Dynamic virtual cell formation considering new product development

Ahmadreza Rostami,
MSc student, Department of Industrial Engineering, Babol Noshirvani University of Technology, Babol, Iran, Postal Code: 4718789157 Tel: +981132360032, Mobile: +989112163880,
E-mail: Ahmadreza.rostami70@gmail.com

Mohammad Mahdi Paydar*,
Assistant professor, Department of Industrial Engineering, Babol Noshirvani University of Technology, Babol, Iran, Postal Code: 4714871167 Tel: +981135501817, Mobile: +989113235979,
E-mail: paydar@nit.ac.ir

Ebrahim Asadi-Gangraj
Assistant professor, Department of Industrial Engineering, Babol Noshirvani University of Technology, Babol, Iran, Postal Code: 4714871167 Tel: +981135501817, Mobile: +989112218300,
E-mail: e.asadi@nit.ac.ir

Abstract
Nowadays, factories should be coordinated with changes in the dynamic environment due to the intense competition in the businesses. Different strategies and systems are existing to help factories in a dynamic situation. In this article, a new multi-objective mathematical model is presented by the implementation of dynamic virtual cellular manufacturing and also considering new product development which enables factories to

* Corresponding author
be successful in their business. This paper contains three objectives including maximizing the total profits of the factory in all the periods, the grouping efficacy and also the number of the new product. After linearization of the proposed model, multi-choice goal programming with utility function is used to solve the model. Also, a case study has been conducted in the real world to show the effectiveness of the proposed model and finally, the results show that the integration of virtual cellular manufacturing with new product development can be helpful for managers and companies and leads to more efficiency.

Keywords: Dynamic virtual cell formation, Grouping efficacy, New product development, Goal programming, Bi-objective optimization.

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 that is able to process a group of parts called as 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]. But, the major disadvantages of classical cellular manufacturing systems are reducing the production flexibility and lack of effective utilization of machine capacity, especially 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 the order, which caused to the dynamism of production and requires to increase the production flexibility. In 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 another word, in a specific period, some products may not have any demand or some product demands may be different toward prior periods. Also, it is possible to produce new products by discontinuing old products for a specific period. The production environment that has the above conditions is so-called dynamic environment. In the case of the composition or level of demand for products is changed periodically, formed cells or cell configurations
of each period, will not necessarily be optimized for the next periods. That means the feasibility of reconfiguration cells at the beginning of each period and thus changing the facility layout and also part families. Dynamic condition mainly entails cell reconfiguration costs such as the cost of relocation of machines between periods, investment in new machines, remove unnecessary machines and also cost of changing the products processing program. That is why the cell formation problem (CFP) in dynamic condition is also called flexible cell formation.

Nowadays, it is necessary to pay more attention to the customer’s requirement such as customer’s demand and produce higher quality products at lower prices to stay alive in the business. In addition to customer attention, continues improvement in the products and processes is one of the important factors to survive businesses 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 reach this goal by concentrating on CMS. CFP is the first and most 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, displacement of machines in each period imposes additional charges to the system in the dynamic environments. Also, this relocation causes to interruption of production as if profits and production will be lost in the time of relocation. On the other side, physically relocation of machines may not be possible or economic. 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 remove unnecessary machines are not imposed. In a virtual cellular manufacturing system, machines and parts temporarily are grouped for the first period. In this situation, machines are physically installed at the beginning of the first period of the planning horizon. But in terms of structure, according to the demand of parts or entering new parts to the system, machine group will be changed in different periods. So, machine group and part families are optimally programmed for each period according to the demand and production conditions without moving machines physically in consecutive periods.
Many companies stop the production and supply of some products or impose the necessary reforms on them in order to have the best response to changes. Also, according to identification requirements and demands of consumers in different markets, and in order to meet these requirements and maintain long-term trade and promoting economic prosperity in the company, companies decide to take advantage from new product development (NPD). One of the important and effective issues in manufacturing productivity, return on investment, and market share are the design and operation of production and manufacturing systems [2]. The aim of the NPD can be responded to customers’ requirements, adapting to market conditions, environmental changes, increasing profit, customer satisfaction and to deal with the competitor’s policies. Successful development and commercialization of new products in the market will cause to move from mass production to customization and shortening product life cycle [3]. Therefore, this trend is a factor for competition in the market according to customers’ requirements, and identification of key factors and structured strategies, make policy makers and companies' planners codify strategies with extensive vision. According to the type of new products, some changes such as changes in cell formation, existing facilities, required material and planning horizon maybe occur in a cellular system by entering these new products in the production line. This shows the importance of having a dynamic system. For example, by the entrance of a new product, the factory may need new machines or raw materials that this would effect on production and supply planning. Therefore, it is necessary for the factory’s R & D teams to identify the feature and the nature of the new product in order to be able to react to the changes with the correct planning and to have the best productivity from the development of the new product [4].

According to previous studies, NPD has some steps from idea generation to commercialization [5]. It is assumed that the development of new product manufacturing is done and the main purpose of this article is to design a better production process when selected new products are entered and also what is the best process of producing a selected product?

The entrance of a new product can lead to changes in production planning. For example, if the new supplier and the raw materials are needed, the plant needs new planning in the production, procurement, distribution system and etc. The entrance of new products
requires the preparation of new materials, new machines in some cases and also new processes, etc. So, the new product development 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

In compare with 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, and something like that [7]. Due to changes in demand and the necessity to reconfiguration, the concept of dynamic virtual cellular manufacturing proposed by researchers that are highly regarded recently. Several studies have been conducted in this field that review some of them in the following. Mahdavi et al. [8] proposed a mathematical model for production planning in a dynamic virtual cellular manufacturing system under conditions of multi-period planning horizons with demand and part mix variation and worker flexibility. A fuzzy goal programming-based approach for solving a multi-objective mathematical model of the CFP and production planning in a dynamic virtual cellular manufacturing system was proposed by Mahdavi et al. [9]. The main benefits of their presented model are the consideration of part mix and demand changes with worker flexibility which is considered in 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 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 probabilistic optimization for designing supply chain and virtual cell formation in multi-period production planning.
The demand and capacity are uncertain in their study. Procurement, distribution and production planning are integrated into the model. The model contains different goals concurrently and also some critical parameters such as customer demands and machine capacities are imprecise. The revised multi-choice goal programming method used to solve the presented mathematical model and to select a suitable solution. Baykasoglu et al. [12] developed a new virtual cellular manufacturing method according to dynamic demand arrivals. To adopt an efficient integrated method, they used an agent-based modeling approach since its benefits. Because agent-based modeling has the ability to track and evaluate real-time information successfully and to model the complex systems effectively. Rabbani et al. [13] presented a dynamic cell formation problem 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 which solved by exact and ant colony optimization methods for three problem sizes. Rabbani et al. [14] provided a new multi-objective mathematical model for dynamic cellular manufacturing system (DCMS) with consideration of machine reliability and alternative process routes.

New product development can change the facility layout and cellular manufacturing system is also not an exception. By entering 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 be included 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 have the best efficiency of new product development. Integration of cellular manufacturing into NPD can lead such benefits as improved quality, reduced 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
introduce the new product and after that phase out the old product. Koca et al. [17] suggested the product rollover strategy decision, in which the factory decides to phase out an old generation of a product and replaced it with a new form of the product. The final build of the old product and pre-announcement of the new, and combination of inventory decisions and dynamic pricing are provided in their model. Beauregard et al. [18] developed a model where queuing theory was used, and specifically, the obtained results of Jackson networks are extended to help management to improve product development (PD) task flow and eventually become leaner. Some factors are considered in their study such as optimal PD task size and multitasking level as well as the utilization level of PD resources. Nafisi et al. [19] identified how and when manufacturing functions such as engineers and operators are involved in an NPD project. Their results from a conducted case study in heavy automotive component assembly show that manufacturing engineers have been more actively involved compared to manufacturing operators during the early phases of the NPD studies.

According to the survey that was conducted in the literature review, it was found that the dynamic virtual cellular manufacturing system assuming new product development was not considered simultaneously.

In this paper, a novel multi-objective optimization mathematical model is defined which covers these two aforementioned issues simultaneously. Manufacturing industries are under severe pressure from the market of global competition, and demand of customers and close competition in the business environment have led industry owners to make optimal decisions in order to meet their customers' requirements. Therefore, the simultaneous design of the cellular system by considering the new product development leads factories to improvements such as cost control, quality and time control, better performance, and overall, the improvement of the output product which will help factories to better utilization of the opportunities ahead.

The remains of this article are organized as follows: In section 3, the notations and problem description are provided and a new multi-objective model presented for the research problem. In order to solve the proposed model, a multi-choice goal programming method with utility function is used in section 4. The proposed solution method is validated by using a case study in section 5. Section 6 explains the impact of
NPD on virtual cellular manufacturing. And finally, conclusion and future study are explained in section 7.

3. Model formulation

In this paper, a novel model is designed for planning of CMS with new product entry including three objective functions. The impact of the new product entry in the cell formation is studied by designed the 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: the products that are being produced by the factory which are represented in the first group and 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 as the following:

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

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 \( t \\
A \)  Big 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 sale for 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 which represents the new product entering time to markets \\
\( DP_{nt} \)  1, if company decide to design product \( n \) in period \( t \), 0, otherwise

**Objective functions**

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

\[ \text{Max } PR = \]

Revenue from sales = \( \sum_t \sum_i PR_{it} Z_{it} \) [1-1] \\
Holding Cost = \( \sum_t \sum_i HC_{it} IP_{it} \) [1-2] \\
Production Cost = \( \sum_t \sum_i PC_{it} Z_{it} \) [1-3] \\
Lost Sale Cost = \( \sum_t \sum_i LC_{it} L_{it} \) [1-4] \\
Designing Cost = \( \sum_t \sum_{n=1}^{N} DC_{it} DP_{nt} \) [1-5]

Equation (1-1) defines the profit from selling products. Terms (1-2) and (1-3) denote the inventory holding cost and production cost of parts in all the periods, respectively. Equation (1-4) computes lost sale cost and cost associated with the new product design is shown in Equation (1-5).
The following equation shows the second objective function which maximizes the grouping efficacy of the produced parts in virtual cells in the planning horizon.

$$\text{Max TVGE} = \sum_{t} \sum_{i} Z_{it} \left( \frac{\sum_{m} a_{im} - \sum_{c} \sum_{m} a_{im}(1 - Y_{ict} X_{mct})}{\sum_{m} a_{im} + \sum_{c} \left( \sum_{m} X_{mct} Y_{ikt} - \sum_{m} X_{mct} Y_{ict} a_{im} \right)} \right)$$  (2)

The third objective maximizes production of the new products. Although producing new products may lead additional costs to the factory, but the factory may suffer losses in a competitive environment if this issue is ignored. So, the following objective function is defined to compute the amount of new products producing during all the periods.

$$\text{Max NPD} = \sum_{n} \sum_{t} Z_{nt}$$  (3)

Constraints

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

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

$$\sum_{i} IP_{it} \leq NP \quad \forall t$$  (6)

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

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

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

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

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

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

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

Equation (4) is relevant to inventory and demand balancing constraint for the products. Relation (5) ensures that summation of the processing time of each product should less than or equal to the total available time of machine $m$ in period $t$. Constraint (6) is
regarding the capacity of manufacturing warehouses. Equation (7) shows that each machine must be allocated to only one virtual cell in each period. Equation (8) guarantees that each product is either allocated to only one virtual cell or is not assigned to any virtual cell in period \( t \). Equation (9) denotes the production allowance and Equation (10) denotes that the new product is not available for production until period \( h+dl_i \). Constraint (11) shows the factory's decision for 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 non-linear due to multiplication and division of the decision variables. Here, an effort is made to make an objective function to a linear fraction form by introducing an auxiliary variable [11]. This attempt can be added some additional constraints to the original model. Therefore, the new variable defines as follow:

\[
F_{imct} = Y_{ict} X_{mct}
\]

New constraints are formed as below:

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

\[
\Delta F_{imct} - Y_{ict} - X_{mct} \leq 0 \quad \forall i,m,c,t \quad (15)
\]

\[
F_{imct} \in \{0,1\} \quad \forall i,m,c,t \quad (16)
\]

\( \Delta \) 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:

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

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

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

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

\( A \) considered as a large positive number in above constraint.

Furthermore, the term of \( \text{Min} (1, Z_{it}) \) in constraint (8) is nonlinear and should be changed to linear form as the following constraint:
\[
\sum_{c} Y_{ict} \leq 1 \quad \forall i, t \quad (21)
\]
\[
Z_{it} \leq A \times \sum_{c} Y_{ict} \quad \forall i, t \quad (22)
\]
\[
Z_{it} \geq \sum_{c} Y_{ict} \quad \forall i, t \quad (23)
\]

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 have a better answer. In this article, a method is used for solving the proposed model which 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 due to their priorities. In this approach, the DM wants to maximize the expected utility. Given that the objective functions in this article are linear, just linear form of utility function \( u_k(y_k) \) considered as follows:

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

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

where \( g_{k,\text{max}} \) and \( g_{k,\text{min}} \) are lower and upper bounds for the \( k \)th goal. Case I and case II defined for maximizing and minimizing objective functions, respectively. According to the principle of expected utility, the DM would like to increase the utility value \( \lambda_k \) as much as possible. In real situations, it is difficult to solve a decision problem by automatically increasing the utility value as much as possible. In order to overcome this difficulty and to improve the utilization of MCGP, the following two linear cases referred
to have 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 when the objective function is minimizing and also it is better to be as close as possible to LLUF when the objective function is maximizing.

The DM would like to increase the utility value \( u_k(y_k) \) as much as possible in the case of LLUF if the objective function is maximizing. 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 \( \sum_{k=1}^{K} \left[ w_k \left( d_k^+ + d_k^- \right) + \beta_k f_k^- \right] \)

s.t.

\[
\begin{align*}
\lambda_k &\leq \frac{g_{k,\max} - y_k}{g_{k,\max} - g_{k,\min}} & k = 1,2,...,K \\
f_k(x) - d_k^+ + d_k^- = y_k & & k = 1,2,...,K \\
\lambda_k + f_k^- = 1 & & k = 1,2,...,K \\
g_{k,\min} \leq y_k \leq g_{k,\max} & & k = 1,2,...,K \\
d_k^+, d_k^-, f_k^-, \lambda_k \geq 0 & & k = 1,2,...,K \\
x \in X 
\end{align*}
\]

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

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

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

s.t.

\[
\begin{align*}
\end{align*}
\]
\[ \lambda_k \leq \frac{y_k - g_{k, \text{min}}}{g_{k, \text{max}} - g_{k, \text{min}}} \quad k = 1,2,...,K \]  (28)

\[ f_k(x) - d_k^+ + d_k^- = y_k \quad k = 1,2,...,K \]  (29)

\[ \lambda_k + f_k^- = 1 \quad k = 1,2,...,K \]  (30)

\[ g_{k, \text{min}} \leq y_k \leq g_{k, \text{max}} \quad k = 1,2,...,K \]  (31)

\[ d_k^+, d_k^-, f_k^-, \lambda_k \geq 0 \quad k = 1,2,...,K \]

\[ x \in X \]

5. Case study

The case study is accomplished on a machinery factory in Mazandaran in the north of Iran. 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 & Harvesting Series (11) Fruit Disinfecting (12) Sorting (13) Fruit Cartoon Montaging (14) Packing (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 old products that company produces them from the past to now, but products 12, 13, 14 and 15 are new products and duration of designing of these new outputs is 2, 1, 2 and 1 periods, respectively. Also, designing cost for new products is 930, 2125, 2125 and 15950 dollars, respectively. The survey was conducted on seven periods and each period includes three months. The unit of the processing time of parts on machines is an hour. The unit of the cost is a dollar. Tables 1 to 3 represent the major parameters.

Insert Table 1

Insert Table 2

Insert Table 3
To demonstrate the validity and capability of the suggested model, the case study has been solved by the multi-choice goal programming with utility function under Lingo 16.0 software package. The aforementioned data were used as input parameters. In the first step, just the first objective function of the proposed model is considered (Ob1 sub-problem). In this case, the aim is maximizing the profit of factory in all periods and the following results are obtained:

Factory attains to 10,584,640 dollars profit and in this situation, the second and the third objective functions obtained 2,951 and 415 value, respectively.

At the second step, just 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 value of the first and the third objectives are PR=8,537,222 dollars and NPD=363.

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

On the other hand, the amount of $W_1,W_2,W_3$ and also $\beta_1,\beta_2$ and $\beta_3$ are shown in Table 4.

![Insert Table 4](image)

The objective function of the proposed model becomes as follow by using the MCGP-U method:

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

which $w_1,w_2,w_3$ are weights related to deviations $d$ for the first, second and third objectives respectively and $\beta_1,\beta_2,\beta_3$ are weights for deviation $f$ for the first, second and third objective functions. Some constraint is added to the model regarding applying the MCGP-U method. Following constraints are added regarding to the first objective function:
\[ PR - d_1^+ + d_1^- = y_1 \] (32)

\[ \lambda_1 \leq \frac{g_{1,max} - y_1}{g_{1,max} - g_{1,min}} \] (33)

\[ \lambda_1 + f_1^- = 1 \] (34)

\[ g_{1,min} \leq y_1 \leq g_{1,max} \] (35)

and the following constraints are added to the model regarding to the second objective function:

\[ TVGE - d_2^+ + d_2^- = y_2 \] (36)

\[ \lambda_2 \leq \frac{g_{2,max} - y_2}{g_{2,max} - g_{2,min}} \] (37)

\[ \lambda_2 + f_2^- = 1 \] (38)

\[ g_{2,min} \leq y_2 \leq g_{2,max} \] (39)

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

\[ NPD - d_3^+ + d_3^- = y_3 \] (40)

\[ \lambda_3 \leq \frac{g_{3,max} - y_3}{g_{3,max} - g_{3,min}} \] (41)

\[ \lambda_3 + f_3^- = 1 \] (42)

\[ g_{3,min} \leq y_3 \leq g_{3,max} \] (43)

\[ d_1^+, d_2^+, d_3^+, d_1^-, d_2^-, d_3^- \geq 0 \]

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

\[ g_{1,min} \text{ can also achieved by dissolving Min PR} \]

\[ g_{1,max} \text{ can also achieved by dissolving Max PR} \]
$g_{2,\text{min}}$ can also achieved by dissolving $\text{Min TVGE}$

$g_{2,\text{max}}$ can also achieved by dissolving $\text{Max TVGE}$

$g_{3,\text{min}}$ can also achieved by dissolving $\text{Min NPD}$

$g_{3,\text{max}}$ can also achieved by dissolving $\text{Max NPD}$

**Insert Table 5**

$$d_1^+ = 0, d_1^- = 150565.7, PR = 1,0434,070, y_1 = 1,0283,504.3, f_1^- = 0.52.$$

$$d_2^+ = 0, d_2^- = 172.6, \text{TVGE} = 3,069, y_2 = 2,896.4, f_2^- = 0.4.$$

$$d_3^+ = 0, d_3^- = 0, \text{NPD} = y_3 = 463, f_3^- = 0.$$

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

**Insert Table 6**

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 toward the best value of each objective function. The optimum amount of products produced in each period is shown in Table 8.

**Insert Table 7**
According to the achieved optimal solution, the design of new products 12 and 13 starts in the first period and also designing of products 14 and 15 occurs in periods 3 and 4, respectively. Therefore, new products 12, 13, 14 and 15 are available in production plan in periods 3, 2, 5 and 5, respectively due to the considered duration of the new product design (Table 9).

Insert Table 8

Insert Table 9

The design of cells and allocation of workstations and products to each cell are obtained and Figure 1 illustrates the virtual cell configuration for seven periods, where some of the positive features of the model can be realized. However, assignment of workstations can be changed in each virtual cell. For example, workstations 1 and 4 move from cells 3 and 1 to cells 1 and 2 respectively in period 3. Although, there is a demand for some products but the manufacturer 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 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 using this model in the company's strategic planning. Manufacturers seek to improve their production plan, gain more profit, customer satisfaction, being updated in a competitive market and so on. Therefore, the proposed model can be helpful for many industries.

Insert Figure 1
6. Impact of the NPD on VCM

A company should not be dependent on its current manufacturing products exclusively due to the changing in consumers’ tastes and developments in the competitive and technological environment. Customers are asking for new products and more advanced products which are what competitors are looking for. The concept of new product development is one of the important strategies in each company. NPD is an important part of every business which 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 new product development will helpful for companies to maintain in competitive and exclusive position and also helpful for better use of funds and the company's production and profits enhancement. Companies should confront their competitors, and should always have a good response to the market changes. According to the virtual cell formation concept, virtual cells are configuring 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 for product development. Therefore, virtual cell formation should be designed for the current period when the new products and parts entering into the production system. So, this could change the existing virtual formation which can affect on the grouping efficacy. The optimal configuration is performed at the beginning of planning horizon (first period), and the configuration of virtual cells in each period are made due to the situation of that period (product-workstation matrix and demand). Suppose that the company doesn't want to produce new products. So, the product-workstation matrix remains constant and the configuration of the first period may be optimal up to the end of the planning horizon. Manufacturers may confront with losses if they ignore new product development. Therefore, manufacturing firms prefer to use this concept in their strategies. For example, the product-workstation matrix changes by entering product 13 in the production line in period 2, but these changes are not leading to interfere the virtual cell formation. The existing product-workstation matrix has been changed by entering the product 12 into the production line in period 3, and the virtual cell formation changes accordingly. Due to this, the workstation 4 is added to virtual cell
2 and also the workstation 1 is moved from virtual cell 3 to virtual cell 1. Table 10 is an example of products workstations assignment in period 2 and 3.

**Insert Table 10**

Figure 2 shows the virtual cell formation for the second period which contains three virtual cells with 11 products. Dyeing, assembly and packing workstations are located in the first virtual cell. Also molding, machining and die casting workstations are located in the second virtual cell and 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 entering product 12 in the production system. As is shown in Figure 3, the machining workstation moved to virtual cell 2 and the Dyeing workstation moved to virtual cell 1. So, it indicates that the production of new products can affect the formation of the cells.

**Insert Figure 2**

**Insert Figure 3**

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

**Insert Table 11**

Table 11 represents the assignment of workstations and parts in each virtual cell. For example, workstations 1, 5, 7, 8 and 10, also products 2, 7, 10, 11, 12 and 13 are assigned to virtual cell 1 in period 4. Furthermore, in period 5, the virtual cell 1 includes workstations 1, 7, 8, 10 and products 2, 7, 10, 11, 12. As it shown in Table 11, new products 14 and 15 entered to the production line in period 5 which leads to change in the
product-workstation matrix. As mentioned above, the assignment of workstations and products in cells are changed in comparison with the previous period. Figures 4 and 5 are shown the virtual cell formation for periods 4 and 5 which help us to understand this concept better.

Insert Figure 4

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

- Product 13 moves from virtual cell 1 to virtual cell 2.
- Product 4 moves to virtual cell 2.
- Products 14 and 15 enter into virtual cells 3 and 2, respectively.
- Workstation 5 (molding) moves from virtual cell 1 to virtual cell 2.

Insert Figure 5

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 used to illustrate the impact of NPD on the proposed model:
State1: We have 11 old products and 4 new products (As we proposed in this article).
State2: The company wants to continue producing 11 old products and they don’t want to have any new product development.

Insert Table 12

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 that takes 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 decreased by entering new products, but company gains more profit and also has new products to gain more market share and be alive in the competitive market. The amount of the second objective function of state 1 is 3069.3 which is less than the second objective function of state 2 (3465.97). But the amount of 3069.3 is acceptable and it is not intangible. On the other hand, the proposed model considers new products development which persuades the company to produce new products (to have more market share). If the company neglected the market's changes, it may lead to lose its market and customers. Also, due to the demands for new products, the company may lose profit by discarding this issue.
It can be understanding from the results that the studied company may has less grouping efficacy but the reduction of GE is not too much. Also, the company has good benefits by producing new products and it makes company to be one of the pioneers in this particular industry in its area. The integration of CMS (as one of the best manufacturing systems) and NPD leads company to gain the benefits of CMS and NPD simultaneously and helps company to be alive in the competitive business environment.

7. Conclusion
In this paper, the virtual cellular manufacturing system considering new product development was discussed. This issue has many benefits which can be helpful for managers and manufacturers to adopt better decisions in their planning. Virtual cellular manufacturing has many advantages which lead to better respond in a dynamic environment and on the other hand new product development can help factories to be update and successful in a competitive market due to demand changes. In this regard, a mathematical model defined which has three objectives including maximizing profit, maximizing grouping efficacy and maximizing the production of new products. After linearization of the mathematical model, the proposed model solved by multi-choice goal programming with utility function which the results were shown. According to results,
the factory’s benefit 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 are simultaneously used in the mathematical model, which helps manufacturers to benefit from these two concepts. It is recommended that the senior managers of the plant should improve the factory level by assigning and appointing a team of researcher and specialist in the field of product design and development by considering identify the demands of customers. Because customers are the main asset for the manufacturer. From a strategic point of view, it is suggested to managers to gain more market share, due to the competitive environment of the present world and according to the variety of brands in a specific industry by placing customer orientation and production based on customer demand as a principle as well as adopting a production system that has more benefits than other systems.

More research in this field could be explored in future studies by considering the following topics:

- Considering old product which improves and changes to new product.
- It is possible to need new machines for producing new products.
- Evaluate the effect of new product development on the supplier selection and supply of materials.
References


Ahmadreza Rostami is a graduated master of Science student of industrial engineering at Babol Noshirvani University of Technology. He received his BSc in Mazandaran University of Science and Technology. His research interests include supply chain management and design, cellular manufacturing systems and new product development. The title of his thesis is “Designing of virtual cellular manufacturing with supply chain management by considering new product development”.

Mohammad Mahdi Paydar is the assistant professor of Industrial Engineering at Babol Noshirvani University of Technology. He received his PhD in Industrial Engineering from Iran University of Science and Technology. His research interests are cellular manufacturing systems, supply chain design and modelling of manufacturing applications. He has published articles in journals such as Computer and Industrial Engineering, Computer and Operation Research, Expert Systems with Applications, Computer and Chemical Engineering, International Journal of Advanced Manufacturing Technology, Journal of Manufacturing Systems, International Journal of Production Research and International journal of Operational Research and 25 papers in international conferences.

Ebrahim Asadi-Gangraj received his BS degree in Industrial Engineering from Isfahan University of Technology, Isfahan, Iran, in 2005; MS degree in Industrial Engineering from the Tarbiat Modares University in 2008; and PhD degree in Industrial Engineering from the Tarbiat Modares University, Iran, in 2014. He is currently Assistant Professor of Industrial Engineering at Babol Noshirvani University of Technology, Babol, Iran. His research interests include applied operations research, sequencing and scheduling, production planning, and supply chain management.
Figure 1. Optimal cell configurations in each period
Figure 2. Cell formation in period 2
Figure 3. Virtual cell formation in period 3
Figure 4. Cell formation in period 4
Figure 5. Virtual cell formation in period 5

Table 1. Demand for customer group in each period (unit of product)
Table 2. Product processing on workstations (Processing time(Hour))
Table 3. Production cost of products on the workstation
Table 4. Weights of deviation $d$ and $f$ for each objective function
Table 5. Target value for each objective function
Table 6. Optimum solution with using MCGP-U
Table 7. The deviation percentage of sub-problems toward goal of each objective
Table 8. Optimum amount of products in each period
Table 9. Start designing new products
Table 10. Machine and part assignment in periods 2 and 3
Table 11. Workstations and part assignment in periods 4 and 5
Table 12. Results of two proposed situations
Figure 1.
Figure 4.

Figure 5.
Table 1.

<table>
<thead>
<tr>
<th>Product</th>
<th>Period 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>20</td>
<td>20</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>23</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>23</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>20</td>
<td>20</td>
<td>23</td>
<td>20</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>17</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>19</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>22</td>
<td>21</td>
<td>21</td>
<td>23</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>9</td>
<td>25</td>
<td>19</td>
<td>20</td>
<td>22</td>
<td>21</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>22</td>
<td>20</td>
<td>21</td>
<td>21</td>
<td>23</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>11</td>
<td>23</td>
<td>21</td>
<td>21</td>
<td>25</td>
<td>23</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>12</td>
<td>21</td>
<td>19</td>
<td>20</td>
<td>23</td>
<td>21</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>24</td>
<td>21</td>
<td>20</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>14</td>
<td>22</td>
<td>25</td>
<td>20</td>
<td>21</td>
<td>23</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>15</td>
<td>26</td>
<td>23</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 2.

<table>
<thead>
<tr>
<th>Product</th>
<th>Workstations 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1(10)</td>
<td>0</td>
<td>1(8)</td>
<td>0</td>
<td>1(14)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1(6)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1(13)</td>
<td>1(9)</td>
<td>0</td>
<td>1(12)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1(11)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1(15)</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1(8)</td>
<td>1(12)</td>
<td>1(10)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Period</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>173</td>
<td>180</td>
<td>180</td>
<td>185</td>
<td>186</td>
<td>199</td>
<td>212.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>100</td>
<td>106</td>
<td>106</td>
<td>120</td>
<td>120</td>
<td>133</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>319</td>
<td>319</td>
<td>332</td>
<td>345.4</td>
<td>372</td>
<td>372</td>
<td>372</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.
<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>139.5</td>
<td>146</td>
<td>146</td>
<td>159</td>
<td>159</td>
<td>173</td>
</tr>
<tr>
<td>5</td>
<td>159</td>
<td>173</td>
<td>173</td>
<td>186</td>
<td>186</td>
<td>199</td>
</tr>
<tr>
<td>6</td>
<td>239</td>
<td>239</td>
<td>252</td>
<td>265.7</td>
<td>265.7</td>
<td>292</td>
</tr>
<tr>
<td>7</td>
<td>93</td>
<td>93</td>
<td>93</td>
<td>106</td>
<td>106</td>
<td>113</td>
</tr>
<tr>
<td>8</td>
<td>359</td>
<td>365</td>
<td>365</td>
<td>372</td>
<td>372</td>
<td>385</td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>40</td>
<td>53</td>
<td>53</td>
<td>60</td>
<td>66</td>
</tr>
<tr>
<td>10</td>
<td>319</td>
<td>332</td>
<td>345</td>
<td>372</td>
<td>372</td>
<td>385</td>
</tr>
<tr>
<td>11</td>
<td>398</td>
<td>425</td>
<td>438</td>
<td>451</td>
<td>478</td>
<td>491</td>
</tr>
<tr>
<td>12</td>
<td>106</td>
<td>119</td>
<td>119</td>
<td>133</td>
<td>146</td>
<td>159</td>
</tr>
<tr>
<td>13</td>
<td>159</td>
<td>173</td>
<td>173</td>
<td>186</td>
<td>199</td>
<td>199</td>
</tr>
<tr>
<td>14</td>
<td>332</td>
<td>332</td>
<td>339</td>
<td>339</td>
<td>345</td>
<td>358</td>
</tr>
<tr>
<td>15</td>
<td>1993</td>
<td>2125</td>
<td>2258</td>
<td>2391</td>
<td>2391</td>
<td>2524</td>
</tr>
</tbody>
</table>

**Table 4.**

<table>
<thead>
<tr>
<th>W</th>
<th>PR</th>
<th>TVGE</th>
<th>NPD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.45</td>
<td>0.35</td>
<td>0.2</td>
</tr>
<tr>
<td>β</td>
<td>0.5</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Table 5.**

<table>
<thead>
<tr>
<th>g&lt;sub&gt;max&lt;/sub&gt;</th>
<th>PR</th>
<th>TVGE</th>
<th>NPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>281222</td>
<td>3,242</td>
<td>463</td>
<td></td>
</tr>
<tr>
<td>g&lt;sub&gt;min&lt;/sub&gt;</td>
<td>265569</td>
<td>2,800</td>
<td>430</td>
</tr>
</tbody>
</table>

**Table 6.**

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCGP-U</td>
<td>2.503</td>
</tr>
<tr>
<td>PR</td>
<td>277222</td>
</tr>
<tr>
<td>TVGE</td>
<td>3,069</td>
</tr>
</tbody>
</table>
Table 7.

<table>
<thead>
<tr>
<th></th>
<th>PR</th>
<th>TVGE</th>
<th>NPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ob1</td>
<td>0.00</td>
<td>8.98</td>
<td>10.37</td>
</tr>
<tr>
<td>Ob2</td>
<td>0.518</td>
<td>0.00</td>
<td>21.60</td>
</tr>
<tr>
<td>Ob3</td>
<td>1.614</td>
<td>69.65</td>
<td>0.00</td>
</tr>
<tr>
<td>MCGP-U</td>
<td>0.038</td>
<td>5.34</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 8.

<table>
<thead>
<tr>
<th>Product</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 9.

<table>
<thead>
<tr>
<th>New product</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>*</td>
</tr>
<tr>
<td>13</td>
<td>*</td>
</tr>
<tr>
<td>14</td>
<td>*</td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

* Starting time of designing  # Available in the production system

Table 10.

<table>
<thead>
<tr>
<th>Period</th>
<th>Cell1</th>
<th>Cell2</th>
<th>Cell3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Workstation</td>
<td>8-10-4-5-7</td>
<td>6-2</td>
</tr>
<tr>
<td></td>
<td>Products</td>
<td>2-4-13-7-10-9-11</td>
<td>1-6</td>
</tr>
<tr>
<td>3</td>
<td>Workstation</td>
<td>8-10-1-5-7</td>
<td>4-2-6</td>
</tr>
<tr>
<td></td>
<td>Products</td>
<td>2-4-12-13-7-10-11</td>
<td>9-1-6</td>
</tr>
</tbody>
</table>

Table 11.

<table>
<thead>
<tr>
<th>Period</th>
<th>Cell1</th>
<th>Cell2</th>
<th>Cell3</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Workstations</td>
<td>8-10-1-5-7</td>
<td>6-2-4</td>
</tr>
<tr>
<td></td>
<td>Products</td>
<td>11-10-7-13-12-2</td>
<td>9-1-6</td>
</tr>
<tr>
<td>5</td>
<td>Workstations</td>
<td>7-1-10-8</td>
<td>4-2-6-5</td>
</tr>
<tr>
<td></td>
<td>Products</td>
<td>7-11-12-10-2</td>
<td>4-6-1-9-13-15</td>
</tr>
</tbody>
</table>

Table 12.

<table>
<thead>
<tr>
<th>State</th>
<th>MCGP-U</th>
<th>PR</th>
<th>TVGE</th>
<th>NPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>State1</td>
<td>2.503</td>
<td>277222</td>
<td>3069.3</td>
<td>463</td>
</tr>
<tr>
<td>State2</td>
<td>2.612</td>
<td>250475</td>
<td>3465.97</td>
<td>0</td>
</tr>
</tbody>
</table>