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# Material Requirements Planning with A Fuzzy Model

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**ABSTRACT**

Material Requirements Planning (MRP) systems are inherently sensitive to various sources of uncertainty, which can significantly impact their effectiveness in production and inventory management. This study aims to address these challenges by developing a fuzzy multi-objective decision-making framework for MRP problems. Specifically, a fuzzy multi-objective linear programming (FMOLP) approach is proposed, incorporating fuzzy lead times (LTs) into the MRP model. In this framework, classical deterministic MRP models are integrated with the probabilistic distribution of possible lead times, allowing the system to account for the likelihood of each LT occurrence. An objective function is then formulated to maximize the overall probability of favorable LT realizations, providing a balanced trade-off among competing objectives. The initial MRP parameters are applied to this objective function, demonstrating that decision-makers, depending on their risk preferences, may accept certain low-probability LTs that enhance other performance measures, such as inventory levels or service rates. Numerical examples are presented to illustrate the applicability and effectiveness of the proposed model, highlighting its ability to accommodate uncertainty while supporting strategic and operational decision-making. The results indicate that the fuzzy multi-objective approach not only improves the robustness of MRP systems under uncertain conditions but also offers a practical decision-support tool for managers seeking to optimize multiple objectives simultaneously.

## 1. INTRODUCTION

Material Requirement Planning (MRP) is used in the production planning and control systems for batch production [1].have completely defined the MRP systems, whose definition can be referred and used. The logical validity of MRP is derived from its ability in dealing with complexity, diversity, and uncertainty. There are two forms of uncertainty that can affect MRP [2]:

1- Environmental uncertainty

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2- System uncertainty

There are three forms of uncertainty in the industrial decision-making environment, which can influence the production planning processes:

1- Market demand
2- Capacity-related data
3- Cost information

The system uncertainty appears as one of the forms of system efficiency uncertainty, uncertainty in the production lead time, quality uncertainty, failure of the production system and changes in the product structure. In addition, three key features of such systems include coordination in assembling, requirements for components purchased through the order registration phases and reducing the settings by collecting the needs of the shared sectors.

Different models for MRP with uncertainty [3] are introduced under the uncertainty constraints [4] and fuzzy constraints [5]. The demand for product is one of the uncertainties in the production/distribution systems [6] to [8] which consists of two components:

1- Demand forecasting
2- Market orders

Since the demand forecasting is done based on various parameters such as the supply of resources, competitors, previous sales, etc., which are conditional, uncertain and un plan able, thus, it has a fuzzy nature, while the orders received can be determined at the beginning of the planning. In this paper, a fuzzy multi-objective integer linear programming mathematical model was provided for problems with MRP approach with fuzzy lead times. Then, the model was solved using the fuzzy goal programming approach.

## 2. STATEMENT OF THE PROBLEM

Different probability modeling techniques based on probability distribution have been used for the production planning problem in a random mode [6] to [13].

However, the probable distributions obtained from the pre-existing data are not always available and reliable, since the market conditions are changing, which affect the demand, order postponement costs and, technological innovations and available capacity. The theory of fuzzy sets is used to model the systems, which parameters are difficult to be accurately defined [14] to [16]. Reference [17] provides a comprehensive study on the use of the theory of fuzzy sets in the production management. We should initially clarify the difference fuzzification and flexibility in the limitations, goals, lack of knowledge on the data and conditions of uncertainty.

Flexibility is modeled using fuzzy constraints, while fuzzy coefficients are used under uncertainty conditions. Some applications of flexible planning in production planning problems can be found in the reference [18] to [21]. Other applications of contingency planning in production planning problems are mentioned in the references [22] to [26].

The proposed model in this section examines the inaccessibility of the required data and the use of fuzzification to resolve this issue. The Mo linear programming model presented in article [27] was used as a basis for developing a new model based on the fuzzy mathematical planning. Mo is a model for optimizing the problem of material requirements planning in the multi-product, multi-interval, and multi-level production conditions while considering the capacity constraints. In [27], Mo is also transformed into three fuzzy models based on a flexible programming approach under the circumstances where the optimal level of total costs, market demand, and the available capacity are considered vague. Here, we also consider the lack information on the cost of deferred orders and the required capacity. Thus, we provide a fuzzy programming model with fuzzy coefficients and constraints.

In this study, the symbol (,) is used to describe triangular fuzzy numbers. The values on the left indicate the most probable value of the fuzzy set, while the values on the right represent the deviation from the most probable value. For example, a triangular fuzzy number represented as (40, 10) indicates that "40" has the highest degree of membership and the values of 30 and 50 have the lowest membership rates in this set of fuzzy numbers.

The variables and parameters required for modeling are presented in Table 1:

**Table 1.** Decision variables and model parameters

| **T** | **Number of periods in the planning horizon (t = 1,2, ..., T)** |
|---|---|
| **I** | Number of products (i = 1,2, ..., I) |
| **J** | Number of final items (final products) available in the materials form (BOM) (j = 1,2, ..., J) |
| **R** | Number of sources (r = 1,2, ..., R) |
| $\mathbf{P_{it}}$ | Amount of product i produced in period t |
| $\mathbf{q_{it}}$ | Amount of product i requiring to be reworked in time t |
| $\mathbf{P_{jt}}$ | Amount of the final product j produced in period t |
| $\mathbf{INVT_{it}}$ | Product I inventory i at the end of period t |
| $\mathbf{B_{it}}$ | Postponed orders of product i at the end of period t |
| $\mathbf{Tun_{rt}}$ | Hours of unemployment of source r at time t |
| $\mathbf{Tov_{rt}}$ | Overtime hours of source r at time t |
| $\mathbf{Cp_{it}}$ | Cost of producing each product unit i at time t |
| $\mathbf{Cq_{it}}$ | Cost of reworking each unit of product i in period t |
| $\mathbf{Ci_{it}}$ | Cost of inventory of each unit of product i at time t |
| $\mathbf{Ctun_{rt}}$ | Cost of each hour of unemployment source r at time t |
| $\mathbf{Ctov_{rt}}$ | Cost per hour of overtime of the resource r at time t |
| $\mathbf{(AR_{ir}, A_{ir})}$ | (Fuzzy) time required by source r to produce each product unit i |
| $\mathbf{(BR_{ir}, B_{ir})}$ | (Fuzzy) time required source r for rework on each product unit i |
| $\mathbf{(cap_{rt}, cap_{rt} + pp_{rt})}$ | (Fuzzy) available capacity of source r at period t |
| $\mathbf{(d_{it}, d_{it} + dd_{it})}$ | (Fuzzy) demand of product i in period t |
| $\boldsymbol{\alpha_{ij}}$ | Required quantity of product i to produce a unit of final product j |
| $\mathbf{(Lt_i, LL)}$ | (Fuzzy) lead time for product i |
| $\mathbf{INVT_{i0}}$ | Initial inventory of product i at zero period |
| $\mathbf{B_{i0}}$ | Postponed order of the product i in the zero period |
| $\mathbf{SR_{it}}$ | Scheduled receives for i product t |
| $\mathbf{SR_{jt}}$ | Scheduled receives for the final product j at time t |
| **N** | Maximum material storage capacity |

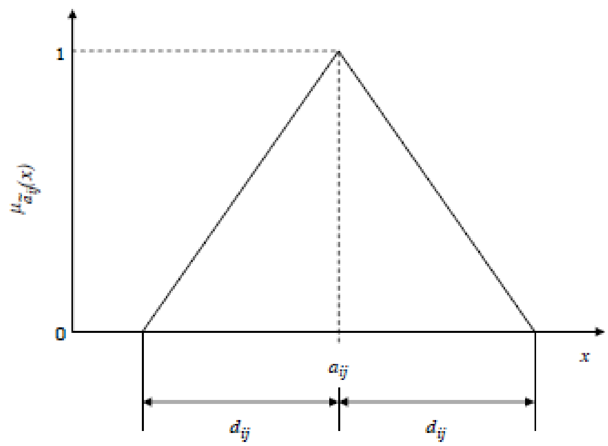


**Fig. 1.** An overview of the concept of a triangular fuzzy number $(a_{ij}, d_{ij})$

## 3. MODEL

The model proposed in this research is a multi-objective fuzzy mathematical model as follows:

$$\min \quad z_1 \cong \sum_{i=1}^{I}\sum_{t=1}^{T} Cp_{it} \, . \, P_{it} + Ci_{it} \, . \, INVT_{it} + Cq_{it} \, . \, q_{it} \tag{1}$$

$$\min \quad z_2 \cong \sum_{i=1}^{I}\sum_{t=1}^{T} B_{it} \tag{2}$$

$$\min \quad z_3 \cong \sum_{r=1}^{R}\sum_{t=1}^{T} Tun_{rt} \tag{3}$$

$$\min \quad z_4 \cong \sum_{r=1}^{R}\sum_{t=1}^{T} Tov_{rt} \tag{4}$$

Subject to

$$INVT_{i(t-1)} + P_{i(t-Lt)} + SR_{it} - INVT_{it} - B_{i(t-1)} - \sum_{j=1}^{J} \alpha_{ij} \left(P_{jt} + SR_{jt}\right) + B_{it} \lesssim d_{it} \tag{5}$$

$$INVT_{i(t-1)} + P_{i(t-Lt)} + SR_{it} - INVT_{it} - B_{i(t-1)} - \sum_{j=1}^{J} \alpha_{ij} \left(P_{jt} + SR_{jt}\right) + B_{it} \gtrsim d_{it} \tag{6}$$

$$\sum_{i=1}^{I} P_{it} \, . AR_{ir} + q_{it} . BR_{ir} + Tun_{rt} - Tov_{rt} \lesssim cap_{rt} \tag{7}$$

$$\sum_{i=1}^{I} P_{it} \, . AR_{ir} + q_{it} . BR_{ir} + Tun_{rt} - Tov_{rt} \gtrsim cap_{rt} \tag{8}$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} INVT_{it} \le N \tag{9}$$

$$B_{iT} = 0 \tag{10}$$

$$P_{it}, q_{it}, INVT_{it}, B_{it}, Tun_{rt}, Tov_{rt} \ge 0 \tag{11}$$

In the above model, Equation 1 represents the sum of production, reworking and maintenance costs. Many of these costs cannot be easily measured since their values depend on a number of factors such as manpower, and thus, they cannot be calculated accurately. Therefore, the optimal level of costs will be fuzzy. Equation 2 indicates the number of delayed orders, which we want to minimize them. Equation 3 and Equation 4 are provided to minimize the total inaction time of the resources and to minimize the total overtime hours of sources, respectively.

Equations 5 and 6 represent the balance of inventory in different periods, which are presented in the form of fuzzy constraints. In this equations, the delayed demand is considered as a negative stock. We also consider the fuzzy market demand by using the fuzzy constraints in the planning horizon. The symbol $\lesssim$ is the fuzzy mode of symbol $\geq$, which can be called almost "smaller or equal". This constraint states that the left side of the inequality, i.e., the fulfilled demand, must be smaller or almost equal to the right value, the anticipated demand. Here, the equality constraint is presented by use of two constraints of the inequality.

Fuzzy equations 7 and 8 consider the capacity constraint of the production resources. In these constraints, the right side amount, i.e., the available capacity, is also written as a triangular fuzzy number. Equation 9 indicates the limitation of the warehouse capacity. Equation 10 states that all the demands are met during the planning horizon. In other words, no overdue order should be left at the end of the horizon of planning. Finally, in Equation 11, the constraints relating to the non-negative variables are presented.

## 4. METHODOLOGY OF THE MODEL SOLVING

Considering the concept of a fuzzy mathematical model, we have:

If "n" fuzzy objectives are defined in the form of G1, G2, ..., Gn and "m" fuzzy constraints as C1, C2, ..., Cm, then, the fuzzy set of decisions is obtained by sharing the fuzzy goals and the fuzzy constraints:

$$D = (G_1 \cap G_2 \cap \dots \cap G_n) \cap (C_1 \cap C_2 \cap \dots \cap C_m) \quad (12)$$

Due to the concept of fuzzy numbers, the membership function is as follows:

$$\mu_D = \min\ (\mu_{G_1}, \mu_{G_2}, \dots, \mu_{G_n}, \mu_{C_1}, \mu_{C_2}, \dots, \mu_{C_m}) \quad (13)$$

In the other words:

$$\mu_D = \min\ (\mu_{G_i}, \mu_{C_j}) \quad , \quad i = 1,2,\dots,n \quad , \quad j = 1,2,\dots,m \quad (14)$$

To solve the fuzzy model proposed in this article, we need to initially calculate the upper limit ($Z_U$) and the lower limit ($Z_L$) for each objective function. To this end, we solve the model for each of the objective functions once with the highest RHS values (to get $Z_U$) and once with the lowest RHS values (to obtain $Z_L$). Then, according to the concept of triangular fuzzy numbers, we compute the membership function. Thus, we have:

$$\mu_Z = \begin{cases} 1 & Z < Z_L \\ \dfrac{Z_U - Z}{Z_U - Z_L} & Z_L \le Z \le Z_U \\ 0 & Z > Z_U \end{cases} \quad (15)$$

The $\mu_Z$ values are obtained for all objective functions.

In addition, for any fuzzy constraint with respect to the concept of fuzzy triangular numbers, the value for the degree of demand satisfaction is calculated. For each restriction K, we would have:

$$\mu_K = \begin{cases} 0 & X \le A - aa \\ \dfrac{X - (A - aa)}{A - (A - aa)} = \dfrac{X - (A - aa)}{aa} & A - aa \le X \le A \\ \dfrac{(A + aa) - X}{(A + aa) - A} = \dfrac{(A + aa) - X}{aa} & A \le X \le A + aa \\ 0 & X \ge A + aa \end{cases} \quad (16)$$

Therefore, according to the above, we will have:

$$\text{Max } \min\ (\mu_Z, \mu_K, \mu_L) \quad \forall Z, \forall K, \forall L \quad (17)$$

$$\min\ (\mu_Z, \mu_K, \mu_L) = \lambda_0 \rightarrow \text{Max } \lambda_0 \quad (18)$$

Based on the method proposed by Torabi and Hosseini, a fuzzy ideal planning model with several objective functions can be transformed into a mathematical model with an objective function:

$$\begin{aligned} &\text{Max} \\ &\lambda(x) = \gamma\lambda_0 + (1-\gamma)\textstyle\sum_K \theta_K \mu_K(x) \\ &\text{Subject to} \\ &\qquad \lambda_0 \le \mu_K(x) \quad K = 1,2,\dots,n \\ &x \in F(x) \end{aligned} \quad (19)$$

Given the above relations, the final model is turned into the following form:

$$\text{Max } \lambda(x) = \gamma\lambda_0 + (1-\gamma)\left(\theta_1 \frac{Z_{1_U} - Z_1}{Z_{1_U} - Z_{1_L}} + \theta_2 \frac{Z_{2_U} - Z_2}{Z_{2_U} - Z_{2_L}} + \theta_3 \frac{Z_{3_U} - Z_3}{Z_{3_U} - Z_{3_L}} + \theta_4 \frac{Z_{4_U} - Z_4}{Z_{4_U} - Z_{4_L}}\right) \quad (20)$$

Subject to

$$K_1 : INVT_{i(t-1)} + P_{i(t-(Lt+\lambda_0 LL))} + SR_{it} - INVT_{it} - B_{i(t-1)} - \sum_{j=1}^{J} \alpha_{ij}\left(P_{jt} + SR_{jt}\right) + B_{it} \leq d_{it} + dd_{it} - \lambda_0 dd_{it} \quad (21)$$

$$K_2 : INVT_{i(t-1)} + P_{i(t-(Lt-\lambda_0 LL))} + SR_{it} - INVT_{it} - B_{i(t-1)} - \sum_{j=1}^{J} \alpha_{ij}\left(P_{jt} + SR_{jt}\right) + B_{it} \geq d_{it} - dd_{it} + \lambda_0 dd_{it} \quad (22)$$

$$K_3 : \sum_{i=1}^{I} P_{it} . AR_{ir} + q_{it} . BR_{ir} + Tun_{rt} - Tov_{rt} \leq cap_{rt} + pp_{rt} - \lambda_0 pp_{rt} \quad (23)$$

$$K_4 : \sum_{i=1}^{I} P_{it} . AR_{ir} + q_{it} . BR_{ir} + Tun_{rt} - Tov_{rt} \geq cap_{rt} - pp_{rt} + \lambda_0 pp_{rt} \quad (24)$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} INVT_{it} \leq N \quad (25)$$

$$B_{iT} = 0 \quad (26)$$

$$\lambda_0 \leq \mu Z_1 \quad (27)$$

$$\lambda_0 \leq \mu Z_2 \quad (28)$$

$$\lambda_0 \leq \mu Z_3 \quad (29)$$

$$\lambda_0 \leq \mu Z_4 \quad (30)$$

$$\lambda_0 \leq \mu K_1 \quad (31)$$

$$\lambda_0 \leq \mu K_2 \quad (32)$$

$$\lambda_0 \leq \mu K_3 \quad (33)$$

$$\lambda_0 \leq \mu K_4 \quad (34)$$

$$0 \leq \lambda_0 \leq 1 \quad (35)$$

$$0 \leq \mu_{Z_1} \leq 1 \quad (36)$$

$$0 \leq \mu_{Z_2} \leq 1 \quad (37)$$

$$0 \leq \mu_{Z_3} \leq 1 \quad (38)$$

$$0 \leq \mu_{Z_4} \leq 1 \quad (39)$$

$$0 \leq \mu_{K_1} \leq 1 \quad (40)$$

$$0 \leq \mu_{K_2} \leq 1 \quad (41)$$

$$0 \leq \mu_{K_3} \leq 1 \quad (42)$$

$$0 \leq \mu_{K_4} \leq 1 \quad (43)$$

$$0 \leq \mu_{L_1} \leq 1 \quad (44)$$

$$0 \leq \mu_{L_2} \leq 1 \quad (45)$$

$$0 \leq \theta_i \leq 1 \quad (46)$$

$$0 \leq \gamma \leq 1 \quad (47)$$

$$\lambda(x) \leq 1 \quad (48)$$

$$P_{it}, q_{it}, INVT_{it}, B_{it}, Tun_{rt}, Tov_{rt} \geq 0 \quad (49)$$

This model aims to maximize the degree of membership associated with the constraints, minimize the production costs, and meet the demand and the available capacity. The variable λ (x) is the desirability level, which is initialized in the range (0, 1).

The steps to solve the model are as follows:

a. Formulate the main Fuzzy Ideal Planning Model (FGP) for the Material Requirements Planning (MRP) problem.

b. Specify the membership functions for all fuzzy objectives.
c. Determine the importance ratio of each of the objective functions ($\theta_i$) and the coefficient of influence $\gamma$.
d. Convert the FGP original model by using the existing methods (here, using the method proposed by Torabi and Hosseini) to a mixed integer linear mathematical model with an objective function of (MILP).
e. Formulate the definite single-objective model with the help of one of the available software and obtain the possible fuzzy solution set.
f. Convert the fuzzy answer obtained to a non-fuzzy mode with the help of existing methods (here, the centroid method).
g. Obtain the Manhattan distance or Euclidean distance for each solution.
h. Choose the best solution with the shortest distance.

Then, the problem is solved using a solver such as GAMS or Cplex. The Cplex works very well for solving linear programming models, integer programming models, and complex integer programming models. The input and output of the model are managed using the database. Therefore, by updating the data and for a new planning horizon, the material requirements planning can be easily implemented again.

### 4.1. Implementing the model for sample

The proposed model was evaluated using real data from a manufacturing company of car seats. This assembling company belongs to a leading multinational group in supplying the seats required by the car manufacturers. The company employs a production planning system, which is integrated with a business resource planning system. The assumptions used in this problem are as follows:

1. In this problem, only a standard product, which is a standard seat, is considered. It is the result of the assembly of two products with consumption coefficients of 1 and 3.
2. The decision variables of $P_{it}$, $q_{it}$, $INVT_{it}$, $B_{it}$ are considered integer.
3. Only the final product has an external demand.
4. The orders received from automobile factories cannot be ruled out, even if they trigger delayed orders (backlogs).
5. Delaying the demand can be considered at a high-cost fine since the service level for service provision is considered to be 100%.
6. For some parts, the company considers assurance time.
7. There is only one source of production that limits the production and that is the assembly line.
8. The planning horizon consists of 30 time periods.
9. The lead times for raw materials from the supplier are assumed to be fuzzy.
10. The inventory capacity is limited.

## 5. CONCLUSION

In many manufacturing environments, such as automotive industry, the decisions on the issue of production planning should be made under uncertainty conditions on important parameters such as demand, capacity, and the cost data. In this case, the uncertainty and dynamics of production plans preparation seem to be very difficult. A fuzzy production planning model was developed in this article to improve such situations. The proposed fuzzy model makes the existing difficult constraints flexible, found in traditional production planning models, by fuzzification and use of a contingency planning approach.

The solution presented to solve the fuzzy model is a sustainable solution without making many changes in the calculations time to get the answer. In practice, it is proven that models with fuzzy constraints have a better performance than the models with fuzzy coefficients and constraints. However, we managed to add both types of uncertainty to our model. The newer versions of the suggested model can be studied in various references by considering the models and solutions presented. Ultimately, testing and evaluating this model for a variety of products of other plants seems to be a valuable target.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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