(t)	2.68
	L(t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Step t = 7 Allocated according to Johnson J1
If J1 is allocated to MP2, the machine weigh will be 20.3 which is greater than 20.9 and this machine becomes rich, thus the allocation is made on machine 3 and load vector{15.6, 16.6, 4.7, 0}	μ(t)	2.66
	L(t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Step t = 8 Allocated according to Johnson J8
Load vector {15.6, 16.6, 9.3, 0} all machines at this stage are poor and printing machine 3 is selected randomly	μ(t)	3.46
	L(t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Step t = 9 Allocated according to Johnson J9
Load vector {15.6, 16.6, 13.5, 0} all machines at this stage are poor and printing machine 3 is selected randomly	μ(t)	3.81
	L(t)	5.80
	L(i)<sqrt(n)*L(t)	20.09
		Phase t = 10 Allocated according to Johnson J10
Load vector {15.6, 16.617.2, 0} all machines at this stage are poor and printing machine 3 is selected randomly	μ(t)	4.11
	L(t)	5.80
	L(i)<sqrt(n)*L(t)	20.09

It can be observed that the order is not allocated to printing machine 4. Table 5 presents job allocation to the machines based on the Robin Hood algorithm.

Table 5
Jobs assigned to the printing press

Assigned to the printing press							
Printing Machine 4	Printing Machine 3		Printing Machine 2		Printing Machine 1		
	Duration	Job	Duration	Job	Duration	Job	
	120	J1	160	J2	160	J7	
	160	J8	120	J5	120	J6	
	140	J9	140	J3	130	J4	
	120	J10					
	540		420		410	Total time	

Table 6
Determining the sequence of orders in the Robin Hood algorithm

J7	J2	J1	6	J5	J4	J3

Similar to section 4.1 order allocation of laminating machines is done through the Robin Hood algorithm. The final vector is {10.8, 7.2, 6.5} and the sequence of allocation of orders is presented in Tables 7 and 8.

Table 7
Allocation of orders to laminate machines

Lamination 3		Lamination 2		Lamination 1	
Duration	Job	Duration	Job	Duration	Job
60	J1	68	J2	70	J7
62	J4	68	J5	60	J6
				65	J3
122		136		195	Total time

Table 8
Allocation of orders to laminate machines based on the Robin Hood algorithm

T=7	**T=6**	**t=5**	**t=4**	**T=3**	**T=2**	**T=1**	Robin hood Laminate
ML1	ML3	ML2	ML1	ML3	ML2	ML1	Machine
J3	J4	J5	J6	J1	J2	J7	Job

Table 9: Determining the sequence of orders in the Robin Hood algorithm

J8	J11	J12	J9	J10	J7	J2	J1	J4	J6	J5	J3

Similar to section 5.1 order allocation of laminating machines is done through the Robin Hood algorithm. The final vector is {17.57,16.4,17.73,0,0} and are not allocated to the cutting machines 4 and 5. The sequence of allocation of orders is presented in Tables 10 and 11.

Table 10
Allocation of orders to cutting machines

Cutting machine5		Cutting machine4		Cutting machine3		Cutting machine2		Cutting machine1	
Duration	Job	Duration	Job	Duration	Job	Duration	Job	Duration	Job
--		--		75	J12	70	J11	80	J8
				90	J7	70	J10	75	J9
				82	J4	80	J1	90	J2
				85	J3	88	J5	85	J6
--		--		332		308		330	Total time

Table 11
Allocation of orders to cutting machines based on the Robin Hood algorithm

T=12	**T=11**	**T=10**	**T=9**	**T=8**	**T=7**	**T=6**	**t=5**	**t=4**	**T=3**	**T=2**	**T=1**	Robin hood print
MC3	MC2	MC1	MC3	MC2	MC1	MC3	MC2	MC1	MC3	MC2	MC1	Machine
J3	J5	J6	J4	J1	J2	J7	J10	J9	J12	J11	J8	Job

5. Conclusions and Further Research Directions

The aim is to minimize the maximum load by minimizing the sum of the value of the difference between the loads on each machine and the average value. According to Table 12, it can be observed that any different job allocation does not realize this goal.

$$X: Min \sum |(\mu(t) - L_i(t)| \quad (5)$$

Table 12
Load difference on each of the machines with average load on the system

Average load on printing machine			The average load on a cutting machine		Average load on lamination machine
4.363038392			4.312644496		3.452656183
Machine1	Machine 2	Machine 3	Machine 4	Machine 5	
15.6	16.6	17.2	0		Load vector of printing machines
17.57	16.4	17.73	0	0	Load vector of cutting machines
10.8	7.2	6.5			Load vector of laminating machines
36.31	The load difference of the printing machines with average load on the system				
38.76	The load difference of the cutting machines with average load on the system				
14.14	The load difference of the laminating machines with average load on the system				

According to the results in Section 4 it can be seen that in the printing and cutting machines, the three machines to which the job order is allocated have almost similar load which causes similar depreciation, and the machine to which the job order is not allocated can be considered as the alternative machine at the time of need in technical failures of other machines. The lack of job allocation to them leads to saving energy and the lack of employing operators for those machines. In the group of laminating machines, we see that two machines have similar loads or have lower loads than other machines which indicate that the machines with lower load can process the orders in case of the failure of other machines. The above-mentioned cases can lead to saving the operational costs and optimal use of the existing capacity at the production line. The problem of balanced planning is the concern of manufacturing managers due to the load of the orders on the machinery in assembly lines of various factories. This can be resolved by Robin Hood algorithm so that it would be possible to deliver the order on time, eliminate uneven depreciation of the lines and reduce the costs of operation. The results showa that the implementation of the Robin Hood algorithm along with the Johnson method in real production conditions affects the production line balancing. Future studies can analyze the objective function of this study in other methods of online balance on the production lines versus each other and assembly line balancing algorithms. Also, it is possible to analyze the methods of prioritizing job orders in terms of their effect on providing an optimal solution in a constant online balancing algorithm.

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