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A Novel Interactive Possibilistic Mixed Integer Nonlinear Model for Cellular Manufacturing Problem under Uncertainty

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A B S T R A C T

Elaborating an appropriate cellular manufacturing system (CMS) could solve many structural and operational issues. Thereby, considering some significant factors as worker skill, machine hardness, and product quality levels could assist the companies in current competitive environment. This paper proposes a novel interactive possibilistic mixed integer nonlinear approach to minimize the total costs of cellular manufacturing design. The proposed approach is elaborated regarding operation sequence, worker and machine assignments, route and worker flexibility, machine hardness level, worker and machine capacity, worker skill level, and product quality level based on imprecise information. Meanwhile, the product demand parameter because of its nature is defined based on fuzzy setting environment. Then, the interactive possibilistic approach is provided to cope with the existed uncertainty according to the problem environment. Finally, a numerical experiment is considered to show the capability of the proposed approach. The results of the proposed interactive possibilistic model show that the presented approach could assist companies for minimizing their costs and manipulating the machines and workers' suitability. In this respect, comparing the obtained results from the proposed approach and similar circumstances shows that the proposed model could reduce the total costs by 27.8%.

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1. INTRODUCTION

Cellular manufacturing systems (CMSs) have some suitable properties as machine utilizing improvement, quality management, material handling cost reduction, work-in-process inventory management, and setup time reduction. In this respect, some phases should be considered for designing a suitable CMS including: *i*. Cell formation, which means that a group of product with similar jobs assigned in families of parts and related machines in machine cells; *ii*. Group layout, which is established from the intracellular arrangement (i.e. machines assigned within each cell) and intercellular arrangement (i.e. related cells); *iii*. Planning of groups, and *iv*. Allocation of resources such as allocation of human resource, tools, and material [1-3].

In this study, the first, second, and fourth phases of cellular manufacturing design are provided. Meanwhile, the group layout, resource allocation, and cell formation are considered regarding the final product quality based on the hardness level of jobs on machines, the demand quality level, and the workers skill level. In some studies, these features are considered based on multi-period approach which is named dynamic cellular manufacturing system [2, 4, 5]. To address the issue, some researchers focused on CMS problems based on mathematical programming approach and under the certain or precise information [6-8].

In this sake, Rosenblatt [9] introduced the dynamic programming modeling for elaborating a cellular manufacturing layout problem. In addition, Mahdavi et al. [10] presented an integer programming approach for the CMS design to minimize the machine and reconfiguration costs, backorder and holding costs, hiring, firing and salary costs, and intercellular material handling cost. Their approach is developed based on some properties as the multi-period production planning, machine capacity, system reconfiguration, worker assignment, duplicate machines, and available time of workers. Saxena and Jain

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[11] developed an integrated model based on dynamic approach which integrates some properties of existing models in a single model consisting reliability, machine breakdown, production planning, production cost and intracellular movement to minimize the total costs. Rabbani et al. [12] focused on manpower allocation and cell loading problem with the aim of manpower allocation in cellular manufacturing with consideration to training and learning policies where demand is stochastic.

Paydar et al. [13] presented an elaborative mathematical model based on operations sequence, intracellular layout, lot splitting, alternative process routing, duplicate machines, multi-period production planning, system reconfiguration, machine capacity, and material flow between machines, which is called comprehensive integer linear programming approach. Kia et al. [14] proposed a dynamic nonlinear mixed integer programming approach to provide a group layout of CMS concerning the production planning decisions. Lim et al. [6] presented multi-objective hybrid algorithms for layouts optimization in multi-robot assembly for solving the cellular manufacturing problems. Rezazadeh and Khiali-Miab [15] developed a novel mathematical model for designing the reliable cellular manufacturing systems that leads to decrease in the manufacturing costs, improved total reliability of the manufacturing system and improved product quality. In addition, a two-layer genetic algorithm is presented to address the complexity of cell formation problems to obtain near optimal solutions. Kia et al. [16] proposed a novel mixed integer nonlinear mathematical model for elaborating the group layout of unequal area facilities in a dynamic CMS. Sakhaii et al. [3] presented a robust mixed integer linear programming approach with the goal of minimizing the total costs related to machines, production, workers, and part movements. Aalaei and Davoudpour [8] proposed a novel mathematical programming model for a CMS along supply chain design regarding labor assignment with the goal of minimizing the total cost of holding, inter-cell material handling, external transportation, fixed cost for producing each part in each plant, machine and labor salaries.

Traditional cell formation techniques, designed cells and assigned the workers to them, while avoiding the relationships between the required skills of jobs and skills of workers. Furthermore, the workers' skill levels could be related to jobs hardness on the machines. Thus, providing the workers' skills level regarding the jobs hardness could be considered as an important issue for machine/worker assignment. Thereby, a few studies have focused on workers' skills level to solve the CMSs problems.

In this respect, Norman et al. [17] presented a mixed integer mathematical model for assigning the workers to manufacturing with the aim of maximizing the efficiency of the organization cells regarding their skills. Suksawat et al. [18] developed a new methodology considering the skills of workers based on scheduling method to solve the manufacturing cell problem. In addition, Duan et al. [19] presented an assembly system-based on CMS properties and providing the collaboration between worker and machine, workers skill, safe design for collaboration, and assembly information guidance. Egilmez et al. [20] proposed an optimization methodology with the goal of maximizing the rate of production based on workers skills allocation, which the performance of each worker is provided to allocate the worker to the manufacturing cells. The literature review of worker skills studies in CMS problems indicates that little attentions have been paid to this area. Therefore, this study is focused on the worker skill level for allocating the workers to machines with specific job hardness level.

In real-life complexity of CMSs problems, some significant parameters (e.g., available machine capacity, product mix, processing time, inter-arrival time, and product demand) are difficult to be specified precisely. In this respect, these parameters should be expressed under uncertainty to address the imprecise condition in cellular manufacturing issues [21-23]. Thus, various approaches which have been developed to deal with imprecise information are robust optimization approach, stochastic programming, and fuzzy programming [16, 24-26].

In the field of fuzzy condition, Safaei and Tavakkoli-moghaddam [27] extended a mixed-integer mathematical model for solving the manufacturing problems based on imprecise information and dynamic condition. In addition, they considered the machine capacity and product demand as fuzzy parameters. Also, Kia et al. [28] presented a novel integer non-linear mathematical model based on fuzzy information for solving the layout design of CMS. In addition, Behret and Satoglu [29] investigated the fuzzy approaches, especially fuzzy clustering and fuzzy programming elaborated for designing the CMS. They considered the machine purchasing, intercellular flow cost, and product demand based on imprecise information. Paydar and Saidi-Mehrabad [30] developed a new bi-objective possibilistic programming model for integrating distribution, procurement, and production planning regarding the uncertain nature of some main parameters as customers demands and machine capacity. Therefore, considering the fuzzy set theory could deal with vague situation and incomplete information, appropriately [31].

The survey of the literature shows that considering the worker skill, job hardness, and product quality properties based on incomplete information could enhance the modeling approaches for CMS problems. However, this study proposed a new mixed integer nonlinear programming model based on imprecise information. Furthermore, the products quality is managed in process of the operation procedure regarding the jobs hardness and workers skill levels on machines. Then, an interactive fuzzy approach is implemented to cope with existing uncertainty of the CMS problem. However, the gap of recent literature is represented in Table 1. This table shows that the job hardness level and the product quality level are not considered in the literature. Moreover, little attentions have been paid to provide a mathematical model based on other properties.

TABLE 1. Cellular manufacturing models and their characteristics

Author	Model characteristic							
	Uncertainty	Worker capacity	Worker flexibility	Operation sequence	Worker allocation	Job hardness	Worker skill	Product quality
Mahdavi et al. [32]		✓	✓		✓			
Solimanpur et al. [33]				✓				
Mahdavi et al. [34]	✓	✓	✓		✓			
Torabi and Amiri [35]	✓			✓				
Kia et al. [36]				✓				
Chang et al. [37]				✓				
Kia et al. [38]				✓				
Shirazi et al. [39]				✓				
Egilmez et al. [20]	✓	✓	✓		✓		✓	
Sakhaii et al. [40]	✓	✓			✓			
Deep and Singh [7]								
This paper	✓	✓	✓	✓	✓	✓	✓	✓

The reminder of this paper is organized as follows: in section 2, the problem description about the cellular manufacturing problem regarding cost and quality is defined. Then, the assumptions and proposed model are provided in section 3. In addition, in section 4, the interactive possibilistic approach is provided to cope with existing uncertainty. In section 5, a numerical experiment is considered to indicate the applicability of the proposed model. Finally, some concluding remarks and future directions are explained in section 6.

2. PROBLEM DESCRIPTION

In the CMS problem, a number of machines (*m*) and cells (*c*) which operate specific jobs (*j*) for various products (*r*) by worker (*w*) are considered. The worker has a specific skill (*s*) according to jobs hardness of machines (*h*), which leads to a specific product quality level (*q*). Furthermore, machines have a certain capacity (ML_m) and products is produced based on imprecise processing time (φ_{jwm}). Also, number of cell (*NC*) must be specified and the maximum (*NU*) and minimum (*NL*) number of machines which must be set in each cell are specified by experts. Hence, workers have an available time to work (WL_w) which must satisfy the minimum working time (ΔW_w). For this sake, available time of machines must satisfy the minimum machine working time (ΔM_m). Moreover, the customer demands of one product with a specific quality level (d_{rq}) is obtained. Thereby, the worker skills (ω^s_{wm}) and the job hardness of machines (ψ^h_{jm}) affects the output quality level of produced products ($\wp^w_{\eta_{jrm}}$). For instances, if the worker is expert in skill level, then the final product quality is the best. Therefore, the final products quality level is specified based on minimum quality level of product production procedure. Hence, products need some various operation process (η_{jrm}) in available routing (L_r) which should be produced in a suitable route (γ_{lr}) according to allocating the products to a cell (Y^c_{jrm}) and to a machine (ξ^h_{jrm}). Meanwhile, the products have concatenated production sequence and material flow conservation ($\partial^{mm'}_{jrcc'}$). For this sake, if one cell is constructed (CF_c), the machines could be assigned to cells (X_{mc}) and workers could be allocated to machines (ϑ_{wjm}) regarding the worker skills level (ϖ^s_{wjm}). However, the presented model is designed with the goal of minimizing the total costs consisting of processing cost of machine (CM^h_m), employment cost of worker (CW^s_w), fixed cost of establishing each cell (FC_c), intercellular movement cost between cells ($CO_{cc'}$) and intracellular movement cost of cell (CI_c).

3. PROPOSED APPROACH

In this section the proposed mixed integer nonlinear programming approach is presented based on some assumptions.

3. 1. Assumptions

The proposed mixed integer nonlinear mathematical model with the goal of minimizing the total costs of cellular manufacturing design is established based on the following assumptions:

1) Each machine must be allocated to only one cell;
2) Each product must be allocated to only one cell;
3) The processing time of products can be various on different machines (i.e. routing flexibility);
4) The hardness of job is not related to each product;
5) The processing time for needed jobs for a product on each machine is known;
6) Inventory is not allowable;
7) Each product has a number of jobs that must be processed based on its jobs sequence;
8) Each product has a number of procedures routing, which could be chosen among the available routs;
9) There is only one type of each machine.

3. 2. Nomenclature In this section, the nomenclature is defined as follows:

Sets

j	Index of job, $j = 1,2,...,J$
h	Index of hardness, $h = 1,2,...,H$
c, c'	Index of cell, $c = 1,2,...,C$, $c' = 1,2,...,C'$
m, m'	Index of machines, $m = 1,2,...,M$, $m' = 1,2,...,M'$
w	Index of workers, $w = 1,2,...,W$
s	Index of skills, $s = 1,2,...,S$
r	Index of products, $r = 1,2,...,R$
q	Index of quality, $q = 1,2,...,Q$
l	Index of route, $l = 1,2,...,L$

Parameters

$\wp^{w}_{\eta_{jrm}}$	The output quality q of required job j for product r by worker w on machine m;
ψ^{h}_{jm}	The hardness level h of job j on machine m
L_r	Number of available routing for product r
η_{jrm}	The required job j for product r that needs to be processed by machine m
ω^{s}_{wm}	The skill level s of worker w on machine m
d_{rq}	The demand of product r with quality q
db_{rq}	$db_{rq} = \begin{cases} 1 & d_{rq} > 0 \\ 0 & d_{rq} = 0 \end{cases} \quad \forall r,q$
$CO_{cc'}$	The intercellular movement cost of cell c to cell c'
CI_c	The intracellular movement cost of cell c
CM^{h}_{mj}	The processing cost of machine m with hardness level h for job j
CW^{s}_{w}	The employment cost of worker w with skill level of s
FC_c	Fixed cost of establishing each cell
ΔM_m	The lower bound of machine load for machine m
ML_m	The load of machine m, for available time of machine m
φ_{jwm}	Processing time of job j which is done by worker w on machine m
NC	Number of cells that should be formed
NU	Maximum number of machine in each cell
NL	Minimum number of machine in each cell
ΔW_w	The lower bound of worker load for worker k
WL_w	The load of worker w, for available time of worker w

Decision variables

CF_c	1 if cell c is formed; 0 otherwise
X_{mc}	1 if machine m is assigned to cell c ; 0 otherwise
$\partial^{mm'q}_{jrcc'}$	1 if job j+1 of product r with quality level q is processed by machine m' in cell c' after performing job j on machine m in cell c; 0 otherwise
ϑ_{wjm}	1 if worker w is assigned to machine m for job j; 0 otherwise
γ_{lr}	1 if route l of product r is selected as process plan; 0 otherwise
δ_{rq}	Number of produced product r with quality level q
ϖ^{s}_{wjm}	1 if worker w for performing the job j on machine m which has level skill s; 0 otherwise
Y^{cq}_{jrm}	1 if product r with quality level q is processed by job j on machine m in cell c; 0 otherwise
ξ^{hq}_{jrm}	1 if product r with quality level q is processed by job j on machine m which has hardness h; 0 otherwise
PQ_{rq}	The quality level q of product r; its value is relating to the quality level of produced product; where $PQ_{rq} = \begin{cases} \begin{cases} q_1 \\ q_2 \\ q_3 \end{cases} & \text{If } \delta_{rq} > 0 \\ 0 & \text{If } \delta_{rq} = 0 \end{cases} \quad \forall r,q$

3. 3. Modelling

$$\text{Min } Z = \sum_{s=1}^{S}\sum_{w=1}^{W}\sum_{j=1}^{J}\sum_{m=1}^{M}\varpi_{wjm}^{s}CW_{w}^{s} + \sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{m=1}^{M}\sum_{m'=1}^{M'}\sum_{c=1}^{C}\sum_{c'=1}^{C'}CO_{cc'}\partial_{jrcc'}^{mm'q} + \sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{m=1}^{M}\sum_{c=1}^{C}CI_{c}Y_{jrm}^{cq} + \sum_{c=1}^{C}FC_{c}CF_{c} + \sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{m=1}^{M}\sum_{h=1}^{H}\xi_{jrm}^{hq}CM_{mj}^{h} \quad (1)$$

$$\Delta W_{w} \le \sum_{j=1}^{J}\sum_{m=1}^{M}\varphi_{jwm}\vartheta_{wjm} \le WL_{w} \quad \forall w \quad (3)$$

$$\Delta M_{m} \le \sum_{r=1}^{R}\sum_{j=1}^{J}\sum_{w=1}^{W}\sum_{l=1}^{L}\varphi_{jwm}Y_{jrm}^{cq}\gamma_{lr} \le ML_{m} \quad \forall m \quad (4)$$

$$\sum_{c=1}^{C}CF_{c} \le NC \quad (5)$$

$$\sum_{c=1}^{C}X_{mc}CF_{c} = 1 \quad \forall m \quad (6)$$

$$NL \le \sum_{c=1}^{C}\sum_{m=1}^{M}X_{mc}CF_{c} \le NU \quad (7)$$

$$\delta_{rq} \le d_{rq} \quad \forall r,q \quad (8)$$

$$\sum_{h=1}^{H}\xi_{jrm}^{hq} \ge Y_{jrm}^{cq} \quad \forall j,r,q,m,c \quad (9)$$

$$\sum_{c=1}^{C}\sum_{m=1}^{M}Y_{jrm}^{cq}\eta_{jrm} = db_{rq} \quad \forall j,r,q \quad (10)$$

$$\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{q=1}^{Q}\sum_{m=1}^{M}\psi_{jm}^{h}\xi_{jrm}^{hq} \ge \sum_{w=1}^{W}\sum_{m=1}^{M}\wp_{\eta_{jrm}}^{w} \quad \forall j,r,h \quad (11)$$

$$\sum_{w=1}^{W}\sum_{m=1}^{M}\sum_{j=1}^{J}\wp_{\eta_{jrm}}^{w}\varpi_{wjm}^{s}\xi_{jrm}^{hq} \ge PQ_{rq} \quad \forall r,q,s,h \quad (12)$$

$$\sum_{w=1}^{W}\sum_{j=1}^{J}\sum_{m=1}^{M}\omega_{wm}^{s}\varpi_{wjm}^{s} \ge \sum_{w=1}^{W}\sum_{m=1}^{M}\wp_{\eta_{jrm}}^{w} \quad \forall j,r,s \quad (13)$$

$$Y_{jrm}^{cq} + Y_{(j+1)rm'}^{c'q} - 2\times\partial_{jrcc'}^{mm'q} \ge 0 \quad \forall j,r,q,m,m',c,c' \quad (14)$$

$$Y_{jrm}^{cq} + Y_{(j+1)rm'}^{c'q} - \partial_{jrcc'}^{mm'q} \le 1 \quad \forall j,r,q,m,m',c,c' \quad (15)$$

$$\sum_{s=1}^{S}\varpi_{wjm}^{s} \ge \vartheta_{wjm} \quad \forall w,j,m \quad (16)$$

$$\sum_{l=1}^{L_r}\gamma_{lr} = db_{rq} \quad \forall r,q \quad (17)$$

$$X_{mc}, Y_{jrm}^{cq}, \xi_{jrm}^{hq}, \vartheta_{wjm}, \varpi_{wjm}^{s}, \partial_{jrcc'}^{mm'q}, CF_{c}, \gamma_{lr} \in \{0,1\} \text{ and } PQ_{rq}, \delta_{rq} \ge 0 \quad (18)$$

The objective function is minimized for the total costs which the first term is the employment cost of workers according to their skills level, the second and third terms are the intercellular and intracellular movements costs, the fourth term is related to fixed cost of constructing cells, and the fifth term is the processing cost of machines according to their hardness.

Meanwhile, Constraints (3) and (4) express that the minimum and maximum worker load and machine load must be satisfied, respectively. Constraint (5) determines the maximum number of cell that can be formed. Constraints (6) and (7) ensure that each machine can be allocated to only one cell and the minimum and maximum number of machines which should be located in each cell, respectively. Constraint (8) determines that excess production is not allowed. Constraint (9) expresses the reactions between the job allocations to a machine according to machine hardness. Constraint (10) ensures that each required job is allocated to one machine and one cell. Constraint (11) ensures that the machine with lower hardness should be chosen. Constraint (12) constructs the relationship between the workers skill level, the product quality level, and the machines hardness level. Constraint (13) determines that the suitable worker with high skill level is chosen for producing the product with best quality level. Constraints (14) and (15) define the material flow conservation and also ensure that all consecutive jobs of a product include a concatenated production sequence. Constraint (16) guarantees that the worker with minimum skills level for specific job is allocated to machines. Constraint (17) shows that only one procedure routing must be chosen. Equation (18) indicates the binary and positive variables.

4. APPROACH OF DEALING WITH UNCERTAINTY

In this section, the interactive possibilistic programming approach [31] is implemented to cope with the existing uncertainty in CMS problem. Moreover, surveying the CMS problem shows that the most important factor is product demand which experts have not a certain historical data. Therefore, the proposed mixed integer programming model under the interactive possibilistic programming approach regarding fuzzy product demands is established.

In this respect, the product demand parameter regarding the triangular possibility distribution can be defined based on Figure 1.

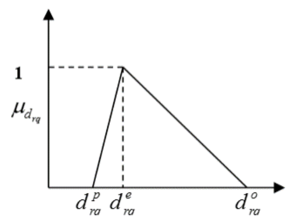

Figure 1. The triangular possibility distribution of fuzzy parameter $\tilde{d}_{rq}$

where d^p_{rq}, d^e_{rq}, and d^o_{rq} are defined as the pessimistic value, the possible value, and the optimistic value of $\tilde{d}_{rq}$ which is determined by experts.

Then, the interactive possibilistic mixed integer programming model can be converted to a crisp mixed integer programming model based on the weighted average method [23, 41, 42] which can be utilized for defuzzification procedure and converting the $\tilde{d}_{rq}$ parameter into crisp value. As indicated in Equation (8), the right hand side of this equation is imprecise product demand. Hence, the equivalent auxiliary crisp constraint can be constructed regarding minimum acceptable possibility (α) as follows:

$$\delta_{rq} \leq \alpha\left[\hbar_p d^p_{rq} + \hbar_e d^e_{rq} + \hbar_o d^o_{rq}\right] \quad \forall r, q \tag{19}$$

where $\hbar_p + \hbar_e + \hbar_o = 1$, and $\hbar_p, \hbar_e$, and $\hbar_o$ define the weight of pessimistic value, the possible value, and the optimistic value of fuzzy product demand. The appropriate values for the weights as well as α are specified subjectively based on knowledge and experience of experts. Therefore, in this study, these weights are defined based on likely values which are defined by Lai and Hwang [41] as: $\hbar_p = \frac{4}{6}, \hbar_e = \hbar_o = \frac{1}{6}$, and $\alpha = 0.5$.

5. NUMERICAL EXPERIMENT

To represent the practically and validity of the proposed interactive possibilistic mixed integer nonlinear programming model, an industrial numerical experiment inspired from a manufacturing company is provided. In this numerical example, two products with three quality level as best, moderate, and worst are produced by three workers with three skills level as expert, semiskilled, and beginner based on four machines with three hardness level as easy, moderate, and hard under five jobs. In this respect, the demand of each product with certain quality is determined based on triangular fuzzy number in Table 2. In addition, the needed jobs for each product regarding each machine are defined in Table 3.

TABLE 2. The demand of each product with specified quality level (d_{rq})

Quality level	Products	
	***r*=1**	***r*=2**
Best quality	$\tilde{d}_{11} = (U[6,8], U[9,10], U[13,15])$	$\tilde{d}_{21} = (U[91,95], U[96,100], U[101,105])$
Moderate quality	$\tilde{d}_{12} = (U[82,86], U[88,92], U[93,95])$	$\tilde{d}_{22} = (U[52,57], U[58,62], U[63,68])$
Worst quality	$\tilde{d}_{13} = (U[36,38], U[39,40], U[43,48])$	$\tilde{d}_{23} = (U[14,16], U[18,21], U[23,27])$

TABLE 3. The required jobs for each product which could be processed by each machine (η_{jrm})

Jobs	Machines	Products	
		***r*=1**	***r*=2**
j=1		1	1
j=2		0	1
j=3	*m*=1	1	1
j=4		0	0
j=5		0	0
j=1		0	0
j=2		0	1
j=3	*m*=2	1	1
j=4		1	1
j=5		0	0
j=1		1	1
j=2		0	0
j=3	*m*=3	0	0
j=4		1	1
j=5		0	0
j=1		1	1
j=2		0	1
j=3	*m*=4	1	1
j=4		0	0
j=5		0	0

Furthermore, the processing time of each job which is done by workers regarding each machine is shown in Table 4.

However, the proposed model is solved by ILOG CPLEX 10.1 optimization software and all results are obtained on a 3 GHz computer with 4 GB RAM. Thereby, the obtained value of objective function is 369, and the computational time of running the proposed model is 43 seconds. Meanwhile, two cells are constructed and the first and third machines are assigned to second cell. In versus, the second and fourth machines are allocated to first cell. The number of produced products is represented in Table 5.

For instances, sequence of produced procedure for first product with moderate quality and second product with best quality are schematically represented in Figures 2 and 3, respectively. However, the proposed model could reduce the total costs which are the employment cost of workers according to their skills level, the intercellular and intracellular movements costs, the fixed cost of constructing cells, and the processing cost of machines according to their hardness. In similar circumstances, the total costs are calculated to indicate the efficiency and capability of the proposed approach regarding the workers skills and machines hardness.

TABLE 4. Processing time of each job by each worker on each machine per minute (φ_{jwm})

Jobs	Machines	Workers		
		w=1	*w*=2	*w*=3
j=1		21	16	8
j=2		24	15	14
j=3	*m*=1	16	8	9
j=4		∞	∞	∞
j=5		19	13	9
j=1		∞	∞	∞
j=2		19	17	8
j=3	*m*=2	16	10	9
j=4		9	11	13
j=5		∞	∞	∞
j=1		13	9	9
j=2		∞	∞	∞
j=3	*m*=3	∞	∞	∞
j=4		16	19	8
j=5		19	6	11
j=1		17	5	11
j=2		9	8	9
j=3	*m*=4	9	5	11
j=4		∞	∞	∞
j=5		∞	∞	∞

TABLE 5. Number of produced product with specific quality level

Quality levels	Products	
	r=1	*r*=2
Best quality	7	95
Moderate quality	93	59
Worst quality	46	17

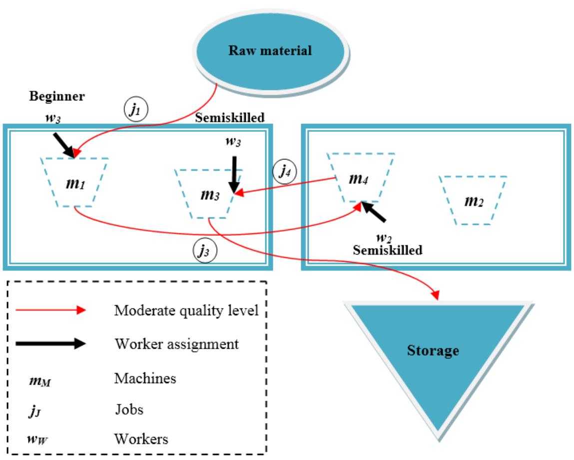

Figure 2. The produced procedure of first product with moderate quality level regarding the required jobs on each machine based on worker skills

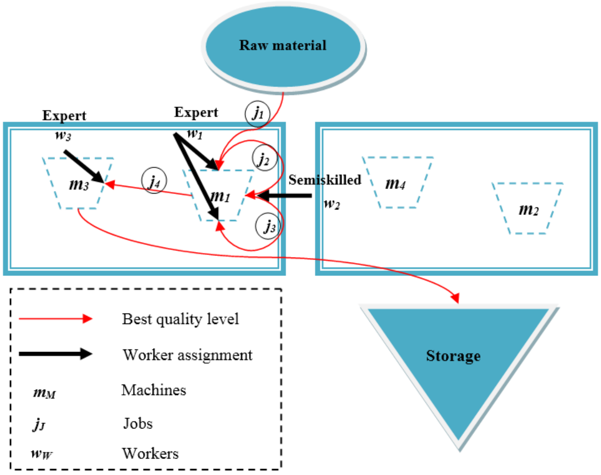

Figure 3. The produced procedure of second product with best quality level regarding the required jobs on each machine based on worker skills

In this case, the total costs are obtained as 511 which shows that the proposed approach could improve the total costs by 27.8%. These obtained results are approved by experts to verify the proposed approach.

6. CONCLUSIONS AND FUTURE DIRECTIONS

Manipulating an appropriate CMS leads to production efficiency and system flexibility by utilizing the procedure similarities of the products. For this sake, an important problem in these systems is considering the worker skill, the machine hardness, and the product quality levels in the production process which could affect the designing of the CMSs. Moreover, the survey of the literature also represents that the job hardness level and the product quality level are not considered in the literature. Also, little attentions have been paid for providing a mathematical model based on other properties. Therefore, this study considers the products quality in the procedure of the operation process according to the jobs hardness and workers skill levels on machines. For this sake, a novel mixed integer non-linear mathematical model is presented under uncertain environment with the goal of minimizing the total costs of cellular manufacturing design to manipulate an appropriate CMS. Meanwhile, the product demand with a specific quality level is denoted based on fuzzy information. Meanwhile, the interactive fuzzy approach is tailored to address with fuzzy impute parameters. Finally, a numerical experiment is considered to demonstrate the applicability and efficiency of the proposed approach. The obtained results show that two cells are established and the produced process of two products is manipulated regarding worker skills, machine hardness, and product quality. Furthermore, comparing the actual practice and obtained results from the presented model shows that the performance of the proposed approach is validated regarding the experts' confirmation by reducing the total costs by 27.8%. For future researches, considering more parameters based on fuzzy setting information is interested to survey the CMS problem under more aspects. In addition, developing a bi-objective model regarding minimizing the total inaction of machines and workers under the dynamic environment could improve the proposed approach.

7. REFERENCES

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A Novel Interactive Possibilistic Mixed Integer Nonlinear Model for Cellular Manufacturing Problem under Uncertainty

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چکیده

ارائه‌ی یک سیستم تولید سلولی مناسب می‌تواند بسیاری از مسائل عملیاتی و ساختاری را حل نماید. بنابراین، در نظر گرفتن چند فاکتر مهم مانند: سطح مهارت کارگر، سطح سختی ماشین و سطح کیفیت محصول می‌تواند شرکت‌ها را در محیط رقابتی فعلی کمک نماید. این مقاله با ارائه‌ی یک رویکرد غیرخطی عدد صحیح مختلط امکانی تعاملی جدید به کاهش هزینه‌های طراحی تولید سلولی می‌پردازد. رویکرد پیشنهادی بر مبنای توالی عملیات، تخصیص ماشین و کارگر، انعطاف‌پذیری مسیر و کارگر، سطح سختی ماشین، ظرفیت کارگر و ماشین، سطح مهارت کارگر و سطح کیفیت محصول تحت اطلاعات غیرقطعی ارائه شده است. از این‌رو، پارامتر تقاضای محصولات بنا به ماهیت آن تحت محیط فازی تعریف شده است. سپس، رویکرد امکانی تعاملی به منظور برخورد با عدم قطعیت موجود در محیط مسئله فراهم گردید. در پایان، یک مثال عددی به منظور نشان دادن توانایی رویکرد پیشنهادی در نظر گرفته می‌شود. نتایج مدل امکانی تعاملی پیشنهادی نشان می‌دهد که رویکر پیشنهادی می‌تواند شرکت‌ها را به منظور کاهش هزینه‌ها و بکارگیری مناسب ماشین‌ها و کارگران یاری رساند. در این رابطه، مقایسه‌ی نتایج بدست آمده حاصل از روکرد پیشنهادی با شرایط مشابه، نشان می‌دهد که مدل پیشنهادی می‌تواند هزینه‌های کل را ۲۷٫۸٪ کاهش دهد.

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