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Comparative Analysis of Membership Functions in Multi Objective Fuzzy Linear Programming for the Apparel Industry

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Abstract

Decision making in the apparel industry often involves trade-offs between multiple conflicting objectives under uncertain environments. While linear programming (LP) is widely used for profit maximization and cost minimization, it cannot effectively handle imprecision in objective and constraints. Fuzzy Multi Objective Linear Programming (FMOLP) addresses this limitation by incorporating uncertainty through membership functions. This study presents a comparative analysis of different membership functions specifically linear and trapezoidal in the development of an FMOLP model for an apparel manufacturing company producing polo, basic, mock-neck T shirts, singlets and short pants. Unlike the reference study, which used all available raw materials to maximize profit without accounting for excess production, the proposed FMOLP model aims to maximize profit while minimizing total production, overproduction, material wastage, and unnecessary costs. Overproduction is specifically defined as output that exceeds the allowable level after accounting for a 4% defect rate. To evaluate the impact of different membership functions, each LP models were solved separately to construct a pay-off matrix, establishing the lower and upper bounds of each objective functions. The FMOLP models were developed using linear and trapezoidal membership functions and solved using Julia. The results show that the choice of membership function significantly influences model performance. FMOLP model with linear membership function achieved a 25% reduction in total production, while with the trapezoidal membership function achieved a higher 35.2% reduction compared with the reference study. For overproduction, with the linear and trapezoidal membership function achieved reductions of 61% and 75.8%, respectively. These findings demonstrate the effectiveness of incorporating appropriate membership functions in FMOLP and highlight the advantages of the trapezoidal approach for improving production planning in the apparel industry.

Keywords: Fuzzy Multi-Objective Linear Programming, Membership Functions, Overproduction, Pay-off Matrix, Apparel Industry

1. Introduction

Production planning is a critical function in the apparel industry because manufacturers must efficiently utilize limited resources while satisfying customer demand and remaining competitive in a rapidly changing market. The industry operates under dynamic conditions characterized by seasonal demand fluctuations, evolving fashion trends, variability in raw material availability, and labor constraints. These uncertainties complicate production planning and may lead to excessive inventory, unnecessary production, delayed order fulfilment, and increased operating costs. Consequently, optimization-based decision support tools have become increasingly important for improving production efficiency and overall organizational performance [1,2].

Among the available optimization techniques, linear programming (LP) has been widely adopted for production planning and resource allocation problems due to its ability to identify optimal production plans while satisfying resource limitations[3]. Nevertheless, conventional LP models rely on the assumption that all input parameters, including demand, resource availability, and production costs, are known with certainty. In practice, this assumption is rarely satisfied because manufacturing environments are affected by uncertainty and imprecise information, reducing the applicability of deterministic optimization models.

To overcome this limitation, fuzzy linear programming (FLP) incorporates fuzzy set theory into the optimization process, enabling uncertain or imprecise parameters to be represented more realistically [7–10]. Instead of requiring exact numerical values, FLP allows decision variables and model parameters to reflect the uncertainty that commonly exists in industrial production systems. As a result, fuzzy optimization models often provide solutions that are more practical and flexible than those generated by traditional deterministic approaches.

Production planning decisions are also inherently multi objective, requiring manufacturers to balance competing goals such as maximizing profit while simultaneously reducing production costs, labor utilization, and unnecessary production. Multi objective fuzzy linear programming (MOFLP) offers an effective framework for addressing these conflicting objectives under uncertain conditions. Previous studies have demonstrated the usefulness of MOFLP in supporting production planning and resource allocation across various manufacturing applications, including the apparel industry [11].

Despite these developments, limited attention has been given to the influence of different fuzzy membership functions on MOFLP solutions for apparel production planning. Since the choice of membership function directly affects the representation of uncertainty and the resulting optimal solutions, evaluating their performance is important for developing reliable decision support models.

This study addresses this gap by comparing linear and trapezoidal membership functions within a multi-objective fuzzy linear programming framework for apparel production planning. Using an apparel manufacturing case study, the proposed model simultaneously maximizes profit while minimizing labour cost and unnecessary production. The findings provide insights into how the choice of membership function influences optimization results and offer practical guidance for selecting appropriate fuzzy representations when solving production planning problems under uncertainty.

2. Materials and Methods

2.1 Method

The overall workflow of the Multi-Objective Fuzzy Linear Programming (MOFLP) approach is illustrated in Fig.1. The process begins by solving each linear programming (LP) model independently to obtain the optimal solution for each objective function. These individual optimal values are then used to construct the payoff matrix, which provides the best and worst objective values and forms the basis for conflict analysis among the objectives.

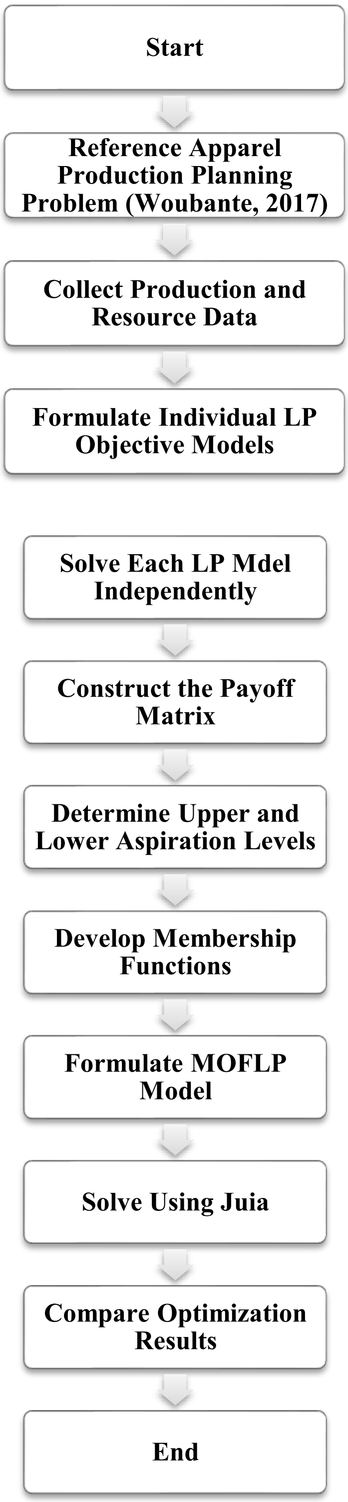

Fig. 1: Flowchart illustrating the methodology of the Multi-Objective Fuzzy Linear Programming (MOFLP) approach, including independent solution of LP models, construction of the payoff matrix, determination of aspiration levels, development of membership functions, formulation of the MOFLP model, solution using Julia, and comparison of the optimization results.

Using the payoff matrix, the upper and lower aspiration levels for each objective are determined. These aspiration levels are subsequently employed to develop the corresponding membership functions, which quantify the degree of satisfaction associated with each objective. The membership functions are then incorporated into the formulation of the MOFLP model, transforming the multi-objective optimization problem into a single fuzzy optimization framework. The resulting MOFLP model is solved using the Julia programming language, which efficiently computes the optimal compromise solution. Finally, the optimization results obtained from the MOFLP model are compared with those from the individual LP models to evaluate the effectiveness of the proposed fuzzy optimization approach and to identify the most balanced solution.

2.2 Algorithm for Solving MOFLP

The steps for solving the Multi Objective Fuzzy Linear Programming (MOFLP) problem are as follows:

Step 1: Solve each developed linear programming (LP) model by considering only one objective at a time.
Step 2: Determine the corresponding values of each objective at the solutions obtained from Step 1.
Step 3: Construct the payoff matrix by determining the lower and upper bounds of each objective function.
Step 4: Formulate the membership function for each objective.
Step 5: Develop the multi objective fuzzy linear programming (MOFLP) model.
Step 6: Determine the solution along with the degree of satisfaction.

2.3 Case Study

In the case study [1], customer demand is provided for the apparel products. In this research overproduction is defined by considering the average defect percentage. The 4% defect rate was adopted from Wijekoon et al. (2021), which reported an average defect rate for apparel manufacturing. This value was used as a representative benchmark to account for the expected proportion of defective products during production. Accordingly, production up to the demand adjusted for the 4% defect rate was considered acceptable, while any output exceeding this adjusted demand was classified as overproduction.

- Average percentage of defects of the product in apparel company = 4% [18]

Table 1
Customer demand and demand with defects.

	Polo T-shirts	Basic T-shirts	Mock neck T-shirts	Singlets	Short pants
Demand	15000	35800	13500	12500	16100
Demand with defects	15600	37232	14040	13000	16744

In the reference study, the model was developed to maximize profit while optimizing the production cost according to linear programming, using the demand of the product. The objective was defined as profit maximization, and the constraints included the amount of threads and fabrics, material cost, overheads, time for cutting, sewing, and finishing, and customer demand. There were decision variables as follows:

x_1 – the number of polo T-shirts
x_2 – the number of basic T-shirts
x_3 – the number of mock neck T-shirts
x_4 – the number of singlets
x_5 – the number of short pants

$$\text{Max } Z = 4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5$$

Subject to

$$\begin{array}{lll}
315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5 & \leq 38665000 & \text{(Fabrics)} \\
230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5 & \leq 26638120 & \text{(Threads)} \\
11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5 & \leq 1009008 & \text{(LaborCost)} \\
30.6x_1 + 19.1x_2 + 20.1x_3 + 37.5x_4 + 20.1x_5 & \leq 4979414 & \text{(Overheads)} \\
1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5 & \leq 346200 & \text{(Cutting)} \\
22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 40.1x_5 & \leq 2670300 & \text{(Sewing)} \\
2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5 & \leq 371700 & \text{(Finishing)} \\
x_1 & \geq 15000 & \\
x_2 & \geq 35800 & \\
x_3 & \geq 13500 & \\
x_4 & \geq 12500 & \\
x_5 & \geq 16100 &
\end{array}$$

Table 2
Results of the reference study

Products	Value
Polo T-shirts	15000
Basic T-shirts	102287.8
Mock neck T-shirts	13500
Singlets	12500
Short pants	16100

By considering the results of the reference study, it was observed that Basic T-shirts are produced unnecessarily compared to actual customer demand. In real world scenarios, some companies sell the surplus products in the local market after fulfilling customer demand. However, certain companies have agreements with customers that prohibit selling the remaining products in the local market. In such cases, the surplus products are treated as waste or are destroyed. Considering this situation, the case study highlights a significant amount of wastage. Therefore, this study aims to reduce such wastage by formulating new Multi Objective Linear Programming (MOLP) models.

2.4 Case I- Minimize Total Number of Production while Maximizing Profit

The minimization model for the total number of production is developed to address the issue identified in the reference study related to excessive production levels. As a result, production related wastage is significantly controlled.

2.4.1 Minimization Model for Total Number of Production

The minimization model for total number of production is formulated as follow:

$$\text{Min } Z_1 = x_1 + x_2 + x_3 + x_4 + x_5$$

Subject to

$$\begin{array}{lll}
315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5 & \leq 38665000 & \text{(Fabrics)} \\
230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5 & \leq 26638120 & \text{(Threads)} \\
11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5 & \leq 1009008 & \text{(LaborCost)} \\
30.6x_1 + 19.1x_2 + 20.1x_3 + 16.5x_4 + 37.5x_5 & \leq 4979414 & \text{(Overheads)} \\
1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5 & \leq 346200 & \text{(Cutting)} \\
22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 20.1x_5 & \leq 2670300 & \text{(Sewing)} \\
2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5 & \leq 371700 & \text{(Finishing)} \\
x_1 & \geq 15000 & \\
x_2 & \geq 35800 & \\
x_3 & \geq 13500 & \\
x_4 & \geq 12500 & \\
x_5 & \geq 16100 &
\end{array}$$

According to the algorithm of FMOLP, the developed model should be solved. It was solved using Julia software.

Table 3
The table of the optimal solution for total number of production model.

Type	Optimal solution
x_1	15000
x_2	35800
x_3	13500
x_4	12500
x_5	16100

2.4.2 Maximization Model for Profit

The maximization model for profit is formulated as follow:

$$\text{Max } Z_2 = 4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5$$

Subject to

$$\begin{array}{lll}
315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5 & \leq 38665000 & \text{(Fabrics)} \\
230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5 & \leq 26638120 & \text{(Threads)} \\
11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5 & \leq 1009008 & \text{(LaborCost)} \\
30.6x_1 + 19.1x_2 + 20.1x_3 + 16.5x_4 + 37.5x_5 & \leq 4979414 & \text{(Overheads)} \\
1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5 & \leq 346200 & \text{(Cutting)} \\
22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 20.1x_5 & \leq 2670300 & \text{(Sewing)} \\
2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5 & \leq 371700 & \text{(Finishing)} \\
x_1 & \geq 15000 & \\
x_2 & \geq 35800 & \\
x_3 & \geq 13500 & \\
x_4 & \geq 12500 & \\
x_5 & \geq 16100 &
\end{array}$$

Table 4
The table of the optimal solution for profit model.

Type	Optimal solution
x_1	15000
x_2	35800
x_3	13500
x_4	12500
x_5	69211

2.4.3 Formulation of MOFLP Model Using Linear Membership Function

As a 2nd step of the algorithm of MOFLP, the values of objective functions should be determined for each optimal solution. Those values are as follows:

Table 5
Objective function values for each optimal solution.

Optimal Solutions	Z_1	Z_2
15000	92900	386626
35800		
13500		
12500		
16100		
15000	146011	745125.3
35800		
13500		
12500		
69211		
Maximum Value	**146011**	**745125.3**
Minimum Value	**92900**	**386626**

3rd step of the algorithm of MOFLP is to be the construction of the pay off matrix using the lower bound and upper bound of each objective. The pay off matrix is as follows:

$$\begin{bmatrix} 146011 & 745125.3 \\ 92900 & 386626 \end{bmatrix}$$

Based on the results obtained, the Multi Objective Fuzzy Linear Programming (MOFLP) model can be formulated by constructing membership functions for each objective.

The linear membership function for the minimization model of total number of production is as follows:

$$\mu_1(Z_1(x)) = \frac{146011 - Z_1(x)}{146011 - 92900}$$

The linear membership function for the maximization model of profit is as follows:

$$\mu_2(Z_2(x)) = \frac{Z_2(x) - 386626}{745125.3 - 386626}$$

Using these linear membership functions, fuzzy constraints are as follows:
For total number of production minimization;

$$\frac{146011 - Z_1(x)}{146011 - 92900} \geq \alpha \quad \Rightarrow \quad Z_1(x) + 53111\,\alpha \leq 146011$$

For profit maximization;

$$\frac{Z_2(x) - 386626}{745125.3 - 386626} \geq \alpha \quad \Rightarrow \quad Z_2(x) - 358499.3\,\alpha \geq 386626$$

According to the proposed algorithm, the MOFLP model is formulated using membership functions for each objective. In this formulation, the parameter α represents the overall degree of satisfaction, indicating the extent to which all objectives are simultaneously satisfied.

Max α
Subject to

$4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5 - 358499.3\alpha$	$\geq$	386626
$x_1 + x_2 + x_3 + x_4 + x_5 + 53111\alpha$	$\leq$	146011
$315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5$	$\leq$	38665000
$230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5$	$\leq$	26638120
$11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5$	$\leq$	1009008
$30.6x_1 + 19.1x_2 + 20.1x_3 + 16.5x_4 + 37.5x_5$	$\leq$	4979414
$1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5$	$\leq$	346200
$22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 20.1x_5$	$\leq$	2670300
$2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5$	$\leq$	371700
x_1	$\geq$	15000
x_2	$\geq$	35800
x_3	$\geq$	13500
x_4	$\geq$	12500
x_5	$\geq$	16100

2.4.4 Formulation of MOFLP Model Using Trapezoidal Membership Function

For the formulation of the trapezoidal membership function, the parameters must be defined to represent the degree of satisfaction. In this case, the parameters are determined using a 30% tolerance, which reflects the acceptable range of variation for each objective.The tolerance represents a percentage of the difference between the upper and lower bounds of an objective.

To evaluate the robustness of the proposed MOFLP model, a sensitivity analysis was conducted by varying the tolerance parameter used in the trapezoidal membership function. The tolerance value determines the width of the full satisfaction region and therefore influences the compromise solution obtained by the optimization model. The analysis was performed using tolerance values of 10%, 20%, 30%, 40%, and 50%, while keeping all other model parameters unchanged.

The results indicate that increasing the tolerance parameter provides greater flexibility in satisfying the conflicting objectives. However, excessively large tolerance values lead to a reduction in profit while only marginally improving overproduction. Among the tested values, a tolerance of 30% provided a balanced compromise between profit, production level, and overproduction, and was therefore adopted in this study.

The trapezoidal membership function for the minimization model of total number of production is as follows:

$$\mu_1(Z_1(x)) = \begin{cases} \dfrac{Z_1(x) - 92900}{108833.3 - 92900} \\ \dfrac{146011 - Z_1(x)}{146011 - 130077.7} \end{cases}$$

The trapezoidal membership function for the maximization model of profit is as follows:

$$\mu_2(Z_2(x)) = \begin{cases} \dfrac{Z_2(x) - 386626}{494175.79 - 386626} \\ \dfrac{745125.3 - Z_2(x)}{745125.3 - 637575.51} \end{cases}$$

Using these trapezoidal membership functions, fuzzy constraints are as follows:

For total number of production minimization;

$$\frac{Z_1(x) - 92900}{108833.3 - 92900} \geq \alpha \quad \Longrightarrow \quad Z_1(x) - 15933.3\,\alpha \geq 92900$$

$$\frac{146011 - Z_1(x)}{146011 - 130077.7} \geq \alpha \quad \Longrightarrow \quad Z_1(x) + 15933.3\,\alpha \leq 146011$$

For profit maximization;

$$\frac{Z_2(x) - 386626}{494175.79 - 386626} \geq \alpha \quad \Longrightarrow \quad Z_2(x) - 107549.79\,\alpha \geq 386626$$

$$\frac{745125.3 - Z_2(x)}{745125.3 - 637575.51} \geq \alpha \Longrightarrow \quad Z_2(x) + 107549.79\,\alpha \leq 745125.3$$

The MOFLP model can be formulated as follows:

Maxα
Subject to

$4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5 - 107549.79\alpha$	$\geq$	386626
$4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5 + 107549.79\alpha$	$\leq$	745125.3
$x_1 + x_2 + x_3 + x_4 + x_5 - 15933.3\alpha$	$\geq$	92900
$x_1 + x_2 + x_3 + x_4 + x_5 + 15933.3\alpha$	$\leq$	146011
$315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5$	$\leq$	38665000
$230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5$	$\leq$	26638120
$11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5$	$\leq$	1009008
$30.6x_1 + 19.1x_2 + 20.1x_3 + 16.5x_4 + 37.5x_5$	$\leq$	4979414
$1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5$	$\leq$	346200
$22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 20.1x_5$	$\leq$	2670300
$2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5$	$\leq$	371700
x_1	$\geq$	15000
x_2	$\geq$	35800
x_3	$\geq$	13500
x_4	$\geq$	12500
x_5	$\geq$	16100

The formulated MOFLP model was solved using Julia software.

2.5 Case II- Minimize Overproduction while Maximizing Profit

In Case II, the study focuses on minimizing overproduction while simultaneously maximizing profit. Overproduction is defined as the excess quantity produced beyond the effective customer demand, where the demand includes allowable defects. Let u_i denote the demand of product i adjusted for defects, and let x_i represent the corresponding production quantity. Overproduction is mathematically formulated as

$$o_i = \max(0, x_i - u_i),$$

which implies that overproduction occurs only when the production quantity exceeds the defect adjusted demand. If $x_i \leq u_i$, no overproduction is generated and $o_i = 0$. However, when $x_i > u_i$, the surplus quantity is considered overproduction and contributes directly to waste or unnecessary inventory. By incorporating this definition into the profit maximization framework, the model implicitly discourages excessive production, ensuring that higher profit levels are achieved through better alignment of production quantities with actual demand. Consequently, this approach supports sustainable production planning by reducing waste while maintaining economic efficiency.

2.5.1 Minimization Model for Overproduction

The minimization model for overproduction is formulated as follow:

Min $z_1 = O_1 + O_2 + O_3 + O_4 + O_5$
Subject to

$$
\begin{array}{lll}
315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5 & \leq & 38665000 \\
230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5 & \leq & 26638120 \\
11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5 & \leq & 1009008 \\
30.6x_1 + 19.1x_2 + 20.1x_3 + 16.5x_4 + 37.5x_5 & \leq & 4979414 \\
1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5 & \leq & 346200 \\
22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 20.1x_5 & \leq & 2670300 \\
2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5 & \leq & 371700 \\
O_1 & \geq & x_1 - 15600 \\
O_2 & \geq & x_2 - 37232 \\
O_3 & \geq & x_3 - 14040 \\
O_4 & \geq & x_4 - 13000 \\
O_5 & \geq & x_5 - 16744 \\
x_1 & \geq & 15000 \\
x_2 & \geq & 35800 \\
x_3 & \geq & 13500 \\
x_4 & \geq & 12500 \\
x_5 & \geq & 16100 \\
O_i & \geq & 0, \quad i = 1,2,3,4,5
\end{array}
$$

Table 6
The table of the optimal solution for overproduction model.

Type	Optimal solution
x_1	15000
x_2	35800
x_3	13500
x_4	12500
x_5	16100

2.5.2 Formulation of MOFLP Model Using Linear Membership Function

Table 7
Objective function values for each optimal solution

Optimal Solutions	Z_1	Z_2
15000	0	386626
35800		
13500		
12500		
16100		
15000	52467	745125.3
35800		
13500		
12500		
69211		
Maximum Value	**52467**	**745125.3**
Minimum Value	**0**	**386626**

The overproduction minimization model and previous profit maximization model were considered to develop the MOFLP model for minimizing the above wastage. 3rd step of the algorithm of MOFLP is to be the construction of the pay off matrix using the lower bound and upper bound of each objective. The pay off matrix is as follows:

$$\begin{bmatrix} 52467 & 745125.3 \\ 0 & 386626 \end{bmatrix}$$

Based on the results obtained, the MOFLP model can be formulated by constructing membership functions for each objective.
The linear membership function for the minimization model of overproduction is as follows:

$$\mu_1(Z_1(x)) = \frac{52467 - Z_1(x)}{52467 - 0}$$

The linear membership function for the maximization model of profit is as follows:

$$\mu_2(Z_2(x)) = \frac{Z_2(x) - 386626}{745125.3 - 386626}$$

Using these linear membership functions, fuzzy constraints are as follows:
For overproduction minimization;

$$\frac{52467 - Z_1(x)}{52467 - 0} \geq \alpha \quad \Longrightarrow \quad Z_1(x) + 52467\,\alpha \leq 52467$$

For profit maximization;

$$\frac{Z_2(x) - 386626}{745125.3 - 386626} \geq \alpha \quad \Longrightarrow \quad Z_2(x) - 358499.3\,\alpha \geq 386626$$

According to the proposed algorithm, the MOFLP model is formulated using membership functions for each objective as follows:

Max α
Subject to

$$
\begin{array}{lll}
4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5 - 358499.3\alpha & \geq & 386626 \\
O_1 + O_2 + O_3 + O_4 + O_5 + 52467\alpha & \leq & 52467 \\
315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5 & \leq & 38665000 \\
230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5 & \leq & 26638120 \\
11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5 & \leq & 1009008 \\
30.6x_1 + 19.1x_2 + 20.1x_3 + 16.5x_4 + 37.5x_5 & \leq & 4979414 \\
1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5 & \leq & 346200 \\
22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 20.1x_5 & \leq & 2670300 \\
2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5 & \leq & 371700 \\
O_1 & \geq & x_1 - 15600 \\
O_2 & \geq & x_2 - 37232 \\
O_3 & \geq & x_3 - 14040 \\
O_4 & \geq & x_4 - 13000 \\
O_5 & \geq & x_5 - 16744 \\
x_1 & \geq & 15000 \\
x_2 & \geq & 35800 \\
x_3 & \geq & 13500 \\
x_4 & \geq & 12500 \\
x_5 & \geq & 16100 \\
O_i & \geq & 0, i = 1,2,3,4,5
\end{array}
$$

2.5.3 Formulation of MOFLP Model Using Trapezoidal Membership Function

For the formulation of the trapezoidal membership function, the parameters must be defined to represent the degree of satisfaction. In this case, the parameters are determined using a 30% tolerance, which reflects the acceptable range of variation for each objective.The tolerance represents a percentage of the difference between the upper and lower bounds of an objective.

The trapezoidal membership function for the minimization model of overproduction is as follows:

$$\mu_1(Z_1(x)) = \begin{cases} \dfrac{Z_1(x) - 0}{15740.1 - 0} \\ \dfrac{52467 - Z_1(x)}{52467 - 36726.9} \end{cases}$$

The trapezoidal membership function for the maximization model of profit is as follows:

$$\mu_2(Z_2(x)) = \begin{cases} \dfrac{Z_2(x) - 386626}{494175.79 - 386626} \\ \dfrac{745125.3 - Z_2(x)}{745125.3 - 637575.51} \end{cases}$$

Using these trapezoidal membership functions, fuzzy constraints are as follows:
For overproduction minimization;

$$\frac{Z_1(x) - 0}{15740.1 - 0} \geq \alpha \quad \Rightarrow \quad Z_1(x) - 15740.1\,\alpha \geq 0$$

$$\frac{52467 - Z_1(x)}{52467 - 36726.9} \geq \alpha \quad \Rightarrow \quad Z_1(x) + 15740.1\,\alpha \leq 52467$$

For profit maximization;

$$\frac{Z_2(x) - 386626}{494175.79 - 386626} \geq \alpha \quad \Rightarrow \quad Z_2(x) - 107549.79\,\alpha \geq 386626$$

$$\frac{745125.3 - Z_2(x)}{745125.3 - 637575.51} \geq \alpha \Rightarrow \quad Z_2(x) + 107549.79\,\alpha \leq 745125.3$$

The MOFLP model can be formulated as follows:

Max α
Subject to

$$\begin{array}{lll}
4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5 - 107549.79\alpha & \geq & 386626 \\
4.22x_1 + 3.62x_2 + 3.43x_3 + 3.10x_4 + 6.75x_5 + 107549.79\alpha & \leq & 745125.3 \\
O_1 + O_2 + O_3 + O_4 + O_5 - 15740.1\alpha & \geq & 0 \\
O_1 + O_2 + O_3 + O_4 + O_5 + 15740.1\alpha & \leq & 52467 \\
315x_1 + 200x_2 + 195x_3 + 180x_4 + 280x_5 & \leq & 38665000 \\
230x_1 + 110x_2 + 140x_3 + 100x_4 + 200x_5 & \leq & 26638120 \\
11.6x_1 + 5x_2 + 6.3x_3 + 4.15x_4 + 7.5x_5 & \leq & 1009008 \\
30.6x_1 + 19.1x_2 + 20.1x_3 + 16.5x_4 + 37.5x_5 & \leq & 4979414 \\
1.8x_1 + 1.1x_2 + 1.7x_3 + 1.1x_4 + 2.6x_5 & \leq & 346200 \\
22.7x_1 + 5.4x_2 + 10.4x_3 + 4.5x_4 + 20.1x_5 & \leq & 2670300 \\
2x_1 + 1.3x_2 + 1.9x_3 + 1.3x_4 + 2.6x_5 & \leq & 371700 \\
O_1 & \geq & x_1 - 15600 \\
O_2 & \geq & x_2 - 37232 \\
O_3 & \geq & x_3 - 14040 \\
O_4 & \geq & x_4 - 13000 \\
O_5 & \geq & x_5 - 16744 \\
x_1 & \geq & 15000 \\
x_2 & \geq & 35800 \\
x_3 & \geq & 13500 \\
x_4 & \geq & 12500 \\
x_5 & \geq & 16100 \\
O_i & \geq & 0, \quad i = 1,2,3,4,5
\end{array}$$

3. Results and Discussion

3.1 Case I

The proposed MOFLP model was solved using both linear and trapezoidal membership functions. The optimal production quantities obtained under each approach are presented in Table 8 and 9. Both membership functions generated feasible production plans while satisfying all resource constraints. Compared with the reference LP model, the proposed models reduced the total production quantity, indicating that incorporating production minimization as an additional objective effectively controls unnecessary manufacturing.

Table 8:
The table of the optimal solution for MOFLP model using linear MF.

Type	Optimal solution
x_1	15000
x_2	35800
x_3	13500
x_4	12500
x_5	42709
α	0.499

Table 9
The table of the optimal solution for MOFLP model using trapezoidal MF.

Type	Optimal solution
x_1	15000
x_2	35800
x_3	13500
x_4	12500
x_5	26350
α	0.64

3.1.1 Comparison of Results of Reference Study, MOFLP Model with Linear MF and MOFLP Model with Trapezoidal MF

Table 10
Comparison of production quantities between reference study and MOFLP solutions.

Product	Reference study	Results of MOFLP		Percentage change	
		Linear	Trapezoidal	Linear	Trapezoidal
Polo T-shirts	15,000	15,000	15,000	–	–
Basic T-shirts	102,287.8	35,800	35,800	65% ↓	65% ↓
Mock neck T-shirt	13,500	13,500	13,500	–	–
Singlets	12,500	12,500	12,500	–	–
Short pants	16,100	42,709	26,350	62.3 % ↑	39% ↑
Total production	159,387.8	119,509	103,150	25% ↓	35.2% ↓

The results show that the Reference Study proposed a production plan with inefficient resource allocation, leading to potential waste. This is especially evident for Basic T-shirts, where the initial target of 102,288 units was much higher than needed. The FMOLP models address this by reducing production to 35,800 units, a 65% decrease that better matches actual demand. This reduction allows for a more balanced increase in Short Pants production. Overall, the FMOLP approaches lower total production, with a 25% reduction using the linear membership function and a 35.2% reduction using the trapezoidal membership function, resulting in a more efficient and economically viable plan compared to the original study.

According to the above results, a comparison can be made in terms of profit, labor cost, and other available resources.

Table 11
Comparison of Reference Study and FMOLP Results with Percentage Decrease.

Item	Reference Study	Results of FMOLP		Percentage Decrease	
		Linear	Trapezoidal	Linear	Trapezoidal
Profit	777,877.3	566,236.75	455,813.12	27.2%	41.0%
Labor Cost	1,009,008	810,242.5	687,550.0	19.7%	31.8%
Overheads	3,494,046.98	3,221,967.5	2,608,505.0	7.8%	25.3%
Fabrics	34,573,064	28,726,020	24,145,500	16.9%	30.1%
Threads	21,061,660	19,069,800	15,798,000	9.4%	25.0%
Cutting	218,076.2	214,123.4	171,590	1.8%	21.6%
Sewing	1,423,343	1,588,920.9	1,260,105	-10.4%	11.4%
Finishing	246,734.2	229,483.4	186,950	7.0%	24.2%

3.2. Case II

One of the primary objectives of this study is to minimize unnecessary production while maintaining satisfactory profitability. Therefore, the overproduction quantities obtained from the proposed linear and trapezoidal membership function models were compared with those of the reference LP model. This comparison highlights the effectiveness of each membership function in controlling excess production.

Table 12
The table of the optimal solution for MOFLP model using linear MF.

Type	Optimal solution
x_1	15600
x_2	37232
x_3	14040
x_4	13500
x_5	41999
α	0.52

Table 13
The table of the optimal solution for MOFLP model using trapezoidal MF.

Type	Optimal solution
x_1	31293
x_2	37232
x_3	14040
x_4	13000
x_5	16744
α	0.75

3.2.1 Comparison of Results of Reference Study, MOFLP Model with Linear MF and MOFLP Model with Trapezoidal MF

The results indicate that the Reference Study generally produced quantities higher than actual demand, leading to potential overproduction. For example, Basic T-shirts were produced at 102,288 units, whereas both FMOLP models reduced this to 37,232 units, a 63.6% decrease. Polo T-shirts, Mock neck T-shirts, and Singlets showed small increases under FMOLP Linear and more significant increases under FMOLP Trapezoidal. Short Pants production was drastically reduced in the Trapezoidal model compared to the Reference Study. Overall, total overproduction decreased from 65,056 units in the Reference Study to 25,255 units (Linear) and 15,693 units (Trapezoidal), representing reductions of 61.1% and 75.8%, respectively, demonstrating the effectiveness of FMOLP in aligning production with realistic demand.

According to the above results, a comparison can be made in terms of profit, labor cost, and other available resources.

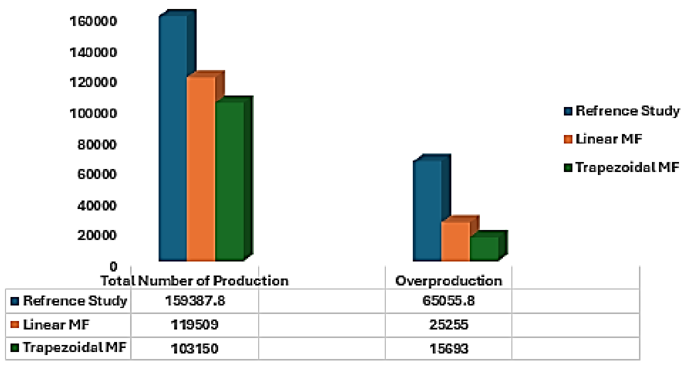

Fig. 2: Results of reference study, linear membership function and trapezoidal membership function

Table 14
Comparison of production quantities between reference study and MOFLP solutions.

Product	Reference study	Results of MOFLP		Percentage change	
		Linear	Trapezoidal	Linear	Trapezoidal
Polo T-shirts	15,000	15,600	31,293	4% ↑	52% ↑
Basic T-shirts	102,287.8	37,232	37,232	63.6% ↓	63.6% ↓
Mock neck T-shirt	13,500	14,040	14,040	4% ↑	4% ↑
Singlets	12,500	13,000	13,000	4% ↑	4% ↑
Short pants	16,100	41,999	16,744	62% ↑	4% ↑
Overproduction	65,055.8	25,255	15,693	61.1% ↓	75.8% ↓

Table 15
Comparison of Reference Study and FMOLP Results with Percentage Decrease.

Item	Reference Study	Results of FMOLP		Percentage Change	
		Linear	Trapezoidal	Linear	Trapezoidal
Profit	777,877.3	572,562.29	468,315.5	26.3%	39.7%
Labor Cost	1,009,008	824,514.5	817,140.8	18.3%	19.0%
Overheads	3,494,046.98	3,260,157.7	2,793,301	6.7%	20.1%
Fabrics	34,573,064	29,197,920	27,069,815	15.5%	21.7%
Threads	21,061,660	19,348,920	17,907,310	8.1%	14.9%
Cutting	218,076.2	216,400.6	178,985	0.76%	17.9%
Sewing	1,423,343	1,603,868.7	1,452,474.3	-12.7%	-2.1%
Finishing	246,734.2	232,375	198,098	5.8%	19.7%

3.3 Results of Reference Study, Linear Membership Function and Trapezoidal Membership Function

The comparison between the reference study and the MOFLP models shows that using fuzzy membership functions improves the production plan. In the reference study, the total production is 159,387.8 units, which results in a high overproduction of 65,055.8 units. This indicates inefficient use of resources.

When the linear membership function is used, total production decreases to 119,509 units and overproduction is reduced to 25,255 units. The trapezoidal membership function further improves the results by reducing total production to 103,150 units and minimizing overproduction to 15,693 units.

These outcomes confirm that the MOFLP framework effectively controls excessive production while better aligning output with demand, with the trapezoidal membership function yielding the most efficient solution among the considered approaches.

4. Conclusion

This study proposed a multi-objective fuzzy linear programming (MOFLP) model for apparel production planning and compared the performance of linear and trapezoidal membership functions under uncertain production conditions. The proposed approach simultaneously maximized profit while minimizing unnecessary production and labor cost, thereby providing a more balanced production planning strategy than the reference linear programming model.

The results demonstrate that both membership functions effectively reduced unnecessary production and improved resource utilization. Compared with the reference model, the linear membership function reduced total production by approximately 25% and overproduction by 61%, while the trapezoidal membership function achieved larger reductions of approximately 35% and 76%, respectively. These improvements indicate that incorporating fuzzy membership functions enables production plans that are better aligned with actual demand and more effective in reducing excess production. However, these reductions were accompanied by a decrease in profit, highlighting the trade-off between economic performance and production efficiency. The linear membership function provided a better balance between profitability and production reduction, whereas the trapezoidal membership function was more effective in minimizing overproduction and resource waste.

Overall, the findings demonstrate that MOFLP provides a practical decision-support framework for apparel production planning under uncertainty. The comparative analysis further shows that the choice of membership function has a significant influence on optimization outcomes, emphasizing the importance of selecting an appropriate fuzzy representation based on the decision maker's priorities.

This study is limited to a single apparel manufacturing case study, and therefore the findings may not be directly generalizable to all production environments. Future research should validate the proposed framework using multiple industrial case studies, investigate alternative fuzzy membership functions and optimization techniques such as Goal Programming, and perform more comprehensive sensitivity analyses to further evaluate the robustness of the proposed model.

Competing Interests

The authors have no competing interests to declare

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