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The Role of Linear Programming and Sensitivity Analysis in Improving the Transportation and Distribution of Vegetable Oils: A Case Study of the State Company for Vegetable Oils in Iraq

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ENGLISH ARTICLE

The Role of Linear Programming and Sensitivity Analysis in Improving the Transportation and Distribution of Vegetable Oils: A Case Study of the State Company for Vegetable Oils in Iraq

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ABSTRACT

The State Company for Vegetable Oils in Iraq faces a fundamental challenge of high transportation costs and inefficiency in distributing products across factories and warehouses to meet growing demand. Accordingly, this study aims to employ operations research methods—specifically linear programming and sensitivity analysis—to design a distribution plan that enhances efficiency and minimizes costs.

The methodology involved developing a mathematical model of the transportation problem based on actual data related to supply quantities, demand requirements, and transportation costs between production sources and distribution outlets. The model was solved using **WinQSB** software to determine the optimal solution. Sensitivity analysis was then conducted to assess the impact of changes in supply, demand, and transportation costs on the stability of the solution.

The results showed that applying linear programming led to an optimal distribution plan with a total cost of **$1,547,800**, representing the lowest possible cost compared to alternative plans. Sensitivity analysis further demonstrated that the model provides flexibility in handling input variations while maintaining effectiveness within specific limits.

These findings confirm the effectiveness of operations research in improving the efficiency of transportation and distribution processes in the industrial sector, highlighting its role as a decision-support tool that reduces costs and strengthens organizational competitiveness.

Keywords: Linear programming, Sensitivity analysis, Transportation problem, Vegetable oils

1. Introduction

The importance of employing operations research methods in modern management has increased as a result of the significant growth in the size and complexity of administrative

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and production problems. Traditional approaches based on personal experience or trial and error are no longer sufficient to achieve the required efficiency. Transportation and distribution activities are among the most critical areas in this regard, as they represent a fundamental component of supply chain management and involve substantial financial costs that directly affect the competitiveness of industrial organizations (Stockemer et al., 2019).

Linear programming and sensitivity analysis are among the most effective quantitative tools that enable the formulation of transportation and distribution problems into precise mathematical models. These tools assist decision-makers in identifying optimal alternatives and minimizing costs as much as possible. Despite the wide range of global studies on this subject, practical applications of these methods in the food industry sector in Iraq remain limited, highlighting a research gap that requires further attention (Borgonovo, 2023; Gass, 2003).

Accordingly, this study aims to develop a mathematical model using linear programming supported by sensitivity analysis to optimize the distribution of products of the State Company for Vegetable Oils in Iraq. The objective is to reduce transportation costs and achieve greater efficiency in distribution management. Furthermore, the research seeks to demonstrate the practical value of operations research methods in supporting administrative decision-making and enhancing the economic performance of industrial enterprises.

2. Search problem

The State Company for Vegetable Oils in Iraq faces a fundamental challenge of high transportation costs and inefficiency in distribution between factories and warehouses to meet increasing demand. Although operations research provides advanced quantitative tools—such as linear programming and sensitivity analysis—to propose optimal solutions to these problems, practical applications of these tools in the Iraqi food industry remain limited. This highlights an important research gap that requires further investigation.

Accordingly, the research problem can be formulated as follows:

To what extent do linear programming and sensitivity analysis contribute to reducing transportation costs and achieving optimal distribution of vegetable oils in Iraq?

3. Research objective

This study aims to analyze the transportation and distribution problem in the State Company for Vegetable Oils in Iraq by achieving the following objectives:

1. **To develop a mathematical model using linear programming** in order to determine the optimal distribution plan that minimizes transportation costs and improves the efficiency of resource utilization.
2. **To apply sensitivity analysis** to the proposed model to evaluate the stability of the optimal solution under potential changes in supply, demand, and transportation costs.

4. Operations research concept

4.1. Definition

Operations research is an applied branch of management sciences concerned with the use of mathematical methods and quantitative models to support decision-makers in analyzing complex problems and identifying optimal alternatives. According to the British Operations Research Society, it is “the systematic application of scientific and mathematical methods in studying large and complex problems related to the management of systems involving labor, equipment, raw materials, and other resources, with the purpose of supporting decision-making and achieving the best possible outcomes.” Thus, operations research represents a precise scientific tool that avoids randomness and trial-and-error approaches, aiming instead to provide quantitative, applicable solutions (Churchman et al., 1957; Sakarovitch, 2013).

4.2. Advantages

- Provides the ability to formulate administrative and economic problems into clear mathematical models.
- Assists in selecting optimal alternatives and reducing risks associated with decisions.
- Contributes to saving time, effort, and costs when searching for practical solutions.
- Enables forecasting of outcomes and assessing the effects of different variables through sensitivity analysis (Borgonovo, 2023; Iheonu & Inyama, 2016; Lee, 2006; Miller, 2014).

4.3. Methods

Operations research relies on several quantitative methods, the most notable of which are (Badra, 2007; Dharma & Ahmad, 2005; Karloff, 2008):

- **Linear programming:** for allocating limited resources to achieve objectives such as minimizing costs or maximizing profits.
- **Transportation and distribution models:** to determine the optimal plan for transferring products from production centers to demand locations.
- **Queuing theory, inventory control, and network analysis:** tools used according to the nature of the problem.

4.4. Relevance to the study

The role of operations research is particularly evident in the field of transportation and distribution, as these activities represent one of the costliest components of supply chain management. By employing **linear programming and sensitivity analysis**, transportation and distribution problems of the State Company for Vegetable Oils in Iraq can be formulated into a mathematical model that identifies the optimal quantities to be transferred between factories and warehouses. Consequently, operations research contributes to **reducing costs and increasing distribution efficiency**, which represents the core objective of this study.

5. Linear programming

Linear programming is a mathematical technique that seeks a solution to a specific problem, helping to find the optimal solution by allocating the limited resources used to different uses, taking into account obligations or restrictions that may be the number of working hours, the quantity of a particular product to be produced or distributed, the amount of raw materials available, etc. Among the problems addressed by linear programming are determining product configurations, planning production and inventory,

Table 1. Operational research methods used in organizations (Najm, 2008).

	Production and Operations Management	Transport and marketing	Storage	Human resources management	Financial management
linear programming	Life is beautiful	Optimal distribution of products		Optimal use of human resources	Optimize the allocation of existing resources
Transportation models	Exchanges between production lines	Factory Marketing	Transfer of purchases from the warehouse		
Business networks	Project implementation	flow of resources and goods			
Decision analysis	The world is beautiful		Identify the best purchasing sources		Determine the best investment returns
inventory control			Determine the amount of the economic payment		

preparing machine operating schedules, analyzing traffic problems, transportation problems, evaluating jobs, etc (Karloff, 2008).

There are many situations that require the allocation of limited resources to alternative uses. The linear programming method focuses on the process of allocating these resources to these uses in an ideal manner, that is, according to a specific priority criterion. The situations requiring the use of linear programming are varied. It is used for the allocation or distribution of production resources among products, investment planning, product transportation scheduling, production planning, solving matching patterns and many other problems that linear programming can help solve (Gass, 2003).

Linear programming has fundamental properties and conditions that allow it to be formulated as a mathematical model. The most important of these conditions are (Dharma and Ahmad, 2005; Karloff, 2008):

- There is a specific objective to be achieved, such as maximizing profits or minimizing costs. This objective is called the "objective function" or "economic function."
- The presence of limited resources, with the possibility of using them in different ways, is expressed by technical constraints.

If we assume that we have (n) variables and express the relationships between the variables and the available resources or production conditions, for example, with (m) equations or inequalities, then the general form of these restrictions is (Khalaf et al., 2021):

$$r_{1j}y_1 + r_{2j}y_2 + r_{3j}y_3 + \cdots + r_{nj}y_n \leq, =, \geq p_i$$

Where p_i represents the available quantity of raw material, and y_i represents the variables of the model whose values we seek to find and represent the quantities produced, for example, of certain goods.

r_{1j} represents the quantity used from resource p_i to produce one unit of the first product, r_{2j} represents the quantity used from resource p_i to produce one unit of the second product, and so on (Lee, 2006).

There are restrictions called non-negativity restrictions, which mean that negative values are not allowed in the linear model $y_i \geq 0$.

The objective function is to maximize profits or minimize costs, as follows: $Max\ or\ Min\ S = c_1y_1 + c_2y_2 + c_3y_3 + \cdots + c_ny_n$, where S represents the value of profit, for example if the function is maximized, while in the case of minimization, S can be a cost. The values of c_j represent the selling price of a unit if the economic function is maximized, and in the case of minimization, they represent the cost of producing a unit (Lee, 2006).

The mathematical model is formulated as follows (Sakarovitch, 2013; Stockemer et al., 2019):

$$Max\ or\ Min\ S = \sum c_jy_j$$

$$p_i \ \leq, =, \geq \sum r_{ij}y_j$$

$$y_j \geq 0$$

6. Solve linear programming problems

After creating and formulating the linear program, comes the step of solving this program, where linear programming problems can be solved using the graphical method, and they can also be solved using the simplex method (Dharma and Ahmad, 2005; Gass, 2003; Miller, 2014).

- **Solving Linear Programming Problems Using the Graphical Method:** The simplest method for solving a linear programming problem is the graphical method, which is used to solve problems that contain only two variables. the steps to solve a linear program using this method are:
- Draw lines that represent equations or inequalities and express technical constraints in a perpendicular plane.
- Determine the domain in which each technical constraint is satisfied, i.e., determine the engineering domain in which the technical constraint is satisfied.
- Determine the region common to the technical constraints, that is, the region where all the technical constraints are satisfied, including the non-negativity constraints. This region is generally limited to several points.
- In order to determine the furthest point that maximizes the objective function or the lowest point that brings the objective function to its minimum value, two methods can be used:

A. We substitute the coordinates of the vertices of the possible solution region into the objective function and choose the largest value in the case of maximization, while in the case of minimization we choose the smallest value.

B. We draw a ray starting from the origin and extending to the point that represents the coefficients of the two variables of the objective function in coordinate form.

- We draw a line perpendicular to this ray and passing through the origin (0,0), where this line represents the objective function when it is zero.
- We shift this line perpendicular to the ray. If the optimality condition of the objective function is maximization, then the optimal solution is the one that satisfies the technical constraints and simultaneously gives the largest division of Z, that is, the point furthest from the origin, belongs to the region of possible solutions and touches the line perpendicular to the ray.

- If the objective function is in a state of minimization, the optimal solution is the one that fulfills the technical constraints and at the same time gives the lowest or minimum value for, i.e. the point closest to the principle and belongs to the region of possible solutions and touches the line perpendicular to the ray.
- Then the coordinates of this point are substituted into the objective function and we find the value of Z, which is the optimal value for the objective function.

– **Solving Linear Programming Problems Using the Simplex Method:** In most cases, linear programming problems involve not just two variables, but three, four, or even more. Therefore, it is necessary to find a method to solve linear programming problems involving more than two variables. The simplex method is considered the most effective for solving this type of problem. We will first discuss solving linear programming problems using the simplex method for models of the form (Jensen & Bard, 2002):

$Max\ or\ Min\ S = \sum c_j y_j$

$p_i \ \le \sum r_{ij} y_j$

$y_j \ge 0$

Which models have technical constraints in the form less than or equal to, and in order to solve any model of the previous form, we follow the following steps:

– We transform the technical limitations of form $\le$ In the form of the equations by adding a variable symbolized by (S_i) to the left side, the inequality then becomes of the form: $\sum r_{ij} y_j + S_i = 0$ then we add the difference variables to the objective function, but with zero coefficients, which becomes: $\sum c_j y_j + 0S_1 + 0S_2 + 0S_3 + \cdots + 0S_n$.

– We transfer this data into a table called the initial solution table, which is as follows:

the solution	Difference variables	base variables	
	$S_1, S_2, S_3, \ldots, S_n$	$y_1, y_2, y_3, \ldots, y_n$	Objective function variables
	0 0 0 … 0	$-c_1 - c_2 - c_3, \ldots, -c_n$	Coefficients of the objective function
p_1	1 0 0 … 0	$a_{11}\ a_{12}\ a_{13}\ \ldots\ a_{1n}$	Initial solution variables S_i
p_2	0 1 0 … 0	$a_{21}\ a_{22}\ a_{23}\ \ldots\ a_{2n}$	
…	....	....	
p_m	0 0 0 … 1	$a_{m1}\ a_{m2}\ a_{m3}\ \ldots\ a_{mn}$	

– The coefficients of the objective function are multiplied by (-1), then we start solving the model by looking for the initial solution and then the final solution.

– The initial solution represents the inactivity condition, which means that the values of $y = 0$. In this case, all variables of the objective function are equal to zero, and therefore the objective function is equal to zero.

– The difference variables in the initial solution table are equal to the values on the right side, which is the amount of available resources (p_i), meaning that $(S_1 = p_1,\ S_2 = p_2, \ldots, S_m = p_m)$ the initial solution is acceptable if the objective function is zero and if the coefficients of the technical constraint difference variables form the identity matrix, next comes the step of finding the optimal solution: if the initial solution is acceptable, we rely on it or start from it to find an optimal solution, The following steps are followed:

- We start by entering the basic variables one by one into the solution rule, where the entry criterion is the least negative value in the case where the objective function is a maximizing function, while in the case of cost minimization the criterion is the largest positive value.

- When a variable is introduced into the solution rule, a variable must be excluded from the initial variables of the solution. To find out which initial variables are excluded from the solution rule, we calculate the ratio ($\frac{p_i}{r_{ij}}$) we choose the lowest percentage among the values obtained.
- It is known that the coefficients of the variables in the initial solution form a unit matrix between them. Therefore, when a variable is removed from the initial solution, the added variable must take the values of the removed variable, thus becoming a unit matrix with the other variables in the solution.
- We stop searching for an optimal solution when all the coefficients of the objective function become positive or zero in the case of the profit-maximizing objective function, or all become negative or zero in the case of the cost-minimizing objective function.

After presenting the theoretical solution methods such as the graphical method and the simplex method, it is essential to highlight how these techniques are practically implemented using specialized software. Therefore, the following section introduces the computer-based application of linear programming, demonstrating how tools such as WinQSB were employed to solve the transportation model in this study.

7. Computer-based implementation of linear programming solutions

The application of linear programming extends beyond the theoretical dimension to the practical implementation through specialized software that provides solution algorithms and enables the structured input of data. In this study, **WinQSB** software was employed as it is one of the widely used tools for analyzing transportation and distribution problems. The program allows for entering supply, demand, and transportation cost data in matrix form, then generates the optimal solution using the simplex algorithm tailored for transportation problems. It also provides detailed reports that specify the quantities to be transported from each factory to each demand point, the total optimal cost, and the results of **sensitivity analysis**, which indicate the stability of the solution when changes occur in supply, demand, or transportation costs.

Such software represents a practical and efficient alternative to manual calculations, as it saves time and effort while enabling researchers and decision-makers to rebuild the model quickly when new data are introduced. Moreover, computer-based implementation makes it possible to handle large-scale real transportation problems that are difficult to solve manually. Accordingly, incorporating the computational aspect in this study enhances the reliability of the results and reinforces their applicability within the operational context of the State Company for Vegetable Oils in Iraq.

8. The practical side

Linear programming represents one of the most important practical applications of operations research. It is used, alongside other OR methods, to address transportation and distribution problems. In this study, linear programming was applied to the problem of transporting and distributing vegetable oils.

In this format, each row represents a supply source (factory), and each column represents a demand point (region). The values in the middle of the table indicate transportation costs per unit.

The values in the table are the transportation costs per unit, and if we symbolize the quantity that needs to be transported from the source to the requesting party as y_{ij}, then

Table 2. Shows the supply and demand of vegetable oils in tonnes.

	vegetable oil factories					
	S_1	S_2	S_3	S_4	S_5	Demand (thousand units)
D_1	112	33	79	23	55	6400
D_2	97	44	69	18	48	9500
D_3	116	72	91	36	30	10000
D_4	61	47	87	28	105	6000
D_5	104	73	64	80	110	4000
D_6	5	63	100	72	138	4200
the offer	7000	5000	8000	3000	10000	

the cost of transporting quantity y_{ij} from the source to the requesting party is $y_{ij},\ C_{ij}$ the total cost of transporting all quantities from the source to the requester is as follows: $S_n = \sum_{i=1} \sum_{j=1} y_{ij} C_{ij}$ finding the smallest possible total transport network between the source and the demander, thus reducing the total transport cost, requires determining the values of the quantities to be transported, which reduces the objective function to the maximum, taking into account the technical constraints. We also note that demand is greater than supply: 40100 demand-side unit vs. 33000 One unit on the supply side, meaning the model is open. This is a special case of transportation problems. To solve it, we assume the source is imaginary and displays a quantity equal to the difference between the two values (40100 – 33000 = 7100) this deficiency is actually filled by other sources.

The solution to the mathematical model of this problem is as follows:

$$Min\ S = 112x_{11} + 33x_{12} + 79x_{13} + 23x_{14} + 55x_{15} + 97x_{21} + 44x_{22} + 69x_{23} + 18x_{24} + 48x_{25}$$

$$+116x_{31} + 72x_{32} + 91x_{33} + 36x_{34} + 30x_{35} + 61x_{41} + 47x_{42} + 87x_{43} + 28x_{44} + 105x_{45}$$

$$+104x_{51} + 73x_{52} + 64x_{53} + 80x_{54} + 110x_{55} + 5x_{61} + 63x_{62} + 100x_{63} + 72x_{64} + 138x_{65}$$

$s.t:$

$$y_{11} + y_{12} + y_{13} + y_{14} + y_{15} = 6400$$

$$y_{21} + y_{22} + y_{23} + y_{24} + y_{25} = 9500$$

$$y_{31} + y_{32} + y_{33} + y_{34} + y_{35} = 10000$$

$$y_{41} + y_{42} + y_{43} + y_{44} + y_{45} = 6000$$

$$y_{51} + y_{52} + y_{53} + y_{54} + y_{55} = 4000$$

$$y_{61} + y_{62} + y_{63} + y_{64} + y_{65} = 4200$$

$$y_{11} + y_{21} + y_{31} + y_{41} + y_{51} = 7000$$

$$y_{12} + y_{22} + y_{32} + y_{42} + y_{52} = 5000$$

$$y_{13} + y_{23} + y_{33} + y_{43} + y_{53} = 8000$$

$$y_{14} + y_{24} + y_{34} + y_{44} + y_{54} = 3000$$

$$y_{15} + y_{25} + y_{35} + y_{45} + y_{55} = 10000$$

$$y_{16} + y_{26} + y_{36} + y_{46} + y_{56} = 3000$$

$$y_{ij} \geq 0$$

The following results were obtained after applying the Win Qsb program, which shows that region (D_1) can be supplied with 5,000 units from source (S_2) at a cost of $171,000 and 600 units from source (S4) at a cost of $170,000, the second region (D2) can be supplied with 7,000 units from source (S3) at a cost of $490,000 and 2,500 units from source (S4) at a cost of $425,000, region (D3) can be supplied with 10,000 units from source (S5) at a cost of $310,000, region (D4) can be supplied with 2,800 units from source (S1) at a cost of $173,600, region (D5) can be supplied with 1,000 units from source (S3) at a cost of $630,000, region (D6) can be supplied with 4,200 units from source (S1) at a cost of $168,000, and the optimal total cost to transport all the products from the source to the requesting party is $1,547,800, which is the lowest possible total transportation cost.

9. Sensitivity analysis of the objective function to variations in supply and demand

The results we have reached previously are correct in the case of unchanged transport costs from source to demander, and also in the case of constant supply and demand, but in reality, these values are constantly changing, especially with regard to supply and demand. therefore, a sensitivity study or analysis is a study of the effect of changes in inputs on the mathematical model representing the problem and its solution (outputs), to do this, the linear model can be solved again after adding the changes that have occurred to it. However, this method is not practical and requires a lot of time, especially if many changes are made.

Since the transport model is considered a special case of linear programming, we study its sensitivity analysis, i.e., the variations in transport costs when supply and demand vary, in some cases, the values on the right side of supply and demand change, so that the values of the corresponding variables in the model remain stable (Badra, 2007).

Within this range, the model remains valid as long as the values of the corresponding variables are stable. Outside this range, the model becomes unsuitable for studying the problem and another linear model must be reconstructed for this problem.

In order to calculate the values of the range of variation on the right side of the technical constraints (supply and demand), we multiply the values of the right column in the table of the final optimal solution by 1, then we divide these values by the values of the column whose range of variation we want to evaluate, then among these values we choose the least positive value and the largest negative value, and we will explain this as follows.

For the first order item (6400) units:

$$p_1 : \frac{-6400}{-M} = \infty$$

$$\frac{-3000}{1} = -3000$$

$$\frac{-10000}{-1} = 10000$$

$$\frac{-1000}{0} = Unknown$$

$$\frac{-4000}{1} = -4000$$

$$\frac{-7000}{0} = Unknown$$

$$\frac{-5000}{0} = Unknown$$

$$\frac{-2000}{-1} = 2000$$

$$\frac{-3000}{-1} = 3000$$

$$\frac{-3000}{0} = Unknown$$

$$\frac{0}{0} = Unknown$$

Among these values, the highest negative value was chosen (−4000) and the least positive value (2000) it is:

$$-4000 \le p_1 \le 2000$$

$$-4000 + 6400 \le p_1 \le 2000 + 6400$$

$$2400 \le p_1 \le 8400$$

This shows that the value of demand 6400 for the first region can vary within this range without affecting the mathematical model, i.e., the model remains valid. To find out the magnitude of the impact on the value of the objective function, i.e., the change in the total cost of transferring the cost of products from the source to the demander, we multiply the shadow price, which is the value of the first corresponding variable, by the increase or decrease in the quantity demanded by the first region. We add or subtract this amount from the value of the objective function, and we obtain the new cost. And so on for the remaining quantities demanded and supplied.

10. Solution steps using WinQSB software

After formulating the transportation model mathematically, the solution process was implemented using the **WinQSB software**, which provides a structured procedure for solving linear programming and transportation problems. The steps followed were as follows:

1. **Data Input**
   - A transportation table was created in WinQSB, where the **rows represented the supply sources (factories)** and the **columns represented the demand points (regions)**.
   - The corresponding **transportation costs per unit** were entered into the cells of the matrix.
   - The total supply for each source and the total demand for each destination were also entered.
2. **Model Verification**
   - WinQSB automatically checked whether the total supply equaled total demand.
   - Since the model was unbalanced (demand exceeded supply), a dummy source was added by the program to absorb the difference and ensure feasibility.
3. **Initial Feasible Solution**
   - The software generated an initial feasible solution using standard methods (Northwest Corner, Least Cost, or Vogel's Approximation).
   - This provided a valid but not necessarily optimal allocation.
4. **Optimization (Simplex Method for Transportation)**
   - The program applied the **Modified Distribution Method (MODI)** to test the optimality of the initial solution.
   - Iterative adjustments were made until the lowest possible total transportation cost was obtained.
5. **Sensitivity Analysis**
   - After achieving the optimal solution, WinQSB performed a sensitivity analysis.
   - This analysis examined how changes in **supply, demand, or transportation costs** would affect the stability of the solution, thereby providing decision-makers with flexibility in planning.

11. Conclusions and recommendations

The findings of this study revealed that applying linear programming to the transportation and distribution problem of the State Company for Vegetable Oils successfully minimized the total transportation cost to **$1,547,800**, representing the optimal solution compared to alternative plans. Sensitivity analysis further demonstrated that the model is highly flexible in handling variations in supply, demand, and transportation costs, thereby confirming its applicability in real industrial contexts.

Thus, the study highlights that the use of operations research techniques—particularly linear programming—constitutes an effective decision-support tool in the Iraqi food industry, enabling cost reduction and improved distribution efficiency.

12. Recommendations

1. **Practical level:**
   - Industrial organizations should adopt quantitative models as supportive tools for planning and distribution.
   - Establish accurate databases for transportation costs, supply, and demand to ensure continuous model updates.

- Integrate specialized software such as **WinQSB** or modern alternatives into planning and production departments.

2. **Research level:**
   - Extend the application of operations research methods to other industrial sectors in Iraq, such as pharmaceuticals and food industries.
   - Explore combining linear programming with other techniques (e.g., goal programming, stochastic models) to address uncertainty.
   - Conduct future studies on integrating artificial intelligence and predictive analytics with transportation and distribution models.

Conflict of interest

The authors declare no conflict of interest.

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Author contribution

Data availability

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

References

Badra, N. M. (2007). Sensitivity analysis of transportation problems. *Journal of Applied Sciences Research 3*(8), 668–675.

Borgonovo, E. (2023). Sensitivity analysis. *Tutorials in operations research: Advancing the frontiers of OR/MS: From methodologies to applications* 52–81.

Churchman, C. W., Ackoff, R. L., & Arnoff, E. L. (1957). Introduction to operations research.

Dharma, S., & Ahmad, A. (2005). Optimization of transportation problem with computer aided linear programming. In *Proceedings of the Postgraduate Annual Research Seminar* (p. 140).

Gass, S. I. (2003). Linear programming: methods and applications. Courier Corporation.

Iheonu, N., & Inyama, S. (2016). On the optimization of transportation problem. *British Journal of Mathematics & Computer Science 13*(4), 1–11.

Jensen, P. A., & Bard, J. F. (2002). *Operations research models and methods*. John Wiley & Sons.

Karloff, H. (2008). *Linear programming*. Springer Science & Business Media.

Khalaf, W. S., Khalaf, B. A., & Abid, N. O. (2021). A plan for transportation and distribution the products based on multi-objective travelling salesman problem in fuzzy environmental. *Periodicals of Engineering and Natural Sciences 9*(4), 5–22.

Lee, Y. J. (2006). Transit network sensitivity analysis. *Journal of Public Transportation 9*(1), 21–52.

Miller, E. J. (2014). Transportation models. In *Handbook of microsimulation modelling* (Vol. 293, pp. 385-420). Emerald Group Publishing Limited.

Najm, A. (2008). Introduction to quantitative methods with application using Microsoft Excel. Amman, Jordan: Al-Warraq for publishing and distribution.

Sakarovitch, M. (2013). *Linear programming*. Springer Science & Business Media.

Stockemer, D., Stockemer, G., & Glaeser, J. (2019). Quantitative methods for the social sciences (Vol. 50, p. 185). Cham, Switzerland: Springer International Publishing.