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Dynamic virtual cell formation considering new product development

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Goal programming;
Bi-objective optimization.

Abstract. Nowadays, factories should exercise and develop adaptability to the competitively dynamic environment of current markets and businesses. Different strategies and systems exist to help factories in a dynamic environment. In this paper, a new multi-objective mathematical model was presented by implementing dynamic virtual cellular manufacturing and considering new product development, which enable factories to be successful in their business. This paper follows three objectives: maximizing the total profits of the factory in all the periods, the grouping efficacy, and the number of new products. Following the linearization of the proposed model, multi-choice goal programming with utility function was used to solve the model. Further, a case study was conducted in the real world to show the effectiveness of the proposed model and, finally, the results showed that the integration of virtual cellular manufacturing with new product development could be helpful for managers and companies and ensure higher efficiency.

1. Introduction

One of the efficient methods for facility planning is group technology that is highly regarded because of its advantages. One of the primary uses of the group technology is cellular manufacturing in which each cell consists of some machines and production equipment able to process a group of parts called part families, which have the same production processes. In cellular manufacturing, machines with different functions gather together to produce a batch of parts with similar manufacturing processes [1]. However, the major disadvantages of classical cellular manufacturing systems are their low production flexibility and failure to effectively utilize machine capacity; these flaws are more noticeable in the face of changes in demand or demand combination. Nowadays, fluctuations in the amount and composition of product demand have convinced manufacturers to produce their products according to placed order, which leads to the dynamism of production and an increase in production flexibility. In the dynamic mode, the planning horizon is divided into several smaller periods so that the amount and composition of demand can vary in different periods. In other words, in a specific period, some products may not receive any demand, or some product demands may vary in periods. Further, it is possible to produce new products by discontinuing old products for a specific period. The production environment that is characterized by the above conditions is the so-called dynamic environment. The composition or level of demand for products varies periodically, and formed cells or cell configurations of each period will not

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necessarily be optimized for the next periods. As implied, the feasibility of cell reconfiguration at the beginning of each period and, thus, the changing of the facility layout and part families are to be noted. Dynamic conditions mainly entail cell reconfiguration costs such as the relocation cost of machines between periods, investment in new machines, removal of unnecessary machines, and also cost of changing the product processing program. Accordingly, the Cell Formation Problem (CFP) in a dynamic condition is also called flexible cell formation.

Nowadays, it is necessary to carefully consider customer requirements such as customer's demand and produce higher quality products at lower prices to survive in the business. In addition to customer appreciation, the improvement of products and processes is one of the important factors in business survival in a competitive world. Many of the businesses concentrate on agility and quick response to the customer's demand in this environment. Group technology makes it possible for companies to realize this goal by concentrating on Cellural Manufacturing System (CMS). CFP is the first and foremost important problem in the design of cellular manufacturing. Many types of research and methods have been proposed to solve these problems. According to the above, the displacement of machines in each period imposes additional charges on the system in dynamic environments. Moreover, this relocation causes an interruption in production such that profits and production may be lost during relocation. On the other side, the physical relocation of machines may not be possible or economically justifiable. To overcome this problem, Virtual Cellular Manufacturing (VCM) is introduced. In contrast to dynamic cellular systems, there is a configuration in the first period of production in the VCM systems and, according to the virtual nature of the cells, some costs such as machine relocation between two periods, investment in new machines, and removal of unnecessary machines are not imposed. In a VCM system, machines and parts are temporarily grouped for the first period. In this situation, machines are physically installed at the beginning of the first period of the planning horizon. However, in terms of structure, according to the demand for parts or the introduction of new parts to the system, machine group may change in different periods. Therefore, machine group and part families are optimally programmed for each period according to the demand and production conditions without the machines moving physically in consecutive periods.

Many companies cease the production and supply of some products or apply necessary reforms in order to ensure the best response to changes. Moreover, to identify consumers' demand and requirements in different markets and in order to meet these requirements, maintain long-term trade, and promote economic prosperity in the company, companies have decided to make the best use of New Product Development (NPD). One of the important and effective issues in manufacturing productivity, return on investment, and market share includes the design and operation of production and manufacturing systems [2]. The objective of the NPD is:

(a) To respond to customer requirements;

(b) Ensure better adaptability to the market variations and environmental changes, increased profit, and customer satisfaction;

(c) To deal with the competitor's policies.

Successful development and commercialization of new products in the market will cause a shift from mass production to customization and shortening of product life cycle [3]. Therefore, this trend is a factor in the market competition according to customer requirements, and the identification of key factors and structured strategies can assist policy-makers and organizational planners in codifying strategies with an extensive and inclusive vision. According to the type of new products, some changes such as changes in cell formation, existing facilities, required material, and planning horizon may occur in a cellular system by adding these new products to the production line. This shows the importance of a dynamic system. For example, with the introduction of a new product, the factory may need new machines or raw materials to affect production and supply planning. Therefore, it is necessary for the factory's R & D teams to identify the features and the nature of a new product in order to be able to react to the changes through proper planning and ensure the best productivity from the development of the new product [4]. According to previous studies, NPD should go through a series of steps, ranging from idea generation to commercialization [5]. The development of new product manufacturing is assumed to be done, and the main purpose of this article is to design a better production process when selected new products are added and, also, to answer the following question: "what is the best process of producing a selected product?"

The introduction of a new product can lead to changes in production planning. For example, if new suppliers and raw materials are needed, a plant management would require new planning in the production, procurement, distribution system, etc. The introduction of new products requires the preparation of new materials, new machines in some cases, new processes, etc. Therefore, NPD can affect production planning. Therefore, the adoption of a system for dealing with changes is one of the most important elements of a factory. NPD influences the supply chain and can change the configuration of the chain and its sections such as procurement, production, and distribution [6]. Therefore, the manufacturing system as an important section of the chain is not an exception.

2. Literature review

Compared to other manufacturing systems, many studies on cellular manufacturing have focused on increasing the company's performance for different purposes such as minimizing costs, decreasing voids and exceptional elements, maximizing the total profit, etc. [7]. Due to changes in demand and the necessity of reconfiguration, researchers have proposed the concept of dynamic VCM that has received significant attention recently. Several studies have been conducted in this field, some of which will be reviewed in the following. Mahdavi et al. [8] proposed a mathematical model for production planning in a dynamic VCM system on multi-period planning horizons with demand and part mix variation and worker flexibility. A fuzzy goal programming-based approach to solving a multi-objective mathematical model of the CFP and production planning in a dynamic VCM system was proposed by Mahdavi et al. [9]. The main benefits of their presented model include the consideration of part mix and demand changes with worker flexibility, as assumed on a multi-period planning horizon. Han et al. [10] studied the problems of virtual cellular multi-period dynamic reconfiguration. They developed a reconfigurable system programming model. Their model incorporates the parameters of the problems of product dynamic demand, balanced workload, machine capacity, operation sequence, alternative routings, and batch setting. They presented a mixed integer programming model to minimize the total costs of operation, moving raw materials, inventory holding, and process routes setup. Paydar and saeidi-Mehrabad [11] offered a bi-objective mathematical model, which is of probabilistic optimization type, to design a supply chain and virtual cell formation in the multi-period production planning. Demand and capacity were considered uncertain in their study. Procurement, distribution, and production planning were integrated into the model. The model contained different objectives concurrently, and also some critical parameters such as customer demands and machine capacities were imprecise. A revised multi-choice goal programming method was used to solve the presented mathematical model and select a suitable solution. Baykasoglu et al. [12] developed a new VCM method according to dynamic demand arrivals. To adopt an efficient integrated method, they used an agent-based modeling approach because, among other benefits, it enjoys the ability to track and evaluate real-time information successfully and model the complex systems effectively. Rabbani et al. [13] presented a dynamic CFP considering some new and special characteristics. The concept of machine requirement by lucky parts, the parts that are allowed to be produced in a specific period, is combined with the depreciable property of machines. They proposed a new mathematical model that was solved by exact ant colony optimization method for three problem sizes. Rabbani et al. [14] provided a new multi-objective mathematical model for dynamic cellular manufacturing system that considers machine reliability and alternative process routes.

NPD can change the facility layout, and CMS is not an exception. By adding a new product to the manufacturing systems, some changes may occur in cellular manufacturing due to the nature of the product, which shows the importance of having a dynamic system. These changes can include cell structure, existing facilities, raw materials, production volume, and so on. Therefore, it is necessary for R&D group of factories and companies to identify the characteristics and nature of the new product to be able to plan properly and logically to deal with the changes and ensure the best efficiency of NPD. The integration of cellular manufacturing into NPD can provide such benefits as improved quality, shorter product development time, and improved access to and application of technology [15].

Lim and Tang [16] considered an analytical model to analyze the profits associated with two product rollover strategies: single-product rollover and dual-product rollover. The single-product rollover strategy calls for the simultaneous introduction of the new product and the elimination of the old product. For the dual-product rollover, at first, they introduced a new product and, then, phased out the old product. Koca et al. [17] suggested the product rollover strategy decision in which the factory decides to phase out the older generation of a product and replace it with a new form of the product. The final build of an old product, the pre-announcement of a newer one, and the combination of inventory decisions and dynamic pricing were considered in their model. Beauregard et al. [18] developed a model where queuing theory was used and, specifically, the obtained results of Jackson networks were extended to help management improve Product Development (PD) task flow and eventually make it leaner. Some factors were considered in their study such as optimal PD task size, multi-tasking level, and the utilization level of PD resources. Nafisi et al. [19] identified how and when manufacturing functions such as engineers and operators were involved in an NPD project. Their results from a conducted case study in heavy automotive component assembly showed that manufacturing engineers were more actively involved than manufacturing operators during the early phases of the NPD studies.

According to the survey of the literature, it was found that the dynamic VCM system in terms of NPD was not considered.

In this paper, a novel multi-objective optimization mathematical model is defined that covers these two aforementioned issues simultaneously. Manufacturing industries are under severe pressure due to global competition, and customers' demand and close competition in the business environment have led industry owners to make optimal decisions to meet their customers' requirements. Therefore, the simultaneous design of the cellular system by considering the NPD improves factories in terms of cost control, quality and time control, and performance and ensures the overall improvement of the output product, thus facilitating better utilization of the opportunities ahead.

The rest of this article is organized as follows: Section 3 provides the notations and problem description and gives a new multi-objective model for the research problem. Section 4 presents a multi-choice goal programming method with utility function in order to solve the proposed model. Section 5 presents a case study to validate the proposed solution method. Section 6 explains the impact of NPD on virtual cellular manufacturing. Finally, conclusion and future study are explained in Section 7.

3. Model formulation

In this paper, a novel model is designed for the CMS planning with new product entry including three objective functions. The impact of the new product entry in the cell formation is studied based on the designed model. The indices, parameters, and decision variables, which are used to formulate the proposed model, are defined as follows:

Indices:

t	Index of periods
c	Index of cells
m	Index of machines
i	Index of products

It is noted that products contain two groups:

(a) The products that are produced by the factory as represented in the first group,

(b) The new products that the company decides to produce during the planning horizon, which is indicated in the second group.

The indices defined for products are given below:

$$i = \begin{cases} o\ (old) & o = 1, \cdots, O \\ n\ (new) & n = O+1, \cdots, I \end{cases}$$

where o represents the first group, and n shows the second group of products.

Parameters:

D_{it}	Demand of customer group for product i in period t
dl_n	New product designing duration of product n
MT_{im}	Processing time of product i on machine m
T_{mt}	Available time of machine m in period t
a_{im}	1 if product i should be processed on machine m; 0 otherwise
PC_{it}	Unit production cost of product i manufactured in period t
HC_{it}	Unit inventory holding cost of product i in period t
LC_{it}	Unit lost sale cost of product i in period t
DC_i	Designing cost of new product i
R_{it}	Sailing price of product i in period t
A	Large number (positive)
NP	Storage capacity at factory's storehouse

Decision variables:

Z_{it}	Number of products i produced during period t
L_{it}	The amount of lost sales of product i in period t
IP_{it}	Inventory of product i at the end of period t
X_{mct}	1 if machine m is assigned to cell c in period t; 0 otherwise
Y_{ict}	1 if product i is assigned to cell c in period t; 0 otherwise
ET_{it}	Binary variable that represents the time when a new product becomes available in the market
DP_{nt}	1 if company decides to design product n in period t; 0 otherwise

Objective functions

The total profit is the most practical decision objective that is usually used in many production planning models. In this study, the total profit is considered and obtained from the differences between the revenue of selling products and such costs as the holding cost, production cost, lost sale, and designing costs that are calculated as follows:

$$\max \ PR =$$

$$\text{Revenue from sales} = \sum_t \sum_i PR_{it} Z_{it} - \quad (1\text{-}1)$$

$$\text{Holding cost} = \sum_t \sum_i HC_{it} IP_{it} - \quad (1\text{-}2)$$

$$\text{Production cost} = \sum_t \sum_i PC_{it} Z_{it} - \quad (1\text{-}3)$$

$$\text{Lost sale cost} = \sum_t \sum_i LC_{it} L_{it} - \quad (1\text{-}4)$$

$$\text{Designing cost} = \sum_t \sum_{n \in i} DC_i DP_{nt} \quad (1\text{-}5)$$

Eq. (1-1) defines the profit received from selling products. Eqs. (1-2) and (1-3) denote the inventory holding cost and production cost of parts in all the periods, respectively. The lost sale cost is computed through Eq. (1-4), and the cost associated with the new product design is obtained by Eq. (1-5).

The following equation shows the second objective function that maximizes the grouping efficacy of the produced parts in virtual cells on the planning horizon:

$$\max \ TVGE = \sum_t \sum_i Z_{it} \left(\frac{\sum_m a_{im} - \sum_c \sum_m a_{im}(1 - Y_{ict} X_{mct})}{\sum_m a_{im} + \sum_c \left(\sum_m X_{mct} Y_{ikt} - \sum_m X_{mct} Y_{ict} a_{im} \right)} \right). \quad (2)$$

The third objective maximizes the production of new products. Although producing new products may incur additional costs for the factory, the factory may suffer further losses in a competitive environment if this issue is ignored. Therefore, the following objective function is defined to compute the number of new products produced during all the periods:

$$\max \ NPD = \sum_{n \in i} \sum_t Z_{nt}. \quad (3)$$

Constraints:

$$IP_{i(t-1)} + Z_{it} - IP_{it} + L_{it} = D_{it} \qquad \forall\, i, t, \quad (4)$$

$$\sum_i MT_{im} \times Z_{it} \leq T_{mt} \qquad \forall\, m, t, \quad (5)$$

$$\sum_i IP_{it} \leq NP \qquad \forall\, t, \quad (6)$$

$$\sum_c X_{mct} = 1 \qquad \forall\, m, t, \quad (7)$$

$$\sum_c Y_{ict} = \min(1, Z_{it}) \qquad \forall\, i, t, \quad (8)$$

$$Z_{it} \leq A \times ET_{it} \qquad \forall\, t, i, \quad (9)$$

$$ET_{nt} < \sum_h DP_{nh} \qquad \forall\, t \geq h + dl(i), \quad n \in i, \quad (10)$$

$$\sum_t DP_{nt} \leq 1 \qquad \forall\, n \in i, \quad (11)$$

$$Z_{it}, IP_{it}, L_{it} \geq 0 \text{ and integer} \qquad \forall\, i, t, \quad (12)$$

$$Y_{ict}, X_{mct}, DP_{nt}, ET_{it} \in \{0, 1\} \qquad \forall\, i, m, c, t. \quad (13)$$

Eq. (4) relates to inventory and demand balancing constraint for the products. Relation (5) ensures that the summation of the processing time of each product should be less than or equal to the total available time of machine m in period t. Constraint (6) considers the capacity of manufacturing warehouses. Eq. (7) shows that each machine must be allocated to only one virtual cell in each period. Eq. (8) guarantees that each product is either allocated to only one virtual cell or not assigned to any virtual cell in period t. Eq. (9) illustrates the production allowance, and Eq. (10) expresses the unavailability of a new product for production until period $h + dl_i$. Constraint (11) shows the factory's decision on producing a new product. Relations (12) and (13) specify the type of decision variables.

3.1. Linearization

It is clear that the second objective of the proposed model is nonlinear due to the multiplication and division of the decision variables. Herein, an attempt is made to make an objective function in the linear fraction form by introducing an auxiliary variable [11]. This attempt can add some additional constraints to the original model. Therefore, the new variable is defined as follows:

$$F_{imct} = Y_{ict} X_{mct}.$$

New constraints are formed below:

$$F_{imct} - Y_{ict} - X_{mct} + \Delta \geq 0 \qquad \forall\, i, m, c, t, \quad (14)$$

$$\Delta^* F_{imct} - Y_{ict} - X_{mct} \leq 0 \qquad \forall\, i, m, c, t, \quad (15)$$

$$F_{imct} \in \{0, 1\} \qquad \forall\, i, m, c, t. \quad (16)$$

Δ is constant, $\Delta \in R$ and $1 < \Delta < 2$. Afterwards, non-negative variable $S_{imct} = Z_{it} F_{imct}$ is defined, and some extra constraints are added to the original model:

$$S_{imct} \leq Z_{it} - A \times (1 - F_{imct}) \qquad \forall\, i, m, c, t, \quad (17)$$

$$S_{imct} \geq Z_{it} + A \times (1 - F_{imct}) \qquad \forall\, i, m, c, t, \quad (18)$$

$$S_{imct} \leq A \times F_{imct} \qquad \forall\, i, m, c, t, \quad (19)$$

$$S_{imct} \geq 0 \text{ and integer} \qquad \forall\, i, m, c, t. \quad (20)$$

A is considered as a large positive number in the above-mentioned constraint.

Furthermore, the term of $\min(1, Z_{it})$ in Constraint (8) is nonlinear and should be changed to a linear form as in the following constraint:

$$\sum_c Y_{ict} \leq 1 \qquad \forall\, i, t, \tag{21}$$

$$Z_{it} \leq A \times \sum_c Y_{ict} \qquad \forall\, i, t \tag{22}$$

$$Z_{it} \geq \sum_c Y_{ict} \qquad \forall\, i, t. \tag{23}$$

Since Y_{ict} is a binary variable, $\sum_c Y_{mct} = 1$.

4. Solution procedure

Different methods for solving multi-objective problems have been identified, which have been used in many papers. Some of these techniques have been improved to provide a better answer. In this article, a method is used for solving the proposed model, as introduced by Chang [20]. This method aims to derive the achievement function of Multi-Choice Goal Programming with Utilities (MCGP-U) for Decision-Makers (DM) to formulate the multi-objective problems in line with their priorities. In this approach, the DM seeks to maximize the expected utility. Given that the objective functions in this article are linear, only a linear form of utility function $u_k(y_k)$ is considered as follows:

Case I:

$$u_k(y_k) = \begin{cases} 1 & \text{if } y_k \leq g_{k,\min}, \\ \frac{g_{k,\max} - y_k}{g_{k,\max} - g_{k,\min}} & \text{if } g_{k,\min} \leq y_k \leq g_{k,\max}, \\ 0 & \text{if } y_k \geq g_{k,\max}, \end{cases}$$

Case II:

$$u_k(y_k) = \begin{cases} 1 & \text{if } y_k \geq g_{k,\max}, \\ \frac{y_k - g_{k,\min}}{g_{k,\max} - g_{k,\min}} & \text{if } g_{k,\min} \leq y_k \leq g_{k,\max}, \\ 0 & \text{if } y_k \leq g_{k,\min}, \end{cases}$$

where $g_{k,\max}$ and $g_{k,\min}$ are the lower and upper bounds for the kth goal. Cases I and II are defined for maximizing and minimizing objective functions, respectively. According to the principle of expected utility, the DM would increase the utility value λ_k by as much as possible. In real situations, it is difficult to solve a decision problem by automatically increasing the utility value by as much as possible. In order to overcome this difficulty and improve the utilization of MCGP, the following two linear cases, i.e., Left Linear Utility Function (LLUF) and Right Linear Utility Function (RLUF), should be addressed. It is better to be as close as possible to RLUF and LLUF when the objective function is minimized and maximized, respectively.

The DM would like to increase the utility value $u_k(y_k)$ by as much as possible in the case of LLUF if the objective function is maximized. In order to achieve this goal, the value of y_k should be as close as possible to the target value $g_{k,\min}$.

$$\min \sum_{k=1}^{K} \left[w_k (d_k^+ + d_k^-) + \beta_k f_k^- \right],$$

s.t.:

$$\lambda_k \leq \frac{g_{k,\max} - y_k}{g_{k,\max} - g_{k,\min}} \qquad k = 1, 2, \cdots, K, \tag{24}$$

$$f_k(x) - d_k^+ + d_k^- = y_k \qquad k = 1, 2, \cdots, K, \tag{25}$$

$$\lambda_k + f_k^- = 1 \qquad k = 1, 2, \cdots, K, \tag{26}$$

$$g_{k,\min} \leq y_k \leq g_{k,\max} \qquad k = 1, 2, \cdots, K, \tag{27}$$

$$d_k^+, d_k^-, f_k^-, \lambda_k \geq 0 \qquad k = 1, 2, \cdots, K,$$

$$x \in X,$$

where w_k and β_k are the weights attached to deviations d_k^+, d_k^-, and f_k^-. The role of weight β_k can be seen as an excellent part for utility value $u_k(y_k)$. λ_k is the value of linear utility function.

On the other hand, the DM would like to increase the utility value $u_k(y_k)$ by as much as possible in the case of RLUF if the objective function is minimized. In order to achieve this goal, the value of y_k should be as close as possible to the target value $g_{k,\max}$. Further, this case can be formulated as in the following program:

$$\min \sum_{k=1}^{K} \left[w_k (d_k^+ + d_k^-) + \beta_k f_k^- \right],$$

s.t.

$$\lambda_k \leq \frac{y_k - g_{k,\min}}{g_{k,\max} - g_{k,\min}} \qquad k = 1, 2, \cdots, K, \tag{28}$$

$$f_k(x) - d_k^+ + d_k^- = y_k \qquad k = 1, 2, \cdots, K, \tag{29}$$

$$\lambda_k + f_k^- = 1 \qquad k = 1, 2, \cdots, K, \tag{30}$$

$$g_{k,\min} \leq y_k \leq g_{k,\max} \qquad k = 1, 2, \cdots, K, \tag{31}$$

$$d_k^+, d_k^-, f_k^-, \lambda_k \geq 0 \qquad k = 1, 2, \cdots, K,$$

$$x \in X.$$

5. Case study

The case study of a machinery factory in Mazandaran in the north of Iran was selected. The company produces fifteen products consisting of: (1) Rotocultivator, (2) Sprayer, (3) Stalk Shredder, (4) Mover, (5) Chipper, (6) Roller Chisel, (7) Borer, (8) Ditcher, (9) Rear Hydraulic Crane Arm, (10) Pruning and Harvesting Series, (11) Fruit Disinfecting, (12) Sorting, (13) Fruit Cartoon Montaging, (14) Packing, and (15) Label Dispenser. Ten workstations (machines) include: (1) Dyeing, (2) Welding, (3) Press, (4) Machining, (5) Molding, (6) Die-casting, (7) Bending, (8) Electricity, (9) Packing, and (10) Assembly are active in the company. Products 1 to 11 are the old products that the company has produced in the past up until now; moreover, products 12, 13, 14, and 15 are new, and the duration of designing these new outputs includes 2, 1, 2, and 1 periods, respectively. Moreover, designing the cost of new products is 930, 2125, 2125, and 15950 dollars, respectively. The survey has been conducted in seven periods, each of which spans a duration of three months. The unit of the processing time of parts on machines is in hour. The unit of the cost is in dollar. Tables 1 to 3 show the major parameters.

To demonstrate the validity and capability of the suggested model, the case study has been solved by the MCGP-U function with Lingo 16.0 software package. The aforementioned data were used as input

Table 1. Demand for customer group in each period (unit of product).

		Period						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Product	1	20	21	22	20	20	11	19
	2	25	23	21	21	21	23	20
	3	18	20	20	20	23	20	21
	4	16	19	20	20	21	20	19
	5	18	19	20	18	19	20	22
	6	19	21	22	20	20	21	22
	7	17	20	20	20	19	20	22
	8	20	22	21	21	23	20	23
	9	25	19	20	22	21	20	21
	10	22	20	21	21	23	20	22
	11	23	21	21	25	23	20	23
	12	21	19	20	23	21	21	20
	13	24	21	20	22	22	22	21
	14	22	25	20	21	23	20	21
	15	26	23	20	20	21	22	23

parameters. In the first step, only the first objective function of the proposed model is considered (Ob1 sub-problem). In this case, the aim is to maximize the profit of the factory in all periods, and the following results are obtained.

The factory attains 10,584,640 dollars of profit and, accordingly, the second and third objective functions are obtained as 2,951 and 415 values, respectively.

In the second step, only the second objective function of the proposed model was evaluated (Ob2 sub-problem), and the following results were achieved: The value of TVGE is 3,242 in this step, and the values of the first and the third objectives are PR $= 8,537,222$ dollars and NPD = 363.

Finally, only the third objective function of the proposed model was assessed (Ob 3 sub-problem), and it was found that the optimum value of manufacturing new products was 463. In this case, the factory gains 4,155,619 dollars and the second objective equals 984.

On the other hand, the amounts of W_1, W_2, W_3 and β_1, β_2 and β_3 are shown in Table 4.

The objective function of the proposed model is obtained through the MCGP-U method:

$$\min = \left[w_1\left(d_1^+ + d_1^-\right) + w_2\left(d_2^+ + d_2^-\right) + w_3\left(d_3^+ + d_3^-\right) + \beta_1 f_1^- + \beta_2 f_2^- + \beta_3 f_3^-\right],$$

where w_1, w_2, w_3 are the weights related to deviations d for the first, second, and third objectives, respectively, and β_1, β_2, β_3 are the weights for deviation f for the first, second, and third objective functions. Some constraints are added to the model for applying the MCGP-U method. The following constraints are added to the first objective function:

$$PR - d_1^+ + d_1^- = y_1, \tag{32}$$

$$\lambda_1 \leq \frac{g_{1,\max} - y_1}{g_{1,\max} - g_{1,\min}}, \tag{33}$$

$$\lambda_1 + f_1^- = 1, \tag{34}$$

$$g_{1,\min} \leq y_1 \leq g_{1,\max}. \tag{35}$$

Moreover, the following constraints are added to the model to the second objective function:

$$TVGE - d_2^+ + d_2^- = y_2, \tag{36}$$

$$\lambda_2 \leq \frac{g_{2,\max} - y_2}{g_{2,\max} - g_{2,\min}}, \tag{37}$$

$$\lambda_2 + f_2^- = 1, \tag{38}$$

$$g_{2,\min} \leq y_2 \leq g_{2,\max}. \tag{39}$$

Finally, the following constraints relating to the third objective function are added to the model:

Table 2. Product processing on workstations (processing time (hour)).

Product	Workstations 1	2	3	4	5	6	7	8	9	10
1	0	1(10)	0	1(8)	0	1(14)	0	0	0	0
2	1(6)	0	0	0	0	0	1(13)	1(9)	0	1(12)
3	0	0	1(11)	0	0	0	0	0	1(15)	0
4	0	0	0	1(8)	1(12)	1(10)	0	0	0	0
5	0	0	1(13)	0	0	0	0	1(15)	1(11)	0
6	0	1(8)	0	0	1(10)	1(14)	0	0	0	0
7	0	0	0	0	0	0	1(6)	0	0	1(10)
8	1(8)	0	1(11)	0	0	0	0	0	1(12)	0
9	0	1(9)	0	1(11)	1(8)	1(10)	0	0	0	0
10	1(11)	0	0	0	0	0	1(7)	0	0	1(6)
11	1(10)	1(8)	0	0	1(7)	0	0	1(11)	0	1(6)
12	1(9)	0	0	0	0	0	1(7)	0	0	1(10)
13	0	1(6)	0	0	1(7)	0	0	1(9)	0	0
14	0	0	1(8)	1(8)	0	1(7)	0	0	1(6)	0
15	0	1(7)	0	0	1(12)	0	0	1(8)	0	0

Table 3. Production cost of products on the workstation.

Product	Period 1	2	3	4	5	6	7
1	173	180	180	185	186	199	212.5
2	100	100	106	106	120	120	133
3	319	319	332	345.4	372	372	372
4	139.5	146	146	159	159	173	173
5	159	173	173	186	186	199	212
6	239	239	252	265.7	265.7	292	292
7	93	93	93	106	106	113	120
8	359	365	365	372	372	385	398
9	40	40	53	53	60	66	66
10	319	332	345	372	372	385	398
11	398	425	438	451	478	491	505
12	106	119	119	133	146	159	173
13	159	173	173	186	199	199	212
14	332	332	339	339	345	358	372
15	1993	2125	2258	2391	2391	2524	2656

$$NPD - d_3^+ + d_3^- = y_3, \tag{40}$$

$$\lambda_3 \leq \frac{g_{3,\max} - y_3}{g_{3,\max} - g_{3,\min}}, \tag{41}$$

$$\lambda_3 + f_3^- = 1, \tag{42}$$

Table 5. Target value for each objective function.

	Objective function PR	TVGE	NPD
$g_{\max}$	281222	3,242	463
$g_{\min}$	265569	2,800	430

$$g_{3,\min} \leq y_3 \leq g_{3,\max}, \tag{43}$$

$$d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, f_1^-, f_2^-, f_3^- \geq 0,$$

where d_1^+, d_2^+, d_3^+ are the positive deviation variables of goals PR, TVGE, and NPD, respectively, and d_1^-, d_2^-, d_3^- are the negative deviation variables of goals PR, TVGE, and NPD, respectively. According to the above steps, the following six sub-problems should be solved to obtain $g_{\max}$ and $g_{\min}$ values for each objective function. After solving these sub-problems, the results are shown in Table 5.

$g_{1.\min}$ can also be achieved by dissolving min PR

$g_{1.\max}$ can also be achieved by dissolving max PR

$g_{2.\min}$ can also be achieved by dissolving min $TVGE$

$g_{2.\max}$ can also be achieved by dissolving max $TVGE$

$g_{3.\min}$ can also be achieved by dissolving min NPD

$g_{3.\max}$ can also be achieved by dissolving max NPD

Table 4. Weights of deviation d and f for each objective function.

	Obj. function 1 (PR)	Obj. function 2 (TVGE)	Obj. function 3 (NPD)
W	0.45	0.35	0.2
β	0.5	0.3	0.2

Note: $W(PR) = W_1$; $W(TVGE) = W_2$; $W(NPD) = W_3$.
β is the same as W.

$$d_1^+ = 0, \qquad d_1^- = 150565.7, \qquad PR = 1,0434,070,$$

$$y_1 = 1,0283,504.3, \qquad f_1^- = 0.52,$$

$$d_2^+ = 0, \qquad d_2^- = 172.6, \qquad TVGE = 3,069,$$

$$y_2 = 2,896.4, \qquad f_2^- = 0.4,$$

$$d_3^+ = 0, \qquad d_3^- = 0, \qquad NPD = y_3 = 463,$$

$$f_3^- = 0.$$

According to the results, the third objective is completely satisfied because its positive and negative deviations of this goal are zero. Although the first objective has negative deviation (d_1^-) that has a 1.5% gap from the goal and, also, the second objective has negative deviation (d_2^-) from the goal level with a 5% gap from the goal, the obtained results are shown to be reasonable and appropriate. Moreover, the objective functions of the proposed model are considered as constraints, and the objective function of MCGP-U is examined, where the results are presented in Table 6 in this case.

According to Table 6, it can be found that the factory can gain 10,434,070 thousand dollars by producing 463 new products, and the grouping efficacy is 3,069 in this case. The result of MCGP-U is 2.503 in this situation. Table 7 shows the deviation percentage of different sub-problems from the best value of each objective function. The optimum number of products produced in each period is shown in Table 8.

According to the achieved optimal solution, the design of new products 12 and 13 starts in the first period; moreover, the design of products 14 and 15 occurs in periods 3 and 4, respectively. Therefore, new products 12, 13, 14, and 15 are available in the production plan in periods 3, 2, 5, and 5, respectively,

Table 6. Optimum solution with using MCGP-U.

Objectives	Value
MCGP-U	2.503
PR	277222
TVGE	3069
NPD	463

Table 7. The deviation percentage of sub-problems from each objective.

	PR	TVGE	NPD
Ob1	0.00	8.98	10.37
Ob2	0.518	0.00	21.60
Ob3	1.614	69.65	0.00
MCGP-U	0.038	5.34	0.00

Table 8. Optimum number of products in each period.

		Period						
		1	2	3	4	5	6	7
Product	**1**	20	21	22	20	20	11	19
	2	25	38	6	27	17	21	20
	3	15	40	20	6	15	12	14
	4	16	19	40	0	21	20	19
	5	40	0	11	20	7	12	10
	6	29	11	22	20	20	21	22
	7	19	20	20	20	19	42	0
	8	20	20	30	45	10	11	12
	9	20	45	10	15	17	20	21
	10	22	20	21	21	23	20	22
	11	23	21	21	25	23	20	23
	12	0	0	20	23	21	21	20
	13	0	21	20	20	35	12	20
	14	0	0	0	0	30	21	13
	15	0	0	0	0	21	63	82

Table 9. Initiation of designing new products.

		Period						
		1	2	3	4	5	6	7
New product	**12**	*		#				
	13	*	#					
	14			*		#		
	15				*	#		

*: Starting time of designing;

#: Available in the production system.

due to the considered duration of the new product design (Table 9).

The design of cells and the allocation of workstations and products to each cell are obtained. Figure 1 illustrates the virtual cell configuration for seven periods, where some of the positive features of the model can be realized. However, the assignment of workstations can change in each virtual cell. For example, workstations 1 and 4 are moved from cells 3 and 1 to cells 1 and 2, respectively, in period 3. Although there is demand for some products, the manufacturer has decided not to produce these products in some periods due to the type of objective functions and constraints such as capacity constraint. For example, products

		Cell 1					Cell 2		Cell 3		
		Workstations									
		8	10	4	5	7	6	2	3	1	9
Product	2	1	1			1				1	
	4			1	1		1				
	5	1							1		1
	7		1			1					
	10		1			1				1	
	9			1	1		1	1			
	11	1	1			1				1	
	1			1			1	1			
	6				1		1	1			
	3								1		1
	8								1	1	1

Period 1

		Cell 1					Cell 2		Cell 3		
		Workstations									
		8	10	4	5	7	6	2	3	1	9
Product	2	1	1			1				1	
	4			1	1		1				
	13	1			1			1			
	7		1			1					
	10		1			1				1	
	9			1	1		1	1			
	11	1	1			1				1	
	1			1			1	1			
	6				1		1	1			
	3								1		1
	8								1	1	1

Period 2

		Cell 1					Cell 2			Cell 3	
		Workstations									
		8	10	1	5	7	6	2	4	3	9
Product	2	1	1	1		1					
	4				1		1		1		
	12		1	1		1					
	13	1			1			1			
	7		1			1					
	10		1	1		1					
	11	1	1	1		1					
	9				1		1	1	1		
	1						1	1	1		
	6				1		1	1			
	3									1	1
	8			1						1	1
	5	1								1	1

Period 3

		Cell 1					Cell 2			Cell 3	
		Workstations									
		8	10	1	5	7	6	2	4	3	9
Product	2	1	1	1		1					
	12		1	1		1					
	13	1			1			1			
	7		1			1					
	10		1	1		1					
	11	1	1	1		1					
	9				1		1	1	1		
	1						1	1	1		
	6				1		1	1			
	3									1	1
	8			1						1	1
	5	1								1	1

Period 4

		Cell 1				Cell 2				Cell 3	
		Workstations									
		8	10	1	7	5	6	2	4	3	9
Product	2	1	1	1	1						
	10		1	1	1						
	12		1	1	1						
	11	1	1	1		1		1			
	7		1		1						
	15	1				1		1			
	13	1				1		1			
	9					1	1	1	1		
	1						1	1	1		
	6					1	1	1			
	4					1	1		1		
	8			1						1	1
	5	1								1	1
	14						1		1	1	1
	3									1	1

Period 5

		Cell 1				Cell 2				Cell 3	
		Workstations									
		8	10	1	7	5	6	2	4	3	9
Product	2	1	1	1	1						
	10		1	1	1						
	12		1	1	1						
	11	1	1	1		1		1			
	7		1		1						
	15	1				1		1			
	13	1				1		1			
	9					1	1	1	1		
	1						1	1	1		
	6					1	1	1			
	4					1	1		1		
	8			1						1	1
	5	1								1	1
	14						1		1	1	1
	3									1	1

Period 6

		Cell 1			Cell 2					Cell 3	
		Workstations									
		7	10	1	8	5	6	2	4	3	9
Product	2	1	1	1	1						
	10	1	1	1							
	12	1	1	1							
	11	1	1	1	1	1		1			
	15				1	1		1			
	13				1	1		1			
	9					1	1	1	1		
	1						1	1	1		
	6					1	1	1			
	4					1	1		1		
	8			1						1	1
	5				1					1	1
	14						1		1	1	1
	3									1	1

Period 7

Figure 1. Optimal cell configurations in each period.

5, 4, and 7 are not processed in periods 2, 4, and 7, respectively.

The proposed model enables managers to take advantage of using the virtual cell formation and the optimum amount of new products' production to reach the desired profit. Therefore, administrators can be successful in a competitive market by applying this model to the company's strategic planning. Manufacturers seek to improve their production plan, gain more profit, ensure customer satisfaction, stay updated

Table 10. Machine and part assignment in periods 2 and 3.

		Cell 1	Cell 2	Cell 3
Period 2	Workstation	8-10-4-5-7	6-2	3-1-9
	Products	2-4-13-7-10-9-11	1-6	3-8
Period 3	Workstation	8-10-1-5-7	6-2-4	3-9
	Products	2-4-12-13-7-10-11	9-1-6	3-8-5

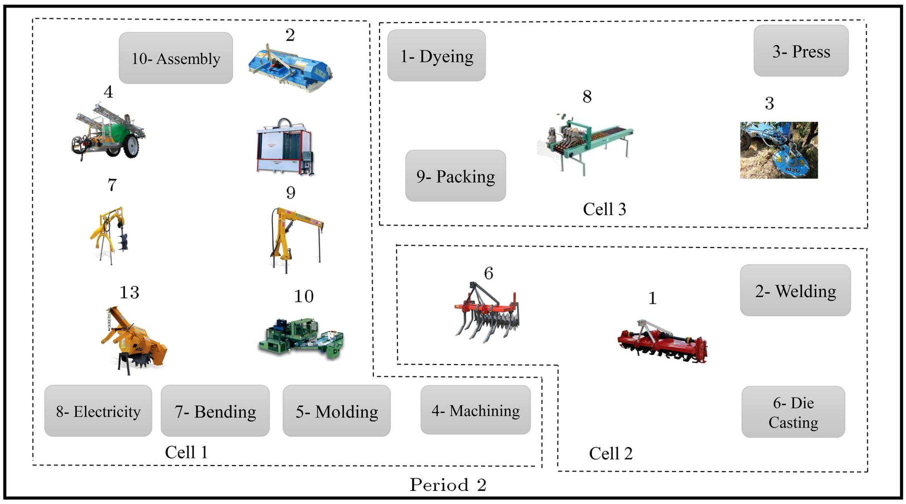

Figure 2. Cell formation in period 2.

in a competitive market, and so on. Therefore, the proposed model can be helpful for many industries.

6. Impact of the NPD on VCM

A company should not be dependent on its current manufacturing products exclusively due to the changing consumers' tastes and developments in a competitively technological environment. Customers ask for new and more advanced products, which are what competitors are looking for. The concept of NPD is one of the important strategies in each company. NPD is an important part of every business that provides opportunities for growth and competitive advantage for companies. The company studied in this article is no exception and uses this concept in its policy to take advantage of developing a new product. The NPD will assist companies with maintaining their competitive and exclusive positions, facilitate a better use of funds, and enhance the company's production and profits. Companies should confront their competitors and always prepare a good response to the market changes. According to the virtual cell formation concept, virtual cells are configured at the beginning of each period according to the product-workstation matrix and the demand for the current period. On the other hand, the studied company is seeking product development. Therefore, virtual cell formation should be designed for the current period when new products and parts are introduced to the production system. Therefore, this could change the existing virtual formation that can affect the grouping efficacy. The optimal configuration is performed at the beginning of the planning horizon (first period), and the configuration of virtual cells in each period is made due to the certain circumstances of that period (product-workstation matrix and demand). Suppose that the company does not want to produce new products. Then, the product-workstation matrix remains constant, and the configuration of the first period may remain optimal up to the end of the planning horizon. Manufacturers could confront losses if they ignore NPD. Therefore, manufacturing firms prefer to use this concept in their strategies. For example, the product-workstation matrix changes by introducing product 13 to the production line in period 2; however, these changes do not disrupt the virtual cell formation. The existing product-workstation matrix has changed by introducing product 12 to the production line in period 3, and the virtual cell formation changes accordingly. Thus, workstation 4 is added to the virtual cell no. 2 and, also, workstation 1 is moved from the virtual cell no. 3 to the virtual cell no. 1. Table 10 offers an example of product workstation assignment in periods 2 and 3.

Figure 2 shows the virtual cell formation in the

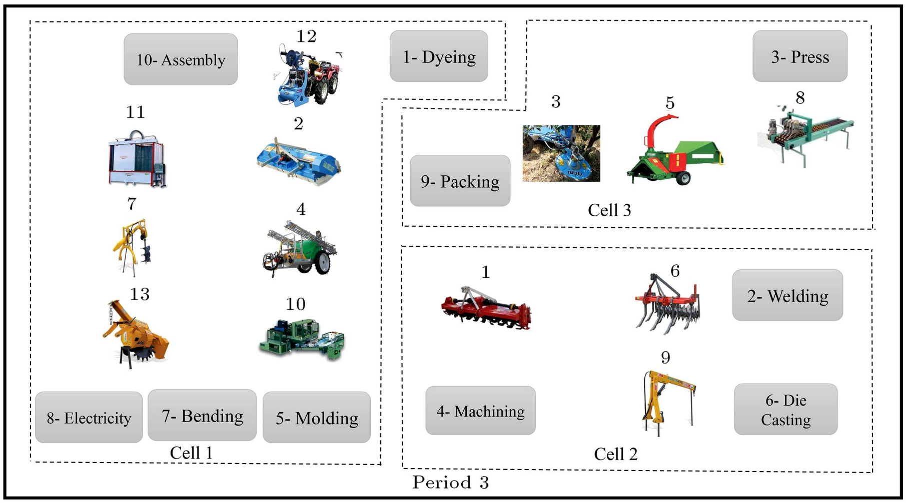

Figure 3. Virtual cell formation in period 3.

second period that contains three virtual cells with 11 products. Dyeing, assembly, and packing workstations are located in the first virtual cell. Moreover, molding, machining, and die casting workstations are located in the second virtual cell; bending, press, electricity, and welding workstations are assigned to the third virtual cell. Therefore, the product-workstation matrix and also the formation of the cells are changed in the third period by introducing product 12 to the production system. As shown in Figure 3, the machining workstation is moved to the virtual cell no. 2 and the dyeing workstation is moved to the virtual cell no. 1. Thus, it is indicated that the production of new products can affect the formation of the cells.

Moreover, the addition of new products 14 and 15 to the production system in period 5 can be affected by the virtual formation of cells.

Table 11 shows the assignment of workstations and parts in each virtual cell. For example, workstations 1, 5, 7, 8, and 10 and also products 2, 7, 10, 11, 12, and 13 are assigned to the virtual cell no. 1 in period 4. Furthermore, in period 5, the virtual cell no. 1 includes workstations 1, 7, 8, 10 and products 2, 7, 10, 11, 12. As shown in Table 11, new products 14 and 15 are added to the production line in period 5, leading to a change in the product-workstation matrix. As mentioned above, the assignment of workstations and products in cells varies, compared to that in the previous period. Figures 4 and 5 show the virtual cell formation in periods 4 and 5, facilitating a better understanding of this concept.

According to Figures 4 and 5, the following changes occurred in period 5 (introducing products 14 and 15):

- Product 13 moves from the virtual cell no. 1 to no. 2;
- Product 4 moves to the virtual cell no. 2;
- Products 14 and 15 are added to the virtual cells 3 and 2, respectively;
- Workstation 5 (molding) is moved from the virtual cell no. 1 to no. 2.

Two states can be defined to compare the results of the proposed model with the condition without new products. Each of these two mathematical models is solved by Lingo software, and results are presented in Table 12. The following two situations are considered to illustrate the impact of NPD on the proposed model:

State 1: We have 11 old products and 4 new products (as proposed in this article);

Table 12. Results of the two proposed situations.

	MCGP-U	PR	TVGE	NPD
State 1	2.503	277222	3069.3	463
State 2	2.612	250475	3465.97	0

Table 11. Workstations and part assignment in periods 4 and 5.

		Cell 1	Cell 2	Cell 3
Period 4	Workstations	8-10-1-5-7	6-2-4	3-9
	Products	11-10-7-13-12-2	9-1-6	3-5-8
Period 5	Workstations	7-1-10-8	4-2-6-5	3-9
	Products	7-11-12-10-2	4-6-1-9-13-15	3-14-5-8

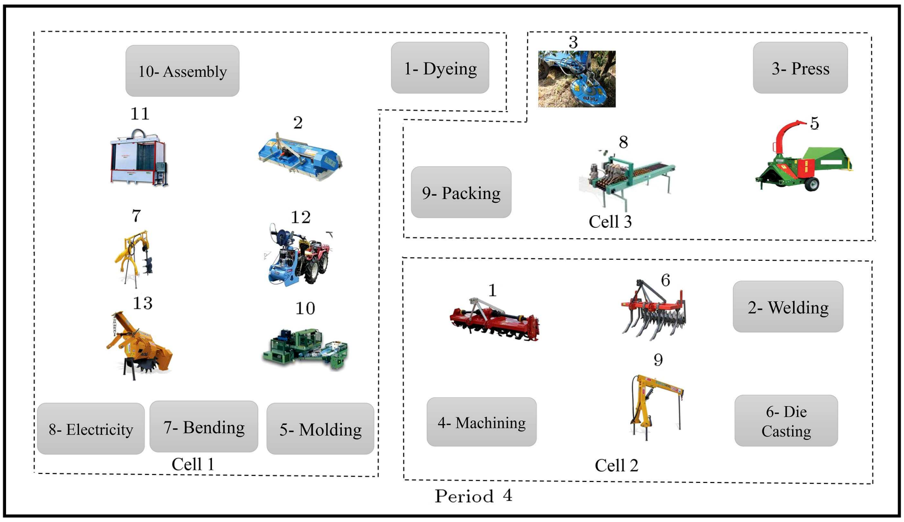

Figure 4. Cell formation in period 4.

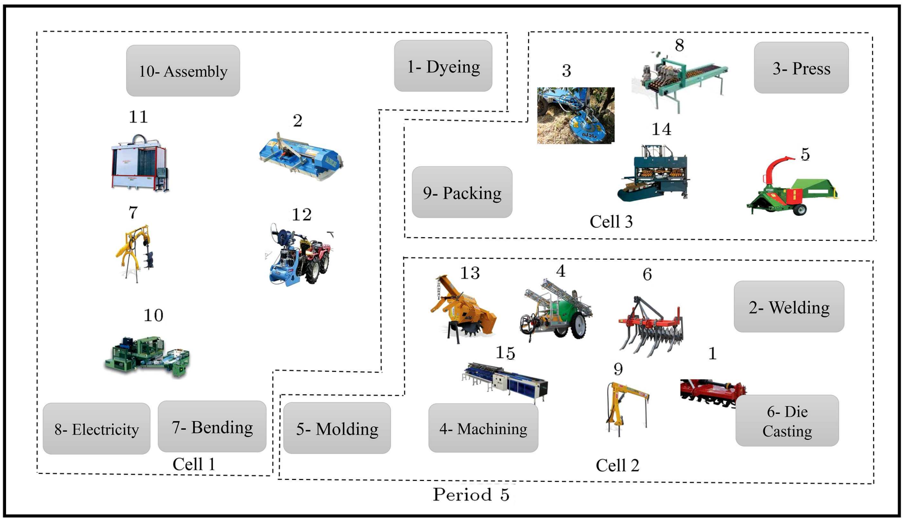

Figure 5. Virtual cell formation in period 5.

State 2: The company wants to continue producing 11 old products and does not seek any NPD.

The results show the priority of the proposed model of this article (11 old products and 4 new products) in comparison with the situation without new products (11 old products). The first objective function belongs to profit with a better value in State 1 (277222 thousand dollars).

As mentioned in the article, GE is one of the well-known factors in evaluating the effectiveness of cell formation. Cell formation with higher GE has better performance. Although the GE has decreased by adding new products, the company gains greater profit and possesses newer products to gain more market share and survive in the competitive market. The value of the second objective function of State 1 is 3069.3, which is less than that of State 2 (3465.97). However, the value of 3069.3 is acceptable and tangible. On the other hand, the proposed model considers new product development to persuade the company to produce new products (to have more market share). If the company neglects the market changes, it may lose its market and customers. Moreover, due to the demands for new products, the company may lose profit by discarding this issue.

Based on the results, the studied company may have lower grouping efficacy; however, the reduction of GE is not too much. The company enjoys good benefits by producing new products, which makes the company one of the pioneers of this particular industry in its particular domain. The integration of CMS (as one of the best manufacturing systems) and NPD leads the company to gain the benefits of CMS and NPD simultaneously and helps the company survive in the competitive business environment.

7. Conclusion

In this paper, a virtual cellular manufacturing system with the objective of new product development was discussed. This issue brings about many benefits that can be helpful for managers and manufacturers to make better decisions in their planning. Virtual cellular manufacturing has many advantages that can facilitate a better response in a dynamic environment; in addition, new product development can help factories to be updated and successful in a competitive market due to demand changes. In this regard, a mathematical model was defined that enjoyed three objectives: maximizing profit, grouping efficacy, and the production of new products. After linearizing the mathematical model, the proposed model was solved by multi-choice goal programming with utility function, whose results were shown. According to results, the factory's return (profit) is 277222 dollars when 463 new products are produced and the grouping efficacy is 3,069.

In this study, the concept of a cellular production system and the development of a new product were simultaneously used in the mathematical model, which helped manufacturers to benefit from these two concepts. It is recommended that the senior managers of the plant improve the factory level with a team of researchers and specialists in the field of product design and development by considering the demands of customers, because customers are the main valuable assets for the manufacturer. From a strategic point of view, it is suggested that managers gain more market share due to the competitive environment of the present world; in addition, because of a variety of brands in every industry, managers should consider customer orientation and production based on customer demand as a principle and adopt a production system that enjoys more benefits than other systems.

This field of research needs further study with the following topics:

- Considering old products that improve or change into new products;
- Requiring new machines for producing new products;
- Evaluating the effect of new product development on the supplier selection and supply of materials.

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