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Using Newton's Divided Polynomial to Solve a Multiple-Choice Programming Problem

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Abstract

This study aims to convert a multi-choice linear programming problem into a conventional mathematical programming problem, focusing on constraints with a "multi-choice" nature on their right-hand side. Any limitation may have many objectives, each necessitating careful selection. To choose objectives wisely, ensure that combining the choices for each constraint yields the best approach to an objective function. For the best results, try a few different combinations. Nonetheless, conventional linear programming techniques are inadequate for resolving the problem. This study introduces a novel transformation technique to address the current multi-choice linear programming problem. A non-linear mixed-integer programming model is generated using binary variables in the transformation approach. The best answer for the suggested model can be found using conventional non-linear programming methods. The multi-choice model was employed to manage the variable demand for different gasoline varieties in oil refineries, ensuring the requisite amounts were met while addressing uncertainty; the model demonstrated its efficacy in identifying the ideal option.

1. Introduction

The field of operations research (OR) seeks to identify the best course of action by mathematically modelling a real-world decision-making situation. Maximising or minimising one or more mathematical functions, called objective functions, while considering specified restrictions, is the goal of mathematical programming (MP) problems, which are optimisation problems. The decision variables are constrained by these constraints, which are expressed as mathematical equations or inequalities. Extending an MP problem to include a parameter space (p) is typical.

As a mathematical model, an optimisation problem looks like this:

$$\text{maxmize /minmize: } f(x;p))$$

subject to:"

$$g(x;p) \leq 0 \ldots \qquad (1)$$
$$x \geq 0 \ldots \quad "$$

Definitions of $x \subset R^n$ as well as functions f،g given as $f,: R^n \to R$ An examination of functions that are linear f and g enables the division of the MP problem into two separate sets of problems: linear and nonlinear optimisation problems. The parameter space structure of the MP problem encompasses most acknowledged subsets, such as constrained and unconstrained optimisation, optimisation with one or more objectives, optimisation with discrete or continuous variables, and optimisation with a mix of integers, as well as deterministic, fuzzy, and stochastic optimisation. Acknowledging that the parameter space may include parameters with many choices is essential. This indicates that a parameter can provide various options, from which one must choose the most effective goal function(s). Multi-choice optimisation corresponds to a distinct category of optimum programming problems.

Nevertheless, specialists and decision-makers sometimes lack accurate knowledge of the specific value of those factors. If we propose precise values, they are merely statistical inferences derived from historical data, and their stability remains unclear. Therefore, the decision-maker often establishes the problem's parameters ambiguously or through language statements. Decision-making approaches in the presence of uncertainty have adopted several modelling philosophies, such as minimising the anticipated value of loss, minimising deviations from objectives, minimising overall costs, and maximising profits. The primary approaches for decision-making under uncertainty include fuzzy programming, which encompasses flexible and possibility programming, and stochastic programming, which incorporates probabilistic models, resilient stochastic programming, and recourse models. However, decision-makers perceive the parameters or coefficients as multiple-choice options in specific scenarios.

2. Literature review

Using “Multiple Choice Programming (MCP) problem”, first introduced by Healey[8], is a way to optimise a collection of combinations. A constrained set of constraints is considered and an objective function is optimised by choosing one combination among multiple choices. It is possible to broaden the scope of MCP to encompass problems involving generalised assignments, multiple-choice knapsacks, sales resource allocation, scheduling numerous items, timetabling, and similar tasks. In MCP, a subset of mixed binary programming, each binary variable forms an option from a set of mutually incompatible alternatives; the goal is to select one of these variables. Lin [15] conducted a comprehensive survey on MCP. A common occurrence in managerial decision-making challenges is the presence of multiple choices for a parameter. In this research, we look at a few linear programming parameters with multiple-choice answers. A decision-maker (DM) can set a maximum number of possible values for each given parameter. Chang's [5] looks at a mathematical model that chooses a good constraint using the help of binary strings. Within the bounds of, as the number of alternatives increases, so does the requirement for binary variables. Chang developed MCGP to prevent underestimation in decision-making by establishing multi-choice aspiration levels for objectives using multiplicative formulas for binary variables. A decision support system can readily implement Chang et al. [6] modified the mathematical programming approach to assign aspiration levels, where 'i is the quantity of aspiration levels. The number of aspiration levels must be an integral power of 2 for the model formulation to be challenging. He removes the multiplicative parts of the binary variables and replaces them with continuous ones. Liao [10] proposes a solution that approaches the multi-segment aspiration levels of the differential matrix (DM) as nearly as possible to resolve the target programming challenge involving multiple segments. His proposal suggests that a multi-choice parameter can support a maximum of three choices. Biswal and Acharya [3] developed a transformation method to address an MCLP problem, with each goal potentially containing up to eight possible solutions. To avoid duplication, we have implemented certain additional restrictions. Several authors, specifically [9, 11], have used a multi-choice goal programming technique to address practical decision-making challenges. Biswal [4] Formulating an interpolating polynomial with functional values at non-negative integer nodes allows for handling any multi-choice parameter.. Furthermore, Chang and Paksoy [5,13] have applied Chang's (2007) updated multi-choice goal programming method to design a supply chain network with multiple choice parameters. Ibrahim Özkan [12] This underscores the continued deficiency in comprehensive information about the environment and decision outcomes. Unspecified ideas may evolve in unexpected ways. Knowing how to deal with uncertainty and the resources available can significantly improve our decision-making abilities.[2,14]

Numerous challenges exist when converting a regular mathematical programming problem-solving from an MCLP context, with additional parameters,(i) deciding on binary variables, (ii) deciding on boundary values for binary codes, and (iii) establishing auxiliary constraints to limit binary codes.[1,7] . a random multi-choice transportation problem formulated in which the multi-choice parameters (supply and demand) are treated as random variables that follow the normal distribution with mean and variance. The main aim is to minimise the transportation cost. This methodology helps us find the optimal choice so that the decision-maker can make the best decision according to the problem.[16]

To mitigate such challenges, we employ a numerical technique known as the polynomial interpolation method for a dataset with multiple-choice parameters. We derive an interpolation polynomial for each of the problem's multi-choice parameters. By substituting the multi-choice parameters with appropriate interpolating polynomials, we formulate a mixed-integer nonlinear programming problem. Nonlinear programming techniques can handle this problem.

The study is structured as follows: Section 3 presents a mathematical model of the MCLP problem, following the introduction and literature review. Section 4 outlines mathematical programming models that are equivalent under various interpolating polynomial types. Section 5 incorporates a case study to illustrate the proposed strategy. In Section 6, we conclude with a discussion of the outcomes.

3. Materials and Methods:

The mathematical formulation of a Mode-Controlled Linear Programming (MCLP) problem is presented here. Determine the value of $x_i = (x_1, x_2, x_3, \dots, x_n)$In order to.

$$\text{maxmaiz} : Z = \sum_{j=1}^{n} c_j x_j$$

Subject to: (2)

$$\sum_{j=1}^{n} a_{ij} x_j \le \left\{ b_i^{(1)}, b_i^{(2)}, \dots, b_i^{(k_i)} \right\},\ i. = 1.,2.,3., \dots, m x_j \ge 0, j. = 1.,2.,3., \dots, n$$

The objective function can be maximized by selecting a single goal from the set of k_iObjectives that are on the opposite side of the i th restriction (2). We employ interpolating polynomials to deal with the parameter system with several choices. Some mathematical models include the interpolation of polynomials. We assign integral values to the positions of the nodes to produce polynomials that interpolate the multi-choice parameters. Every node represents a single functional value generated by a parameter with many answer options. If a parameter can take on k_i values, then precisely. It's necessary to have k_i Nodes. At each place, an interpolating polynomial will intersect the affine function precisely once. An interpolating polynomial substitutes the multiple-choice parameter. The most commonly used interpolating polynomials are the Lagrange, Newton's divided difference, Newton's forward, and Newton's backward methods . Furthermore. [17][4]

1.3 Modelling with Lagrange interpolation polynomials

It is necessary to consider the MCLP problem's limitation (2). Let $0,1,2, \dots, (k_i - 1)$ be k_i space between each pair of nodes, where $b_i^{(1)}, b_i^{(2)}, \dots, b_i^{(k_i)}$ stands for the functional values that are associated with the interpolating polynomial at $k_i$distinct node positions. A polynomial of degree $P_{k_i-1}(z)$ is derived, which interpolates the provided data:

With $j = 0,1,2, \dots, (k_i - 1)$ and $i = 1,2,3, \dots, m$ the equation $P_{k_i-1}(j) = b_i^{(j+1)}$ holds.

For the ith multiple-choice parameter, we derive an interpolating polynomial by applying the mathematical technique of Lagrange interpolation

The revised MCLP problem can also be expressed as

$$\max: Z = \sum_{j=1}^{n} c_j x_j$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j \le \frac{(z-1)(z-2)\dots(z-k_i+1)}{(-1)^{(k_i-1)}(k_i-1)!} b_i^{(1)} + \frac{z\,(z-2)\dots(z-k_i+1)}{(-1)^{(k_i-2)}(k_i-2)!} b_i^{(2)} + \frac{z(z-1)(z-3)\dots(z-k_i+1)}{(-1)^{(k_i-3)}(k_i-3)!\,2!} b_i^{(3)} + \dots + \frac{z(z-1)\dots(z-k_i+2)}{(k_i-1)!} b_i^{(k_i)} \quad (3)$$

$z^i = 0,1,2,\dots,(k_i-1), \quad i = 1,2,3,\dots m$

$x_j = 1,2,3,\dots n$

Table (1) points of information

$j = z$	0	1	2	$\cdots$	$k_i - 1$
$f(z) = b_i$	$b_i^{(1)}$	$b_i^{(2)}$	$b_i^{(3)}$	$\cdots$	$b_i^{(k_i)}$

2.3 An interpolating polynomial model based on Newton's divided differences

The split difference of Newton Interpolating polynomial best matches a specific set of data points. Consider the set of node points $0,1,2,\dots,(k_i-1)$ 0, where $b_i^{(1)}, b_i^{(2)}, \dots, b_i^{(k_i)}$ are the functional values associated with the interpolating polynomial of the k_i distinct node points. The polynomial $P_{k_i-1}(z)$ of degree (k_i-1) is derived to interpolate the provided data. Consider the set of values of;

$$P_{k_i-1}(j) = b_i^{(j+1)}, \qquad j = 0,1,2,\dots,(k_i-1), \qquad i = 1,2,3,\dots,m \quad (4)$$

We use the format in Table (2) to create the divided differences. To calculate divided differences, use the formula given below.

"$f[0,1] = f(1) - f(0)$"
"

$$f[0,1,2] = \frac{f[1,2] - f[0,1]}{2} \quad (5)$$

$$f[0,1,2,\dots,j] = \frac{f[1,2,\dots,j] - f[0,1,2,\dots,j-1]}{j}$$

Using Newton's divided differences formula, we obtain an interpolating polynomial equation for the parameters with many choices.

Further, the modified MCLP problem is formulated as

$$\text{maxmaiz}: Z = \sum_{j=1}^{n} c_j x_j$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \le \text{"}b_i^{(1)} + z.f[0,1] + z.(z-1)\,f[0,1,2] + \dots + z.(z-1)\dots(z-k_i+2)\text{"} \quad (6)$$

$z^i = 0,1,2,\dots,(k_i-1), \quad i = 1,2,3,\dots m$

$x_j = 1,2,3,\dots n$

3.3 Modelling based on the notion of forward difference interpolating polynomials proposed by Newton.

Each row in Table (1) represents a data point that follows the pattern $0,1,2,\dots,(k_i-1)$. In this analysis, we set the initial value to 0 and the step size to 1. This means that straight forward differences , rather than divided differences , can be computed. The forward Δf_j or the backward differences ∇f_j might be seen as these basic disparities. The forward differences will be defined first, and then the interpolating polynomial obtained from them will be shown. The following formula can be used to determine the p order forward difference $\Delta^p f_j$, using Table (3).

$$\Delta f_j = f_{j+1} - f_j$$
$$\Delta^p f_j = \Delta^{p-1} f_{j+1} - \Delta^{p-1} f_j. \quad (7)$$

Table (2) Dividing the difference table by Newton

Z	f (z.)	First	second	⋯	$(k_i - 1)$ the difference by th order
0	$f(0)$	f [0,1]			
1	$f(1)$	f [1,2]	f [0,1,2]		
2	$f(2)$	f [2,3]	f [1,2,3]		
3	$f(3)$	...	...	⋯	$f[0,1,2,\ldots,(k_i-2),(k_i-1)$
...	...	$f[(k_i-2),(k_i-1)]$	$f[(k_i-3),(k_i-2),(k_i-1)]$		
$k_i - 2$	$f(k_i - 2)$				
$k_i - 1$	$f(k_i - 1)$				

Table (3) Newton’s forward difference table

Z	first	second	...	k_i difference of the order
0	$f(z)$	Δf_0	$\Delta^2 f_0$	
1	$f(1)$	Δf_1	$\Delta^2 f_1$	
2	$f(2)$	Δf_2		
3	$f(3)$	...	…	$\Delta^{(k_i-1)} f_0$
...	...	$\Delta f_{(k_i-3)}$	$\Delta^2 f_{ki-3}$	
$k_i - 3$	$f(k_i - 3)$	$\Delta f_{(k_i-2)}$		
$k_i - 2$	$f(k_i - 2)$			
$k_i - 1$	$f(k_i - 1)$			

A more advanced version of the MCLP problem can also be as

$$\max: Z = \sum_{j=1}^{n} c_j x_j$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j \le b_i^{(1)} + \mathrm{z}\,\Delta f_0 + \frac{\mathrm{z}(\mathrm{z}-1)}{2!}\Delta^2 f_0 + \cdots + \frac{\mathrm{z}(\mathrm{z}-1)\ldots(\mathrm{z}-k_i+2)}{(k_i-1)!}\Delta^{(k_i-1)} f_0 \quad (8)$$

***4.3 Modelling based on the notion of backward difference interpolating polynomials proposed by Newton*.**

The formula for backward difference is defined as:

$$\nabla f_j = f_j - f_{j-1}$$
$$\nabla^2 f_j = \nabla f_j - \nabla f_{j-1}$$
$$\vdots \quad (9)$$
$$\nabla^p f_j = \nabla^{p-1} f_j - \nabla^{p-1} f_{j-1}$$

Table (4) Newton's table of backward differences .

Z	f(z)	first	second	...	$(k_i - 1)$ th difference of the order

0	$f(0)$	∇f_1	$\nabla^2 f_2$		
1	$f(1)$	∇f_2	$\nabla^2 f_3$		
2	$f(2)$	∇f_3			
3	$f(3)$	…	…	…	$\nabla^{(k_i-1)} f_{(k_i-1)}$
…					
k_i-3	$f(k_i-3)$	$\nabla f_{(k_i-2)}$			
k_i-2	$f(k_i-2)$	$\nabla f_{(k_i-1)}$	$\nabla^2 f_{(k_i-1)}$		
k_i-1	$f(k_i-1)$				

$$\max: Z=\sum_{j=1}^{n} c_j x_j$$

subject to

$$\sum_{j=1}^{n} a_{ij}x_j \le b_i^{(k_i)} + (z-k_i+1)\nabla f_{(k_i-1)} + \frac{(z-k_i+1)(z-k_i+2)}{2!}\nabla^2 f_{(k_i-1)} \qquad (10)$$

$z^i = 0,1,2,\dots,(k_i-1), \quad i = 1,2,3,\dots m$

$x_j = 1,2,3,\dots n$

4. Experimental Work.

The table below shows the expected or fluctuating daily demand for premium (super), improved, and regular gasoline for the country, where the percentage of demand varies from month to month and from one season to another, and there is a continuous increase in demand for these materials. The table also shows the expected demand for refineries, where x_1 represents premium gasoline, x_2 Improved gasoline and regular gasoline x_3. The requirement is to achieve the expected demand at the lowest possible cost because the state subsidises gasoline. The daily demand for gasoline ranges from 28-30 million litres, depending on the season.

Table 5: The demand and available capacities for the refineries.

Oil refinery	Barrel/day	DEMAND(1000)litter
Al-Doura	140000	3400,3700,4100
Al-Shu'aybah	210000	5700,6100,6400
Karbala	140000	3400,4000
Al-Faw	300000	7900,8400,8600
Al-Anbar	150000	3600,3800,4100,4400
Al-Kut	100000	2900,3100,3400
The remaining oil refineries	2300000	5000,5300,5700

$$\begin{aligned}\min Z = {} & 1250x_{11} + 850x_{21} + 450x_{31} + 1250x_{12} + 850x_{22} + 450x_{32} + 1250x_{13} \\ & + 850x_{23} + 450x_{33} + 1250x_{14} + 850x_{24} + 450x_{34} + 1250x_{15} + 850x_{25} \\ & + 450x_{35} + 1250x_{16} + 850x_{26} + 450x_{36} + 1250x_{17} + 850x_{27} + 450x_{37}\end{aligned}$$

subject to

$x_{11} + x_{21} + x_{31} \ge 3400,3700,4100$

$x_{12} + x_{22} + x_{32} \ge 5700,6100,6400$

$x_{13} + x_{23} + x_{33} \ge 3400,4000$

$x_{14} + x_{24} + x_{34} \ge 7900,8400,8600$ (11)

$x_{15} + x_{25} + x_{35} \ge 3600,3800,4100,4400$

$x_{16} + x_{26} + x_{36} \ge 2900,3100,3400$

$x_{17} + x_{27} + x_{37} \ge 5000,5300,5700$

$x_{11} \ge 280$, $x_{21} \ge 340$, $x_{13} \ge 280$, $x_{23} \ge 340$ $x_{14} \ge 632$, $x_{24} \ge 790$, $x_{16} \ge 230$,

$x_{26} \geq 290$ $x_{12} \geq 450$, $x_{22} \geq 570$, $x_{15} \geq 288$, $x_{25} \geq 360$, $x_{17} \geq 400$, $x_{27} \geq 500$
$x_j = 0,1,2,3$; $j = 1,2,3,\ldots,7$

To solving model.by using new technical "Newton's divided polynomial "

$$\min Z = 1250x_{11} + 850x_{21} + 450x_{31} + 1250x_{12} + 850x_{22} + 450x_{32} + 1250x_{13} + 850x_{23} + 450x_{33} + 1250x_{14} + 850x_{24} + 450x_{34} + 1250x_{15} + 850x_{25} + 450x_{35} + 1250x_{16} + 850x_{26} + 450x_{36} + 1250x_{17} + 850x_{27} + 450x_{37}$$

subject to

$$x_{11} + x_{21} + x_{31} \geq 3400 + 250Z_1 + 50Z_1^2$$
$$x_{12} + x_{22} + x_{32} \geq 5700 + 400Z_2 + (-\frac{100Z_1(Z_1 - 1)}{2})$$
$$x_{13} + x_{23} + x_{33} \geq 3400 + 600Z_3$$
$$x_{14} + x_{24} + x_{34} \geq 7900, +200Z_4 \text{-} 150Z_4^2$$
$$x_{15} + x_{25} + x_{35} \geq 3600 + 100\left(\frac{Z_5(Z_5 - 1)}{2}\right) + (-\frac{100(Z_5 - 1)(Z_5 - 2)}{6})$$
$$x_{16} + x_{26} + x_{36} \geq 2900 + 200Z_6(-\frac{100Z_6(Z_6 - 1)}{2}) \quad (12)$$
$$x_{17} + x_{27} + x_{37} \geq 5000 + 300Z_7 + \frac{100\,Z_7(Z_7 - 1)}{2})$$

$x_{11} \geq 280$, $x_{21} \geq 340$
$x_{12} \geq 450$, $x_{22} \geq 570$
$x_{13} \geq 280$, $x_{23} \geq 340$
$x_{14} \geq 632$, $x_{24} \geq 790$
$x_{15} \geq 288$, $x_{25} \geq 360$
$x_{16} \geq 230$, $x_{26} \geq 290$
$x_{17} \geq 400$, $x_{27} \geq 500$

x_{ij} , i = 0,1,2,3; $j = 1,2,3,\ldots,7$
Z_j , $j = 1,2,3,\ldots,7$

5.Results.

Using the lingo program, the following results were obtained:[18]

Table (6) Optimal solution.

variable	value	Variable	value	variable	value	variable	Value
x_{11}	400	x_{21}	500	x_{31}	2500	Z_1	0
x_{12}	280	x_{22}	340	x_{32}	5080	Z_2	0
x_{13}	450	x_{23}	570	x_{33}	2380	Z_3	0
x_{14}	280	x_{24}	340	x_{34}	7330	Z_4	1
x_{15}	632	x_{25}	790	x_{35}	2178	Z_5	0
x_{16}	288	x_{26}	360	x_{36}	2252	Z_6	0
x_{17}	230	x_{27}	290	x_{37}	4480	Z_7	0

6.Discussions.

1. According to the above results, obtained from solving the proposed model, the daily production of the refineries according to each of the three gasoline products (super premium, improved, and regular) is shown in Table No. (5).
2. The gasoline production quantities in the refineries for a single day reached 29,481,000 litres/day, which is produced at the lowest cost and meets the actual daily demand of 28,000,00-30,000,000 litres/day.
3. The daily production value of the refineries amounted to (17,701,000,000 dinars), which is considered a moderate cost according to what was announced about the daily consumption value of gasoline.
4. The multi-choice programming approach simplifies problem-solving by solving linear programming problems, but large computations make it unworkable. The MCLP approach is also necessary.
5. The present methodology can be extended to a multi-objective multi-choice linear programming problem.

7. Conclusions.

The suggested strategy and solution procedure provide a fresh perspective when dealing with MCLP problems, including various objectives on the right-hand side restrictions. For decision-makers looking for the right ways to proceed, the current MCLP method is a great tool. Further investigation shows that some of the objective function's cost and constraints' coefficients are multi-choice, a hallmark of linear programming problems.

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المستخلص

تهدف هذه الدراسة إلى تحويل مشكلة برمجة خطية متعددة الخيارات إلى مشكلة برمجة رياضية تقليدية، مع التركيز على القيود ذات الطبيعة "المتعددة الخيارات" على الجانب الأيمن منها. أي قيد قد يحتوي على العديد من الأهداف، كل منها يتطلب اختيارًا دقيقًا. لاختيار الأهداف بحكمة، تأكد من أن دمج الخيارات لكل قيد يؤدي إلى أفضل نهج لدالة الهدف. للحصول على أفضل النتائج، جرب بعض التركيبات المختلفة. ومع ذلك، فإن تقنيات البرمجة الخطية التقليدية غير كافية لحل المشكلة. تقدم هذه الدراسة تقنية تحويل جديدة لمعالجة مشكلة البرمجة الخطية متعددة الخيارات الحالية. يتم إنشاء نموذج برمجة مختلطة غير خطية باستخدام المتغيرات الثنائية في نهج التحويل. يمكن العثور على أفضل إجابة للنموذج المقترح باستخدام طرق البرمجة غير الخطية التقليدية. تم استخدام نموذج الاختيار المتعدد لإدارة الطلب المتغير على أنواع البنزين المختلفة في مصافي النفط، مما يضمن تلبية الكميات المطلوبة مع معالجة عدم اليقين؛ وقد أظهر الأنموذج فعاليته في تحديد الخيار المثالي.

معلومات البحث

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