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# Performance evaluation in aggregate production planning using integrated RED-SWARA method under uncertain condition

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## KEYWORDS

Aggregate production planning;  
Performance evaluation;  
SWARA method;  
RED model;  
Grey system theory.

**Abstract.** Nowadays, increasing the efficiency of production and determining the proper tools and methods of measuring performance are the biggest challenges faced by managers in the context of significant competition among companies and manufacturing centers. In aggregate production planning, performance evaluation is necessary for reducing the waste of resources due to the common use of resources for product family manufacturing. The present study aims to evaluate the performance of the Aggregate Production Planning (APP). In this regard, the optimal values were determined by the multi-objective Grey Aggregate Production Planning (GAPP) model, and the weights of the input and output indicators for the performance evaluation were characterized by the Step-wise Weight Assessment Ratio Analysis (SWARA) method. Further, the efficiency of Decision-Making Units (DMUs) was determined by the Ratio Efficiency Dominance (RED) model. Then, DMUs were ranked. In the case study of the automobile parts manufacturing industry in Iran, sensitivity analysis was performed on the proposed model and its effects were evaluated. The results indicated that the proposed model had a higher degree of accuracy in evaluating performance than previous models, thus helping managers make better decisions so that the efficiency and the waste of resources can increase and decrease, respectively.

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## 1. Introduction

Production planning plays an influential role in developing and maintaining a factory. The importance of production planning in making decisions is substantially increasing, due to the rapid internationalization of jobs under globalism and the intense competition of manufacturing industries to gain an upper hand

in global markets. Production planning aims to use limited resources in production processes, leading to an appropriate use of available capacities and resources by properly forecasting the raw materials, which are necessary for producing and determining the required time for production. Increasing the efficiency of production and determining the tools and methods used for measuring performance are one of the biggest challenges faced by managers, especially under increasing competition among the companies and manufacturing centers. The performance evaluation in production planning can help each organization solve problems, find defects, and reduce delayed orders, inventory surplus, and additional production costs that are imposed on the organization, making the organization maximize

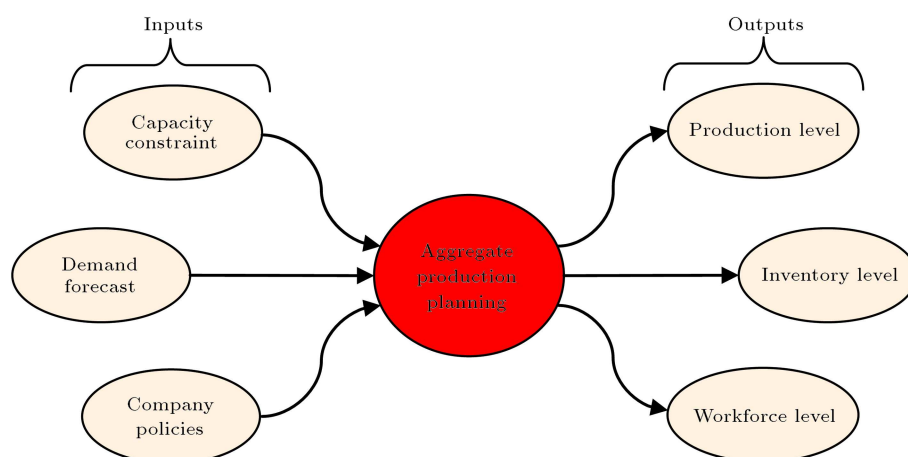
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the profit and sell the products. It is widely felt that the performance evaluation in production planning provides a theoretical and practical overview since it is a key to success and has a critical role in industries.

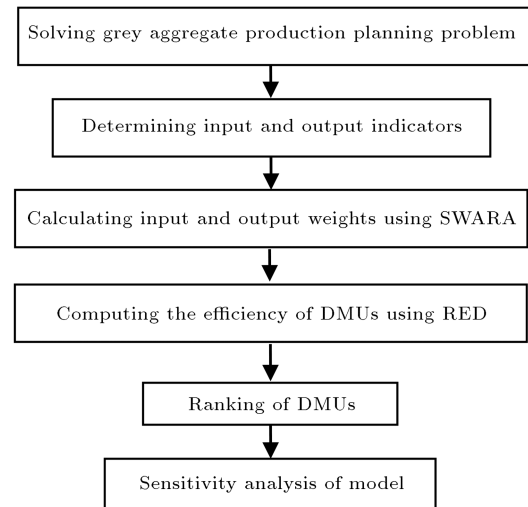
An Aggregate Production Planning (APP) is an activity done to determine an aggregate plan for production systems within the time period of 3-18 months so that the total cost is minimized [1] and the optimal production, labor, and inventory level are determined for each planning period in the form of product family production based on the available sources of production and restrictions. Figure 1 indicates inputs and outputs of the APP process [2].

Given that planning is conducted at a general level and is used to represent demand and production capacity from a single unit of the product family, the performance evaluation in the APP is of significance while reducing the waste of common resources. In previous studies, performance evaluation was less considered in production planning and few studies have focused on it in the field of production planning [3-5]. Data Envelopment Analysis (DEA) is an approach to estimating the relative efficiency of Decision-Making Units (DMUs) [6]. DEA is also regarded as a powerful mathematical tool used for measuring the relative efficiency of DMUs that utilize inputs to produce outputs [7] and is a nonparametric approach that does not require any assumption about the functional form of production [8]. Further, in DEA models, the effect of experts' opinions is taken into account to ensure the accuracy of the results. In this paper, the Multi-Attribute Decision Making (MADM) method, as the effect of experts' opinions, is used for weighting the input and output indicators of the DEA model. The MADM models are selector models that are used for evaluating, ranking, and choosing the most appropriate alternative among other alternatives [9].

The present study aimed to evaluate the performance of APP using the integrated method of



**Figure 1.** Inputs and outputs of Aggregate Production Planning (APP) process [2].



**Figure 2.** Proposed algorithm of the study.

Ratio Efficiency Dominance (RED) and the Step-wise Weight Assessment Ratio Analysis (SWARA) under uncertainty (grey environment). The results of the previous studies indicate that uncertainty in production planning plays a significant role in ordering policies and inventory levels [10]. The proposed model was investigated in the form of a case study in Iran automobile parts manufacturing industry during three months and accordingly, sensitivity analysis was performed on the model.

The study is organized as follows: Sections 2, 3, and 4 include related literature, methodology, and experiment and results, respectively. Finally, Section 5 concludes the study. In addition, Figure 2 shows the proposed algorithm of this study.

## 2. Literature review

A few studies have focused on the performance evaluation in production planning. In previous studies,

performance evaluation has been insignificantly applied in production planning, and few studies have focused on the development of the CCR model (proposed by Charnes, Cooper, and Rhodes) from DEA models [3] for evaluating efficiency or performance in a centralized decision-making environment and predictable conditions of demand variations [4], as well as for discussing cellular manufacturing [5].

Many studies have been conducted on the APP in uncertainty environment. Tang et al. [11] proposed the multi-product APP model with fuzzy demands and fuzzy capacities, and the objective of their considered problem was to minimize the total costs of quadratic production and linear inventory holding. Moreover, an interactive Multiple Fuzzy Objective Linear Programming (MFOLP) model was presented to minimize the total production costs, carrying and backordering costs, and costs of changes in labor levels while considering the inventory levels, labor levels, machine capacity, warehouse space, and time value of money [12]. Multi-product APP problems with fuzzy demands and fuzzy capacities were formulated and simulated for further analysis [13]. Having considered the need for a general joint strategic plan for production and distribution and also vague planning data, Aliev et al. [14] suggested a fuzzy-integrated multi-period and multi-product production and distribution model in the supply chain. Jamalnia and Soukhakian [15] used the Hybrid (including qualitative and quantitative objectives) Fuzzy Multi-Objective Non-Linear Programming (H-FMONLP) model for minimizing the total production costs, carrying and back ordering costs, and costs of changes in workforce level (quantitative objectives), and maximizing total customer satisfaction (qualitative objective) with regard to the inventory level, demand, labor level, machine capacity, and warehouse space.

Furthermore, Yaghin et al. [16] proposed a hybrid fuzzy multi-objective programming model that comprised both quantitative and qualitative constraints and objectives to maximize the total profit of manufacturers, total profit of retailers, and improve service aspects of retailing simultaneously. Sadeghi et al. [17] suggested a multi-objective model for aggregate planning problem in which the parameters of the model were expressed in the form of grey numbers. This grey multi-objective model was solved based on a goal programming problem with fuzzy aspiration levels. Moreover, their presented model features the Fuzzy Multi-Objective Mixed-Integer Non-Linear Programming (FMOMINLP) with four conflicting objectives: (i) to minimize the total cost, (ii) to improve customer satisfaction, (iii) to minimize the fluctuations in workforce changes, and (iv) to maximize the total value of purchasing in order to consider the impact of qualitative performance criteria [18]. Mosadegh et al. [19] applied a fuzzy goal programming model with

four criteria: shortage and inventory, overtime and idle time, labor level, and currency saving in a mid-term planning horizon.

In previous studies, the combined models of MADM and DEA were used. Opricovic and Tzeng [20] presented the DEA/VIKOR method and examined the results. Raju and Kumar [21] compared two integrated DEA/EXPROM and DEA/PROMETHEE methods. Xiong [22] proposed an entropy/DEA model and evaluated the effectiveness of industrial pollution control in terms of both inputs and outputs, namely input-entropy DEA model and output-entropy DEA model. He also discussed such issues as model solving, identification of effective DMUs, and improvement of non-effective DMUs. Shakouri et al. [23] employed the DEA/SAW method to compare the same fossil fuel (coal) power plants with nuclear power plants. Moreover, one can refer to the supplier selection by using the DEA/ANP method [24] and introducing the active companies in the cement industry accepted in Tehran stock market by using DEA/TOPSIS method [25].

### 3. Methodology

The present study aims to evaluate the performance of the APP in uncertain conditions. In this regard, the optimal values of decision variables were determined using a multi-objective Grey Aggregate Production Planning (GAPP). The weights of indicators were determined using the SWARA method after identifying the input and output criteria for efficiency evaluation. Then, the efficiency of DMUs was characterized using the RED model and DMUs were ranked next.

#### 3.1. Grey Aggregate Production Planning (GAPP)

In the APP problems, different models were used such as transportation models, simulation models, multi-objective linear programming models, and the goal programming [26]. In the present study, the multi-objective linear programming model was employed to determine the optimal values with objective functions of maximizing the utilization rate of machine capacity and total profit as well as of minimizing the cost of reworking defective products in the grey environment. The multi-objective linear programming models have appropriate flexibility and extensibility capabilities and various objective functions can be defined in this regard [27]. Furthermore, the use of grey theory plays an influential role in the flexibility of the APP model. On the contrary, the uncertainty of the model could be a better representation of real-world issues than definitive models.

In this model, the collateral contract is not allowed and the level of labor, machine capacity, warehouse capacity, and number of delayed orders should

not exceed its maximum. Sadeghi et al. [17] considered the values of decision variables as the grey numbers. This research considers the values of decision variables as grey numbers. Further, the production planning horizon is based on performance in three months. In the following, the GAPP model is presented.

### 3.1.1. Notations

- Indices

$n$  : The index of the product  
 $t$  : The index of the planning period

- Decision variables

$\otimes Q_{nt}$  : Production of the  $n$ th product in period  $t$  in regular time (unit)  
 $\otimes O_{nt}$  : Production of the  $n$ th product in period  $t$  in overtime (unit)  
 $\otimes I_{nt}$  : Inventory level for the  $n$ th product in period  $t$  (unit)  
 $\otimes B_{nt}$  : Backorder level for the  $n$ th product in period  $t$  (unit)  
 $\otimes H_t$  : Workers hired in period  $t$  (man-hour)  
 $\otimes F_t$  : Laid-off workers in period  $t$  (man-hour)

- Parameters

$\otimes D_{nt}$  : Forecasted demand for the  $n$ th product in period  $t$  (unit)  
 $\otimes a_{nt}$  : Production cost per unit for the  $n$ th product in period  $t$  in regular time (IRR\*/unit)  
 $\otimes b_{nt}$  : Production cost per unit for the  $n$ th product in period  $t$  (IRR/unit)  
 $\otimes c_{nt}$  : Unit revenue for the  $n$ th product in period  $t$  (IRR/unit)  
 $\otimes d_{nt}$  : Inventory carrying cost per unit of the  $n$ th product in period  $t$  (IRR/unit)  
 $\otimes e_{nt}$  : Backorder cost per unit of the  $n$ th product in period  $t$  (IRR/unit)  
 $\otimes k_t$  : Cost of hiring workers in period  $t$  (IRR/man-hour)  
 $\otimes m_t$  : Cost of laying off one worker in period  $t$  (IRR/man-hour)  
 $\otimes L_{nt}$  : Hours of labor per unit of the  $n$ th product in period  $t$  (man-hour/unit)  
 $\otimes r_{nt}$  : Hours of machine usage per unit of the  $n$ th product in period  $t$  (machine-hour per unit)  
 $\otimes v_{nt}$  : Warehouse space per unit of the  $n$ th product in period  $t$  (in square meter per unit)  
 $\otimes q_{nt}$  : Defect rate of the  $n$ th product in period  $t$  at regular time

$\otimes p_{nt}$  : Defect rate of the  $n$ th product in period  $t$  in overtime  
 $\otimes u_{nt}$  : Repairing cost of the  $n$ th product in period  $t$  in regular time (IRR/unit)  
 $\otimes h_{nt}$  : Repairing cost of the  $n$ th product in period  $t$  in overtime (IRR/unit)  
 $\otimes W_{t\max}$  : Maximum labor level available in period  $t$  (man-hour)  
 $\otimes M_{t\max}$  : Maximum machine capacity available in period  $t$  (machine-hour)  
 $\otimes V_{t\max}$  : Maximum warehouse space available in period  $t$  (in square meter)  
 $\otimes I_{nt\min}$  : Minimum inventory level available of the  $n$ th product in period  $t$  (unit)  
 $\otimes B_{nt\max}$  : Maximum backorder level available of the  $n$ th product in period  $t$  (unit)

### 3.1.2. Functions

The proposed model is characterized by three objective functions as follows:

- The total profit:

$$\begin{aligned} \max z_1 \cong & \sum_{n=1}^N \sum_{t=1}^T \otimes c_{nt} (\otimes Q_{nt} + \otimes O_{nt}) \\ & - \sum_{n=1}^N \sum_{t=1}^T (\otimes a_{nt} \cdot \otimes Q_{nt} + \otimes b_{nt} \cdot \otimes O_{nt}) \\ & - \sum_{n=1}^N \sum_{t=1}^T (\otimes d_{nt} \cdot \otimes I_{nt} + \otimes e_{nt} \cdot \otimes B_{nt}) \\ & - \sum_{t=1}^T (\otimes k_t \cdot \otimes H_t + \otimes m_t \cdot \otimes F_t). \end{aligned} \quad (1)$$

- The cost of reworking defective products:

$$\begin{aligned} \min z_2 \cong & \sum_{n=1}^N \sum_{t=1}^T \sqrt[t]{\frac{\otimes q_{nt}}{t}} \cdot \otimes u_{nt} \cdot \otimes Q_{nt} \\ & + \sum_{n=1}^N \sum_{t=1}^T \sqrt[t]{\frac{\otimes p_{nt}}{t}} \cdot \otimes h_{nt} \cdot \otimes O_{nt}. \end{aligned} \quad (2)$$

- The utilization rate of machine capacity:

$$\max z_3 \cong \sum_{n=1}^N \sum_{t=1}^T \otimes r_{nt} (\otimes Q_{nt} + \otimes O_{nt}). \quad (3)$$

The proposed model has three objective functions. Therefore, Eq. (1) is related to the total profit of production, and Eq. (2) minimizes the cost of reworking defective products in regular time and

overtime. In the current situation, the utilization rate of machine capacity is quite low and companies are interested in increasing this level [28]. Therefore, Eq. (3) specifies the utilization rate of machine capacity.

### 3.1.3. Constraints

- Constraints on carrying inventory:

$$\otimes I_{nt} - \otimes B_{nt} = \otimes I_{nt-1} - \otimes B_{nt-1} + \otimes Q_{nt} + \otimes O_{nt} - \otimes D_{nt}; \quad \forall n, t, \quad (4)$$

$$\otimes I_{nt} \geq \otimes I_{nt\min}; \quad \forall n, t \quad (5)$$

$$\otimes B_{nt} \leq \otimes B_{nt\max}; \quad \forall n, t \quad (6)$$

- Constraints on labor levels:

$$\sum_{n=1}^N \otimes L_{nt-1} (\otimes Q_{nt-1} + \otimes O_{nt-1}) + \otimes H_t - \otimes F_t = \sum_{n=1}^N \otimes L_{nt} (\otimes Q_{nt} + \otimes O_{nt}); \quad \forall t, \quad (7)$$

$$\sum_{n=1}^N \otimes L_{nt} (\otimes Q_{nt} + \otimes O_{nt}) \leq \otimes W_{t\max}; \quad \forall t \quad (8)$$

- Constraints on machine capacity and warehouse:

$$\sum_{n=1}^N \otimes r_{nt} (\otimes Q_{nt} + \otimes O_{nt}) \leq \otimes M_{t\max}; \quad \forall t, \quad (9)$$

$$\sum_{n=1}^N \otimes v_{nt} \cdot \otimes I_{nt} \leq \otimes V_{t\max}; \quad \forall t. \quad (10)$$

- Non-negativity constraints on decision variables:

$$\otimes Q_{nt}, \otimes O_{nt}, \otimes I_{nt}, \otimes B_{nt}, \otimes H_t, \otimes F_t \geq 0; \\ \forall n = 1, \dots, N, \\ \forall t = 1, \dots, T. \quad (11)$$

### 3.2. Step-wise Weight Assessment Ratio Analysis (SWARA)

The Step-wise Weight Assessment Ratio Analysis (SWARA) method as one of the new MADM methods was developed by Kersulienė, Zavadskas, and Turskis in 2010. The relative importance value ( $S_j$ ) is regarded as the input of SWARA method provided by decision-makers. The SWARA method has 4 steps [29]:

**Step 1:** Initially, indicators are prioritized. Beginning with the second attribute, the relative importance indicates the  $j$ th attribute in relation to the previous attribute ( $j - 1$ ), and this process is conducted for each attribute. This ratio is called “average relative importance” ( $S_j$ ) [29].

**Step 2:** The coefficient  $K_j$  is determined through Eq. (12):

$$K_j = \begin{cases} 1 & j = 1 \\ S_j + 1 & j = 1, \dots, n \end{cases} \quad (12)$$

**Step 3:** The recalculated weight is determined using Eq. (13):

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{q_j}{K_j} & j = 1, \dots, n \end{cases} \quad (13)$$

1. **Step 4:** The weights of attributes are calculated through Eq. (14):

$$W_j = \frac{q_j}{\sum_{j=1}^n q_j}; \quad j = 1, \dots, n. \quad (14)$$

### 3.3. Ratio Efficiency Dominance (RED)

The Ratio Efficiency Dominance (RED) model was developed by Farahmand and Desa in 2017. Speed is of significance in computing mainly due to the large amount of information and number of DMUs. Time of computation was obtained for dual and primal simplex in 36 and 136 h for 100,000 DMUs, respectively [30]. This model is useful and practical for calculating and determining the efficiency of DMUs in small, large, and very large problems in the shortest time, and this model can rank the DMUs completely. The RED model includes 5 steps [30]:

**Step 1:** At this stage, the weighted normalized values of inputs and outputs are, respectively, calculated through Eqs. (15) and (16):

$$\omega_{ij} = \mu_{ij} \cdot w_{ij}; \quad i = 1, \dots, m, \quad r = 1, \dots, s, \\ j = 1, \dots, n, \quad (15)$$

$$\omega_{rj} = \mu_{rj} \cdot w'_{rj}; \quad i = 1, \dots, m, \quad r = 1, \dots, s, \\ j = 1, \dots, n, \quad (16)$$

based on the weight of the input indicators and the output indicators  $w'_{rj}$ , which is determined by the SWARA method as well as the normalized weight feature of the input and output indicators. In Eqs. (15) and (16), the normalized values for the inputs ( $\mu_{rj}$ ) and outputs ( $\mu_{rj}$ ) are computed through Eqs. (17) and (18) for each DMU:

$$\mu_{ij} = \frac{x_{ij}}{\max_j \{x_{ij}\}}; \quad i = 1, \dots, m, \quad r = 1, \dots, s, \\ j = 1, \dots, n, \quad (17)$$

$$\mu_{rj} = \frac{y_{rj}}{\max_j \{y_{rj}\}}; \quad i = 1, \dots, m, \quad r = 1, \dots, s,$$

$$j=1, \dots, n. \quad (18)$$

**Step 2:** The relative score of DMU<sub>j</sub> is calculated through Eq. (19):

$$SODI_j^* = \sum_{i=1}^m \sum_{r=1}^s \frac{\omega_{rj}}{\omega_{ij}}; \quad i = 1, \dots, m, \quad r = 1, \dots, s,$$

$$j=1, \dots, n. \quad (19)$$

**Step 3:** The maximum relative score is calculated in Eq. (20):

$$SODI^+ = \max_j (SODI_j^*); \quad j = 1, \dots, n. \quad (20)$$

**Step 4:** The efficiency ( $SODI^-$ ) of DMU<sub>j</sub> is determined through Eq. (21):

$$SODI_j^- = \theta S_j = \frac{SODI_j^*}{SODI^+}; \quad j = 1, \dots, n. \quad (21)$$

**Step 5:** In order to rank the DMUs, the efficiency level ( $SODI^-$ ) is arranged in a descending order and then, the complete and final ranking of DMUs is made. The DMU with value 1 is determined as the most efficient DMU.

## 4. Experiment and results

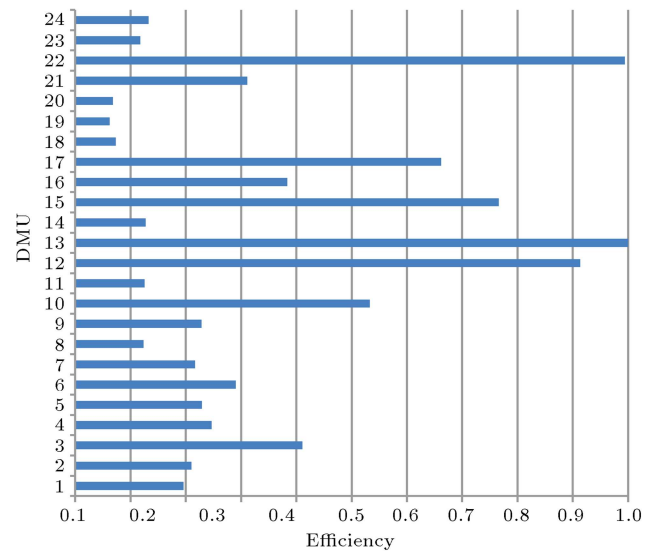
### 4.1. Data collection

In this section, the production efficiency of 24 families of automobile parts was examined in the automobile parts manufacturing industry in Iran. In the present study, the mid-term and three-month planning horizons and the cost of hiring and laying-off of labor force were equal to [42300, 52900] and [50800, 63400], respectively, and the initial inventory was zero. Tables 1 and 2 indicate the values of the other input parameters of the GAPP model from June to August 2017.

The three-objective (GAPP) model was converted to a single-objective model using the integrated method of LP-Metric and weighing method. Then, the optimal values of the GAPP model were coded on GAMS 24.8.3 and solved by CPLEX solver on a PC featuring 1.86 GHz processor and 2 G of RAM.

### 4.2. Results

The optimal grey values of the objective functions of the total profit ( $Z_1$ ), cost of reworking defective products ( $Z_2$ ), and utilization rate of machine capacity ( $Z_3$ ) are presented in Table 3. According to the experts' opinions, five input indicators of the forecasted demand ( $I_1$ ), maximum machine capacity ( $I_2$ ), maximum backorder level ( $I_3$ ), maximum labor level ( $I_4$ ),



**Figure 3.** The final ranking of Decision-Making Units (DMUs).

and minimum inventory level ( $I_5$ ) were investigated on the DMUs; and the three output indicators of the total profit ( $O_1$ ), utilization rate of machine capacity ( $O_2$ ), and cost of reworking defective products ( $O_3$ ) were determined for performance evaluation as output indicators. Then, by whitening the grey values of the input and output, the crisp values of the inputs and outputs are shown in Table 4. Further, Tables 5 and 6 display the weights of input and output indicators determined based on SWARA method.

Finally, the efficiency values and ranks of DMUs (product families) are given in Table 7. In addition, Figure 3 clearly shows the final ranking of DMUs.

### 4.3. Sensitivity analysis

According to the experts' opinions, five input indicators including the forecasted demand ( $I_1$ ), maximum machine capacity ( $I_2$ ), maximum backorder level ( $I_3$ ), maximum labor level ( $I_4$ ), and minimum inventory level ( $I_5$ ), as well as three output indicators including the total profit ( $O_1$ ), utilization rate of machine capacity ( $O_2$ ), and cost of reworking defective products ( $O_3$ ) were selected based on the importance ranking, respectively. Then, sensitivity analysis was evaluated in two scenarios.

**Scenario 1:** The sensitivity analysis was applied to the input indicators to determine the extent of changes in output indicators, which were the optimal values of the GAPP model objective functions. For example, the effects of decreasing and increasing each input indicator on the output indicators of the DMU 22 are shown in Table 8, considering the steady state of the other input indicators.

As observed in Table 8, the decrease and increase in the forecasted demand ( $I_1$ ), maximum backorder

**Table 1.** The main information of the Grey Aggregate Production Planning (GAPP) problem.

Family no.	Part no.	$D_{nt}$	$a_{nt}$	$b_{nt}$	$c_{nt}$	$d_{nt}$
1	1	[20000, 24000]	[12000, 15000]	[18000, 22000]	[40000, 50000]	[2000, 2500]
	2	[20000, 24000]	[9000, 12000]	[13000, 18000]	[30000, 40000]	[1500, 2000]
	3	[20000, 24000]	[6000, 9000]	[9000, 13000]	[20000, 30000]	[1000, 1500]
	4	[20000, 24000]	[42000, 48000]	[63000, 72000]	[140000, 160000]	[7000, 8000]
2	1	[20000, 24000]	[12000, 15000]	[18000, 22000]	[40000, 50000]	[2000, 2500]
	2	[20000, 24000]	[9000, 12000]	[13000, 18000]	[30000, 40000]	[1500, 2000]
	3	[20000, 24000]	[12000, 15000]	[18000, 22000]	[40000, 50000]	[2000, 2500]
3	1	[50000, 60000]	[680000, 790000]	[980000, 1140000]	[1970000, 2280000]	[98500, 114000]
	2	[50000, 60000]	[560000, 640000]	[810000, 920000]	[1620000, 1850000]	[81000, 92500]
4	1	[20000, 24000]	[29000, 30000]	[45000, 50000]	[85000, 100000]	[4500, 5000]
	2	[20000, 24000]	[19000, 21000]	[27000, 31000]	[56000, 70000]	[3000, 3500]
5	1	[80000, 96000]	[100000, 110000]	[155000, 161000]	[340000, 380000]	[17500, 18000]
	2	[80000, 96000]	[97000, 98000]	[145000, 146000]	[310000, 350000]	[15500, 16000]
6	1	[20000, 24000]	[350000, 360000]	[530000, 540000]	[1190000, 1200000]	[59000, 60000]
	2	[20000, 24000]	[290000, 300000]	[440000, 450000]	[990000, 1000000]	[49000, 50000]
7	1	[10000, 12000]	[360000, 450000]	[54000, 67500]	[120000, 150000]	[6000, 7500]
	2	[10000, 12000]	[210000, 270000]	[31000, 40000]	[70000, 90000]	[3500, 4500]
8	1	[20000, 24000]	[2500, 5000]	[4000, 8000]	[10000, 20000]	[500, 1000]
	2	[20000, 24000]	[500, 1000]	[800, 1600]	[2000, 4000]	[100, 200]
	3	[20000, 24000]	[750, 1250]	[1200, 2000]	[3000, 5000]	[150, 250]
9	1	[20000, 24000]	[105000, 108000]	[157000, 160000]	[350000, 360000]	[35000, 36000]
	2	[20000, 24000]	[40000, 45000]	[63000, 67000]	[140000, 150000]	[14000, 15000]
10	1	[20000, 24000]	[130000, 140000]	[190000, 200000]	[380000, 400000]	[19000, 20000]
	2	[20000, 24000]	[140000, 150000]	[200000, 215000]	[400000, 430000]	[20000, 21500]
11	1	[40000, 48000]	[24000, 27000]	[36000, 40000]	[80000, 90000]	[4000, 4500]
	2	[40000, 48000]	[30000, 33000]	[45000, 49000]	[100000, 110000]	[5000, 5500]
12	1	[10000, 12000]	[75000, 80000]	[112000, 120000]	[250000, 270000]	[12500, 13500]
	2	[10000, 12000]	[1170000, 1200000]	[1775000, 1800000]	[3900000, 4000000]	[195000, 200000]
13	1	[10000, 12000]	[680000, 690000]	[980000, 990000]	[1960000, 1980000]	[196000, 198000]
	2	[10000, 12000]	[780000, 790000]	[1120000, 1140000]	[2250000, 2280000]	[225000, 228000]
14	1	[20000, 24000]	[50000, 57000]	[80000, 85000]	[180000, 190000]	[90000, 95000]
	2	[20000, 24000]	[50000, 57000]	[80000, 85000]	[180000, 190000]	[90000, 95000]
15	1	[10000, 12000]	[52000, 59000]	[75000, 85000]	[150000, 170000]	[7500, 8500]
	2	[10000, 12000]	[120000, 130000]	[175000, 190000]	[350000, 380000]	[17500, 19000]
16	1	[10000, 12000]	[73000, 77000]	[105000, 110000]	[210000, 220000]	[10500, 11000]
	2	[10000, 12000]	[66500, 70000]	[95000, 100000]	[190000, 200000]	[9500, 10000]
17	1	[20000, 24000]	[1090000, 1110000]	[1570000, 1590000]	[3140000, 3180000]	[157000, 159000]
	2	[20000, 24000]	[847000, 857000]	[1210000, 1220000]	[2420000, 2450000]	[121000, 122500]
18	1	[20000, 24000]	[75000, 10000]	[12000, 16000]	[30000, 40000]	[1500, 2000]
	2	[20000, 24000]	[12000, 15000]	[20000, 24000]	[50000, 60000]	[2500, 3000]
19	1	[160000, 192000]	[5500, 7000]	[8000, 12000]	[20000, 34000]	[1000, 1500]
	2	[160000, 192000]	[3000, 5000]	[4000, 8000]	[10000, 22000]	[500, 1000]
20	1	[10000, 12000]	[10000, 12000]	[16000, 20000]	[40000, 50000]	[2000, 2500]
	2	[10000, 12000]	[5000, 7500]	[8000, 12000]	[20000, 30000]	[1000, 1500]
21	1	[20000, 24000]	[48000, 51000]	[72000, 76000]	[160000, 170000]	[8000, 8500]
	2	[20000, 24000]	[6000, 9000]	[9000, 13000]	[20000, 30000]	[1000, 1500]
	3	[20000, 24000]	[668000, 69000]	[99000, 103000]	[220000, 230000]	[11000, 11500]
22	1	[10000, 12000]	[1750000, 1770000]	[2500000, 25300000]	[5000000, 5060000]	[250000, 253000]
	2	[10000, 12000]	[1030000, 1050000]	[1480000, 1500000]	[2970000, 3000000]	[148000, 150000]
23	1	[80000, 96000]	[27000, 30000]	[40000, 45000]	[90000, 100000]	[4500, 5000]
	2	[80000, 96000]	[15000, 18000]	[22000, 27000]	[50000, 60000]	[2500, 3000]
24	1	[80000, 96000]	[45000, 48000]	[67000, 72000]	[150000, 160000]	[7500, 8000]
	2	[80000, 96000]	[45000, 48000]	[67000, 72000]	[150000, 160000]	[7500, 8000]

**Table 1.** The main information of the Grey Aggregate Production Planning (GAPP) problem (continued).

Family no.	Part no.	$e_{nt}$	$I_{nt \min}$	$B_{nt \max}$	$u_{nt}$	$h_{nt}$
1	1	[6000, 7500]	[2000, 2400]	[1600,1920]	[4000, 5000]	[6000, 7500]
	2	[4500, 6000]	[2000, 2400]	[1600,1920]	[3000, 4000]	[4000, 6000]
	3	[3000, 4500]	[2000, 2400]	[1600,1920]	[2000, 3000]	[3000, 4000]
	4	[21000, 24000]	[2000, 2400]	[1600,1920]	[14000, 16000]	[19000, 21000]
2	1	[6000, 7500]	[2000, 2400]	[1000,1200]	[4000, 5000]	[6000, 8000]
	2	[4500, 6000]	[2000, 2400]	[1000,1200]	[3000, 4000]	[4000, 6000]
	3	[6000, 7500]	[2000, 2400]	[1000,1200]	[4000, 5000]	[6000, 8000]
3	1	[295000, 342000]	[5000, 6000]	[10000,12000]	[220000, 260000]	[320000, 380000]
	2	[243000, 277000]	[5000, 6000]	[10000,12000]	[180000, 210000]	[270000, 300000]
4	1	[14000, 15000]	[1000, 1200]	[800,960]	[9000, 10000]	[15000, 16000]
	2	[9000, 10500]	[1000, 1200]	[800,960]	[6000, 7000]	[9000, 10000]
5	1	[52000, 53000]	[8000, 9600]	[4000,4800]	[33500, 36000]	[52000, 54000]
	2	[48000, 49000]	[8000, 9600]	[4000,4800]	[30500, 33000]	[48000, 50000]
6	1	[52000, 53000]	[2000, 2400]	[4000,4800]	[87000, 90000]	[132000, 135000]
	2	[170000, 180000]	[2000, 2400]	[4000,4800]	[72000, 75000]	[110000, 112000]
7	1	[18000, 22500]	[1000, 1200]	[500,600]	[12000, 19500]	[18000, 25000]
	2	[10000, 13500]	[1000, 1200]	[500,600]	[8000, 13500]	[10000, 16000]
8	1	[1500, 3000]	[2000, 2400]	[1000,1200]	[6000, 1200]	[1000, 2000]
	2	[300, 600]	[2000, 2400]	[1000,1200]	[120, 250]	[200, 400]
	3	[450, 750]	[2000, 2400]	[1000,1200]	[180, 310]	[300, 500]
9	1	[70000, 72000]	[1000, 1200]	[800,960]	[25000, 27000]	[39000, 40000]
	2	[28000, 30000]	[1000, 1200]	[800,960]	[10000, 12000]	[15000, 16000]
10	1	[38000, 40000]	[2000, 2400]	[1000,1200]	[63000, 66000]	[120000, 130000]
	2	[40000, 43000]	[2000, 2400]	[1000,1200]	[66000, 71000]	[130000, 140000]
11	1	[12000, 13500]	[4000, 4800]	[6000,7200]	[8000, 9000]	[12000, 13500]
	2	[15000, 16500]	[4000, 4800]	[6000,7200]	[10000, 11000]	[15000, 16500]
12	1	[37500, 40500]	[1000, 1200]	[1500, 1800]	[25000, 27000]	[37000, 40000]
	2	[585000, 600000]	[1000, 1200]	[1500, 1800]	[390000, 400000]	[585000, 600000]
13	1	[392000, 396000]	[1000, 1200]	[700, 840]	[170000, 172000]	[240000, 247000]
	2	[450000, 456000]	[1000, 1200]	[700, 840]	[190000, 197000]	[280000, 285000]
14	1	[27000, 285000]	[2000, 2400]	[1600, 1920]	[12000, 14000]	[20000, 21000]
	2	[27000, 285000]	[2000, 2400]	[1600, 1920]	[12000, 14000]	[20000, 21000]
15	1	[15000, 17000]	[1000, 1200]	[800, 960]	[17000, 19000]	[25000, 28000]
	2	[35000, 38000]	[1000, 1200]	[800, 960]	[40000, 43000]	[58000, 63000]
16	1	[31500, 33000]	[1000, 1200]	[800, 960]	[21000, 22000]	[31000, 33000]
	2	[28500, 30000]	[1000, 1200]	[800, 960]	[19000, 20000]	[28000, 30000]
17	1	[314000, 318000]	[2000, 2400]	[1600, 1920]	[360000, 370000]	[520000, 530000]
	2	[242000, 245000]	[2000, 2400]	[1600, 1920]	[282000, 285000]	[400000, 406000]
18	1	[4500, 6000]	[2000, 2400]	[2000, 2400]	[3000, 4000]	[4500, 6000]
	2	[7500, 9000]	[2000, 2400]	[2000, 2400]	[5000, 6000]	[7500, 9000]
19	1	[3000, 4500]	[16000, 19200]	[8000, 9600]	[1200, 1700]	[2000, 3000]
	2	[1500, 3000]	[16000, 19200]	[8000, 9600]	[620, 1200]	[1000, 2000]
20	1	[6000, 7500]	[1000, 1200]	[2000, 2400]	[2500, 3000]	[4000, 5000]
	2	[3000, 4500]	[1000, 1200]	[2000, 2400]	[1200, 1800]	[2000, 3000]
21	1	[24000, 25500]	[1000, 1200]	[800, 960]	[12000, 12700]	[18000, 19000]
	2	[3000, 4500]	[1000, 1200]	[800, 960]	[1500, 2200]	[2200, 3200]
	3	[33000, 34500]	[1000, 1200]	[800, 960]	[16500, 17200]	[24000, 25700]
22	1	[750000, 759000]	[500, 600]	[1000, 1200]	[437000, 442000]	[625000, 632000]
	2	[444000, 450000]	[500, 600]	[1000, 1200]	[259000, 262000]	[371000, 375000]
23	1	[13000, 15000]	[8000, 9600]	[6400, 7680]	[14200, 15000]	[21000, 22500]
	2	[7500, 9000]	[8000, 9600]	[6400, 7680]	[3700, 4500]	[5500, 6750]
24	1	[22500, 24000]	[8000, 9600]	[4000, 4800]	[15000, 16000]	[22000, 24000]
	2	[22500, 24000]	[8000, 9600]	[4000, 4800]	[15000, 16000]	[22000, 24000]

**Table 2.** Parameter values for the Grey Aggregate Production Planning (GAPP) problem in planning horizon.

Family no.	$p_{nt}$	$q_{nt}$	$V_{t \max}$	$M_{t \max}$	$W_{t \max}$	$v_{nt}$	$r_{nt}$	$L_{nt}$
1	[0.06, 0.07]	[0.06, 0.07]	600	[8000, 9000]	[10000, 11000]	[0.01, 0.02]	[0.06, 0.07]	[0.08, 0.09]
2	[0.04, 0.05]	[0.04, 0.05]	1000	[9000, 11000]	[13000, 15000]	[0.04, 0.06]	[0.09, 0.11]	[0.14, 0.15]
3	[0.02, 0.03]	[0.02, 0.03]	2000	[21000, 23000]	[24000, 27000]	[0.02, 0.03]	[0.14, 0.15]	[0.16, 0.17]
4	[0.04, 0.05]	[0.04, 0.05]	1600	[7000, 8000]	[10000, 12000]	[0.01, 0.02]	[0.07, 0.09]	[0.1, 0.12]
5	[0.03, 0.05]	[0.03, 0.05]	850	[11000, 13000]	[14000, 16000]	[0.005, 0.01]	[0.04, 0.05]	[0.06, 0.07]
6	[0.02, 0.03]	[0.02, 0.03]	2000	[8000, 9000]	[12000, 15000]	[0.01, 0.012]	[0.13, 0.15]	[0.18, 0.2]
7	[0.04, 0.05]	[0.04, 0.05]	700	[4000, 5000]	[6000, 7000]	[0.01, 0.02]	[0.07, 0.09]	[0.09, 0.11]
8	[0.06, 0.07]	[0.06, 0.07]	450	[4000, 6000]	[7000, 9000]	[0.004, 0.006]	[0.03, 0.05]	[0.06, 0.07]
9	[0.04, 0.05]	[0.04, 0.05]	1300	[4000, 5000]	[6000, 7000]	[0.03, 0.04]	[0.06, 0.07]	[0.08, 0.09]
10	[0.03, 0.04]	[0.03, 0.04]	2500	[10000, 12000]	[12000, 14000]	[0.006, 0.01]	[0.1, 0.13]	[0.13, 0.16]
11	[0.03, 0.05]	[0.03, 0.05]	850	[10000, 11000]	[13000, 14000]	[0.01, 0.02]	[0.07, 0.08]	[0.09, 0.1]
12	[0.04, 0.05]	[0.04, 0.05]	4800	[14000, 16000]	[18000, 20000]	[0.026, 0.028]	[0.14, 0.15]	[0.16, 0.17]
13	[0.03, 0.05]	[0.03, 0.05]	3400	[10000, 11000]	[13000, 14000]	[0.035, 0.04]	[0.15, 0.18]	[0.18, 0.2]
14	[0.02, 0.03]	[0.02, 0.03]	760	[4000, 5000]	[6000, 8000]	[0.01, 0.02]	[0.05, 0.07]	[0.08, 0.09]
15	[0.03, 0.04]	[0.03, 0.04]	2500	[13000, 14000]	[16000, 17000]	[0.007, 0.009]	[0.1, 0.11]	[0.13, 0.14]
16	[0.03, 0.04]	[0.03, 0.04]	2500	[6000, 9000]	[12000, 14000]	[0.025, 0.03]	[0.1, 0.14]	[0.15, 0.17]
17	[0.03, 0.04]	[0.03, 0.04]	2500	[6000, 8000]	[9000, 11000]	[0.07, 0.08]	[0.1, 0.12]	[0.13, 0.15]
18	[0.06, 0.07]	[0.06, 0.07]	600	[3000, 4000]	[6000, 7000]	[0.03, 0.04]	[0.04, 0.05]	[0.07, 0.08]
19	[0.05, 0.06]	[0.05, 0.06]	1300	[5000, 6000]	[9000, 10000]	[0.003, 0.005]	[0.01, 0.02]	[0.03, 0.04]
20	[0.03, 0.04]	[0.03, 0.04]	500	[2000, 3000]	[5000, 6000]	[0.02, 0.03]	[0.05, 0.07]	[0.08, 0.09]
21	[0.04, 0.05]	[0.04, 0.05]	1600	[7000, 8000]	[9000, 10000]	[0.01, 0.02]	[0.07, 0.08]	[0.12, 0.13]
22	[0.02, 0.03]	[0.02, 0.03]	2000	[5000, 6000]	[8000, 10000]	[0.005, 0.01]	[0.16, 0.18]	[0.2, 0.22]
23	[0.02, 0.03]	[0.02, 0.03]	2200	[12000, 14000]	[15000, 17000]	[0.005, 0.01]	[0.05, 0.07]	[0.08, 0.09]
24	[0.03, 0.05]	[0.03, 0.05]	850	[10000, 12000]	[12000, 14000]	[0.005, 0.01]	[0.04, 0.05]	[0.06, 0.07]

level ( $I_3$ ), and minimum inventory level ( $I_5$ ) indicators play a significant role in decreasing and increasing the effect, respectively. However, an increase and decrease in the maximum machine capacity ( $I_2$ ) and maximum labor level ( $I_4$ ) indicators did not affect the total profit ( $O_1$ ), utilization rate of machine capacity ( $O_2$ ), and cost of reworking defective products ( $O_3$ ).

**Scenario 2:** The sensitivity analysis of the input indicators was performed in two ways to examine the variations in the efficiency of DMUs. Figure 4 shows the effects of decreasing and increasing each input

indicator on DMUs with respect to the initial efficiency ( $M$ ) while considering the other input indicators as constant based on the decrease and increase in input indicators in Scenario 1. The error band for the indicators of  $I_1$  equals  $\pm 1000$  unit (Figure 4(a)),  $I_2$  equals  $\pm 500$  machine-hour (Figure 4(b)),  $I_3$  equals  $\pm 1000$  unit (Figure 4(c)),  $I_4$  equals  $\pm 700$  man-hour (Figure 4(d)), and  $I_5$  equals  $\pm 300$  unit (Figure 4(e)).

As observed in Figure 4, a decrease and increase in the maximum machine capacity ( $I_2$ ), maximum backorder level ( $I_3$ ), and maximum labor level ( $I_4$ ) indicators play a slight role in the efficiency of DMUs. However,

**Table 3.** Grey optimal values of the Grey Aggregate Production Planning (GAPP) model.

Family no.	Total profit	Cost of reworking defective products	Utilization rate of machine capacity
1	[8755000000, 11089562340]	[343994386, 448588884]	[18000, 20294]
2	[3695860667, 5943411333]	[112856437, 224857103]	[15900, 25593]
3	[230455000000, 322791000000]	[5135000000, 11770934143]	[40600, 52200]
4	[7418400000, 7700085156]	[118428814, 294433907]	[14000, 16683]
5	[119551000000, 147719000000]	[3604416556, 4771489479]	[25840, 32937]
6	[68128796000, 85659648000]	[1424678408, 18329471119]	[15080, 20880]
7	[6239425964, 7513875822]	[182765518, 187591208]	[9065, 9522]
8	[664178000, 1889711600]	[9767912, 42378661]	[8685, 14370]
9	[15167510400, 25795755120]	[323674560, 453123172]	[7224, 12221]
10	[53617969231, 53795300000]	[2958029340, 3830374198]	[27692, 34125]
11	[15243237143, 19604936500]	[456795381, 511536292]	[22330, 225288]
12	[86524946154, 102760000000]	[2938103402, 3911117353]	[34036, 36244]
13	[101903000000, 108486000000]	[4483260180, 5583984939]	[17590, 21930]
14	[7636040000, 9861681133]	[200739459, 381290209]	[9800, 10805]
15	[29025215385, 48422818056]	[1008582784, 1531858745]	[36923, 38264]
16	[16568550000, 17427663095]	[525146909, 653750815]	[16000, 21747]
17	[157124000000, 192489000000]	[4890587702, 7180014758]	[12080, 17395]
18	[3255773200, 4433601600]	[85831495, 164125714]	[4832, 7248]
19	[8597516000, 22143470400]	[182553273, 473257802]	[9760, 23424]
20	[1130040000, 1506710533]	[6722946, 24756480]	[3150, 4872]
21	[16396900000, 17222759011]	[475872298, 519664016]	[15750, 17822]
22	[109474000000, 132586000000]	[2233488733, 3336988243]	[9440, 12744]
23	[23437150000, 26573781991]	[680455870, 932646997]	[28125, 40589]
24	[51554200000, 56297860000]	[1411078626, 1973350581]	[24000, 30000]

an increase and decrease in the forecasted demand ( $I_1$ ) and minimum inventory level ( $I_5$ ) indicators play a significant role in the efficiency of DMUs with respect to the initial efficiency ( $M$ ).

## 5. Conclusion

Increasing the production efficiency and determining the tools and methods used for measuring performance are the biggest challenges faced by managers through the increasing competition among companies and manufacturing centers. Performance evaluation in produc-

tion planning can help any organization resolve the deficiencies, reduce the waste of resources, maximize the profit and sales of products, and decrease the inventory surplus and additional production costs. In other words, the performance evaluation of product planning provides a theoretical and practical overview. The present study aimed to evaluate the performance of the APP process and the proposed model was investigated in a case study related to the automobile parts manufacturing industry in Iran.

In previous studies, efficiency evaluation in production planning has not received sufficient research

**Table 4.** Input and output values.

DMU	$I_1$	$I_2$	$I_3$	$I_4$	$I_5$	$O_1$	$O_2$	$O_3$
DMU 1	22000	8500	1760	10500	2200	9922281170	19147	396291635
DMU 2	22000	10000	1100	14000	2200	4819636000	20747	168856770
DMU 3	55000	22000	11000	25500	5500	276623000000	46400	8452967072
DMU 4	22000	7500	880	10000	1100	7559242578	15342	206431361
DMU 5	88000	12000	4400	15000	8800	133635000000	29389	4187953018
DMU 6	22000	8500	4400	13500	2200	76894222000	17980	1628812764
DMU 7	11000	4500	550	6500	1100	6876650893	9294	185178363
DMU 8	22000	5000	1100	8000	2200	1276944800	11528	26073287
DMU 9	22000	4500	880	6500	1100	20481632760	9723	388398866
DMU 10	22000	11000	1100	13000	2200	53706634616	30909	3394201769
DMU 11	44000	10500	6600	13500	4400	17424086822	23809	484165837
DMU 12	11000	15000	1650	19000	1100	94642473077	35140	3424610378
DMU 13	11000	10500	770	13500	1100	105194500000	19760	5033622560
DMU 14	22000	4500	1760	7000	2200	8748860567	10303	291014834
DMU 15	11000	13500	880	16500	1100	38724016721	37594	1270220765
DMU 16	11000	8500	880	13000	1100	16998106548	18874	589448862
DMU 17	22000	7000	1760	10000	2200	174806500000	14738	6035301230
DMU 18	22000	3500	1760	6500	2200	3844687400	6040	124978605
DMU 19	176000	5500	8800	9500	17600	15370493200	16592	327905538
DMU 20	11000	2500	2200	5500	1100	1318375267	4011	15739713
DMU 21	22000	7500	880	9500	1100	16809829506	16786	497768157
DMU 22	11000	11500	1100	14000	550	121030000000	11092	2785238488
DMU 23	88000	13000	7040	16000	8800	25005465996	34357	806551434
DMU 24	88000	11000	7040	13000	8800	53926030000	27000	1692214604

**Table 5.** Weights of the input indicators.

Indicator	Comparative Importance of average value (S)	Coefficient (K)	Recalculated weight (q)	Weight (W)
$I_1$	0.1045	1	1	0.2570
$I_2$	0.0545	1.1045	0.9054	0.2327
$I_3$	0.0181	1.1590	0.7812	0.2008
$I_4$	0.0500	1.1771	0.6636	0.1705
$I_5$		1.2271	0.5408	0.1390

**Table 6.** Weights of the output indicators.

Indicator	Comparative Importance of average value (S)	Coefficient (K)	Recalculated weight (q)	Weight (W)
$O_1$	0.1000	1	1	0.3709
$O_2$	0.0545	1.1000	0.9091	0.3371
$O_3$		1.1545	0.7874	0.2920

**Table 7.** The efficiency values and rank of DMUs.

DMU	Efficiency	Rank
DMU <sub>1</sub>	0.1958	16
DMU <sub>2</sub>	0.2100	15
DMU <sub>3</sub>	0.4110	7
DMU <sub>4</sub>	0.2467	11
DMU <sub>5</sub>	0.2290	12
DMU <sub>6</sub>	0.2904	10
DMU <sub>7</sub>	0.2167	14
DMU <sub>8</sub>	0.1235	20
DMU <sub>9</sub>	0.2287	13
DMU <sub>10</sub>	0.5329	6
DMU <sub>11</sub>	0.1258	19
DMU <sub>12</sub>	0.9134	3
DMU <sub>13</sub>	1	1
DMU <sub>14</sub>	0.1273	18
DMU <sub>15</sub>	0.7660	4
DMU <sub>16</sub>	0.3839	8
DMU <sub>17</sub>	0.6621	5
DMU <sub>18</sub>	0.0736	22
DMU <sub>19</sub>	0.0622	24
DMU <sub>20</sub>	0.0683	23
DMU <sub>21</sub>	0.3110	9
DMU <sub>22</sub>	0.9945	2
DMU <sub>23</sub>	0.1176	21
DMU <sub>24</sub>	0.1329	17

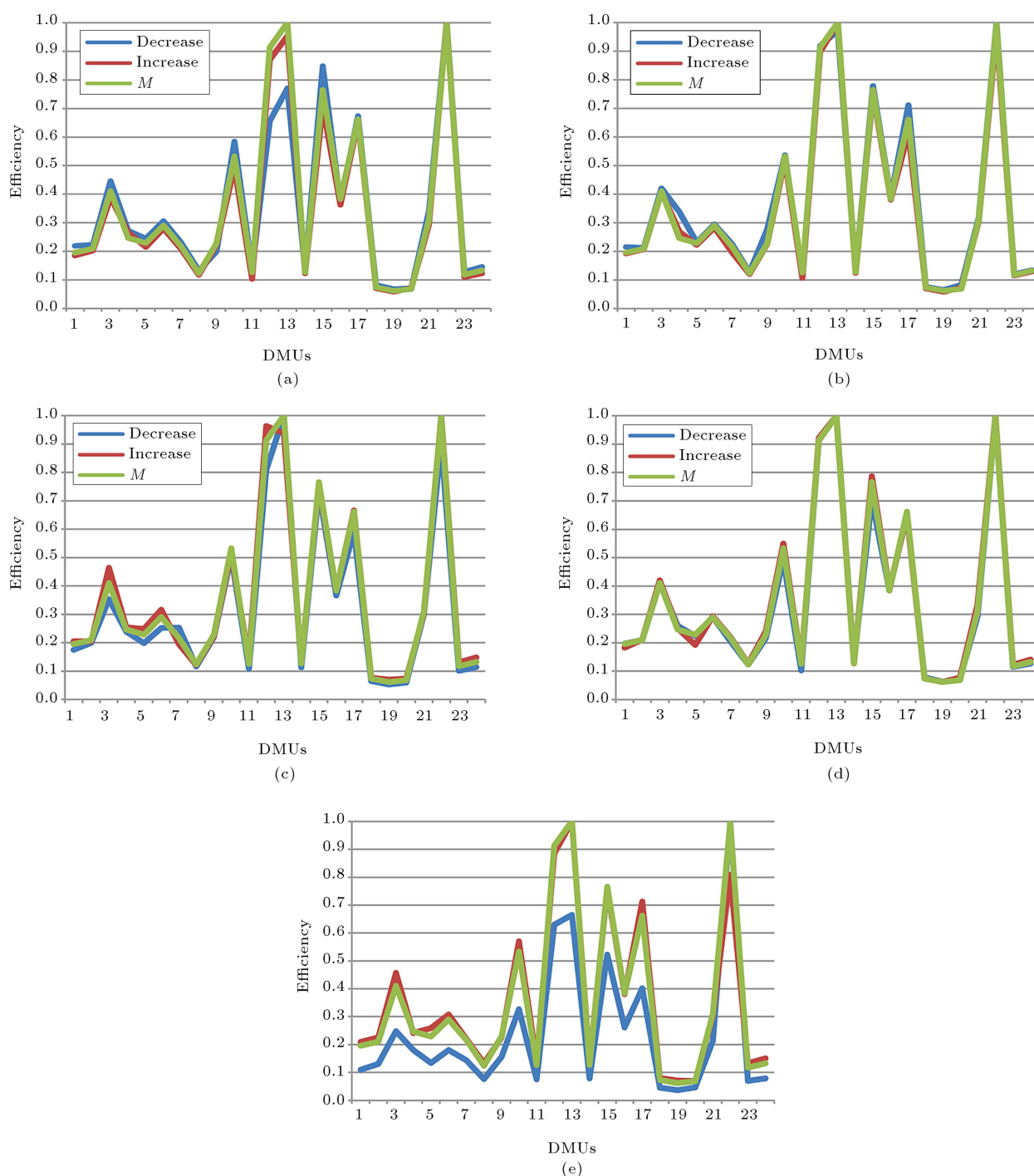
interest. The previous researches either focused on the performance measurement through basic DEA models such as the CCR model [3] or evaluated the performance in the planning field in a centralized decision-making environment and predictable conditions of demand variations [4], as well as discussed cellular

manufacturing [5]. However, the algorithm used in this study, which dealt with the evaluation of performance of the APP using new methods for the first time, aimed to maximize the utilization rates of machine capacity and total profit and also, to minimize the cost of reworking defective products. Moreover, through the development of the GAPP model provided in the study conducted by Sadeghi et al. [17], the optimal values for the objective functions and input and output indicators of the DEA model (with the opinions of experts) were initially determined by identifying the objective functions. Then, the weights of the input and output indicators were added to the RED model (to increase the accuracy of performance evaluation) and the model was improved using the SWARA model, taking into account the experts' opinions. Finally, after determining the efficiency values and final ranking of DMUs (production units in the automobile parts manufacturing industry in Iran), the strengths and weaknesses associated with the performance of decision-making units were examined using sensitivity analysis in the proposed model.

The effect of variation on performance and output indicators was also evaluated by sensitivity analysis of the input indicators of the proposed model. Based on the results of the sensitivity analysis, the changes in the maximum machine capacity ( $I_2$ ), maximum backorder level ( $I_3$ ), and maximum labor level ( $I_4$ ) indicators played an insignificant role in the efficiency of DMUs, compared to those in the forecast demand ( $I_1$ ) and minimum inventory level ( $I_5$ ) indicators. Thus, according to the number of changes in and initial efficiency of each DMU, appropriate decisions should be made. For example, in the case of DMU 3, it is suggested that some changes be made including a decrease in  $I_1$  and  $I_2$  indices and an increase in  $I_3$ ,  $I_4$ , and  $I_5$  indicators to increase the efficiency of this DMU. Furthermore, the changes in the forecasted demand ( $I_1$ ), maximum backorder level ( $I_3$ ), and minimum inventory level ( $I_5$ )

**Table 8.** The results of sensitivity analysis of DMU 22.

Indicator	Target	Changed	$O_1$		$O_2$		$O_3$	
			Target	Result	Target	Result	Target	Result
$I_1$	11000	10000	121030000000	109398450000	11092	10072	2785238488	2530558528
	11000	12000	121030000000	132661000000	11092	12112	2785238488	3039918449
$I_2$	11500	11000	121030000000	121030000000	11092	11092	2785238488	2785238488
	11500	12500	121030000000	121030000000	11092	11092	2785238488	2785238488
$I_3$	1100	800	121030000000	123386500000	11092	11194	2785238488	2809024570
	1100	2100	121030000000	113175000000	11092	10752	2785238488	2705951550
$I_4$	14000	13000	121030000000	121030000000	11092	11092	2785238488	2785238488
	14000	14700	121030000000	121030000000	11092	11092	2785238488	2785238488
$I_5$	550	250	121030000000	120115500000	11092	10990	2785238488	2761452407
	550	1050	121030000000	122554500000	11092	11262	2785238488	2824881957



**Figure 4.** The results of sensitivity analysis on  $I_1$  (a),  $I_2$  (b),  $I_3$  (c),  $I_4$  (d), and  $I_5$  (e) indicators.

indicators had greater impact on the total profit ( $O_1$ ), utilization rate of machine capacity ( $O_2$ ), and cost of reworking defective products ( $O_3$ ) indicators than the maximum machine capacity and maximum labor level indicators. In this section, based on the number of changes and initial values for the objective functions (output indicators), appropriate decisions should be made. For example, the amount of the total profit ( $O_1$ ) and utilization rate of machine capacity ( $O_2$ ) for

DMU 22 increased upon increasing  $I_1$  and  $I_5$  indicators. By reducing  $I_1$  and  $I_5$  indicators and increasing  $I_3$  indicator, a decrease in amount of the cost of reworking defective products ( $O_3$ ) was observed.

The results indicated that the proposed algorithm had a high degree of accuracy and capability to assess the performance and could help managers make better decisions to improve efficiency and reduce waste of resources. The suggestion for future research is to use

the effects of inflation and time value of money on the APP problems.

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