

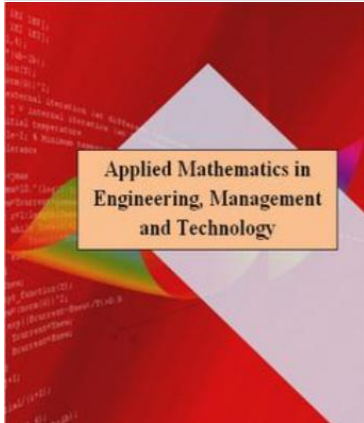
# A Cloud Manufacturing Resource Allocation by Using an Integrated FAHP-FTOPSIS Approach in High-Tech Industries

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## Abstract

Resource allocation is one of the main issues related to high-tech industries. Cloud manufacturing is one of the best manufacturing systems in high-tech industries. In this regard, in order to reduce costs and gain competitive advantage, a cloud manufacturing resource allocation in high-tech industries is considered. The process of resource allocation is a multi-criteria decision making (MCDM) problem with multiple impact criteria. Thus, in this study, machine tool and human resources as two valuable resources are allocated using Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Technique for Order Performance by Similarity to Ideal Solution (FTOPSIS). The proposed model is employed in the Shahab LCD manufacturer company. The results show the effectiveness of the proposed approach as a practical tool to assist managers (especially in the production planning sector) to allocate limited resources, efficiently.

**Keywords:** Resource allocation; Cloud manufacturing; High-Tech Industries; Fuzzy AHP; Fuzzy TOPSIS

## 1. Introduction

According to emerging technologies and severe changing in market demand, manufacturing systems have undergone various main transitions [1], [2]. The first assembly line to produce final products in the more efficiently way are invented by Henry Ford. After that, in the sixties, Toyota production system (TPS) was appeared in order to decrease manufacturing costs. TPS that also known as a just-in-time production system presents several principals that assist in removing waste by reducing waiting time, the quantity of defective products and etc. [3], [4]. Then, In the 1980s, the flexible manufacturing system (FMS) was proposed for responding to changes in products, production technology and markets [4]. To achieve changeable functionality and scalable capacity, the reconfigurable manufacturing systems (RMSs) are designed with the fundamental features such as modularity, integrability, customization and convertibility [5]. Cloud manufacturing is a service-oriented manufacturing model, which is first introduced by Li Bohu et al. [6]. This model developed from advance manufacturing models such as application service providers, agile manufacturing, and networked manufacturing [4].

Cloud manufacturing system has some advantages, including [7]:

- Enhanced efficiency and data security
- Reduced cost
- Increased flexibility
- Improved capabilities for the user
- Improved machine utilization
- Improved resource reuse

The construction of manufacturing resource allocation is a dynamic process to adapt the needs of the production activities to the capabilities of manufacturing resources. The main goal of manufacturing resource allocation problems is to complete the manufacturing tasks with the rational use of limited manufacturing resources [8]. It should be noted that, resources which are mostly occupied can be the bottleneck of the whole manufacturing process, while some of them remains idle, due to lack of usage. Poor resource allocation can contribute to low productivity and increase costs. A balanced resource allocation plays a crucial role in the increase of production productivity. There are several researches on resource allocation issue in the fields of virtual manufacturing [9], agile manufacturing [10] and manufacturing grid [11]. For example, Li Haibo et al. [12] for allocating the limited resources, suggested a workflow based multi-grain method. In this regard, a

multi-objective resource allocation model by using grey relational analysis is proposed by Yin Chao et al. [13]. Zhou Ke et al. [14] proposed a modified Genetic Algorithm (GA) method to find the optimum solution of cloud manufacturing resource allocation with respect to cost, time, quality, service and environment indicators. In the same study, Yu Jianfeng et al. [15] designed an adaptive Ant Colony Optimization (ACO) based framework to optimize time, quality and cost regarding to find the best resource allocation.

As mentioned before, a suitable resource allocation can contribute to enhanced productivity and reduced costs. The process of resource allocation is a multi-criteria decision making (MCDM) problem with multiple impact criteria. Due to the differences and sometimes conflicts in impact criteria, resource allocation problem can be difficult [16].

According to mentioned above, in this study two well-known MCDM methods namely fuzzy analytic hierarchy process (FAHP) and fuzzy TOPSIS are used for allocating the resources in a cloud manufacturing environment. In following the methods are described:

## 2. Fuzzy Analytic Hierarchy Process (FAHP)

The analytic hierarchy process (AHP) is one of the most applicable multiple criteria decision making (MCDM) methods, which was first introduced by Thomas L.Saaty [17]. In the primitive forms of the AHP method, to obtain the expert's knowledge, human judgment cannot be reflected properly. Therefore, many fuzzy AHP methods were proposed to deal with ambiguity and uncertainty in human judgments [18]. For handling fuzzy AHP, Chang (1996) suggested a new approach with employing triangular fuzzy numbers (TFNs) for pair-wise comparison scale of fuzzy AHP. Moreover, in the proposed method, extent analysis technique is used for the synthetic extent values of the pairwise comparisons [18], [19].

## 3. Fuzzy TOPSIS

TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) is another well-known MCDM technique. This method is based on selecting the most appropriate option, which has the shortest distance from the positive-ideal option and the longest distance from the negative-ideal option. More information about TOPSIS technique can be obtained in Hwang and Yoon [20]. In the classic form of the TOPSIS method, experts' judgments about the criteria and alternatives are expressed in the form of precise numbers; however, in several practical cases, the experts' preferences are vague and imprecise. Fuzzy logic is a useful tool in dealing with vagueness and uncertainty [21].

## 4. Proposed Design

Limited production, short product life cycle, various model range and high customer responsiveness are the most crucial issues related to high-tech industries. According to OECD studies, liquid crystal display (LCD) is a high-tech product [22]. Due to low weight, slender profile, low power consumption, high resolution of flat panel displays the use of LCD has been increasing. LCD has a sandwich-like structure containing two high-tech glass substrates [23]. Cloud manufacturing is one of the most appropriate manufacturing systems in high-tech industries (like LCD). Also, a balanced resource allocation plays a key role in the increase of cloud manufacturing productivity. Operators and machine tools are two valuable resources, which should be carefully allocated [16], [24]. In this study, allocation of three operators (OP1, OP2 and OP3) and three machine tools (MT1, MT2 and MT3) for producing LCD in the Shahab Company are determined by using an integrated FAHP-FTOPSIS approach as following.

### Step 1: Identifying the evaluation criteria

In the first step, the evaluation criteria for assessment operators and machine tools should be identified. The evaluation criteria are obtained by reviewing the literature and interviewing experts of Shahab Company. Finally, seven operators' evaluation criteria and seven machine tools evaluation criteria for allocation of three operators and three machine tools are identified, which are shown in Table (1) and (2), respectively.

### Step 2: calculating the weights of criteria

In this step, weights of each criteria are obtained through applying FAHP method. In this study, Chang (1996)'s extent analysis method are employed because of its computational simplicity and effectiveness.

Table 1: Criteria for evaluating candidate operators

| Criteria Code | Criteria                 | References |
|---------------|--------------------------|------------|
| C1            | Technical Capability     | [25], [26] |
| C2            | Level of understanding   | [25], [27] |
| C3            | Experience               | [25], [26] |
| C4            | Personal characteristics | [25], [16] |
| C5            | Assembly capability      | [25], [24] |
| C6            | Operator's Efficiency    | [25], [16] |
| C7            | Synergy                  | [24]       |

Table 2: Criteria for evaluating candidate machine tools

| Criteria Code | Criteria                           | References       |
|---------------|------------------------------------|------------------|
| C1            | Reliability                        | [28], [29]       |
| C2            | Rapid Response                     | [30], [31], [32] |
| C3            | Mean time free to failure          | [16], [29]       |
| C4            | The accuracy of the machine tool   | [16], [31]       |
| C5            | The cost of machine tool           | [16], [33], [34] |
| C6            | The efficiency of the machine tool | [16]             |
| C7            | Simplicity                         | [35], [36], [37] |

The basics of Chang (1996)'s extent analysis method can be summarized in four steps, including: 1) calculating priority weights, 2) comparing degree of possibility, 3) obtaining the weight vector and 4) ranking the alternatives [38]; In the proposed approach of this study, the step four is obtained by FTOPSIS method.

#### Step 2.1: calculating priority weights

In this step, at first for pairwise comparison, TFNs are used by means of FAHP scale. In this regard, the experts are requested to determine the importance of each criteria based on Table 3. This process is done for building the pairwise comparison matrix of operators and machine tools evaluation criteria which matrices are shown in Table (4) and Table (5), respectively. Then, in order to calculate priority weights, the values of synthetic extent must be acquired. In order to obtain synthetic extent values, extent analysis method is employed. Synthetic extent values for  $i$ th object can be obtained as follows:

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[ \sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} \quad (1)$$

Fuzzy addition operation of  $m$  extent analysis values ( $\sum_{j=1}^m M_{gi}^j$ ) and the fuzzy addition operation of  $M_{gi}^j$  ( $j = 1, 2, \dots, m$ ) values can be calculated by using equations (2) and (3), respectively.

$$\sum_{j=1}^m M_{gi}^j = \left( \sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j \right) \quad (2)$$

$$\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j = \left( \sum_{i=1}^n l_i, \sum_{i=1}^n m_i, \sum_{i=1}^n u_i \right) \quad (3)$$

The inverse of  $\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j$  matrix can be obtained by using equation (4).

$$\left[ \sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1} = \left( \frac{1}{\sum_{i=1}^n u_i}, \frac{1}{\sum_{i=1}^n m_i}, \frac{1}{\sum_{i=1}^n l_i} \right) \quad (4)$$

Table 3: Linguistic variables for the importance weight of each criterion [39]

| Linguistic scales for difficulty | Triangular fuzzy scale | Triangular fuzzy reciprocal scale |
|----------------------------------|------------------------|-----------------------------------|
| Perfect                          | (8, 9, 10)             | (1/10, 1/9, 1/8)                  |
| Absolute                         | (7, 8, 9)              | (1/9, 1/8, 1/7)                   |
| Very good                        | (6, 7, 8)              | (1/8, 1/7, 1/6)                   |
| Fairly good                      | (5, 6, 7)              | (1/7, 1/6, 1/5)                   |
| Good                             | (4, 5, 6)              | (1/6, 1/5, 1/4)                   |
| Preferable                       | (3, 4, 5)              | (1/5, 1/4, 1/3)                   |
| Not bad                          | (2, 3, 4)              | (1/4, 1/3, 1/2)                   |
| Weak advance                     | (1, 2, 3)              | (1/3, 1/2, 1)                     |
| Equal                            | (1, 1, 1)              | (1, 1, 1)                         |

Table 4: The pairwise comparisons matrix of operators

|    | C1              | C2              | C3              | C4        | ... | C7        |
|----|-----------------|-----------------|-----------------|-----------|-----|-----------|
| C1 | (1, 1, 1)       | (2, 3, 4)       | (3, 4, 5)       | (6, 7, 8) | ... | (5, 6, 7) |
| C2 | (1/4, 1/3, 1/2) | (1, 1, 1)       | (2, 3, 4)       | (2, 3, 4) | ... | (1, 2, 3) |
| C3 | (1/5, 1/4, 1/3) | (1/4, 1/3, 1/2) | (1, 1, 1)       | (3, 4, 5) | ... | (2, 3, 4) |
| C4 | (1/8, 1/7, 1/6) | (1/4, 1/3, 1/2) | (1/5, 1/4, 1/3) | (1, 1, 1) | ... | (1, 1, 1) |
| ⋮  | ⋮               | ⋮               | ⋮               | ⋮         | ⋮   | ⋮         |
| C7 | (1/7, 1/6, 1/5) | (1/3, 1/2, 1)   | (1/4, 1/3, 1/2) | (1, 1, 1) | ... | (1, 1, 1) |

Table 5: The pairwise comparisons matrix of machine tools

|    | C1              | C2              | C3              | C4              | ... | C7        |
|----|-----------------|-----------------|-----------------|-----------------|-----|-----------|
| C1 | (1, 1, 1)       | (2, 3, 4)       | (1, 2, 3)       | (1/3, 1/2, 1)   | ... | (3, 4, 5) |
| C2 | (1/4, 1/3, 1/2) | (1, 1, 1)       | (1/3, 1/2, 1)   | (1/5, 1/4, 1/3) | ... | (2, 3, 4) |
| C3 | (1/3, 1/2, 1)   | (1, 2, 3)       | (1, 1, 1)       | (1/4, 1/3, 1/2) | ... | (2, 3, 4) |
| C4 | (1, 2, 3)       | (3, 4, 5)       | (2, 3, 4)       | (1, 1, 1)       | ... | (4, 5, 6) |
| ⋮  | ⋮               | ⋮               | ⋮               | ⋮               | ⋮   | ⋮         |
| C7 | (1/5, 1/4, 1/3) | (1/4, 1/3, 1/2) | (1/4, 1/3, 1/2) | (1/6, 1/5, 1/4) | ... | (1, 1, 1) |

### Step 2.2: comparing degrees of possibility

The degree of possibility of  $\tilde{M}_2 = (l_2, m_2, u_2) \geq \tilde{M}_1 = (l_1, m_1, u_1)$ , that is displayed as  $V(\tilde{M}_2 \geq \tilde{M}_1)$ , is defined as follows:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = \sup_{y \geq x} [\min(\lambda\pi_1(x), \lambda\pi_2(y))] \quad (5)$$

In equation (5),  $x$  and  $y$  are the values on the axis of membership function of each criteria and it can be shown as equation (6):

$$V(\tilde{M}_2 \geq \tilde{M}_1) = \text{hgt}(\tilde{M}_1 \cap \tilde{M}_2) = \lambda\pi_2(d) = \begin{cases} 0 & \text{if } m_2 \geq m_1 \\ 1 & \text{if } l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{o.w} \end{cases} \quad (6)$$

In which  $d$  is the ordinate of the highest intersection point between  $\lambda\pi_1$  and  $\lambda\pi_2$ . It's notable that, both the values of  $V(\tilde{M}_1 \geq \tilde{M}_2)$  and  $V(\tilde{M}_2 \geq \tilde{M}_1)$  are needed to be able to compare  $\tilde{M}_1$  and  $\tilde{M}_2$ .

### Step 2.3: obtaining the weight vector

The degree of possibility for a convex fuzzy number to be greater than  $p$  convex fuzzy numbers  $\tilde{M}_i (i = 1, 2, \dots, p)$  can be defined as following:

$$V(\tilde{M} \geq \tilde{M}_1, \tilde{M}_2, \dots, \tilde{M}_p) = V(\tilde{M} \geq \tilde{M}_1), \dots, V(\tilde{M} \geq \tilde{M}_p) = \text{Min}V(\tilde{M} \geq \tilde{M}_i) \quad i = 1, 2, \dots, p \quad (7)$$

If  $d^t(A_i) = \text{Min}V(S_i \geq S_p)$  for  $p = 1, 2, \dots, m; p \neq i$  then the weight vector  $w^t$  can be represented as equation (8):

$$w^t = (d^t(A_1), d^t(A_2), \dots, d^t(A_n))^T \quad (8)$$

By normalization, the normalized weight vector  $W$  can be obtained as following:

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (9)$$

$W$  is a deterministic number and shows the priority weights of an criterion or alternative over other.

**Step 3: calculating scores of each alternative**

In this step, the Fuzzy TOPSIS method is used to determine ranking of operators and machine tools for manufacturing LCD products, as following [40], [41]:

**Step 3.1: Constructing the fuzzy decision matrix**

In this step, first the appropriate linguistic variables for the alternatives with respect to criteria are chosen. After that, according to experts' opinion, the fuzzy decision matrix can be constructed as below:

$$\tilde{D} = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} C_1 & C_2 & \dots & C_n \\ \tilde{x}_{11} & \tilde{x}_{11} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{11} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (10)$$

Where,  $\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$  is the score of  $i$ th alternative  $A_i$  with respect to  $j$ th criteria  $C_j$ .

Table 6: Linguistic variables for constructing fuzzy decision matrix [42]

| Linguistic variables | Triangular fuzzy scale |
|----------------------|------------------------|
| Very Not Poor (VNP)  | (0, 0, 1)              |
| Poor (P)             | (0, 1, 3)              |
| Medium Poor (MP)     | (1, 3, 5)              |
| Fair (F)             | (3, 5, 7)              |
| Medium Good (MG)     | (5, 7, 9)              |
| Good (G)             | (7, 9, 10)             |
| Very Good (VG)       | (9, 10, 10)            |

Based on expert's opinion of Shahab LCD manufacturing company and according to Table (6), the fuzzy decision matrices of operators and machine tools are achieved, which are shown in Table (7) and Table (8), respectively.

**Step 3.2: Normalizing the fuzzy-decision matrix.**

The normalized fuzzy-decision matrix displayed by  $\tilde{R}$  and is indicated as equation (11):

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (11)$$

The normalizing procedure can be carried out by using formula (12):

$$\tilde{r}_{ij} = \left( \frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+} \right), \quad u_j^+ = \max_i \{u_{ij} \mid j = 1, 2, \dots, n\} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (12)$$

Also, we can assign the most appropriate aspired level  $u_j^+$  and  $j = 1, 2, \dots, n$  is equal one and the worst is zero. The normalized  $\tilde{r}_{ij}$  is TFNs. The weighted fuzzy normalized decision matrix displayed by  $\tilde{V}$  and is indicated as equation (13):

$$\tilde{V} = [\tilde{v}_{ij}]_{n \times n} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (13)$$

Where, in the equation (13)  $\tilde{v}_{ij}$  can be obtained by using formula (14):

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j \quad (14)$$

**Step 3.3: Determining the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS)**

After obtaining the weighted normalized fuzzy decision matrix in previous step, the aspiration levels (FPIS( $A^+$ )) and the worst levels (FNIS( $A^-$ )) can be defined using following equations, respectively.

$$A^+ = \{\tilde{v}_1^*, v_2^*, \dots, \tilde{v}_n^*\} \quad (15)$$

$$A^- = \{\tilde{v}_1^-, v_2^-, \dots, \tilde{v}_n^-\} \quad (16)$$

**Step 3.4: computing the distance of each alternative from FPIS and FNIS**

The distance of each alternative from FPIS ( $s_i^+$ ) and the distance of each alternative from FNIS ( $s_i^-$ ) are computed by using Euclidean distance formula as following:

$$s_i^+ = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (17)$$

$$s_i^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (18)$$

**Step 3.5: computing the closeness coefficients distance of each alternative**

Closeness Coefficients (CC) of each alternative can be obtained using formula (19).

$$CC_i = \frac{s_i^-}{s_i^- + s_i^*} \quad i = 1, 2, \dots, m \quad (19)$$

**Step 3.6: Ranking the alternatives**

The ranking of alternatives are obtained by comparing Closeness Coefficients (similarity index) values.

**5. Results and Discussions**

Initially, the weights of seven operators' criteria and seven machine tools criteria are calculated by using FAHP method. The FAHP results show that the weight vector of operators' evaluation criteria is 0.2604, 0.2026, 0.1624, 0.0781, 0.0242, 0.1419 and 0.1305, respectively. Also, The FAHP results for weight vector of machine tools evaluation criteria is 0.1459, 0.0842, 0.1299, 0.1832, 0.2123, 0.1696 and 0.0749, respectively. Then, with respect to experts' opinion, the score of each operator is determined in each criteria. Similarly, this process is performed for machine tools. Table 7 indicates an operators' scores in each criteria. Table 8 indicates a machine tools scores in each criteria, too. Lastly, the final rank of each operator and each machine tool is determined by employing Fuzzy TOPSIS technique, as shown in Table 9 and Table 10, respectively.

Table 7: Fuzzy decision matrix of operators

|     | C1          | C2          | C3         | C4         | ... | C7         |
|-----|-------------|-------------|------------|------------|-----|------------|
| OP1 | (5, 7, 9)   | (7, 9, 10)  | (5, 7, 9)  | (3, 5, 7)  | ... | (3, 5, 7)  |
| OP2 | (7, 9, 10)  | (9, 10, 10) | (3, 5, 7)  | (7, 9, 10) | ... | (7, 9, 10) |
| OP3 | (9, 10, 10) | (5, 7, 9)   | (7, 9, 10) | (3, 5, 7)  | ... | (1, 3, 5)  |

Table 8: Fuzzy decision matrix of machine tools

|     | C1          | C2         | C3          | C4          | ... | C7          |
|-----|-------------|------------|-------------|-------------|-----|-------------|
| MT1 | (9, 10, 10) | (7, 9, 10) | (7, 9, 10)  | (9, 10, 10) | ... | (1, 3, 5)   |
| MT2 | (7, 9, 10)  | (5, 7, 9)  | (9, 10, 10) | (7, 9, 10)  | ... | (3, 5, 7)   |
| MT3 | (7, 9, 10)  | (3, 5, 7)  | (7, 9, 10)  | (5, 7, 9)   | ... | (9, 10, 10) |

Table 9: Scores and ranking of operators

| Resource Type | Resource Code | Score  | Final rank |
|---------------|---------------|--------|------------|
| Operator      | OP1           | 0.6753 | 3          |
|               | OP2           | 0.9598 | 1          |
|               | OP3           | 0.8453 | 2          |

Table 10: Scores and ranking of machine tools

| Resource Type | Resource Code | Score  | Final rank |
|---------------|---------------|--------|------------|
| Machine Tool  | MT1           | 0.7954 | 1          |
|               | MT2           | 0.6895 | 2          |
|               | MT3           | 0.5049 | 3          |

**6. Conclusion**

Resource allocation is one of the key issues related to productivity of high-tech industries. According to emerging technologies and severe changing in market demand, manufacturing systems have undergone various main transitions from Henry Ford mass production system to cloud manufacturing system. Cloud manufacturing system has several advantages such as enhanced efficiency and data security, reduced cost, increased flexibility and etc. Based on these advantages, the cloud manufacturing system is appropriate for production of high-tech products. Hence, for reducing manufacturing costs and increasing competitive advantages, a cloud manufacturing resource allocation in high-tech industries is examined. Resource allocation is a MCDM problem due to its different and sometimes conflicting impact criteria. In this study, the allocations of machine tool and human resources are considered. In this regard, first evaluation criteria for assessment operators and machine tools are identified. Next, weights of each criterion are calculated through employing FAHP method. Finally, ranking of operators and machine tools are determined by using Fuzzy TOPSIS method. The proposed approach is implemented in the Shahab LCD manufacturer company. The results indicate the efficiency of the proposed approach as a useful tool to assist production planning managers to allocate limited resources.

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