A Study of Probabilistic Multi-Objective Linear Fractional Programming Problems Under Fuzziness

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Received 26 July 2019; Revised 29 December 2019; Accepted 15 January 2020; Published online 31 March 2020
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ABSTRACT
This paper investigates a multi-objective linear fractional programming problem that involves probabilistic parameters on the right-hand side of constraints. Probabilistic parameters are randomly distributed with known means and variances through Uniform and Exponential Distributions. After converting the probabilistic problem into an equivalent deterministic problem, a fuzzy programming approach is applied by defining a membership function. A linear membership function is used for obtaining an optimal compromise solution. The stability set of the first kind without differentiability corresponding to the obtained optimal compromise solution is determined. A solution procedure for obtaining an optimal compromise solution and the stability set of the first kind is presented. Finally, a numerical example is given to clarify the practicality and efficiency of the study.

KEYWORDS: Multi-objective linear fractional programming; Uniform distribution; Exponential distribution; Linear membership function; Fuzzy programming; optimal compromise solution; parametric study.

1. Introduction
Fractional problem (FP) is a decision problem that aims to optimize a ratio subject to constraints. In real-world decision cases, a decision-maker (DM) may sometimes need to evaluate the ratio among inventory and sales, actual cost and standard cost, output, etc. while both denominator and numerator are linear. If only one ratio is considered as an objective function, then a problem is said to be a linear fractional programming (LFP) problem under linear constraints. The fractional programming problem, i.e., the maximization of a fraction of two functions subject to given conditions, arises in various decision-making situations; for instance, fractional programming is applied to the fields of traffic planning (Dantzig et al. [11]), network flows (Arisawa and Elmaghraby [5]), and game theory (Isbell and Marlow [17]). In this respect, a review of different applications was given by Schaible [36-37]. Ammar and Khalifa [4] studied the LFP problem with fuzzy parameters. Ammar and Khalifa [3] introduced a parametric approach to solve the multi-criteria linear fractional programming problem. Tantawy [40-41] introduced two approaches to solve the LFP problem: a feasible direction approach and a duality approach. Odior [28] introduced an algebraic approach based on the duality concept and the partial fractions to solve the LFP problem. Pandey and Punnen [31] introduced a procedure based on the Simplex method, developed by Dantzig [11], to solve the LFP problem. Gupta and Chakraborty [14] solved the LFP problem based on the sign in the numerator under the assumption that the denominator is non-vanishing in a feasible region using the fuzzy programming approach. Chakraborty [8] studied a nonlinear fractional programming problem with multiple constraints under a fuzzy environment. Stanojevic and Stancu-Minasian [39] proposed a method for solving a fully fuzzified LFP problem. Buckley and Feuring [7] studied the fully fuzzified linear
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The fuzzy nature of a goal-programming problem was first discussed by Zimmermann [44], followed by Narasimhan [25] and Hanan [16]. Using the main operator and linear and special membership functions, Leberling [21] showed that compromise solutions could always be derived from the original multi-criteria problem. Khalifa [20] studied a linear fractional programming problem with inexact rough intervals in the parameters. Nasseri and Bavandi [26] studied the fuzzy stochastic linear fractional programming in which the coefficients and scalars in the objective function were triangular fuzzy numbers and technological coefficients and the quantities on the right-hand side of the constraints were fuzzy random variables with specific distributions. Ren et al. [33] developed a multi-objective stochastic fractional goal programming for the optimal allocation of water resources based on analysis of water resources quantity, quality, and uncertainty. Acharya et al. [1] proposed a solution methodology for the multi-objective probabilistic fractional programming, where parameters on the right-hand side of constraints follow Cauchy distribution.

The remainder of the paper is organized as follows: In section 2, a probabilistic multi-objective linear fractional programming problem is introduced with specific definitions and properties. In Section 3, a fuzzy programming approach to solving the problem is given. The stability set of the first kind without differentiability is determined in Section 4. In Section 5, a solution procedure for obtaining an optimal compromise solution and the stability set of the first kind corresponding to the resulted
solution is presented. In Section 6, an illustrative numerical example is given to clarify the obtained results. Finally, some concluding remarks are reported in Section 7.

2. Problem Statement and Solution Concepts

In chance-constrained programming, a stochastic multi-objective linear fractional programming problem can be stated as follows:

\[
\max F^k(x) = N^k(x) = \frac{\sum_{j=1}^{n} p_j^k x_j + p_0^k}{\sum_{j=1}^{n} q_j^k x_j + q_0^k}, \quad k = 1, 2, \ldots, K
\]  \hspace{1cm} (1)

subject to:

\[
\text{prob} \left[ \sum_{j=1}^{n} a_{ij} x_j \leq b_i \right] \geq 1 - \alpha_i, \quad i = 1, 2, \ldots, m
\]  \hspace{1cm} (2)

\[
x_j \geq 0, \quad j = 1, 2, \ldots, n
\]  \hspace{1cm} (3)

where \( F^k(x) = \{ F^1(x), F^2(x), \ldots, F^K(x) \} \) is a vector of \( K \) objectives, and the subscript on \( F^k(x) \) represents the number of objectives

\[
g(b_i) = \begin{cases} 
\frac{1}{\beta_i - \gamma_i}, & \gamma_i < b_i < \beta_i, \quad i = 1, 2, \ldots, m \\
0, & \text{otherwise}
\end{cases}
\]  \hspace{1cm} (4)

where \( \mu = \frac{\beta_i + \gamma_i}{2} \) and \( \sigma^2 = \frac{\beta_i^2 - \gamma_i^2}{12} \). It follows that the Constraints (2) become

\[
\int_{x_j} \frac{1}{\beta_i - \gamma_i} db_i \geq 1 - \alpha_i = \left[ \frac{b_i}{\beta_i - \gamma_i} \right]_{\sum_{j=1}^{n} a_{ij} x_j}^{\beta_i} \geq 1 - \alpha_i
\]

Or

\[
\frac{\beta_i - \sum_{j=1}^{n} a_{ij} x_j}{\beta_i - \gamma_i} \geq 1 - \alpha_i \quad \text{or} \quad \sum_{j=1}^{n} a_{ij} x_j \leq c_i, \quad i = 1, 2, \ldots, n
\]  \hspace{1cm} (5)

where \( c_i = \gamma_i + \alpha_i (\beta_i - \gamma_i), \quad i = 1, 2, \ldots, m \).

Therefore, the probabilistic MOLFP problems (1)-(3) become

\[
\text{(a) Uniform Distribution,}
\]

\[
\text{(b) Exponential Distribution.}
\]

(i) When \( b_i \)'s are uniformly distributed continuous random variables, let \( b_i \)'s be uniform random variables. Then,
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\[
(P_1) \quad \text{max} \quad F^k(x) = \frac{N^k(x)}{Q^k(x)} = \frac{\sum_{j=1}^{n} p_j^k x_j + p_0^k}{\sum_{j=1}^{n} q_j^k x_j + q_0^k}, k = 1, 2, \ldots, K
\]

Subject to

\[
\sum_{j=1}^{n} a_{ij} x_j \leq c_i, i = 1, 2, \ldots, m,
\]

\[
x_j \geq 0, \quad j = 1, 2, \ldots, n.
\]

**Definition 1.** (Nondominated solution). A feasible solution \( x^* \in G \) \((G \) is a feasible domain) is said to be the nondominated solution of \( P_1 \) if and only if there is no other feasible solution \( x \in G \) such that

\[
\left( \sum_{j=1}^{n} p_j^k x_j + p_0^k \right) \leq \left( \sum_{j=1}^{n} p_j^k x_j + p_0^k \right), \quad \text{for all } k \text{'s and } k, k = 1, 2, \ldots, K.
\]

**Definition 2.** (Compromise solution). A feasible solution \( x^* \in G \) is said to be a compromise solution of \( P_1 \) if and only if \( x^* \in H \) and \( F(x^*) \geq \bigvee_{x \in G} F(x) \), where \( \bigvee \) and \( H \) represent maximum and a set of efficient solutions, respectively.

(ii) When \( b_i \)'s are exponential random variables, let \( b_i \)'s be exponential random variables.

Then, we get

\[
f(b_i) = \begin{cases} 
\lambda_i \, e^{(-\lambda_i b_i)}, & i = 1, 2, \ldots, m \\
0, & \text{otherwise}
\end{cases}
\]

(6)

where \( \mu = \frac{1}{\lambda_i} \) and \( \sigma^2 = \frac{1}{\lambda_i^2}. \) It follows that

Constraints (2) become

\[
\int \lambda_i e^{(-\lambda_i b_i)} \, dh_i \geq 1 - \alpha_i = e^{(-\sum_{j=1}^{n} s_{ij})} \geq 1 - \alpha_i, \quad i = 1, 2, \ldots, m
\]

\[
\sum_{j=1}^{n} s_{ij} x_j
\]

(7)

It is obvious that (7) can be rewritten as follows:

\[
\sum_{j=1}^{n} a_{ij} x_j \leq d_i, \quad i = 1, 2, \ldots, m.
\]

\[\text{where } d_i = -\frac{\ln(1 - \alpha_i)}{\lambda_i}, i = 1, 2, \ldots, m.\]

Thus, the probabilistic problems (1)-(3) are converted into the following deterministic problem:

\[
(P_2) \quad \text{max} \quad \frac{N(x)}{Q(x)} = \frac{\sum_{j=1}^{n} p_j^k x_j + p_0^k}{\sum_{j=1}^{n} q_j^k x_j + q_0^k}, k = 1, 2, \ldots, K
\]

Subject to

\[
\sum_{j=1}^{n} a_{ij} x_j \leq d_i, \quad i = 1, 2, \ldots, m
\]

\[
x_j \geq 0, \quad j = 1, 2, \ldots, n.
\]

Let the MOLFP problem of the type be

\[
\text{max} \quad \{F_1(x), F_2(x), \ldots, F_k(x)\}
\]

(8)

Subject to

\[
x \in \Omega = \left\{ x \in R^n : Ax \leq b, x \geq 0 \right\}
\]

(9)

It is clear that Problems (8)-(9) are equivalent to the following multi-objective linear programming:

\[\text{(MOLP) problem (Schaible [34])}\]
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\[ \max \{ t N_1(y/t), t N_2(y/t), \ldots, t N_k(y/t) \} \]

Subject to

\[ tQ_k(y/t) \leq 1, k = 1, 2, \ldots, K; A(y/t) - b \leq 0, t > 0, y \geq 0. \]  \hfill (10)

3. Fuzzy Programming Approach for Solving MOLFP Problem

Bellman and Zadeh [6] introduced three basic concepts: fuzzy goal (\(G\)), fuzzy constraints (\(C\)), and fuzzy decision (\(D\)) and explored the application of these concepts to decision-making processes under fuzziness.

The fuzzy decision is a fuzzy set and is defined as follows:

\[ D = G \cap C. \]  \hfill (11)

The fuzzy decision is characterized by its membership function:

\[ \mu_D(x) = \min(\mu_G(x), \mu_C(x)). \]  \hfill (12)

The Membership function of each objective function can be constructed as follows:

\[
\mu_k(tN_k(y/t)) = \begin{cases} 
0, & t N_k(y/t) \leq F_k^- \\
\frac{tN_k(y/t) - F_k^r}{F_k^r - F_k}, & F_k^r < N_k(y/t) < F_k \\
1, & t N_k(y/t) \geq F_k 
\end{cases}
\]  \hfill (13)

Where

\[ F_k^r = \max \left\{ \frac{p_j^k}{q_j}, \frac{p_0^k}{q_0^k}, j = 1, 2, \ldots, n; k = 1, 2, \ldots, K \right\} \]  \hfill (14)

and

\[
G(y/t) = \begin{cases} 
\mu_k(t N_k^k(y/t)) \geq v, & t Q_k^k(y/t) \leq 1, k = 1, 2, \ldots, K; \\
g_r(y/t) - v_r \leq 0, & r = 1, 2, 3, \ldots, m; t > 0, y \geq 0, v \geq 0.
\end{cases}
\]  \hfill (18)

Let \( F(v^*) \) be a subset of efficient solutions to the problem (p3) corresponding to \( v^* \in R^m \).

Based on Zadeh's min operator [43], the fuzzy problem (10) is reduced to the following ordinary model as follows:

\[ \max v \]

Subject to

\[ \mu_k(t N_k^k(y/t)) \geq v, t Q_k^k(y/t) \leq 1, k = 1, 2, \ldots, K, \\
A(y/t) - b \leq 0, t > 0, y, v \geq 0. \]  \hfill (16)

4. Determination of The Stability Set of The First Kind Without Differentiability

In this section, the stability set of the first kind corresponding to the obtained optimal compromise solution \( x^* \) of the deterministic MOLFP problem is obtained under the effect of the probability distributions on the probabilistic MOLFP problem. Let us consider the deterministic MOLFP problem below (p3)

\[ \max F^k(x) = N^k(x) = \sum_{j=1}^{n} p_j^k x_j + p_0^k \\
\min Q^k(x) = \sum_{j=1}^{n} q_j^k x_j + q_0^k \]

Subject to

\[ x \in X(v) = \{ x \in R^n : g_r(x) \leq v_r, r = 1, 2, 3, \ldots, m \} \]

The above problem (p3) can be rewritten according to Problem (16) as follows:

\[ \max v \]

Subject to

\[
\mu_k(t N_k^k(y/t)) \geq v, t Q_k^k(y/t) \leq 1, k = 1, 2, \ldots, K; \\
g_r(y/t) - v_r \leq 0, r = 1, 2, 3, \ldots, m; t > 0, y \geq 0, v \geq 0.
\]  \hfill (18)

\[ F_k^r = \min \left\{ \frac{p_j^k}{q_j}, \frac{p_0^k}{q_0^k}, j = 1, 2, \ldots, n; k = 1, 2, \ldots, K \right\}. \]  \hfill (15)

Definition3. (Osman [29]). The stability set of the first kind of problem (p3) corresponding to
$F(v^*)$, as denoted by $S(F(v^*))$, is defined as follows:
$$S(F(v^*)) = \{ v \in R^m : F(v^*) \subseteq F(v) \},$$
where $F(v)$ is the set of all efficient solutions to the problem (p) corresponding to $v \in R^m$.

It is known that $x^*$ is an efficient solution to the problem (p) if $v^*$ exists such that $(y^*, t^*)$ is the unique optimal solution to Problem (18) corresponding to $v^* \in R^m$.

Let $(y^*, t^*)$ be a unique optimal solution to Problem (18) corresponding to $v^* \in R^m$. The Kuhn-Tucker Saddle point conditions of Problem (18) can be formulated as follows:

$$\psi(y, t, u, w, \beta, v) = v + \sum_{r=1}^{m} u_r (g_r(x) - v_r) + \sum_{k=1}^{K} w_k (t^* N^k(y/t) + v) + \sum_{k=1}^{K} \beta_k (Q^k(y/t) - 1),$$

$$\mu_k(t^* N^k(y^*/t^*)) \geq 0, \quad k = 1, 2, \ldots, K,$n$$
$$t Q^k(y^*/t^*) \leq 1, \quad k = 1, 2, \ldots, K,$n$$
$$g_r(y^*/t^*) - v_r \leq 0, \quad r = 1, 2, 3, \ldots, m,$n$$
$$u_r^*(g_r(y^*/t^*) - v_r) = 0, \quad r = 1, 2, \ldots, m,$n$$
$$w_k^*(- \mu_k(t^* N^k(y^*/t^*)) + v) = 0, \quad k = 1, 2, \ldots, K,$n$$
$$\beta_k^* (Q^k(y^*/t^*) - 1) = 0, \quad k = 1, 2, \ldots, K,$n$$

To determine $S((y/t)^*)$, let us apply the following condition:

$$u_r^*(g_r(y^*/t^*) - v_r) = 0, \quad r = 1, 2, \ldots, m,$n$$
$$w_k^*(- \mu_k(t^* N^k(y^*/t^*)) + v) = 0, \quad k = 1, 2, \ldots, K,$n$$
$$\beta_k^* (Q^k(y^*/t^*) - 1) = 0, \quad k = 1, 2, \ldots, K,$n$$

Considering the following three cases:
is given by \( y^* / t^* \) \( \beta_k \) \( \beta_k^* \) \( 0, k \notin J \).

Let \( M \) be all proper subsets of \([1,2,...,m]\) and \([1,2,...,K]\). Then, the stability set of the first kind corresponding to the subsets \( I \) and \( J \) is given by

\[
S_{1,J}(y^* / t^*)' = \left\{ \begin{array}{l}
v \in \mathbb{R}^m : g_r((y^* / t^*)') = v, r \in I, \mu_k(t^* N^k(y^* / t^*)) \geq v, k \in J, t^* Q^k(y^* / t^*) \leq 1, k \in K \\
\end{array} \right\}
\]

Then,

\[
S_{1}(y^* / t^*)' = \bigcup_{J \in M} S_{1,J}(y^* / t^*)'
\]

(ii) \( u_r^* > 0, r \in I = [1,2,...,m], w_k^*, \beta_k^* > 0, k \in J = [1,2,...,K], w_k^* = \beta_k^* = 0, k \notin J \).

Then,

\[
S_{2}(y^* / t^*)' = \left\{ \begin{array}{l}
v \in \mathbb{R}^m : g_r((y^* / t^*)') \leq v, r \in I, \mu_k(t^* N^k(y^* / t^*)) \geq v, \\
\end{array} \right\}
\]

(iii) \( u_r^* > 0, r \in I = [1,2,...,m], w_k^*, \beta_k^* > 0, k \in J = [1,2,...,K], w_k^* = \beta_k^* = 0, k \notin J \).

Then,

\[
S_{3}(y^* / t^*)' = \left\{ \begin{array}{l}
v \in \mathbb{R}^m : g_r((y^* / t^*)') = v, r \in I, \mu_k(t^* N^k(y^* / t^*)) \geq v, \\
\end{array} \right\}
\]

Hence,

\[
S(F(y^*)) = \bigcap_{i=L} S_i(y^* / t^*)'
\]

The stability set of the first kind \( S(F(y^*)) \) is determined as follows:

\[
S(F(y^*)) = \bigcap_{i=L} S_i(y^* / t^*)'
\]

5. Solution Method

In this section, a methodology for the probabilistic MOLFP problem through the fuzzy programming approach is presented as in the following steps:

**Step 1:** Convert a given probabilistic MOLFP problem into the corresponding deterministic MOLFP problem based on the chance-constrained programming technique, illustrated above.

**Step 2:** From the obtained deterministic MOLFP problem, determine \( F_k \) and \( F_k^* \) as defined in (14) and (15), respectively.

**Step 3:** Using a membership function defined as in (13), find a corresponding fuzzy linear programming, which is discussed as in (16).

**Step 4:** Solve Problem (16) using any computer package to obtain an optimal compromise solution that is an efficient solution to the deterministic MOLFP problem.

**Step 5:** Determine the stability set of the first kind corresponding to the optimal compromise solution obtained in Step 4.

6. Numerical Example

(i) When \( b_i \)'s are uniformly distributed continuous random variables

\[
\max F(x) = \left[ F^1(x) = \frac{5x_1 + 3x_2}{5x_1 + 2x_2 + 1}, F^2(x) = \frac{7x_1 + x_2}{x_1 + 9x_2 + 1} \right]
\]

Subject to

\[
\begin{align*}
3x_1 + 5x_2 & \leq 7.6 \\
5x_1 + 2x_2 & \leq 7.2 \\
x_j & \geq 0, j = 1, 2.
\end{align*}
\]

where \( E(b_1) = 6, V(b_1) = 4, \alpha_1 = 0.95 \), and \( \alpha_2 = 0.8 \).
From Step 1, the following deterministic MOLFP problem is obtained:

\[
\max F(x) = \begin{bmatrix} F^1(x) = \frac{5x_1 + 3x_2}{5x_1 + 2x_2 + 1}, F^2(x) = \frac{7x_1 + x_2}{x_1 + 9x_2 + 1} \end{bmatrix}
\]

Subject to

\[
3x_1 + 5x_2 \leq 0.76, \quad 5x_1 + 2x_2 \leq 0.72, \quad x_1, x_2 \geq 0.
\]

It is clear that \( F^1 = \frac{3}{2} F^2 \) and \( F^- = F^+ = 0 \).

The membership functions of both \( F^1(x) \) and \( F^2(x) \) are as follows:

\[
\mu_i(F^1(y)) = \frac{(5y_1 - 3y_2)}{1.5}, \quad \mu_2(F^2(y)) = \frac{(7y_1 - y_2)}{1.5}. \text{ Now, by means of the membership functions, the following crisp model is obtained:}
\]

\[
\max v \quad \text{Subject to}
\]

\[
10y_1 + 6y_2 - 3v \geq 0, \quad 7y_1 + y_2 - 7v \geq 0, \quad 0.5y_1 + 2y_2 + t \leq 1,
\]

\[
y_1 + 9y_2 + t \leq 1, \quad 3y_1 + 5y_2 - 0.76 \leq 0, \quad 5y_1 + 2y_2 - 0.72 \leq 0,
\]

\[
y_1, y_2, t, v \geq 0.
\]

The solution of the above model is given below:

\[
v = 0.144, \quad y_1 = 0.144, \quad y_2 = 0, \quad t = 01.
\]

For the original problem, the solution is:

\[
x_1 = 1.44, \quad x_2 = 0 \quad F^1 = 0.878, \quad F^2 = 0.9097.
\]

To obtain the stability set of the first kind corresponding to \( F(0.76, 0.72) \), the following system of equations should be solved:

\[
u_1(4.32 - v_1) = 0,
\]

\[
u_2(7.2 - v_2) = 0,
\]

\[
u_3(-1.44 - v_3) = 0,
\]

\[
u_4(0 - v_4) = 0.
\]

We have \( S_{v_0}(1.440) = \{ u \in R^4 : v_r = g_r(1.440), r \in I_u, v_r \geq g_r(1.440), r \in I \} \), where \( I_u \subseteq \{1, 2, 3, 4\} \).

Hence,

\[
S(1.440, 0) = \bigcup_{w=1}^{14} S_{v_0}(1.440, 0) \quad \text{and, thus,}
\]

\[
S(F(v^*)) = \{ v \in R^4 : v_1 \geq 4.32, v_2 \geq 7.2, v_3 \geq 1.44, v_4 \geq 0 \}.
\]

(ii) When \( b_i \)'s are exponential random variables, then

\[
\max F(x) = \begin{bmatrix} F^1(x) = \frac{x_1 - 4}{-2x_2 + 3}, F^2(x) = \frac{-x_1 + 5}{x_2 + 1} \end{bmatrix}
\]

Subject to
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\[
prob[ x_1 + x_2 \leq b_1 ] \geq 0.94, \\
prob[ 4x_1 + 3x_2 \leq b_2 ] \geq 0.93, \\
prob[ 2x_1 + 5x_2 \leq b_3 ] \geq 0.91, \\
x_1, x_2, x_3 \geq 0.
\]

where \( E(b_1) = 7, \ E(b_2) = 9, \ E(b_3) = 8, \ \alpha_1 = 0.06, \ \alpha_2 = 0.07, \) and \( \alpha_2 = 0.09 \)

From Step 1, the following deterministic MOLFP problem is obtained:

\[
\text{max } F(x) = \left[ \frac{x_1 - 4}{2x_2 + 3}, \frac{x_1 + 5}{x_2 + 1} \right] \\
\text{Subject to} \\
x_1 + x_2 \leq 0.433, \\
4x_1 + 3x_2 \leq 0.653, \\
2x_1 + 5x_2 \leq 0.7545, \\
x_1, x_2 \geq 0.
\]

It is obvious that \( \bar{F}^1 = 1, \bar{F}^2 = 5, \) and \( \bar{F}^1 = \frac{-4}{3}, \bar{F}^2 = -1.\)

The membership functions of both \( F^1(x) \) and \( F^2(x) \) are given below:

\[
\mu_1(F^1(y)) = \frac{(y_1 - 4t + 1)}{(1 + 4/3)}, \quad \mu_2(F^2(y)) = \frac{(y_2 + 3t + 1)}{(6 + 1)}
\]

Now, by means of the membership functions, the following crisp model is obtained below:

\[
\text{max } \nu
\]

Subject to

\[
y_1 - 4t - \nu \geq 0, \quad -y_1 + 5t - 5\nu \geq 0, \quad -y_2 + 3t \leq 1, \\
y_2 + t \leq 1, \quad y_1 + y_2 - 0.433t \leq 0, \\
4y_1 + 3y_2 - 0.653t \leq 0, \quad 2y_1 + 5y_2 - 0.7545t \leq 0, \\
y_1, y_2, t, \nu \geq 0.
\]

The solution of the above model is given below:

\[
\nu = 0.83, \quad y_1 = 2.0833, \quad y_2 = 0.5, \quad t = 0.5.
\]

The solution to the original problem is given below:

\[
x_1 = 4.1666, \quad x_2 = 1, \quad F_1 = 0.1666, \quad F_2 = 0.4167.
\]

To get the stability set of the first kind corresponding to \( F(0.94, 0.93, 0.91) \), we get the following system of equations:
\[ u_1(5.1666 - v_1) = 0, \\
u_2(19.6664 - v_2) = 0, \\
u_3(1.3332 - v_3) = 0, \\
u_4(-4.1666 - v_4) = 0, \\
u_5(1 - v_5) = 0, \]

We have
\[ S_{I_w}(4.1666,1) = \left\{ u \in R^5 : v_r = g_r(4.1666,1), r \in I_w, v_r \geq g_r(4.1666,1), r \in I \right\}, \]
where
\[ I_w \subseteq [1, 2, 3, 4, 5]. \]
Hence,
\[ S(4.1666,1) = \bigcup_{w=1}^{32} S_{I_w}(4.1666,1) \text{ and, thus, } \]
\[ S(F(v^*))= \left\{ v \in R^4 : v_1 \geq 5.1666v_2 \geq 19.6664v_3 \geq 1.3332v_4 \geq 4.1666v_5 \geq -1 \right\}. \]

7. Concluding Remarks
In this paper, a multi-objective linear fractional programming problem involving probabilistic parameters on the right-hand side of the constraints was introduced. These probabilistic parameters were randomly distributed with known means and variances through the use of Uniform and Exponential Distributions. Although the probabilistic problem was converted into an equivalent deterministic problem, a fuzzy programming approach was applied by defining a membership function. A linear membership function was applied to obtain an optimal compromise solution. The stability set of the first kind corresponding to the obtained optimal compromise solution was determined. A solution procedure for obtaining an optimal compromise solution and the stability set of the first kind was also presented. An illustrative numerical example was given to clarify the obtained results.

Acknowledgments
The author would like to thank the referees for their suggestively valuable and helpful comments that have led to an improved version of the paper.

Conflicts and Interest
The author declares no conflict of interest.

References
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