Fuzzy linear fractional programming problem using the lexicography method

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Abstract:

Introduction/purpose: In solving real-life fractional programming problems, uncertainty and hesitation are often encountered due to various uncontrollable factors. To overcome these limitations, the fuzzy logic approach is applied to these problems.

Methods: The discussion focused on solving the fuzzy linear fractional programming problem (FLFPP). First, the FLFP problem was converted into a lexicographic optimization problem, which was then solved to obtain the solution.

Results : A numerical example was presented to simplify the explanation of the algorithm. While most researchers solve FLFPPs using the ranking function method, this approach reduces the efficiency of the fuzzy problem.

Conclusion: This research contributes a comprehensive methodology for addressing fuzzy linear fractional programming problems using the lexicography method. The findings offer valuable insights for researchers, *practitioners, and decision-makers grappling with optimization challenges in settings where imprecise information significantly influences the decision landscape.*

Key words: linear fractional programming, lexicography method, triangular fuzzy number.

Nomenclature: FLFP – Fuzzy Linear Fractional Programming
FFLP – Full Fuzzy Linear Programming
MOLFP – Multi Objective Linear Fractional Programming

Introduction

Linear fractional programming is an extension of linear programming where the objective function is a ratio of two linear functions. The goal is still to optimize this ratio subject to linear constraints. Fuzzy linear programming is an extension that incorporates the concept of fuzzy set theory into linear programming. In traditional linear programming, all parameters are assumed to be precise and deterministic. In fuzzy linear programming, some or all of the parameters, including coefficients and constants, are allowed to be fuzzy numbers, representing uncertainty.

The objective function and constraints are formulated with fuzzy coefficients and decision variables. The solution to a fuzzy linear programming problem yields a fuzzy decision variable, providing a range of possible values rather than a single precise value.

Zadeh (1965) has contributed to decision making in fuzzy environment. Specifically, to the concept of decision making in uncertainty and vagueness. This gives to FLFPP all parameters denoted as fuzzy numbers. This technique aims at uncertainty and vagueness in the problem, substituting crisp numbers with fuzzy ones. Consequently, LFP transforms into FLFPP. A pivotal development in FLFPP was introduced by Charnes & Cooper (1962). They successfully transformed LFPP to LPP and got solutions using the Simplex method.

Li (2008) implemented a lexicographic method to solve the matrix game with pay-offs represented by triangular fuzzy numbers. Ebrahimnejad (2017) solved fuzzy transportation problems with triangular fuzzy numbers using lexicographic ordering. Nan et al. (2010) defined the ranking order relations of TIFNs, which are applied to matrix games with payoffs of TIFNs. Prakash & Appasamy (2023) studied fully fuzzy spherical linear programming problems, where spherical fuzzy numbers are utilized as parameters. Hosseinzadeh Lotfi et al. (2009) discussed full fuzzy linear programming (FFLP) problems of which all parameters and variable are triangular fuzzy numbers and the concept of the symmetric triangular fuzzy number and introduced an approach to defuzzify a general fuzzy quantity. Sharma (2015) introduced a new ranking method proposed for L-R flat fuzzy numbers which is based on the lexicographical ordering approach. Pérez-Cañedo et al. (2019) reviewed the established models and methods in FLP, focusing on lexicographic methods for ranking fuzzy numbers (FNs) in single and multi-objective LP, particularly within the context of fuzzy linear assignment problems due to their significance. Demir (2023) investigated the fabric dyeing process in a towel manufacturing factory using the lexicography method. Safaei (2014) approached a new method for solving fully FLFP problems. Dharmaraj & Appasamy (2023) applied a modified Gauss elimination technique for separable fuzzy nonlinear programming. Sivakumar & Appasamy (2024) solved LFPP by a mathematical approach. Abdel-Basset et al. (2019) and Karthick et al. (2024) proposed to solve the neutrosophic linear fractional programming problem with triangular neutrosophic numbers.

Aim: The aim of this research is to propose a novel approach, termed Fuzzy Linear Fractional Programming (FLFP), to address real-life fractional programming problems characterized by uncertainty and imprecision. The primary objective is to develop a robust methodology for decision support in complex decision-making scenarios where parameters exhibit fuzziness.

Novelty: This study introduces a hybrid framework that combines the fuzzy set theory and linear fractional programming, offering a unique solution approach to handle uncertainties in decision-making processes. Unlike conventional methods that may reduce efficiency, the proposed FLFP method aims to provide a more effective solution by incorporating fuzzy coefficients within the objective function and constraints.

Contribution: The research contributes a comprehensive methodology for addressing fuzzy linear fractional programming problems using the lexicography method. By presenting a systematic approach to navigating the complex landscape of fuzzy decision variables, this study offers valuable insights for researchers, practitioners, and decision-makers facing optimization challenges in settings where imprecise information significantly influences decision-making processes. The presented numerical example demonstrates the applicability and effectiveness of the proposed approach, highlighting its potential to overcome limitations associated with uncertainty and hesitation in real-life fractional programming problems.

Here, the NLFP problem is transformed into an equivalent crisp multi-objective linear fractional programming (MOLFP) problem which can be solved by the linear programming technique.

This research article is organized as follows: Section 2 is the discussion about fundamental definitions; Section 3 introduces the mathematical model and demonstrates the proposed method; Section 4 illustrates a suitable numerical example for the proposed method; and in Section 5, some conclusion is pointed out at the end of this paper.

Preliminary concepts

Definition 1 (Zadeh, 1965)

If X is a universal set and $x \in X$, then a fuzzy set $\tilde{A}$ defined as, $\tilde{A} = \{(x, \mu_{\tilde{A}}(x)), x \in X\}$ where $\mu_{\tilde{A}}$ = membership function.

Definition 2 (Zadeh, 1965)

A fuzzy set $\tilde{A}$ is called a fuzzy number if its membership function $\tilde{A}: R \rightarrow [0,1]$ satisfies the following conditions:

- $\tilde{A}$ is convex,
- $\tilde{A}$ is normal, and
- $\tilde{A}$ is piecewise continuous.

Definition 3 (Ebrahimnejad, 2017)

A fuzzy number $\tilde{A}$ on R is said to be a triangular fuzzy number(TFN) if its membership function $\tilde{A}: R \rightarrow [0,1]$ has the following criteria, and this TFN graphical representation is presented in Figure:1:

$$\tilde{A}(x) = \begin{cases} \frac{x-a_1}{a_2-a_1}, & a_1 \leq x \leq a_2 \\ \frac{a_1-x}{a_3-a_2}, & a_2 < x \leq a_3 \\ 0, & \text{otherwise.} \end{cases}$$

The TFN is denoted as notationally by $\tilde{A} = (a_1, a_2, a_3)$. and $F(R)$ is used for the set of all TFNs.

Definition 4 (Demir, 2023)

Let $\leq_{lex}$ be the lexicographic order relation in R^3 and $\tilde{v}_1 = (v_1^l, v_1^c, v_1^u)$ and $\tilde{v}_2 = (v_2^l, v_2^c, v_2^u)$ two TFNs.We say that $\tilde{v}_1$ is relatively smaller than $\tilde{v}_2$, which is denoted by $\tilde{v}_1 < \tilde{v}_2$ iff $(v_1^c, v_1^l - v_1^u, v_1^l + v_1^u) <_{lex} (v_2^c, v_2^l - v_2^u, v_2^l + v_2^u)$.We say that $\tilde{v}_1$ is relatively smaller than or equal to $\tilde{v}_2$, which is denoted by $\tilde{v}_1 \leq \tilde{v}_2$ iff $(v_1^c, v_1^l - v_1^u, v_1^l + v_1^u) \leq_{lex} (v_2^c, v_2^l - v_2^u, v_2^l + v_2^u)$ and $\tilde{v}_1 = \tilde{v}_2$ iff $v_1^c = v_2^c, v_1^l - v_1^u = v_2^l - v_2^u, v_1^l + v_1^u = v_2^l + v_2^u$

Mathematical model

Linear fractional programming problem

The linear fractional programming problem is a mathematical optimization problem that involves maximizing or minimizing a ratio of two linear functions. It can be formulated as follows:

$$MaxQ(x) = \frac{P(x)}{D(x)} = \frac{\sum_{j=1}^{n} p_j x_j + p_0}{\sum_{j=1}^{n} d_j x_j + d_0} \tag{1}$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j \leq or \geq or = b_i, i = 1,2,3,\ldots,m$$

and $x_j \geq 0$. Here, x is the vector of variables to be determined, $P(x)$ and $D(x)$ are vectors of known coefficients, and a_{ij} is a known matrix of coefficients.

Proposed method

The formulation of the FLFP problem with triangular fuzzy parameters is articulated as follows: maximize the sum of products of $\tilde{c}_j$ and $\tilde{x}_j$ divided by $\tilde{d}_j$ and $\tilde{x}_j$ over n, subject to constraints involving the sum of products of $\tilde{a}_{ij}$ and $\tilde{x}_j$, with $\tilde{x}_j$ representing non-negative triangular fuzzy numbers (TFNs) for $j = 1,2,\ldots,n$.

Step 1: Define $\tilde{c}_j = (c_j^l, c_j^c, c_j^u)$,$\tilde{d}_j = (d_j^l, d_j^c, d_j^u)$, $\tilde{a}_{ij} = (a_{ij}^l, a_{ij}^c, a_{ij}^u)$, $\tilde{b}_i = (b_i^l, b_i^c, b_i^u)$, and $\tilde{x}_j = (x_j^l, x_j^c, x_j^u)$, transforming the FFLP problem into an expression maximizing the sum of $(c_j^l, c_j^c, c_j^u)(x_j^l, x_j^c, x_j^u)$, with constraints on $(a_{ij}^l, a_{ij}^c, a_{ij}^u)(x_j^l, x_j^c, x_j^u)$ and conditions on (x_j^l, x_j^c, x_j^u) being non-negative TFNs.

Step 2: Rewrite the FFLP problem by expressing the objective and constraints in terms of new symbols (s_j^l, s_j^c, s_j^u) and $(m_{ij}^l, m_{ij}^c, m_{ij}^u)$, maintaining the relationship with (b_i^l, b_i^c, b_i^u) and the non-negativity of TFNs for each j.

Step 3: Convert the FFLP problem into a lexicographic optimization problem by setting lex max criteria based on the central values, the difference, and the sum of the lower and upper bounds of the sums involved, aligning with the conditions set for equality, and inequality constraints represented by the index sets l_e, l_{le}, l_{ge}.

Step 4: Further articulate the lexicographic maximization with additional constraints represented through the variables y_{i1}, y_{i2}, y_{i3}, introducing the parameters ϵ and L to delineate the ranges for the constraints, adhering to the specifications for l_{le} and l_{ge}.

Step 5: Address the multi-level lexicographic fuzzy linear programming (MLLFP) problem using classical methods for multi-objective optimization to pinpoint an optimal solution.

Step 6: Assess $\sum_{j=1}^{n} \frac{\tilde{c}_j \tilde{x}_j}{\tilde{d}_j \tilde{x}_j}$ with the derived optimal solution to determine the optimal fuzzy value of the FFLP problem, thus concluding the methodological approach for solving FFLP problems with triangular fuzzy parameters.

Numerical example: 1

The given problem involves FLFP, where the coefficients and constraints are represented by fuzzy numbers. Fuzzy numbers here are given in the form of triplets, which could represent, for example, the lower limit, the most probable value, and the upper limit of an estimation. This problem involves maximizing a fuzzy objective function subject to fuzzy constraints. Let us construct a potential application problem that could be represented by this mathematical formulation.

Application Scenario: Production Planning

Imagine a small manufacturing company that produces two types of products: Product 1 and Product 2. The company is operating in an uncertain environment where the profit margins, production costs, and available resources (like raw materials, labor, and machinery time) fluctuate within known ranges. These fluctuations are due to varying market conditions, supplier reliability, and labor availability. The company aims to maximize its profit margin while ensuring that production does not exceed its fuzzy constraints, which represent the uncertain availability of resources.

Variables: - $\tilde{x}_1$ = Quantity of Product 1 to produce. - $\tilde{x}_2$ = Quantity of Product 2 to produce.

Objective Function: Maximize the fuzzy profit ratio $\tilde{Z}$:

$$\tilde{Z} = \frac{(2,4,7)\tilde{x}_1 + (1,3,4)\tilde{x}_2}{(1,2,3)\tilde{x}_1 + (3,5,8)\tilde{x}_2}$$

This represents the goal of maximizing the ratio of total profit (numerator, with uncertain profit margins for products 1 and 2) to total production costs (denominator, with uncertain costs for producing products 1 and 2).

Constraints: 1. Resource Constraint for Resource A (e.g., raw materials):

$$(0,1,2)\tilde{x}_1 + (1,2,3)\tilde{x}_2 \leq (1,10,27)$$

This constraint represents the fuzzy limitation of Resource A available for production, where the availability is uncertain.

2. Resource Constraint for Resource B (e.g., labor hours):

$$(1,2,3)\tilde{x}_1 + (0,1,2)\tilde{x}_2 \leq (2,11,28)$$

This represents the fuzzy limitation of Resource B, reflecting the uncertain availability of labor hours for production.

Application Problem Statement: A small manufacturing company is looking to determine the optimal production levels of two products under uncertain market conditions and resource availabilities. The company wants to maximize its profit ratio, taking into account the uncertain profit margins and production costs for both products, while also ensuring that the production does not exceed the uncertain availability of raw materials and labor hours. How should the company allocate its resources to the production of these two products to achieve its goal?

This problem encapsulates the challenge of making strategic decisions in an uncertain environment, typical of real-world situations faced by businesses. The use of fuzzy numbers allows for a more flexible and realistic modeling of uncertainties compared to traditional deterministic models.

$$Max\tilde{Z} = \frac{(2,4,7)\tilde{x}_1+(1,3,4)\tilde{x}_2}{(1,2,3)\tilde{x}_1+(3,5,8)\tilde{x}_2} \tag{2}$$

Subject to

$$(0,1,2)\tilde{x}_1 + (1,2,3)\tilde{x}_2 \leq (1,10,27)$$

$$(1,2,3)\tilde{x}_1 + (0,1,2)\tilde{x}_2 \leq (2,11,28)$$

From step 3 and step 4, we obatained the simplified form as

$$lexMax\tilde{Z} = \left(\frac{4x_1^c+3x_2^c}{2x_1^c+5x_2^c}, \frac{2x_1^l-7x_1^u+x_2^l-4x_2^c}{x_1^l-3x_1^u+3x_2^l-8x_2^c}, \frac{2x_1^l+7x_1^u+x_2^l+4x_2^c}{x_1^l+3x_1^u+3x_2^l+8x_2^c}\right) \tag{3}$$

subject to

$$\epsilon\, y_{11} \leq 10 - x_1^c - x_2^c \leq Ly_{11}$$

$$-Ly_{11} + \epsilon y_{12} \leq -26 + 2x_1^c - x_2^l + 3x_{12}^u \leq Ly_{12}$$
$$-L(y_{11} + y_{12}) + \epsilon y_{13} \leq 28 - 2x_1^u - x_2^l - 3x_{12}^u \leq Ly_{13}$$
$$\epsilon\, y_{21} \leq 11 - 2x_1^c - x_2^c \leq Ly_{21}$$
$$-Ly_{21} + \epsilon y_{22} \leq -26 - x_1^l + 3x_1^u + 2x_2^u \leq Ly_{22}$$
$$-L(y_{21} + y_{22}) + \epsilon y_{23} \leq 30 - x_1^l - 3x_1^l - 2x_2^u \leq Ly_{33}$$

Steps 5 and 6 yield : $\tilde{x}_1$ = (1.23,2.11,1.23) $\tilde{x}_2$ = (0,0,0) and $\tilde{Z}$ = (2,2,2.33). But for the same problem, Safaei obtained the solution
$\tilde{Z}$ =(1.34, 2, 2.31).

Result analysis

Comparing two fuzzy solutions involves analyzing their ranges, central values, and the overall spread of the outcomes. Our solution is $\tilde{Z} = (2{,}2{,}2.33)$ and Safaei's solution is $\tilde{Z} = (1.34{,}2{,}2.31)$.

Central Value - Both solutions have a central value of 2, indicating that at the most probable estimation, the outcomes are considered equal. This central value suggests that both approaches agree on the most likely efficiency or performance measure under the given conditions.

Upper Limit - The upper limit of this research's solution is 2.33, slightly higher than Safaei's 2.31. Although the difference is minor, it indicates that these authors' solution allows for a slightly more optimistic outcome in the most favorable conditions.

Spread and Uncertainty - Safaei's solution demonstrates a wider spread (1.34 to 2.31) compared to these authors' solution (2 to 2.33). This wider spread suggests a higher level of uncertainty or variability in the outcomes considered by Safaei. A broader spread in the fuzzy solution can indicate that the model accounts for a wider range of factors or uncertainties affecting the optimization problem.

The graphical representation would illustrate the overlap between the two solutions, highlighting their agreement at the central value but differing in their consideration of possible variability and outcomes at the lower and upper bounds.

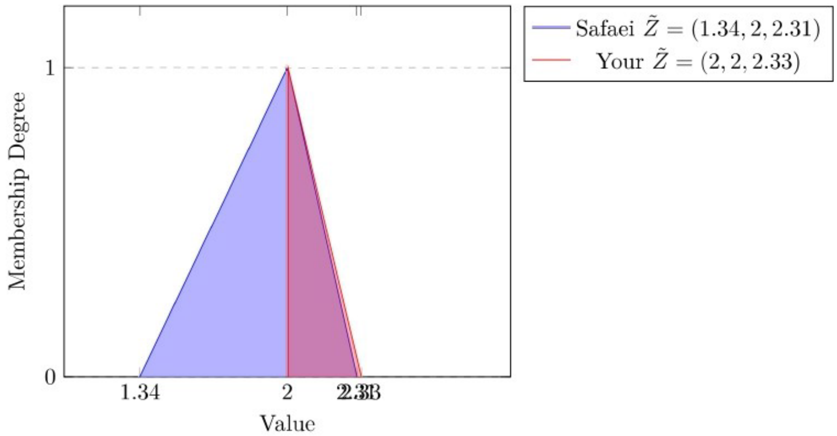

Figure 1 – Comparison of the fuzzy solutions

Future scope

- Extension to Non-linear Problems: One potential avenue for future research is to extend the FLFP problem to handle non-linear optimization problems. Incorporating fuzzy logic into non-linear fractional programming could broaden the applicability of the proposed methodology to a wider range of real-world decision-making scenarios.
- Multi-objective Optimization: Another direction for future research is to extend FLFP to multi-objective optimization problems. Developing methodologies to efficiently handle multiple conflicting objectives under uncertainty could provide decision makers with more comprehensive and informed decision support.

Advantages

- Improved Decision Support: The FLFP framework offers improved decision support by incorporating the fuzzy set theory into linear fractional programming. Decision makers can make more informed decisions in environments characterized by uncertainty and imprecision.
- Adaptability: The FLFP model demonstrates adaptability and versatility in handling diverse optimization challenges. Its ability to capture the intricacies of real-world scenarios makes it well-suited for addressing a wide range of decision-making problems.
- Efficiency: The application of the lexicography method provides a systematic and efficient approach to navigate the complex space of fuzzy

decision variables. This structured approach enhances the efficiency of the decision-making process, particularly in multi-criteria environments.

Limitations

- Computational Complexity: One potential limitation of the FLFP problem is its computational complexity, especially when dealing with large-scale optimization problems. Future research may need to explore techniques to enhance computational efficiency without compromising solution quality.

- Data Dependency: The effectiveness of the FLFP problem may be highly dependent on the availability and quality of data. Decision makers should exercise caution when applying the model in contexts where data availability is limited or uncertain.

Overall, the FLFP problem presents a promising approach for addressing decision-making problems in uncertain environments, but further research is needed to address its limitations and extend its applicability to a wider range of optimization scenarios.

Conclusion

In this article, we proposed the fuzzy linear fractional programming (FLFP) problem utilizing the lexicography method which presents a promising solution for addressing decision-making problems characterized by uncertainty and imprecision. By integrating the fuzzy set theory into linear fractional programming, the model captures the real-world scenarios where parameters exhibit inherent fuzziness.

The application of the lexicography method provides a systematic and efficient approach to navigate the complex space of fuzzy decision variables, offering a structured means of decision support in multi-criteria environments. The mathematical formulation of the FLFP problem demonstrates its adaptability and versatility in handling diverse optimization challenges.

Through illustrative examples and case studies, the research highlights the practical applicability of the proposed methodology, showcasing its effectiveness in comparison to traditional linear programming and linear fractional programming approaches. The findings underscore the advantages of FLFP in providing more realistic and nuanced solutions in the face of uncertainty.

This study contributes not only a novel methodology but also valuable insights for researchers and decision makers dealing with optimization problems in contexts where imprecise information significantly influences decision outcomes. The proposed FLFP framework, with its integration of fuzzy logic and fractional programming principles, stands as a robust tool for addressing real-world complexities and advancing the field of decision support in uncertain environments.

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Problema de programación fraccionaria lineal difusa utilizando el método lexicográfico

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CAMPO: matemáticas, ciencias de computación
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Al resolver problemas de programación fraccionaria de la vida real, a menudo se encuentra la incertidumbre y vacilación debido a varios factores incontrolables. Para superar estas limitaciones, se aplica el enfoque de lógica difusa a estos problemas.

Métodos: La discusión se centró en la solución del problema de programación fraccionaria lineal difusa (FLFPP). Primero, el problema FLFP se convirtió en un problema de optimización lexicográfica, que luego se resolvió para obtener la solución.

Resultados: Se presentó un ejemplo numérico para simplificar la explicación del algoritmo. Si bien la mayoría de los investigadores *resuelven los FLFPP utilizando el método de la función de clasificación, este enfoque reduce la eficiencia del problema difuso.*

Conclusión: Esta investigación aporta una metodología integral para abordar problemas de programación fraccionaria lineal difusa utilizando el método de lexicografía. Los hallazgos ofrecen información valiosa para investigadores, profesionales y tomadores de decisiones que enfrentan desafíos de optimización en entornos donde la información imprecisa influye significativamente en el panorama de decisiones.

Palabras claves: *programación fraccionaria lineal, método lexicográfico, número difuso triangular.*

Задача нечеткого дробно-линейного программирования с использованием лексикографического метода

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РУБРИКА ГРНТИ: 27.47.00 Математическая кибернетика,
27.47.19 Исследование операций,
28.17.31 Моделирование процессов управления
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: При решении реальных задач дробного программирования часто возникают неуверенность и сомнения из-за различных неконтролируемых факторов. Для того чтобы преодолеть эти ограничения, к таким задачам применяется подход нечеткой логики.

Методы: Обсуждение было сосредоточено на решении задачи нечеткого дробно-линейного программирования (LP). Сначала задача FLFP была преобразована в задачу лексикографической оптимизации, которая таким образом была решена.

Результаты: Для упрощения объяснения алгоритма был представлен арифметический пример. Несмотря на то что большинство исследователей решают FLFPPS, используя метод ранжирующей функции, этот подход снижает эффективность нечеткой задачи.

Выводы: Данное исследование представляет собой комплексный метод решения задач нечеткого дробно-линейного *программирования с использованием лексикографического метода. Полученные результаты предоставляют ценную информацию исследователям, практикам и лицам, принимающим решения, которые сталкиваются с проблемами оптимизации в условиях, когда неточная информация существенно влияет на процесс принятия решений.*

Ключевые слова: дробно-линейное программирование, лексикографический метод, треугольное нечеткое число.

Проблем фази линеарног фракционог програмирања помоћу лексикографског метода

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Сажетак:

Увод/циљ: При решавању проблема фракционог програмирања у реалном животу често долази до несигурности и оклевања због различитих фактора које није могуће контролисати. Како би се превазишла ова ограничења, за овакве проблеме примењује се приступ заснован на фази логици.

Методе: Дискусија се фокусира на решавање проблема фази линеарног фракционог програмирања (FLFP). Прво је FLFP проблем пребачен у проблем лексикографске оптимизације и као такав је решен.

Резултати: Представљен је нумерички пример који поједностављује објашњење алгоритма. Док већина истраживача решава FLFP проблеме користећи метод рангирања функција, овај приступ редукује ефикасност фази проблема.

Закључак: Ово истраживање даје допринос путем свеобухватне методологије за решавање проблема фази линеарног фракционог програмирања помоћу лексикографског метода. Налази нуде драгоцене увиде за истраживаче, практичаре и доносиоце одлука који се сусрећу са проблемима оптимизације где непрецизне информације имају велики утицај при одлучивању.

Кључне речи: линеарно фракционо програмирање, лексикографски метод, триангуларни фази број.

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