TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 5, October 2020, pp. 2764~2771
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i5.13979

Determination of flexibility of workers working time through Taguchi method approach

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Article Info

Article history:

Received Aug 26, 2019
Revised Mar 9, 2020
Accepted Jun 12, 2020

Keywords:

Human factors
Job shop scheduling
Signal to noise
Taguchi method

ABSTRACT

Human factor is one of the important elements in manufacturing world, despite their important role in improvement the production flow, they have been neglected while scheduling for many decades. In this paper the researchers taken the human factor throughout their job performance weightage into consideration while using job shop scheduling (JSS) for a factory of glass industry, in order to improving the workers' flexibility. In other hand, the researchers suggested a new sequence of workers' weightage by using Taguchi method, which present the best flexibility that workers can have, while decreasing the total time that the factory need to complete the whole production flow.

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1. INTRODUCTION

Job-shop scheduling problem (JSSP) is placed under a category of combinatorial optimization problems which is recognized as N-hard one. It is a popular scheduling problem encountered in practice [1]. It is a number of n jobs which have to be administered on a group of machines where each of these jobs i consists of a sequence of k operations which are predefined. In this method, no more than one operation can be processed by each of these machines, only a single operation can be processed at a time during a fixed time unit.

A glass factory in Jordan needs to improve its production speed; the factory is considered as one of the biggest and modern glass factories in the Middle East. It hardly covers the local demands; for this reason, this research has two goals: firstly, to improve the total production time needed to finish the production's operation (makespan) and secondly, to add flexibility to workers' working time since the work environment is important in creating motivation. By using a classic Job Shop Scheduling (JSS) and modifying the model to be suitable for the data of the glass factory, the researchers improved the production's total time (makespan). The main aim of this research is to suggest the best sequence of weightage for each workers group by using design of experimental (DOE), the best way to achieve this is to adopt Taguchi's method.

Ergonomics is an expression defined the human factor as following "the theoretical and fundamental understanding of human behavior and performance in purposeful interacting sociotechnical systems, and the application of that understanding to the design of interactions in the context of real settings" [2]. Human factor is one of the important elements in manufacturing world, which cannot be neglected, because it plays an important role in enhancement the production performance [3, 4]. Throughout the last decades, the researchers had not taken ergonomics into their full consideration, as an important factor in improving the production system, hence, the majority of managerial decisions had been difficult to change [3, 5]. Some researchers have concentrated in their studies on the reasons for negligence ergonomics in the production system. In [5, 6], have discussed seven major reasons for pay no attention early to ergonomics in the improvement of the production system, and they determined the main reason for negligence the ergonomics, that the quantifying human issues is sophisticated. Furthermore, some researchers have attributed the cause for priority of designing technical system more than ergonomics, by consider the fact that the people have the ability to be adaptive, hence there is no necessity for consideration human factors in production system [7]. Latterly, many researchers pay attention in incorporating the human factors in production systems, according to the technology revolution and the increasing attention in scheduling problems. In [8-12] have deduced that it's important to include the human factors in production scheduling and operation management activities. In [13] studied the influence of the human factors in the production performance, as worker's intellectual capabilities, knowledgeability, job understanding, and job performance.

In order to study the connotation of multi-level of flexibility of workers, by using a simulation, [14] concluded that the variety of the workers' flexibility is better than fixed flexibility. In [6] concluded that the relations between the production system and human factors are very important, [15] deduced that the variances between workers should be taken into consideration when preparation the procedures and managing the workforce. In [16] constructed a mathematical model, in order to deal with a concurrent dynamic cell forming and the problem of worker mission and pointed out the importance of including human issues into a traditional dynamic cell forming. In [17] developed the conceptual framework in order to help the ergonomists in their investigation, instruction, and the pursuit of understanding how to underpin the strategic targets of a company. This conceptual framework supports the professionals of ergonomics to concentrate their efforts on ergonomics taking into account work performance rather than occupational health and safety [7]. The application of a learning curve of workers in different manufacturing settings has been well documented in the literature [18-21] mentioned that the flexibility in the work's tasks and the convenient task of workers to shifts can both have an influence on worker efficiency. In [15] mentioned that, solving the production scheduling when incorporating the human factors, which matches more to reality of production environments, thus the demonstrate of extensive research is still needed in this field.The major idea in the above literature review, that human factors have the ability to enhancement the production efficiency, therefore, they should be taken into consideration when production scheduling, in spite of little studies that tackled this factor.

Taguchi method is an experimental design which is an attempt to adjust the operators and parameters of the proposed model. First, a fractional factorial experiment (FFE) was developed in order to decrease the number of the required tests [22]. Since all the possible combinations used to estimate the influence of factors and some of their interactions are not permitted by FFEs but rather a small portion, a family of FFE matrices was developed by Taguchi with the hope of decreasing the number of the experiments, but the outcomes showed that it provided insufficient amount of information [23]. Taguchi has formed a transformation of the frequency of data to another value known as the measure of variation. This transformation is the signal-to-noise (S/N) ratio. It is used to explain the reason why this type of parameter design is called robust design [24]. In this fashion, the use of the term 'signal' refers to the desirable value which is the 'mean response variable, whereas the term 'noise' refers to the undesirable value denoting the standard deviation. As a result, the degree of variation found in the response variable can be indicated by the ratio of S/N. Taguchi used three categories to classify the objective functions. These categories or types are the smaller-the-better, the larger-the-better, and nominal-is-best types. Based on these classifications, the corresponding S/N ratio of the objective functions in scheduling, which usually fall under the smaller-the-better type, will be: S/N ratio=$-10\log_{10}(MSD)$ [25].

2. RESEARCH METHOD

The data required for this study are gathered from a glass factory in Jordan which consists of four jobs and seven groups of workers. Furthermore, the data contain the processing time to complete each stage of production operation and the start time for each operation in each job, and the total time that the factory needs to complete the whole production operation.

The first step in this study is proposing a JSS model to find the minimum total time needed to complete the whole production process (makespan) as well as adding flexibility to the workers' working time by using the weightage values which is obtained from the factory. The second step is transforming the proposed model to excel solver to prepare the proposed model to be solved by Taguchi method. Third step, which is the main objective of this study, is looking for the best sequence of weightage that the researchers can choose to obtain the best result. It satisfies two conditions: firstly, minimize the total time of production process; secondly, improving the flexibility of workers' working time. The perfect way to choose the best sequence of weightage is considering Taguchi method which is concerned with design of experiment (DOE).

Using Taguchi method requires determining the suitable design for current data. For this the researchers chose Taguchi design L_9 which requires four factors and three levels. The researchers determined the levels by the sequence of weightages (0.1, 0.15, 0.2) and determined the factors by four groups of workers for Taguchi design as follow: group one and group two in the data are defined by group one, while group three and group four in the data are defined by group two, group five in the data is defined by group three, and group sex and group seven in the data are defined by group four in Taguchi design.

Using Taguchi method requires the analysis of the results that the researchers got by using the suitable design by signal to noise table and to determine the best sequence of weightage for workers' groups. The glass factory of this study possesses modern machines and high-quality products but hardly covers the demands. By gathering the necessary data, the main problem seems to be in the time management; hence using job shop scheduling is the best choice. Data are gathered by contacting the production manager in the factory to get needed data which had been arranged with a disjunctive graph as shown in Figure 1.

As Figure 1 shows that the factory needs to complete the whole production flow in 260 minutes (the longest time needed to complete the whole production flow can be found in job 4). U is the input material and V is the output product, and each square in the figure defined one operation. According to Figure 1, the first row represents the first job which consist of four operations executed by workers' groups 1, 2, 3, and 4 consequently, where first group of workers start at time zero and need 15 minutes to complete their task, hence the number which had been written on the arrow define the processing time for each operation, while the number which had been written above the square define the start time for each operation. Second row represents the second job which executed by workers' group 2, 3, 5, and 6 consequently, as well the third row performs the third job which executed by workers' groups 1, 5, 6, and 7 consequently, and the last row show the sequence of operations in the fourth job which done by workers' group 1, 4, 5, and 7 consequently. For all jobs the representatives of start times and processing times are same as explained for first row. Hence, the whole time that needed to complete the whole production flow will be 260 minutes, which can be calculated by job 4.

The researchers proposed a JSS model by using weightage as Table 1 shows, which obtained from the factory to achieve two goals: firstly, to minimize the total time to complete the whole production flow (i.e. makespan) and secondly, to improve flexibility to workers' working time.

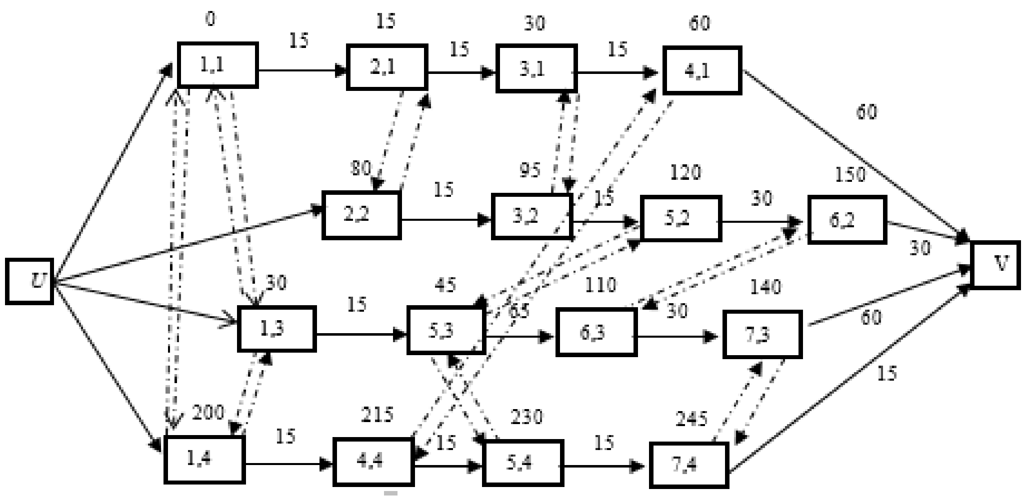

Figure 1. Disjunctive graph of original data

Table 1. Groups' weightage

Group's No.	1	2	3	4	5	6	7
Weightage (μ_i)	0.08	0.1	0.12	0.14	0.17	0.19	0.2

– Proposed model of JSS

The proposed model is detailed as follow, the notation, parameters, and objective function are given below:

$C_{\max}$: is the total time that needed to complete the whole production flow i.e. makespan.

$C_{\max j}$: is the total time that needed to complete job j .

t_{ij} : is the start time of the i^{th} group of workers for their operation in the job j .

p_{ij} : is the processing time of the i^{th} group of workers to execute their task in the job j In this case, $i = 1,...,7$ and $j = 1,...,4$.

– Objective function

$$Min = C_{max} \text{ such that}$$
$$C_{max\,1} \geq \mu_4 * t_{41} + p_{41}, C_{max\,2} \geq \mu_6 * t_{62} + p_{62}$$
$$C_{max\,3} \geq \mu_7 * t_{73} + p_{73}, C_{max\,4} \geq \mu_7 * t_{74} + p_{74} \quad (1)$$

– Constraints

The constraints in proposed JSS model are employed to achieve two purposes, first group of constraints are organized to keep the sequences of the operations in the same job, and the second group of constraints are organized to prevent conflict between groups of workers' tasks.

For Job 1:

$$t_{21} \geq \mu_1 * t_{11} + p_{11}$$
$$t_{31} \geq \mu_2 * t_{21} + p_{21}, t_{31} \geq t_{21} + p_{21}$$
$$t_{41} \geq \mu_3 * t_{31} + p_{31}, t_{41} \geq t_{31} + p_{31} \quad (2)$$

For Job 2:

$$t_{32} \geq \mu_2 * t_{22} + p_{22}, t_{32} \geq t_{22} + p_{22}$$
$$t_{52} \geq \mu_3 * t_{32} + p_{32}, t_{52} \geq t_{32} + p_{32}$$
$$t_{62} \geq \mu_5 * t_{52} + p_{52}, t_{62} \geq t_{52} + p_{52} \quad (3)$$

For Job 3:

$$t_{53} \geq \mu_1 * t_{13} + p_{13}, t_{53} \geq t_{13} + p_{13}$$
$$t_{63} \geq \mu_5 * t_{53} + p_{53}, t_{63} \geq t_{53} + p_{53}$$
$$t_{73} \geq \mu_6 * t_{63} + p_{63}, t_{73} \geq t_{63} + p_{63} \quad (4)$$

For Job 4:

$$t_{44} \geq \mu_1 * t_{14} + p_{14}, t_{44} \geq t_{14} + p_{14}$$
$$t_{54} \geq \mu_4 * t_{44} + p_{44}, t_{54} \geq t_{44} + p_{44}$$
$$t_{74} \geq \mu_5 * t_{54} + p_{54}, t_{74} \geq t_{54} + p_{54} \quad (5)$$

In (2), (3), (4) and (5) are organised in order to preserve the operations' sequence in job 1, 2, 3 and 4 respectively, moreover the researchers used the workers' weightage with a view to improving the workers' flexibility by using the workers' weightage as a parameter of the start time of each operation.

For $i = 1, 2, ..., 7$ and M is a constant choice to be 150, the following constraints organised the tasks of workers':

$$t_{i1} + p_{i1} \leq t_{i2} + M(1 - X_{i12}), t_{i2} + p_{i2} \leq t_{i1} + MX_{i12} \quad (6)$$

In (6) controls the operations executed by each group of workers which has tasks in jobs 1 and 2.

$$t_{i1} + p_{i1} \leq t_{i3} + M(1 - X_{i13}), t_{i3} + p_{i3} \leq t_{i1} + MX_{i13} \quad (7)$$

In (7) determine the constraints that control the allocation of tasks of groups of workers in jobs 1 and 3.

$$t_{i1} + p_{i1} \leq t_{i4} + M(1 - X_{i14}), t_{i4} + p_{i4} \leq t_{i1} + MX_{i14} \quad (8)$$

The third set of constraints are concerned in that groups of workers who are have tasks in each of jobs 1 and 4.

$$t_{i2} + p_{i2} \leq t_{i3} + M(1 - X_{i23}), t_{i3} + p_{i3} \leq t_{i2} + MX_{i23} \quad (9)$$

The fourth set of constraints are determined the allocation of tasks for groups of workers in jobs 2 and 3.

$$t_{i2} + p_{i2} \leq t_{i4} + M(1 - X_{i24}), t_{i4} + p_{i4} \leq t_{i2} + MX_{i24} \quad (10)$$

In (10) are determined the operations' distribution between the groups of workers in job 2 and job 3.

$$t_{i3} + p_{i3} \leq t_{i4} + M(1 - X_{i34}), t_{i4} + p_{i4} \leq t_{i3} + MX_{i34} \quad (11)$$

In (11) organize the work's distribution between the groups of workers that have tasks in jobs 3 and 4.

The non-negative constraints are included in this proposed model of JSS, as well as the definition of X_{ijk}

$$t_{ij} \geq 0, \text{for } i = 1,2,\ldots,7 \text{ and } j = 1,2,3,4 \quad (12)$$

and

$$X_{ijk} = \begin{cases} 1, \text{if job j precedes job k on group i} \\ 0, \text{otherwise} \end{cases} \quad (13)$$

where $i = 1,\ldots,7$ $j = 1,\ldots,4$ and $j \prec k$.

3. RESULTS AND ANALYSIS

In this section, the results of proposed model of JSS and Taguchi method are discussed by details. Moreover, the comparison of the research results with the origin data is included.

3.1. Proposed model of JSSP results

Using Figure 1 and Table 1 in the proposed model of JSS in order to substitute the processing times values p_{ij} and the weightages values μ_i , and solving proposed model using LINGO software, and perform the results by Figure 2, the total time needed to complete the whole production's flow is 230 minutes which is calculated by job 3, which is considered as the longest one.

Depending on Figure 1, the time needed to complete the whole production flow is 260 minutes, but according to Figure 2, the proposed model results show that the total time needed to complete whole production's flow is 231 minutes, which proved that the proposed model improved the factory's production flow by minimizing the time. In addition to this, the proposed model added flexibility to workers' groups which has a high weightage like group 7 and group 6.

3.2. Taguchi method

The main second step in this study is solving the proposed model using excel solver by transforming objective function and all constrains to excel. In this paper the researchers look for the best sequence of weightage to get an optimum solution for the problem of factory which satisfies two important conditions: saving the time and adding flexibility to workers' working time. One of the best methods using design of experiment (DOE) is Taguchi method. The suitable Taguchi design for factory's problem is L_9 which consists of nine experiments; the researchers determined three levels of weightage (0.1, 0.15, 0.2), and considered the workers' groups as four factors as explained above.

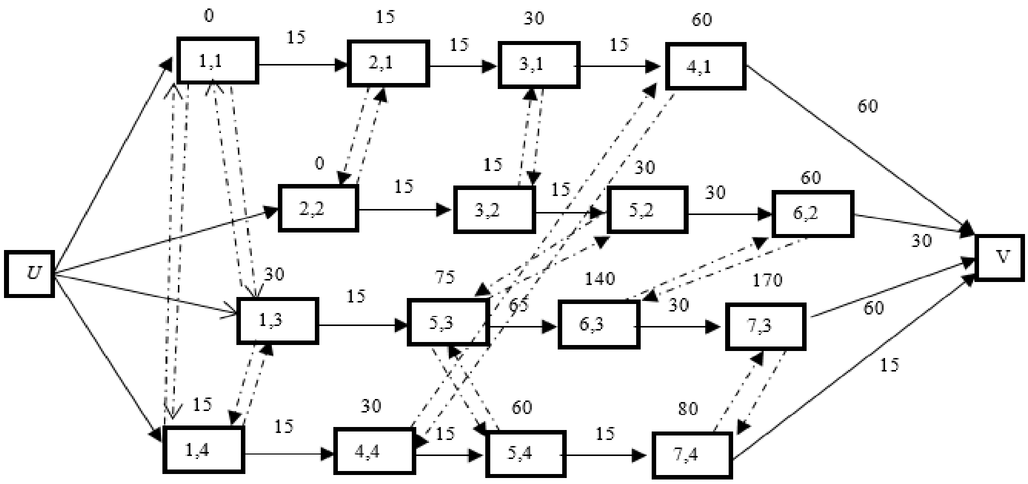

Figure 2. Disjunctive graph of proposed JSS model

Where Y_i is the time needed to complete job *i*, *i=1, 2, 3, 4*. *MSD* is the standard mean deviation, calculated by the equation $MSD = \frac{\sum_{i=1}^{4} Y_i^2}{n}$ where n is the number of jobs. *S/N* is the signal to noise ratio, which is calculated by the following equation: $S/N = -10Log_{10}(MSD)$ which is related for smaller is the better. By using excel solver to obtain C_{max} for each experirment, then analyze the results produced by Taguchi design L_9 by using signal to noise ratio (SNR). To find optimum solution resulted by SNR table, the researchers included in each experiment the result of each job, as shown in Table 2. A little bit of work to get the best sequence of weightage by plotting the graph of S/N ratio depending on Table 2, the researchers prepared Table 3.

Table 2. Signal to noise ratio (SNR)

Experiment number		1	2	3	4	5	6	7	8	9
Factors	1	0.1	0.1	0.1	0.15	0.15	0.15	0.2	0.2	0.2
	2	0.1	0.15	0.2	0.1	0.15	0.2	0.1	0.15	0.2
	3	0.1	0.15	0.2	0.15	0.2	0.1	0.2	0.1	0.15
	4	0.1	0.15	0.2	0.2	0.1	0.15	0.15	0.2	0.1
	Y_1	66	66	66	69	69	69	72	72	72
	Y_2	36	39	42	42	36	39	39	42	36
	Y_3	77	85.5	94	94	77	85.5	85.5	94	77
	Y_4	23	27	31	31	23	27	27	31	23
	Y_1^2	4356	4356	4356	4761	4761	4761	5184	5184	5184
	Y_2^2	1296	1521	1764	1764	1296	1521	1521	1764	1296
	Y_3^2	5929	7310.3	8836	8836	5929	7310	7310	8836	5929
	Y_4^2	529	729	961	961	529	729	729	961	529
	MSD	3027.5	3479.1	3979.3	4081	3129	3580	3686	4186.3	3234.5
	S/N	-34.811	-35.415	-35.998	-36.1	-35	-35.5	-35.7	-36.22	-35.098
	C_{max}	202	217.5	233	236	205	220.5	223.5	239	208

Table 3. S/N ratio mean

A1	A2	A3	B1	B2	B3
-35.41	-35.53	-35.66	-35.53	-35.53	-35.55
C1	C2	C3	D1	D2	D3
-35.52	-35.54	-35.54	-34.95	-35.54	-36.11

A*i*, B*i*, C*i*, and D*i* are the mean value of *S/N* ratios that is related to group 1, 2, 3, and 4 consequently and level i . i.e. each of $Ai, Bi, Ci, Di = \frac{\sum_{j=1}^{3} (S/N)_{ij}}{3}$ where *j* is the number of levels, and i =1, 2, 3. Based on Table 3,and according to the rule of the smaller is the better, the researchers could determine the best sequence of weightage for workers' group, hecne, Taguchi design suggested the best sequence of weightage that let the researchers achieved two goals: decrease makespan and add flexibility to workers' working time. Relying on Table 3, the researchers got the result that for group one, two and four the best weightage is 0.2, and for group three, the best weightage is 0.15. hence, the best sequence for the groups in the proposed model is (0.2, 0.2, 0.2, 0.2, 0.15, 0.2, 0.2).

3.3. Results comparison

Using the proposed sequence of weightage to calculate the starting time for each group in each job, as same as calculating makespan, comparing the results obtained by the proposed model which used LINGO software and Taguchi method which used EXCEL SOLVER with original data, the researchers obtained the results shown in Table 4. Based on Table 4, Taguchi method decreases the time needed to complete the whole production flow and added flexibility to workers' working time more than the results of the proposed model.

Table 4. Results summary

Variable	C_{max}	t_{11}	t_{21}	t_{31}	t_{41}	t_{22}	t_{32}	t_{52}	t_{62}	t_{13}	t_{53}	t_{63}	t_{73}	t_{14}	t_{44}	t_{54}	t_{74}
Taguchi method	239	0	15	30	60	0	15	30	60	15	75	140	170	30	45	60	80
Proposed CJSS	230	0	15	30	60	0	15	30	60	30	75	140	170	15	30	60	80
Original data	260	0	15	30	60	80	95	120	150	30	45	110	140	200	215	230	245

4. CONCLUSION

Depending on Table 4, using Taguchi method for solving the proposed model improved the flexibility of groups of workers especially group seven which has the highest weightage in the proposed model. The researchers of this study suggest that the factory needs to encourage the workers to get a high weightage which will be achieve three goals: firstly, to decrease the total time needed to complete the whole production flow which will be 239 minutes; secondly, to add flexibility to workers' working time without wasting the time; and thirdly, if the weightage for each group becomes higher than the previous one, the factory needs to improve the workers' situation.

By comparison between solving proposed model using computation method and Taguchi method, the researchers noticed that: By computation method the researchers should use fixed values of weightage, while using Taguchi's method they are looking for best values of weightage. By using computation method, the researchers can improve the factory's production progress by decreasing makespan, but cannot improve the workers' weightage, but using Taguchi's method they can improve the factory's production progress as same as improve the workers' weightage.

Results gotten by computation method showed what is the flexibility that the workers' groups will have if the factory apply the proposed model, while the results gotten by Taguchi's method showed what is the best sequence of weightage should have to get the improvement of production's progress, if the factory applies the proposed model with new values of weightage. Taking the human factors into consideration performing by workers' weightage improved the flexibility of the workers' working time as well as decreasing the whole time that the factory needed to complete the whole production flow. Furthermore, change the groups weightage to be better than before required encourage each group to get this weightage by using different methods like provide incentives, improve salaries, etc.

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