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Research Article

Integrated Design of Cellular Production System Using Branch and Bound Algorithm

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Most research done on the design of cellular production systems also has examined one of the main areas of design including cell formation, cellular layout, and material handling. Some research studies also have been done by considering the lack of independence of these areas, two areas simultaneously, and three areas sequentially. The main goal of this research is to present a mathematical framework for designing and also providing the efficient methods for solving the desired problem. Therefore, the main contribution of this paper is to determine the same component according to the characteristics of designs and production requirements. For this purpose, an overall design of a cellular production system or material handling system with cellular layout is examined. Then, the mathematical formulation is presented for the problem and then an efficient solution is presented for the problem. In the provided model, the interaction effects between designs fields are provided. A branch and bound algorithm is also provided to solve this problem. The performance of the provided algorithm and the performance of the provided approach are investigated by using different numerical samples. The results show the performance of the provided algorithm and approach in the design of cellular production systems.

1. Introduction

The issue of cell production integration design is one of the most important and complex issues in the field of production management; because of the existence of a program that can provide an optimal or near-optimal answer in the face of unexpected events or planned stops, it is considered a good program. Today, manufacturing organizations are mostly focused on increasing productivity. To achieve this, it is necessary to have a regular schedule that takes into account the production schedule and maintenance schedule at the same time. In previous research, each of the dual production and maintenance plans has been examined separately. However, there may be limitations such as limited access to productive resources that occur due to a lack of attention to regular operations. For this purpose, by following a regular procedure, we explain simultaneous integration planning for production and maintenance planning, in order to reduce production costs and increase the reliability of production systems [1].

In most production units, effective information is at an undesirable level of coordination and exchange with other activities. The result of such activities is nothing but a waste of resources (cost, time, materials, etc.) [2]. It is very clear that all parts of the production unit are interdependent and it is necessary to use an integrated format that makes vital factors to make management decisions [1]. The need for integration has long been considered by researchers and industry managers. Therefore, in integrated cellular production, it can be seen that the integration of vital information of different parts of production has been the focus of many researchers, because in the past few decades, there have always been many concerns regarding the integration of different areas related to production activities. Areas that are the beating heart of production units should be used in various decisions. Due to the interaction of each of these areas, they cannot be considered as islands and it is very appropriate and reasonable to plan a mechanism that can bring all the important factors together as much as possible Dymitrowski and Mielcarek [3].

Recent advances in the integration of preventive production and maintenance have included linking the issues of economic production value, preventive maintenance policies, and simultaneous production control of preventive maintenance rates [4]. On the other hand, research that has focused on the integration of production, maintenance, and repairs dates back to the 1970s and 1980s. Research in this period focused on several critical effects, such as the effect of production complexity and technology, speed of operation, commissioning planning, and design of tolerances considering the deterioration of production devices and the impact of repair inspection scheduling on production flow and some research has focused on integrating production and maintenance into system depreciation [5].

According to the above-mentioned, designing an efficient cellular production system involves many different decisions. The most important issue in cellular production systems includes cell formation (CF), cellular layout (CL), and management of material handling (MH). Cell formation includes grouping the similar parts as the families of parts and grouping machines into cells. For this purpose, we can determine the same component according to the characteristics of designs and production requirements. Cellular layout has two aspects: cellular layout in the workshop and machinery layout within cells. Design of material handling systems includes determining the movement type within cells and design of delivery locations and receiving the production cells. Therefore, the main contribution of the paper is as follows:

(i) Presenting a mathematical framework for designing and also providing the efficient methods for solving the desired problem.

(ii) Determining the same component according to the characteristics of designs and production requirements.

The rest of paper is organized as follows: Section 2 presents a literature review. In Section 3, presents the proposed framework. In Section 4, results, validation, and sensitivity analysis are presented. In Section 4, managerial insight is presented and finally in Section 6, overall conclusion and suggestion for future research are presented.

2. Literature Review

In most studies, cell formation is considered as default or intercellular and within cellular problems which are examined independently. Salum [6] provided two-step procedures for solving the cellular layout through simulation. Sarker and Xu [7] provided a method according to the sequencing problems for solving the formation cell problem and intracellular layout by minimizing the total costs of material flow and investments for machine preparing. Bazargan-Lari et al. [8] has provided a multi-objective mathematical model to determine the machine layout and cells in the cellular production environment. The provided model considers quantitative and quantitative aspects. The more complete form of the above model was provided by Bazargan-Lari et al. [8] that simultaneously considers the machine grouping and part grouping, and intercellular layout. The provided solution is simulated by a combination of simulated annealing methods and a fuzzy goal programming. And for a number of different cells, this algorithm provides different layouts to decision-makers. Intercellular layout problem has been studied by Solimanpur et al. This problem is modeled as a quadratic assignment problem (QAP) and Ant algorithm is used to solve it. Yu and Sarker [9] considered machine cell-location as a one-dimension problem and in situations that the distance between cells is not equal. Chan et al. [10] provided a two-stage approach for solving the cell formation and intracellular layout problems. The first step includes determining the family segments and machine cell packaging. In the second phase, the cell formation problem is investigated by considering the sequence machine. Rokhi Nasab et al. [11] addressed business intelligence as a process in which raw data is converted into business and management information using data mining. They focused on e-business and data mining and outlined the challenges and benefits of business data mining. They also presented a classification of data mining applications used in e-business. Abnusian et al. [12] reviewed data mining applications in e-commerce, presented its pros and cons, proposed solutions to control its challenges, and highlighted its benefits. Accordingly, data mining is able to improve e-commerce and increase the profitability and customer satisfaction. Nowruzi and Jafari [13] pointed out that one of the most important steps of business process management lifecycle is to monitor the proper implementation of modeled processes in the organization. Questions raised in order to monitor and decide on the improvement of business processes are sometimes complex questions about the efficiency, accuracy of implementation, the way the processes are actually implemented, and social networks formed in the organization. In addition to answering these questions, there are complex patterns and rules that need to be discovered and extracted from data to support the decision-making of a team of process excellence to improve organizational processes. In other words, process mining is a technique that in addition to answering common questions in this regard by exploring patterns, processes, and rules can be used as a decision support system in the business excellence center of the organization. Jia et al. [14] in a study presented the ant colony optimization algorithm for scheduling jobs with fuzzy processing time on parallel batch machines with different capacities. Jobs have non-uniform sizes and fuzzy processing time. After constructing a mathematical model of this problem, in this paper a fuzzy ant colony optimization (FACO) algorithm is proposed. Based on the capacity limit of the device, two lists of candidates are used to select a job to build the batch. In addition, based on the empty space of the solution, heuristic information is designed for each candidate list to guide the ant. Also, fuzzy local optimization algorithm is included to improve solution quality. Finally, the proposed algorithm is compared with several more advanced algorithms than simulated experiments and statistical tests. Comparative results show that the proposed algorithm can find better solutions in a reasonable time than other comparative algorithms. Minatogawa et al. [15] argued that business model innovation is the organizational key to achieving sustainability. However, there are many problems associated with business model innovation. They used a scientific design method to create an artifact to assist in business model innovation measures. The artifact uses performance metrics to measure a company's business model, which uses big data analysis to innovate a customer-centric business model. Then, the artifact was used in a case study, whose findings show that it successfully contributes to an active and continuous effort to innovate the business model. Although the artifact is technically accessible in the context of small businesses, it helps democratize business model innovation practices and big data analytics across large organizations. Martins et al. [1] aimed to evaluate the perception of experts on the contribution of the Brazilian industrial sector in terms of sustainable development, focusing in particular on three of the 17 Sustainable Development Goals (SDG) presented by United Nations (UN). For this purpose, a survey was conducted with professionals from Brazilian industry in order to identify their perceptions. It obtained sixty-one answers and the collected data was evaluated technically and descriptively by TOPSIS analysis. Dymitrowski and Mielcarek [3] determined the influence of BMI based on new technologies on a company's competitive advantage. In order to accomplish the aim, a quantitative research was performed using the computer assisted telephone interview (CATI) method. There are two main outcomes of the research. Firstly, BMI based on new technologies has a positive influence on a company's competitive advantage. Secondly, it was proven that the greater the use of technologies for BMI, the greater a company's competitive advantage is. Franco et al. [2] built a tool for dynamic capabilities evaluation through a systematic literature review. Then the tool was evaluated based on a three-year, in-depth case study of a software company. Findings show that the current business model has a central role in shaping dynamic capabilities for business model innovation. The proposed measures encompass activities and practices and business model structure, highlighting the relevance of the co-evolution between business model and dynamic capabilities. In [16], according to the scientific literature clustering paradigm of grounded theory is used to design business model innovation theory model (BMITM). BMITM and the business model innovation options traced back from 870 labels in the grounded process are integrated into a unified framework to build the business model innovation canvas (BMIC). Luo et al.'s [5] study aimed to conceptualize the business model innovation BMI themes by integrating the business model theory with institutional attributes of BMI. Based on the research literature, two themes of pioneering and perfection were proposed in BMI, where pioneering BMI creates new market rules and perfect BMI improves existing trading rules. After conducting the studies, two-item scales were developed and empirically validated using two primary data sets collected separately in China. The results suggest that both transactional innovation and legitimacy building are critical to BMI in the emerging market. Dai and Liang [17]. Taking the dynamic capability theory as the research framework, using a two-stage questionnaire survey and 318 Chinese enterprises as samples, this study investigates the impact mechanism of big data technical skills on novel business model innovation, as well as the mediator of resource integration and the moderator of environmental uncertainty. The hierarchical regression results show the following: (1) big data technical skills have a significant positive impact on novel business model innovation; (2) resource integration is a partial mediator between big data technical skills and novel business model innovation; (3) environmental uncertainty regulates the relationship between big data technical skills and resource integration; that is, the higher the environmental uncertainty, the stronger the positive relationship between big data technical skills and resource integration; (4) environmental uncertainty has no significant moderating effect on the mediating role of resource integration between big data technology skills and novel business model innovation.

2.1. Research Gap. According to the above-mentioned, this paper investigates the design of cellular production systems and material handling systems with cellular layout. For this purpose, a suitable mathematical model is provided to solve this problem and then an efficient solution for designing is proposed. In the proposed model, interaction effect of different areas will be considered. The effectiveness of the proposed approach is investigated with respect to the various indices. For this purpose, appropriate performance indices are defined and used for cellular production systems. So, the main purpose of this study is providing a mathematical framework for designing and also providing efficient methods for solving the desired problem. The problems of cell formation and cellular layout have a relation with each other and the obtained answer of these problems influences the other answer. If the problem of cell formation is solved regardless of cellular layout, since the intercellular movement and cell spacing are linked to each other, the obtained answer will not be an accurate answer. On the other hand, in order to solve the problem of cellular layout, the formation style of cells should be considered. In fact, the flow between cells and cell dimensions should be obtained from the formation cell problem. In many real situations, intercellular locating from the delivery point to another cell reception takes place. In such circumstances, the displacement between two cells is calculated according to the receipt and delivery points and distance between two cars should not be considered. In order to determine the cells delivery and receipt location, the material handling systems should be designed in cells. Another problem that should be considered is that by

Table 1: Categorized literature.

Author	Year	Model	Research method	Other factors	Tool
Mitogawa et al.	2020	BMI	Big data analysis	Sustainability	—
Martins et al.	2020	BMI	Questionnaire analysis	Sustainable development	TOPSIS
Mytrowsk and Mielcark	2021	BMI	Quantitative research	—	Questionnaire
Jin et al.	2021	BMI	Quantitative research	—	Grounded theory
Lou et al.	2022	BMI	—	—	—
Dai and Liang	2022	BMI	Big data analysis	Dynamic	Questionnaire
This research	2022	Cellular production systems	Big data analysis	Cellular layout	Branch and bound algorithm

considering the distance between receipt and delivery locations the problems of cell formation and intercellular layout are separated from intracellular layouts. In such situations, we can consider the problems of cell formation, intercellular layout, and designing the handling systems as an integrated issue and we can solve the intracellular layout, separately. In Table 1, we categorize literature-based goals, research method, and tools.

3. Research Method

3.1. Problem Statement. The model developed in this section considers the cell formation, intercellular layout, and design of the material handling systems. The final goal of this model is to determine the cell formation, cell layout in the workshop, and material flow in manufacturing systems. So the switching costs of intercellular components will minimize.

3.2. Problem Assumption. This model assumes the following:

(i) Intercellular layout is as a linear and unidirectional current.

(ii) In each cell, the receipt place is located in one side and delivery place is located in the other side.

(iii) Machines are in a shape of square and so the squares with unit dimensions are considered.

(iv) Space between machines is not considered, since the intercellular arrangement is linear and cells are rectangular.

(v) Each cell's width is one and its length equals the assigned machines.

(vi) The material flow in the cells is determined by the model. And this issue specified the receipt and delivery place of cells. For example, if the material flows in one cell are from left to right, the receipt location is in the left side of cell and its delivery place is located in the right side.

As mentioned, the current objective function is considered to minimize the intercellular material current. So, at first the current between machines is calculated according to the sequence operations and manufacturing volume by using the following formula:

$$f_{ij} = \sum_{k=1}^{n} P_k z_{ijk}. \tag{1}$$

In the previous equation, f_{ij} is the material current from machine I to machine j and P_k is the manufacturing volume and n is the total parts number. If in the sequence operations, part k of machine j is placed after the machine I, z_{ijk} is equal to 1 and otherwise it equals 0. The material current matrix from-to machine is determined by using the f_{ij} values.

3.3. Notation. In this section, all notations used in the model are described.

3.3.1. Indices. The used indices in this model are as follows:

M: the number of machines

C: the number of cells

R: maximum allowed machine in cells

V: the workshop length

3.3.2. Binary Variables

z_{ik}: if machine I is located to machine k, it equals 1 and otherwise 0

x_{ij}: if the machines I and j are located in one cell, it equals 1 and otherwise 0

s_k: if the material flow in cell k is from left to right, it equals 1 and otherwise 0

3.3.3. Integer Variables

l_k: the horizontal feature of cell's left side k

y_k: the vertical feature of cell k

3.3.4. Parameters

r_k: the horizontal feature of the right side of cell k

p_k: the horizontal feature of left side of cell

d_k: the horizontal of receipt place in cell k

3.4. Formulation. According to the introduce notation, the mathematical model is follows:

$$\min \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} \left(\left| \sum_{k=1}^{C} z_{ik} y_k - \sum_{k=1}^{C} z_{jk} y_k \right| + \left(1 - x_{ij}\right) \left| \sum_{k=1}^{C} z_{ik} p_k - \sum_{k=1}^{C} z_{jk} p_k \right| \right), \tag{2}$$

$$\sum_{k=1}^{C} z_{ik} = 1, \quad i = 1, \ldots, m, \tag{3}$$

$$1 \leq \sum_{i=1}^{m} z_{ik} \leq R, \quad k = 1, \ldots, C, \tag{4}$$

$$x_{ij} = \sum_{k=1}^{C} z_{ik} z_{jk}, \quad \forall i, j, \tag{5}$$

$$r_k = l_k + \sum_{i=1}^{m} z_{ik}, \quad k = 1, \ldots, C, \tag{6}$$

$$p_k = l_k \left(1 - s_k\right) + r_k s_k, \quad k = 1, \ldots, C, \tag{7}$$

$$d_k = l_k s_k + r_r \left(1 - s_k\right), \quad k = 1, \ldots, C, \tag{8}$$

$$l_k - r_{k'} + M u_{kk'} + M v_{kk'} \geq 0, \quad \forall k, k', \, k \neq k', \tag{9}$$

$$l_{k'} - r_k + M\left(1 - u_{kk'}\right) + M v_{kk'} \geq 0, \quad \forall k, k', \, k \neq k', \tag{10}$$

$$y_k - y_{k'} + M u_{kk'} + M\left(1 - v_{kk'}\right) \geq 1, \quad \forall k, k', \, k \neq k', \tag{11}$$

$$y_{k'} - y_k + M\left(1 - u_{kk'}\right) + M\left(1 - v_{kk'}\right) \geq 1, \quad \forall k, k', \, k \neq k', \tag{12}$$

$$r_k \leq H, \quad k = 1, 2, \ldots, C, \tag{13}$$

$$y_k \leq V, \quad k = 1, 2, \ldots, C, \tag{14}$$

$$z_{ik}, s_k, u_{kk'}, v_{kk'} = 0 \text{ or} 1, \tag{15}$$

$$l_k, y_k = \text{integer}. \tag{16}$$

Equation (2) provides the objective function and it is defined as the total intracellular total current minimizing. The distance between two cells is calculated by the bridges distance of delivery place of a cell to the receipt place of another cell. Constraints (3) cause this situation that each machine is allocated to one cell and equation (4) shows the cell capacity constraints. Equation (5) makes this situation that if machines I and j are allocated to one cell, x_{ij} equals one and otherwise it takes the 0 value. Equation (6) states that the left side horizontal component equals the horizontal left component of a cell and the number of allocated machines to a cell. Constraints (7) and (8) determine the receipt and delivery locations of cell according to the cells currents. Constraints (9) and (10) guarantee the non-overlapping cells. Equations (11) and (12) specify the workshop level and equations (13) and (14) determine the type of variables. The linearization type of mathematical model of an integrated cell formation, intercellular layouts, and the material handling system design is described as follows.

The proposed objective function of model and constraints (5), (7), and (8) are nonlinear. The objective function is replaced by the following linear equation:

$$\min \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} \left(g_{ij} + h_{ij}\right). \tag{17}$$

And the following constraints are added to the model:

$$y_{ik}' \leq y_{ik} + M\left(1 - z_{ik}\right), \quad \forall i, k, \tag{18}$$

$$y_{ik}' \geq y_{ik} - M\left(1 - z_{ik}\right), \quad \forall i, k, \tag{19}$$

$$y_{ik}' \leq M z_{ik}, \quad \forall i, k, \tag{20}$$

$$p_{ik}' \geq p_{ik} - M\left(1 - z_{ik}\right), \quad \forall i, k, \tag{21}$$

$$p_{ik}' \leq M z_{ik}, \quad \forall i, k, \tag{22}$$

$$d_{ik}' \leq d_{ik} + M\left(1 - z_{ik}\right), \quad \forall i, k, \tag{23}$$

$$d_{ik}' \geq d_{ik} - M\left(1 - z_{ik}\right), \quad \forall i, k, \tag{24}$$

$$d_{ik}' \leq M z_{ik}, \quad \forall i, k, \tag{25}$$

$$g_{ij} \geq \sum_{k=1}^{C} y_{ik}' - \sum_{k=1}^{C} y_{jk}', \quad \forall i, j, \tag{26}$$

$$g_{ij} \geq \sum_{k=1}^{C} y_{jk}' - \sum_{k=1}^{C} y_{ik}', \quad \forall i, j, \tag{27}$$

$$h_{ij} \geq \sum_{k=1}^{C} d_{ik}' - \sum_{k=1}^{C} p_{jk}' - M x_{ij}, \quad \forall i, j, \tag{28}$$

$$h_{ij} \geq \sum_{k=1}^{C} p_{ik}' - \sum_{k=1}^{C} d_{jk}' - M x_{ij}, \quad \forall i, j, \tag{29}$$

where y_{ik}', p_{ik}', d_{ik}', and d_{ik} are the variables that are replaced with the variables y_{ik}, p_{ik} in z_{ik}. Constraints (17)–(25) cause that these variables assign desired values. The constraints (26)–(29) are added to the objective function to eliminate absolute terms. In constraints (28) and (29), if the value of x_{ij} equals zero the amount of h_{ij} will equal to the second absolute term and otherwise, both constraints are imposed and since the objective function of the problem is as a type of minimizing, h_{ij} equals zero. Nonlinear equation (5) is replaced by the following equations:

$$M x_{ijk}' \geq z_{ik} + z_{jk} - 1, \quad \forall i, j, k, \tag{30}$$

$$M\left(x_{ijk}' - 1\right) \leq z_{ik} + z_{jk} - 2, \quad \forall i, j, k, \tag{31}$$

$$x_{ij} = \sum_{k=1}^{C} x_{ijk}', \quad \forall i, j. \tag{32}$$

In the previous equations, x_{ijk}' is a variable that if machines I and j are placed in cell k, equals one and otherwise it equals zero. Equation (32) causes that if there is a cell, machines I and j are allocated to it and in this situation, x_{ij} equals one and otherwise it equals zero. Finally, the linear constraints are replaced in (7) and (8) equations in the model.

$$\begin{aligned}
p_k &\le l_k + Ms_k, \quad k = 1, \ldots, C,\\
p_k &\ge l_k - Ms_k, \quad k = 1, \ldots, C,\\
p_k &\le r_k + M(1 - s_k), \quad k = 1, \ldots, C,\\
p_k &\ge r_k - M(1 - s_k), \quad k = 1, \ldots, C,\\
d_k &\le l_k + M(1 - s_k), \quad k = 1, \ldots, C,\\
d_k &\ge l_k - M(1 - s_k), \quad k = 1, \ldots, C,\\
d_k &\le r_k + Ms_k, \quad k = 1, \ldots, C,\\
d_k &\ge r_k - Ms_k, \quad k = 1, \ldots, C.
\end{aligned} \tag{33}$$

As noted above, if the problems of cell formation and intercellular layout are solved by considering the receipt and delivery places, the intercellular layout problem will be separate from cell formation and intercellular layout. In this section, we consider the intracellular layout by considering the linear machine layout. Because the material handling system is considered to be one-sided, the main purpose of this problem is minimizing the reversed current volume. The objective function is defined as to minimizing the amount of return flow. The goal of this study is finding a machine sequence that their return flow is minimized with respect to the matrix material flow. In order to design an efficient mathematical model, also a single zero variable and x_{ij} are used in this model. If the machine I is located before machine j, this variable has the 1 value and otherwise it takes zero. The mathematical model is as follows:

$$\min \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij}\left(1 - x_{ij}\right), \tag{34}$$

$$x_{ij} = 1 - x_{ji}, \quad \forall i, \forall j,\ i \ne j, \tag{35}$$

$$x_{ij} \ge x_{ik} + x_{kj} - 1, \quad \forall i, \forall j, \forall k,\ i \ne j \ne k, \tag{36}$$

$$x_{ij} = 0 \text{ or} 1. \tag{37}$$

Equation (34) shows the objective function of the problem. Constraint (35) states that if the machine I is located before machine j, then the machine j cannot be located before machine i. Equation (36) states that if machine I is located after machine k and machine k is located after machine j, then the machine I will be located before machine j. Equation (37) shows that the variable used in the model is in the type of zero and one.

3.5. Solution Approach

3.5.1. The Integrated Problem Solving of Cell Formation, Intracellular Layout, and Material Handling System with Genetic Algorithm. Due to the complexity of the integrated cell problem, the intracellular arrangement, and the material handling system, the exact solution of the problem is only possible for small or medium-sized problems, and this section describes the problem solving with GA. The overall structure of algorithm and operators design will be explained. And in the next sections, some numerical examples are solved by the desired algorithm and the results will be analyzed.

3.5.2. Solving the Intracellular Layout Problem Using Proposed Branch and Bound Algorithm. The model which is provided to solve the intracellular problem is pure binary programming, and there are several ways to solve this problem. One of the common methods is the branch and bound algorithm. Of the in-layout problem, we consider m machine in one cell; in the provided model, the model's variables will be m^2 and the number of constraints is also obtained from the following equation:

$$N = m(m-1) + m(m-1)(m-2) = m(m-1)^2. \tag{38}$$

By considering the increase of problem dimensions, the number of variables and constraints will not increase exponentially and solving the desired problem will be possible with high dimensions. A problem with 30 machines can be solved with the proposed model by using the branch and bound algorithm and Lingo software. Furthermore, in designing the cellular production systems, even 10 machines within a cell counts as a large number and therefore in practical applications, using the desired model and solving it by using Lingo software can guarantee finding the optimal solutions in a very short time.

4. Results

First, investigating the performance of proposed approach is done. For this purpose, to evaluate the performance of proposed approach, a numerical example was used by Mahdavi et al. [18]. The reason for choosing this example is that in the approach of Mahdavi et al. [18] current matrix is used. The desired example has 25 machines and 40 components. The machine-component matrix of this example shows the operations sequence which is shown in Table 2. In order to compare this example with the obtained results by Mahdavi et al., the production volume is considered. As the production volume is the same, without prejudice of the generality, the production size is considered as Table 2.

4.1. Validation. In order to evaluate the effectiveness of the algorithm, 8 numerical samples with different aspects are considered; in order to produce the numerical samples in Table 3, the flow material matrix for each problem is randomly generated. Each of the samples is solved ten times and in each case the best answer, the mean, and median duration

Table 2: Machine-component matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1				5			3			1						4		2				6			
2	2	3															4								1
3			2								3									1					
4												1											2		
5				3								2						1							
6												3				2							1		
7				3			2			5						4		1							
8					1											3			2						
9			3								4									1					2
10								2	1																3
11								2					3								1				
12	1		4														3							2	5
13			3								2									1					
14			4		1						2									3					
15		4			3					5						1			2						
16				1			3									2		4							
17							1			3								2							
18														3	2							1			
19								1	3	2															
20																2							1		
21								1	3	2															
22			3					4	2								1								
23					2											3			1						
24					1											2									
25						1									3						2				
26				2								3			4								1		
27												1									3	2			
28								2	1	3															
29					3	2															1				
30				4			2									3		1							
31					2												1		3						
32													2	1	3							4			
33											1									3					2
34												2											1	3	
35						2									4						1	3			
36	2	3									4						1								
37							3					2											1		
38								2	3													1			
39							2					1													
40						2									3						1				

time are recorded. Then, according to the response of the branch and border and the genetic algorithm, the absolute relative error (ARE) was calculated as recommended by Abolghasemian et al. [19]. ARE is calculated as equation (39) based on the comparison of genetic output and branches and borders. Table 4 compares the results obtained from the branch and bound algorithm.

$$\frac{|\text{Branch and bound output} - \text{genetic algorithm output}|}{\text{genetic algorithm output}}. \tag{39}$$

According to the ARE results that shown in Table 4, for each sample, calculate lower than 0.1; therefore, the error difference between the results of the two algorithms is negligible.

4.2. Sensitivity Analysis. In this section, according to the examples considered in the previous step, we change the value of some key parameters to examine their effect on the target function according to the branch and boundary method. As shown in Figure 1, Experiment 4 significantly increases response time. The response time increases to the maximum possible in the sixth experiment. Given that there are many changes in the number of machines from Experiment 4, we can conclude that the response time is highly dependent on the number of machines.

4.3. Discussion. Integrated design like as mathematical modelling has already strongly transformed many industries such as cellular manufactures. The aim of this research is to study the impact and significance of integrated design in the cellular manufactures. For this purpose, we conducted a literature review of the research articles. As a result of these steps, research gaps in the application of integrated design were identified. These gaps can be beneficial for researchers

TABLE 3: Material flow matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	1	0	0	0
5	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	2	0	0	0	0	0	0
6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
9	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
11	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
12	0	0	0	1	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
16	0	0	0	2	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
17	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
20	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
21	0	0	0	0	0	3	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0
23	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
25	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

TABLE 4: Comparing the obtained results from branch and bound algorithm.

The number of problem	Number of machines	Number of cells	Maximum number of machines	Response		
				Genetic response time (seconds)	Branch and bound response time (second)	ARE
1	6	3	3	203	194	0.04
2	8	3	3	230	250	0.08
3	10	3	4	436	450	0.03
4	12	3	5	434	442	0.01
5	14	4	5	1053	1100	0.04
6	16	4	5	1899	2100	0.09
7	18	5	5	4049	4100	0.01
8	20	5	6	6560	6600	0.006

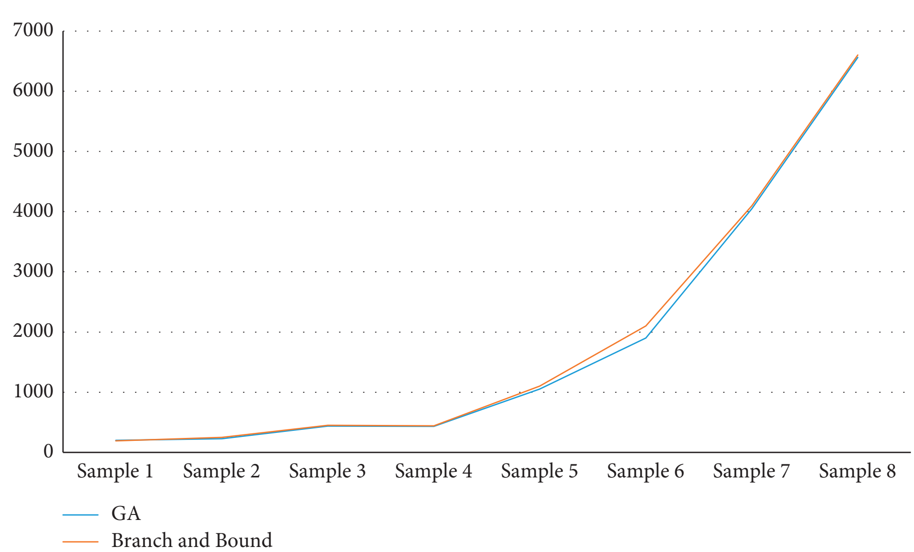

FIGURE 1: Comparison between GA and branch and bound.

in the academic world as future lines of research. Then, we proposed an integer mathematical programming. To solve mathematical programming, we introduced a branch and bound approach. Then, the proposed approach was formed with the genetic algorithm. The results shown for each sample are calculated to be less than 0.1, and the error difference between the results of the two algorithms is insignificant.

5. Managerial Insight

Most research done on the design of cellular production systems also has examined one of the main areas of design including cell formation, cellular layout, and material handling. Some researches also have been done by considering the lack of independence of these areas, two areas simultaneously and three areas sequentially. In addition, it is also considered in the models presented to solve the problems of cell formation and cell arrangement simultaneously. Many realistic situations of the workshop environment are not considered. In fact, in none of the studied models, the exact layout of machines within cells and cell layout are not determined in the workshop. In most models, only one of the cells or intercells is solved, and the output of the model solution is a sequence of cells or machines.

6. Conclusion

In the research conducted in the design of cell production systems, interactions such as cell formation, arrangement, and management systems have been neglected. In addition, the research that simultaneously considers the cell formation and cell layout does not consider the real situation of workshop. In the present study, the comprehensive mathematical framework for designing the cellular production systems together with the solution algorithm is presented.

The main goal of this research is to present a mathematical framework for designing and also providing the efficient methods for solving the desired problem. Therefore, the main contribution of this paper is to determine the same component according to the characteristics of designs and production requirements. This study includes a different approach in integrated design of cellular production system. In this approach, by considering the material handling system, cell formation and cellular layout are investigated separate from intracellular layout. Intercellular layout is considered as the production lone and material handling systems. A branch and bound algorithm is also provided to solve this problem. The performance of provide algorithm and the performance of provided approach are investigated by using different numerical samples. The results show the performance of the provided algorithm and approach in design of cellular production systems. So first the mathematical linear model is provided as the integrated problem of cell formation, intracellular layout, and designing the material handling systems by minimizing inter-cell flow. The main results of the paper are as follows:

(i) The proposed model can calculate the best value of the objective function by considering the number of machines, the number of cells, and the maximum number of machines

(ii) The proposed model has a significant difference in terms of computational time compared to the genetic algorithm

(iii) Due to the slight difference between the proposed model and the genetic algorithm, with increasing computational time, we can use the genetic algorithm as it determines the optimal response in less time

For further research, given that we encounter uncertain parameters in the real world, we can get closer to the real world by applying uncertainty in modelling.

Data Availability

Data are available upon reasonable request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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