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Application of Metaheuristic Algorithms for Optimized Cattle Market Distribution and Logistics Network Design

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Abstract

This study investigates the application of heuristic optimization techniques to the classical transportation problem within the context of cattle distribution logistics in Niger State, Nigeria. Heuristic methods, which are widely employed for solving computationally intractable or large-scale optimization problems, provide efficient, intuitive, and near-optimal solutions by exploiting the structural properties of the problem. Their computational efficiency and simplicity make them particularly suitable for real-world logistics systems characterized by multiple supply and demand nodes. The research focuses on optimizing the distribution of cattle from seven major markets—Bangi, Beji, Ibetto, Kawon-Kontagora, Kuta, Mariga, and Tungan-Malam—to selected demand centers in Southwestern Nigeria, including Akure, Ibadan, Ilorin, Ijebu-Ode, Lagos, and Oshogbo. The primary objective is to minimize total transportation cost while satisfying supply and demand constraints across the network. An initial basic feasible solution (IBFS) was obtained using a heuristic approach, yielding a total transportation cost of ₦49,992,919.16. To evaluate optimality, the solution was tested using the Modified Distribution Method (MODI/MDK), which indicated that the heuristic-derived solution was not optimal. Consequently, further optimization was performed using the solver tool in Microsoft Excel Solver, which generated an improved optimal solution with a reduced transportation cost of ₦46,321,081.96. The results demonstrate the effectiveness of heuristic methods in generating rapid and reasonably efficient initial solutions, while highlighting the importance of integrating exact optimization techniques for achieving global optimality in livestock transportation planning systems.

Keywords

Heuristic Methods,
Transportation Problems,
Modified Distribution Method,
Minimum Cost,
Optimization,
Stepping Stone Method

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INTRODUCTION

Cattle are widespread in Nigeria, with the highest concentrations in the northern regions. Seasonal migrations from north to south occur, while nearly half of the country's cattle population resides permanently in the sub-humid zone. Nigeria's cattle population comprises various breeds, including: Humped Zebu, predominantly found in north-central and north-western Nigeria. Keteku, found in limited numbers in south-western Nigeria. Muturu, common in southern regions and Kuri cattle, prevalent in north-eastern Nigeria. (Mubi et al 2013).

Cattle business, no doubt, is a lucrative business employing a large number of people across the nation, especially in Zamfara, Sokoto, Katsina, Borno, Yobe, Jigawa, Adamawa, Kano, Bauchi and part Niger and Kaduna areas of the north where it is common to see entire families or communities earning their livelihood from cattle rearing. One of the primary reasons for Fulanis in taking their animals to distant markets, a pattern of movement has emerged over the years where the Fulanis transfer cattle from producing areas in the north to the consuming areas in the south. The policy of the government on livestock transportation is noticed in extension of roads that will link rural settlers with urban settlers.

The origin of transportation models dates back to 1941 when F. L. Hitchcock presented a study entitled "The Distribution of Product from Several Sources to Numerous Localities." The presentation is regarded as the first important contribution to the solution of transportation problems. In 1947, T. C. Koopman presented a study called "Optimum Utilization of the Transportation System."

These two contributions are mainly responsible for the development of transportation models which involve a number of shipping sources and a number of destinations. Each shipping source has a certain cost capacity and each destination has a certain requirement associated with a certain cost of shipping from the sources to the destinations. The objective is to minimize the cost of transportation while meeting the requirements at the destinations. To run a successful cattle business, you will have to select a cattle market where the cattle trader will purchase the cattle to be delivered whenever the customers need them. If you have only one cattle market, it will be supplying all your customers. However, as soon as you expand too many markets, you will have to make an important decision on the number of cattle at which market will be transported to which of the destinations? Depending on the choice you make, you might save or spend a significant amount of money.

The transportation problem is a distribution - type problem, the main goal is to decide how to transport cattle from various sending locations (also known as origins) to various receiving locations (also known as destinations) with minimal cost or maximum profit. Distribution model or Transportation model deals with the transportation of cattle available at several sources to number of different destinations. As outlined in "Guidelines for Humane Handling, Transport and Slaughter," by Chambers et al (2001). Transporting food animals is crucial in commercial agriculture and, to a lesser extent, in rural or subsistence farming. Animals are moved for various reasons, including marketing, slaughter, restocking, relocating from drought areas to better grazing lands, and transferring ownership.

Mubi et al (2013), Cattle marketing plays a vital role in Nigeria, offering significant economic, social, and cultural benefits to those involved in cattle rearing and marketing. Assessment of costs and returns of cattle marketing in central Adamawa State, Nigeria. Primary data were collected from 120 cattle marketers using a structured questionnaire, with 90 responses analyzed. The study used descriptive statistics (frequency, percentage, and mean) and inferential statistics to analyze the 2012 data. Marketing of cattle just like in any other market in the state is a crucial human invention. It embraces the activities engaged in order to satisfy the economic needs and wants of the people. With these perspectives, cattle marketing can be said to be the performance of all business activities which direct the smooth flow of cattle between breeders, fatteners, sellers and consumers so as to accomplish the producer's objectives. Marketing is a function of so many factors among which include; pricing, transportation, financing and risk bearing (Girei, et al, 2013).

Mafimisebi (2013), this study explored cattle marketing fundamentals in Southwest Nigeria, analyzing primary data from 120 respondents selected via multi-stage sampling. Using descriptive statistics, budgeting, and price formation models, the research revealed a well-organized cattle market with profitable opportunities and potential for employment. To enhance commercialization and performance, recommendations include strengthening marketing institutions, capacity building for stakeholders, reviving rail systems, and improving road infrastructure.

Benefits of Heuristic Method; Easy to Understand: Heuristic methods are relatively

simple to understand and implement. *Fast Solution:* Heuristic methods can provide a solution quickly, even for large problems. *Near-Optimal Solution:* Heuristic methods can provide a near-optimal solution, which may be sufficient for many practical applications.

Limitations of Heuristic Method; No Guarantee of Optimality: Heuristic methods do not guarantee an optimal solution. *May Get Stuck in Local Optima:* Heuristic methods may get stuck in local optima, rather than finding the global optimum.

While heuristic methods can handle complex designs, they're often computationally costly for bi-level problems, especially with many constraints. Therefore, this paper explores classical approaches, which offer a more efficient solution for such complex problems (Biswas & Hoyle, 2019). Silver (1980), defines a heuristic method as an intuitive approach to solving mathematical problems. It leverages the problem's structure to find reasonable solutions, combining insight and intelligent exploitation.

In a comprehensive review of transportation problems using the Analytic Hierarchy Process (AHP) to evaluate criteria and alternatives by Moslem et al (2023). A systematic review methodology (PRISMA protocol) was employed. The study highlights AHP's contributions and extensions in enhancing decision-making support for transportation issues. In a review carried out on transportation problems and solutions. The study examines various problem types, objectives, and constraints, as well as key algorithms used to address them, providing insights into effective transportation optimization (Malacký & Madleňák, 2023).

This study serves as a guide to understanding various transportation problems, presenting a comprehensive survey of mathematical models and algorithms. Díaz-Parra, (2014), it covers diverse transportation modes (ship, plane, train, bus, truck, etc.) and mediums (air, water, space, cables, tubes, and road). This study enhances existing tanker-routing models by developing a novel transportation linear programming algorithm. Our approach optimizes the distribution of petroleum products from supply centers (refineries) to demand centers (filling stations) at minimal cost, building on discrete integer programming methods. (Ogumeyo & Omole, 2024).

This review explores uncertainty in transport planning research from multiple perspectives. Navarro-Ligero *et al* (2019), proposes a heuristic framework identifying three uncertainty sources: reality, knowledge, and products. The framework examines how uncertainties are identified, translated into planning concepts, and managed in decision-making. This research reviews metaheuristics for solving routing problems in Vehicular Ad Hoc Networks (VANETs). It discusses various approaches, technical challenges, and future trends in this field (Hajlaoui *et al*, 2016).

Mohri *et al* (2022), focuses on hazmat routing, routing-scheduling, and network design problems. It has two main objectives: (1) reviewing models' assumptions, objectives, and methodologies, and (2) highlighting key features and challenges in designing models for various transportation modes. In their study addresses the gap by systematically reviewing 59 published articles, selected through a defined search criterion. The articles are categorized based on two attributes: (1) approach used to study the

problem and (2) contribution of the study, providing a structured analysis of existing research (Singh & Singh, 2023).

Gupta & Gulati (2019), examines transportation and distribution problems, focusing on operational management to maximize profit while minimizing cost, time, and distance. A heuristic algorithm is selected and experimentally tested, yielding effective results on standard instances and quickly finding optimal solutions. Qiuping *et al* (2023), in their study proposes a Solid Transportation Problem (STP) framework for uncertain and indeterminate environments, enabling decision-makers to customize their tolerance for acceptance, indeterminacy, and falsity. The results show that the model is flexible, practical, and well-suited for real-world applications. The algorithm's effectiveness lies in its ability to accommodate decision-makers' specific thresholds for acceptance, indeterminacy, and falsity.

These reviews conducted by Castaneda *et al* (2022), applications of simheuristics in logistics and transportation, analyzing documents in the Scopus database. It covers both early and recent uses, and identifies open research opportunities in this field. Simheuristics enhance met heuristics by integrating simulation to handle uncertainty. A review by Juan *et al* (2018), applications of simheuristics in logistics and transportation, covering both early and recent uses. It also explores current trends and identifies open research opportunities.

Cao (2022), addresses the multi-index transportation problem by developing a mathematical model and algorithm. His goal is to optimize transportation methods, reducing

costs and time. Experimental results demonstrate the model's high efficiency in solving complex transportation problems. Transport and logistics face challenges with large-scale, complex problems. However, with growing access to diverse operational data, data-driven heuristic approaches show promise in solving these problems, offering a potential breakthrough in the field (Deniz & Özceylan, 2023).

The overview of transportation-related challenges and mathematical models by Ekanayake et al (2022). These models can effectively address various business problems, particularly those involving product distribution, known as transportation problems. Abdelati et al (2023), utilizes the multi-dimensional solid transportation problem approach to optimize truck fleet allocation for a private sector company in Egypt, aiming to enhance logistics efficiency.

Kacher & Singh (2021), in their paper reviewed summarizes various transportation problem types and their developments, providing a guide for future researchers. It aims to help classify problems and select optimization criteria, facilitating research in transportation optimization. This review focuses on NP-hard problems in green logistics, which are notoriously challenging. Given the need for efficient solutions, various heuristic and hybrid techniques have emerged.

The review provides a comprehensive overview of these methods, highlighting their strategies and components (Fernández, 2022) Optimization problems are widespread across various fields, requiring optimal or near-optimal solutions within constraints. To address this, researchers focus on developing

efficient computing infrastructures to enhance meta-heuristic techniques, improving their performance. As a result, numerous heuristic algorithms have been designed to find near-optimal solutions quickly (Ahmed et al, 2020). Fidanova (2022), in his research shows how real-world problems in engineering, economics, and other fields can be modeled as optimization problems, enabling the application of mathematical techniques to find optimal solutions.

This study pioneers the application of five meta-heuristic algorithms - Flower Pollination Algorithm (FPA), Artificial Bee Colony Algorithm (ABC), Crow Search Algorithm (CSA), Krill Herd Algorithm (KH), and Butterfly Optimization Algorithm (BOA) - to predict Turkey's air transport demand. The models utilize key parameters: Fuel Price, GDP per Capita, Seat Capacity, and Annual Fuel Consumption (Korkmaz & Akgüngör, 2021). Mahmudy et al (2024), reviews an article on meta-heuristic methods for solving Vehicle Routing Problems (VRP), highlighting challenges and popular approaches, including Simulated Annealing, Genetic Algorithm, Particle Swarm Optimization, and Ant Colony Optimization.

This research advances congestion-based accessibility studies by introducing demand constraints and minimum thresholds at individual facilities. Using the bounded transportation problem, we developed novel accessibility metrics that account for congestion and threshold effects. We tested these metrics against the Rational Agent Access Model (RAAM) in a case study on access to ICU beds in Illinois (Lin & Cromley, 2023).

Al-Shaery (2022), in their study carried out, consolidates key aspects of heuristics by reviewing relevant articles, clarifying ambiguities, and summarizing previous works. It also highlights state-of-the-art heuristic solutions for real-world problems, providing a comprehensive overview.

They carried out on optimizes a soft drink company's truck distribution in Egypt using a multi-dimensional solid transportation problem approach by Abdelati et al (2024). By considering vehicle capacities, sources, and destinations, they minimized fuel consumption costs. The results showed a significant 22%

improvement compared to the company's current fleet distribution. Sahani et al (2024), explores an integrated shipping problem involving cargo aggregation, where goods forwarders combine planned and flexible delivery services under time constraints, such as shipping and pickup times.

This research by Gayialis et al (2019), presents a review of Vehicle Routing Problem (VRP) literature in urban freight transportation, based on Scopus database analysis. It provides a taxonomy of recent research, critical insights, and trends in the field.

MATERIALS AND METHODS

General Mathematical Model: The pay-off matrix of a transportation problem model is given in table 1

Table 1: Pay-off Matrix

		Destinations						Capacity
		1	2	3	...	j	n	
Sources (Origin)	1	$C_{11} X_{11}$	$C_{12} X_{12}$	$C_{13} X_{13}$	...	$C_{1j} X_{1j}$	$C_{1n} X_{1n}$	a_1
	2	$C_{21} X_{21}$	$C_{22} X_{22}$	$C_{23} X_{23}$	...	$C_{2j} X_{2j}$	$C_{2n} X_{2n}$	a_2
	3	$C_{31} X_{31}$	$C_{32} X_{32}$	$C_{33} X_{33}$	...	$C_{3j} X_{3j}$	$C_{3n} X_{3n}$	a_3
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	I	$C_{i1} X_{i1}$	$C_{i2} X_{i2}$	$C_{i3} X_{i3}$	...	$C_{ij} X_{ij}$	$C_{in} X_{in}$	a_i
	M	$C_{m1} X_{m1}$	$C_{m2} X_{m2}$	$C_{m3} X_{m3}$	...	$C_{mj} X_{mj}$	$C_{mn} X_{mn}$	a_m
Demand		b_1	b_2	b_3	...	b_j	b_n	

General Mathematical Model

$$\text{Minimize: } \sum_{i=1}^m \sum_{j=1}^n C_{ij} X_{ij} \quad (1)$$

Subject to

$$\sum_{i=1}^n x_{ij} \leq S_i \text{ for } i = 1, 2, \dots, m \text{ (supply)} \quad (2)$$

$$\sum_{j=1}^n x_{ij} \leq D_j \text{ for } j = 1, 2, \dots, n \text{ (demand)} \quad (3)$$

and $x_{ij} \geq 0$

For a feasible solution to exist, it is necessary that total capacity equals total requirements. Total supply = total demand.

$$\text{Or } \sum a_i = \sum b_j. \quad (4)$$

Assumptions in Transportation Problem

Only a single type of commodity is being shipped from an origin to a destination. Total supply is equal to the total demand. Supply (S_i) and Demand (D_j) are all positive integers.

$$\sum_{i=1}^m S_i = \sum_{j=1}^n D_j \quad (5)$$

Heuristic Method

The Heuristic method is an iterative procedure for computing a basic feasible solution of a transportation problem. Heuristic methods can be used to find near-optimal solutions to this problem. Applications of Heuristic Method; *Logistics and Supply Chain Management*: Heuristic methods can be used to optimize transportation routes and schedules. *Manufacturing and Production*: Heuristic methods can be used to optimize production planning and scheduling. *Distribution and Delivery*: Heuristic methods can be used to optimize delivery routes and schedules.

Steps for Finding Initial Feasible Solution using Heuristic Method; Calculate the penalty, Calculate the total, Calculate the product, Identify the smallest product, Identify the cell with the smallest cost, allocate as much as possible, Update the supply and demand, and repeat the process. After computing an initial basic feasible solution, we must now proceed to determine whether the solution so obtained is optimal or not. There are two methods of optimality test; Stepping Stone Method and Modified Distribution Method. For the purpose of this research Modified Distribution Method is use to test the optimality of the initial basic feasible solutions of the two methods discussed above.

RESULTS AND DISCUSSION

Table 2: Market Demand and Supply

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUPPLY
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144
Beji	13455	10024.05	12272.33	6243.24	13509.2	7308.1	752
Ibeto	13662.02	9681.34	12432.69	6486.48	14270.26	7420.56	316
Kawon-Kontagora	11592.03	9424.32	10294.58	5837.85	13318.91	6296.22	1040
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521
Mariga	12420	8569.56	10294.58	5675.67	13794.6	6745.94	400
Tungar-Malam	16249.5	6854.05	12907.85	4861.86	15697.3	8825.94	939
DEMAND	551	1533	1151	714	2496	997	

Demand is greater than supply! Recreate this model with an extra (dummy) row that has a supply equal to the difference between total supply and total demand. Dummy row has been added. Total demand = 7442, Total supply = 5112 and a dummy market with transportation cost of ₦0 and 2330 supply

Table 3: Iteration One

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUPL	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144	8189.17	64864.38	531185434.8
Beji	13455	10024.05	12272.33	6243.24	13509.2	7308.1	752	7265.96	62811.92	45638889.8.2
Ibeto	13662.02	9681.34	12432.69	6486.48	14270.26	7420.56	316	7783.78	63953.35	49779880.6.7
K/Kontagora	11592.03	9424.32	10294.58	5837.85	13318.91	6296.22	1040	7481.06	56763.91	424654216.5
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	8064.86	71525.71	57684483.7.6
Mariga	12420	8569.56	10294.58	5675.67	13794.6	6745.94	400	8118.93	57500.35	466841316.6
T/Malam	16249.5	6854.05	12907.85	4861.86	15697.3	8825.94	939	11387.64	65396.5	744711799.3
Dummy	0	0	0	0	0 2330	0	2330	0	0	0
DEMAND	551	1533	1151	714	2496	997				
Penalty(P)	16249.5	10538.03	12907.85	8108.1	16172.96	8825.94				
Total(T)	96876.02	65372.42	83621.75	43294.29	101033.49	52618.15				
PT	1574186887	68889652.3.1	1079377006	351034432.7	1634010592	464404634.8				

The lowest PT = 0, the minimum transportation cost = ₦0 (Dummy/Lagos) and The maximum allocation in (Dummy/Lagos) is the minimum of (2496, 2330) = 2300

Table 4: Iteration Two

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144	8189.17	64864.38	531185434.8
Beji	13455	10024.05	12272.33	6243.24	13509.2	7308.1	752	7265.96	62811.92	45638889.8.2
Ibeto	13662.02	9681.34	12432.69	6486.48	14270.26	7420.56	316	7783.78	63953.35	49779880.6.7
K/Kontagora	11592.03	9424.32	10294.58	5837.85	13318.91	6296.22	1040	7481.06	56763.91	424654216.5
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	8064.86	71525.71	57684483.7.6
Mariga	12420	8569.56	10294.58	5675.67	13794.6	6745.94	400	8118.93	57500.35	466841316.6
T/Malam	16249.5	6854.05	12907.85	4861.86	15697.3	8825.94	939	11387.64	65396.5	744711799.3
Dummy	0	0	0	0	0 2330	0	0	----	0	---
DEMAND	551	1533	1151	714	166	997				
Penalty(P)	4657.47	3683.98	2613.27	3246.24	2854.05	2529.72				
Total(T)	96876.02	65372.42	83621.75	43294.29	101033.49	52618.15				
PT	451197156.9	240830687.8	218526211	140543656	288354632	133109186.4				

The lowest PT = 133109186.400. The minimum transportation cost = ₦6296.22 (Kawon-Kontagora/Oshogbo) and the maximum allocation in (Kawon-Kontagora/Oshogbo) is the minimum of (997, 1040) = 997

Table 5: Iteration Three

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144	8189.17	57275.19	469036267.7
Beji	13455	10024.05	12272.33	6243.24	13509.2	7308.1	752	7265.96	55503.82	403288536
Ibeto	13662.02	9681.34	12432.69	6486.48	14270.26	7420.56	316	7783.78	56532.79	440038800.1
K/Kontagora	11592.03	9424.32	10294.58	5837.85	13318.91	6296.22 997	43	7481.06	50467.69	377551817
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	8064.86	63093.51	508840325.1
Mariga	12420	8569.56	10294.58	5675.67	13794.6	6745.94	400	8118.93	50754.41	412071502
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3	8825.94	225	11387.64	56570.56	644205171.9
Dummy	0	0	0	0	0	2330	0	----	0	---
DEMAND	551	1533	1151	0	166	0				
Penalty(P)	4657.47	3683.98	2613.27	---	2854.05	---				
Total(T)	96876.02	65372.42	83621.75	43294.29	101033.49	52618.15				
PT	451197156.9	240830687.8	218526211	---	288354632	---				

The lowest PT = 140543656. The minimum transportation cost = ₦4861.85 (Tungar-Malam/Ilorin). And the maximum allocation in (Tungar-Malam/Ilorin) is the minimum of (714, 939) = 714

Table 6: Iteration Four

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144	3989.19	51194.1	204222991.8
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69	6486.48	14270.26	7420.56	316	4588.92	50046.31	229658512.9
K/Kontagora	11592.03	9424.32	10294.58	5837.85	13318.91	6296.22 997	43	3894.59	44629.84	173814928.6
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	5634.93	54985.41	309838936.4
Mariga	12420	8569.56	10294.58	5675.67	13794.6	6745.94	400	5225.04	45078.74	235538219.6
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3	8825.94	225	9395.45	51708.7	485826505.4
Dummy	0	0	0	0	0	2330	0	----	0	---
DEMAND	551	781	1151	0	166	0				
Penalty(P)	3989.19	37221.59	148483994.6	---	37221.59	---				
Total(T)	3485.15	35805.58	124787817.1	43294.27	35805.58	52618.15				
PT	4588.92	36384.29	166964596.1	---	36384.29	---				

The lowest PT = 124787817.100. The minimum transportation cost = ₦10024.05 (Beji/Ibadan). And the maximum allocation in (Beji/Ibadan) is the minimum of (1533, 752) = 752

Table 7: Iteration Five

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144	3989.19	51194.1	204222991.8
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69	6486.48	14270.26	7420.56	316	4588.92	50046.31	229658512.9
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	44629.84	---
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	5634.93	54985.41	309838936.4
Mariga	12420	8569.56	10294.58	5675.67	13794.6	6745.94	400	5225.04	45078.74	235538219.6
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3	8825.94	225	9395.45	51708.7	485826505.4
Dummy	0	0	0	0	0 2330	0	0	----	0	---
DEMAND	551	738	1151	0	166	0				
Penalty(P)	3829.5	3683.98	2613.27	---	2854.05	---				
Total(T)	71828.99	55348.37	71349.42	43294.29	87524.29	52618.15				
PT	275069117.2	203902288.1	186455298.8	----	249798700	---				

The lowest PT = 173814928.600. The minimum transportation cost = ₦9424.32 (Kawon-Kontagora/Ibadan). The maximum allocation in (Kawon-Kontagora /Ibadan) is the minimum of (781.43) = 43

Table 8: Iteration Six

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144	3989.19	51194.1	204222991.8
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69	6486.48	14270.26	7420.56	316	4588.92	50046.31	229658512.9
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	33037.81	---
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	5634.93	54985.41	309838936.4
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	0	---	45078.74	---
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3	8825.94	225	9395.45	51708.7	485826505.4
Dummy	0	0	0	0	0 2330	0	0	----	0	---
DEMAND	551	738	751	0	166	0				
Penalty(P)	3829.5	3683.98	2613.27	---	2378.36	---				
Total(T)	71828.99	45924.05	61054.84	43294.29	74205.38	52618.15				
PT	275069117.2	169183281.7	159552781.7	----	176487107.6	---				

The lowest PT = 159552781.700. The minimum transportation cost = ₦10294.58 (Mariga/Ijebu-Ode) and the maximum allocation in (Mariga/Ijebu-Ode) is the minimum of (1151, 400) = 400

Table 9: Iteration Seven

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26	6081.09	14270.26	7589.19	144	3989.19	51194.1	204222991.8
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69 316	6486.48	14270.26	7420.56	0	---	50046.31	----
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	33037.81	---
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	5634.93	54985.41	309838936.4
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	0	5225.04	32658.74	170643222.8
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3	8825.94	225	9395.45	51708.7	485826505.4
Dummy	0	0	0	0	0 2330	0	0	3989.19	51194.1	204222991.8
DEMAND	551	738	435	0	166	0				
Penalty(P)	2587.48	3683.98	475.16	---	1902.7	---				
Total(T)	59408.99	37354.49	50760.26	43294.29	60410.78	52618.15				
PT	153719573.4	137613194.1	24119245.14	----	114943591.1	---				

Lowest PT = 24119245.140. The minimum transportation cost = ₦12432.69 (Ibeto/Ijebu-Ode). And the maximum allocation in (Ibeto/Ijebu-Ode) is the minimum of (751, 316) = 316

Table 10: Iteration Eight

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26 144	6081.09	14270.26	7589.19	0	---	51194.1	---
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69 316	6486.48	14270.26	7420.56	0	---	36384.29	---
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	33037.81	---
Kuta	15524.96	10538.03	12749.46	8108.1	16172.96	8432.2	1521	5634.93	54985.41	309838936.4
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	0	---	32658.74	---
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3	8825.94	225	9395.45	51708.7	485826505.4
Dummy	0	0	0	0	0 2330	0	0	----	0	---
DEMAND	551	738	291	0	166	0				
Penalty(P)	2276.99	3683.98	237.59	---	1902.7	---				
Total(T)	45746.97	27673.15	38327.57	43294.29	46140.52	52618.15				
PT	104165393.2	101947331.1	9106247.356	----	87791567.4	---				

The lowest PT = 9106247.356. The minimum transportation cost = ₦12670.26 (Bangji/Ijebu-Ode) and the maximum allocation in (Bangji/Ijebu-Ode) is the minimum of (435, 144) = 144

Table 11: Iteration Nine

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUPL	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281	12670.26 144	6081.09	14270.26	7589.19	0	---	37221.59	---
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69 316	6486.48	14270.26	7420.56	0	---	36384.29	---
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	33037.81	---
Kuta	15524.96	10538.03	12749.46 291	8108.1	16172.96	8432.2	1230	5634.93	54985.41	309838936.4
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	0	---	32658.74	---
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3	8825.94	225	8843.25	50984.16	450865672.9
Dummy	0	0	0	0	0 2330	0	0	----	0	---
DEMAND	551	738	0	0	166	0				
Penalty(P)	724.54	3683.98	---	---	1902.7	---				
Total(T)	31774.46	17392.08	25657.31	43294.29	31870.26	52618.15				
PT	23021867.25	64072074.88	---	----	60639543.7	---				

The lowest PT = 4063861.331. The minimum transportation cost = ₦12749.46 (Kuta/Ijebu-Ode) and the maximum allocation in (Kuta/Ijebu-Ode) is the minimum of (291, 1521) = 291

Table 12: Iteration Ten

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26 144	6081.09	14270.26	7589.19	0	---	37221.59	---
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69 316	6486.48	14270.26	7420.56	0	---	36384.29	---
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	33037.81	---
Kuta	15524.96	10538.03	12749.46 291	8108.1	16172.96	8432.2	1230	5634.93	42235.95	237996621.7
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	0	---	32658.74	---
T/Malam	16249.5	6854.05	12907.85	4861.86 714	15697.3 166	8825.94	59	9395.45	38800.85	364551446.1
Dummy	0	0	0	0	0 2330	0	0	----	0	---
DEMAND	551	738	0	0	0	0				
Penalty(P)	----	3683.98	---	---	---	---				
Total(T)	31774.46	17392.08	25657.31	43294.29	31870.26	52618.15				
PT	----	64072074.88	---	----	---	---				

The lowest PT = 23021867.250. The minimum transportation cost = ₦115524.96 (Kuta/Akure) and the maximum allocation in (Kuta/Akure) is the minimum of (551, 1086) = 551

Table 13: Iteration Eleven

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUPL	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26 144	6081.09	14270.26	7589.19	0	---	37221.59	---
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	---
Ibeto	13662.02	9681.34	12432.69 316	6486.48	14270.26	7420.56	0	---	36384.29	---
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	33037.81	---
Kuta	15524.96	10538.03	12749.46 291	8108.1	16172.96	8432.2	1230	4986.93	26062.99	129974306.7
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	0	---	32658.74	---
T/Malam	16249.5	6854.05 59	12907.85	4861.867 14	15697.3 166	8825.94	0	---	23103.55	---
Dummy	0	0	0	0	0 2330	0	0	----	0	---
DEMAND	551	679	0	0	0	0				
Penalty(P)	724.54	3683.98	---	---	---	---				
Total(T)	31774.46	17392.08	25657.31	43294.29	31870.26	52618.15				
PT	23021867.25	64072074.88	---	----	---	---				

Table 13: The lowest PT = 64072074.880. The minimum transportation cost = ₦6854.05 (Tungar-Malam/Ibadan) and the maximum allocation in (Tungar-Malam/Ibadan) is the minimum of (738, 59) = 59

Table 14: Final Iteration

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUP	Penalty (P)	Total (T)	PT
Bangi	13972.51	10281.07	12670.26 144	6081.09	14270.26	7589.19	0	---	37221.59	--
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	0	---	35805.58	--
Ibeto	13662.02	9681.34	12432.69 316	6486.48	14270.26	7420.56	0	---	36384.29	--
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	0	---	33037.81	--
Kuta	15524.96 551	10538.03 679	12749.46 291	8108.1	16172.96	8432.2	0	---	10538.03	--
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	0	---	32658.74	--
T/Malam	16249.5	6854.05 59	12907.85	4861.86 714	15697.3 166	8825.94	0	---	23103.55	--
Dummy	0	0	0	0	0 2330	0	0	----	0	--
DEMAND	0	0	0	0	0	0				
Penalty(P)	---	---	---	---	---	---				
Total(T)	15524.96	10538.03	25657.31	43294.29	31870.26	52618.15				
PT	---	---	---	----	---	---				

The lowest PT = 64072074.880. The minimum transportation cost = ₦6854.05 (Tungar-Malam/Ibadan) and the maximum allocation in (Tungar-Malam/Ibadan) is the minimum of (738, 59) = 59

Table 15: Initial Basic Feasible Solution

Origin	Destination	No of Cattles	Amount	Total Cost
Bangi	Ijebu-Ode	144	12670.26	1824517.44
Beji	Ibadan	752	10024.05	7538085.60
Ibeto	Ijebu-Ode	316	12432.69	3928730.04
K/Kontagora	Ibadan	43	9424.32	405245.76
K/Kontagora	Oshogbo	997	6296.22	6277331.34
Kuta	Akure	551	15524.96	8554252.96
Kuta	Ibadan	679	10538.03	7155322.37
Kuta	Ijebu-Ode	291	12749.46	3710092.86
Mariga	Ijebu-Ode	400	10294.58	4117812.00
T/Malam	Ibadan	59	6854.05	404388.95
T/Malam	Ilorin	714	4861.86	3471368.04
T/Malam	Lagos	166	15697.30	2605751.80
Total				₦49,992,919.16

The total cost of transportation is ₦49,992,919.16

Table 16: Testing the Optimality of the Allocation Using MODI Method

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUPPLY	U _i
Bangi	13972.51	10281.07	12670.26 144	6081.09	14270.26	7589.19	144	0
Beji	13455	10024.05 752	12272.33	6243.24	13509.2	7308.1	752	-434.78
Ibeto	13662.02	9681.34	12432.69 316	6486.48	14270.26	7420.56	316	-237.57
K/Kontagora	11592.03	9424.32 43	10294.58	5837.85	13318.91	6296.22 997	1040	-1034.51
Kuta	15524.96 551	10538.03 679	12749.46 291	8108.1	16172.96	8432.2	1521	79.20
Mariga	12420	8569.56	10294.58 400	5675.67	13794.6	6745.94	400	-2375.68
T/Malam	16249.5	6854.05 59	12907.85	4861.86 714	15697.3 166	8825.94	939	-3604.78
Dummy	0	0	0	0	0 2330	0	2330	-
DEMAND	551	1533	1151	714	2496	997		19302.08
V _j	15445.76	10458.83	12670.26	8466.64	19302.08	7330.73		

Calculating U_i and V_j using $U_i + V_j = C_{ij}$. Substituting $U_1 = 0$

Table 17: Calculating Opportunity Cost Using $C_{ij} - (U_i + V_j)$

Unoccupied cells	Opportunity cost	Unoccupied cells	Opportunity cost
Bangi/Akure	-1473.25	Kawo/Lagos	-4948.66
Bangi/Ibadan	-177.76	Kuta/Ilorin	-437.74
Bangi/Ilorin	-2385.55	Kuta/Lagos	-3208.32
Bangi/Lagos	-5031.82	Kuta/Oshogbo	1022.27
Bangi/Oshogbo	258.46	Mariga/Akure	-650.08
Beji/Akure	-1555.98	Mariga/Ibadan	486.41
Beji/Ijebu-Ode	36.85	Mariga/Ilorin	-415.29
Beji/Ilorin	-1788.62	Mariga/Lagos	-3131.8
Beji/Lagos	-5358.1	Mariga/Oshogbo	1790.89
Beji/Oshogbo	412.15	Tunga/Akure	4408.52
Ibeto/Akure	-1546.17	Tunga/Ijebu-Ode	3842.37
Ibeto/Ibadan	-539.92	Tunga/Oshogbo	5099.99
Ibeto/Ilorin	-1742.59	Dummy/Akure	3856.32

Ibeto/Lagos	-4794.25	Dummy/Ibadan	8843.25
Ibeto/Oshogbo	327.4	Dummy/Ijebu-Ode	6631.82
Kawo/Akure	-2819.22	Dummy/Ilorin	10835.44
Kawo/Ijebu-Ode	-1341.17	Dummy/Oshogbo	11971.35
Kawo/Ilorin	-1594.28		

The solution is not optimal because from this table, the opportunity cost has negative values.

Table 18: Shown the Optimal Solution Obtained Using MS Excel Solver

	Akure	Ibadan	Ijebu-Ode	Ilorin	Lagos	Oshogbo	SUPPLY
Bangi				144			144
Beji				570	166	16	752
Ibeto						316	316
Kawon	551		489				1040
Kuta		594	262			665	1521
Mariga			400				400
Tungar		939					939
Dummy					2330		2330
DEMAND	551	1533	1151	714	2496	997	

Total Transportation Cost = ₦46,321,081.96

Conclusion: From table 15 clearly shows and gives the numbers of cattle to be transported to the various states/cities from different cattle markets in Niger state. The outcome also shows that; certain numbers of the cattle can be transported from a market to more than one particular state/city. For instance, 551, 679 and 291 cattle can be transported from Kuta to Akure, Ibadan and Ijebu-Ode respectively with the total cost stated in table 15. While, the optimality test carried out gives a less cost for transportation of cattle to various locations in the South west of Nigeria with the minimum cost in table 18 above. And, to satisfy the demand of cattle in Lagos, two thousand three hundred and thirty cattle should be transported from other markets.

Reference

Abdelati, M. H., Abd-El-Tawwab, A. M., Ellimony, E. E. M., & Rabie, M. (2023). Solving a Multi-Objective Solid Transportation Problem: A Comparative Study of Alternative Methods for Decision-Making. *Journal of Engineering and Applied Science*, 70(1), 82. <https://doi.org/10.1186/s44147-023-00247-z>

Abdelati, M. H., Abd-El-Tawwab, A. M., Ellimony, E. E. M., & Rabie, M. (2024). Efficient Transportation Planning: A Case Study of Multi-Dimensional Solid Transportation Problem. *Journal of Engineering Science & Technology Review*, 17(5). <https://doi.org/10.25103/jestr.175>.

Ahmed, Z. E., Saeed, R. A., Mukherjee, A., & Ghorpade, S. N. (2020). Energy Optimization In Low-Power Wide Area Networks By Using Heuristic Techniques. *LPWAN Technologies for Iot and M2M Applications*, 199-223.

Al-Shaery, A. M., Khozium, M. O., Farooqi, N. S., Alshehri, S. S., & Al-Kawa, M. A. M. (2022). Problem Solving in Crowd Management using Heuristic Approach. *Ieee Access*, 10, 25422-25434.

Biswas, A., & Hoyle, C. (2019). Solving Constrained Non-Linear Bi-Level Optimization Problems with Classical Methods. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 59193, p. V02BT03A025). American Society of

Mechanical Engineers.

<https://doi.org/10.1115/DETC2019-97192>

Cao, J. (2022). Mathematical Model and Algorithm of Multi-Index Transportation Problem in the Background of Artificial Intelligence. *Journal of Advanced Transportation*, 2022(1), 3664105.

<https://doi.org/10.1155/2022/3664105>

Castaneda, J., Ghorbani, E., Ammouriova, M., Panadero, J., & Juan, A. A. (2022). Optimizing transport logistics under uncertainty with simheuristics: Concepts, review and trends. *Logistics*, 6(3), 42.

<https://doi.org/10.3390/logistics6030042>

Chambers, P. G., Grandin, T., Heinz, G., & Srisuvan, T. (2001). Guidelines for Humane Handling, Transport and Slaughter of Livestock.

<https://openknowledge.fao.org/handle/20.500.14283/x6909e>

Deniz, N., & ÖZCEYLAN, E. (2023). A Bibliometric and Social Network Analysis of Data-Driven Heuristic Methods for Logistics Problems. *Journal of Industrial and Management Optimization*, 19(8).

Díaz-Parra, O., Ruiz-Vanoye, J. A., Bernabe Loranca, B., Fuentes-Penna, A., & Barrera-Cámara, R. A. (2014). A Survey of Transportation Problems. *Journal of Applied Mathematics*, 2014(1), 848129.

<https://doi.org/10.1155/2014/848129>

Ekanayake, E. M. U. S. B., Daundasekara, W. B., & Perera, S. P. C. (2022). An Examination of Different Types of Transportation Problems and Mathematical Models. *American Journal of Mathematical and Computer Modelling*, 7(3), 37-48.

Fernández Gil, A., Lalla-Ruiz, E., Gómez Sánchez, M., & Castro, C. (2022). A Review of Heuristics and Hybrid Methods for Green Vehicle Routing Problems Considering Emissions. *Journal of Advanced*

Transportation, 2022(1), 5714991.

<https://doi.org/10.1155/2022/5714991>

Fidanova, S. (Ed.). (2022). Recent Advances in Computational Optimization: Results of the Workshop on Computational Optimization WCO 2021. <https://doi.org/10.1007/978-3-031-06839-3>

Gayialis, S. P., Konstantakopoulos, G. D., & Tatsiopoulos, I. P. (2019). Vehicle Routing Problem for Urban Freight Transportation: A Review of the Recent Literature. *Operational Research in the Digital Era-Ict Challenges*, 89-104. <https://doi.org/10.1007/978-3-319-95666-4-7>

Girei, A. A., Dire, B., & Bello, B. H. (2013). Assessment of cost and returns of cattle marketing in central zone of Adamawa state, Nigeria. *British J. Marketing Studies*, 1(1), 1-10.

Gupta, R., & Gulati, N. (2019). Survey of Transportation Problems. *International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon)* (pp. 417-422). IEEE.

<https://doi.org/10.1109/COMITCon.2019.8862242>

Hajlaoui, R., Guyennet, H., & Moulahi, T. (2016). A Survey on Heuristic-Based Routing Methods in Vehicular Ad-Hoc Network: Technical Challenges and Future Trends. *IEEE Sensors Journal*, 16(17), 6782-6792.

<https://doi.org/10.1109/JSEN.2016.2583382>

Juan, A. A., Kelton, W. D., Currie, C. S., & Faulin, J. (2018). Simheuristics Applications: Dealing With Uncertainty in Logistics, Transportation, and Other Supply Chain Areas. *Winter Simulation Conference (WSC)* (pp. 3048-3059). IEEE.

<https://doi.org/10.1109/WSC.2018.8632464>

Kacher, Y., & Singh, P. (2021). A Comprehensive Literature Review on Transportation Problems. *International Journal of Applied and*

- Computational Mathematics*, 7(5), 206. <https://doi.org/10.1007/s40819-021-01134-y>
- Korkmaz, E., & Akgüngör, A. P. (2021). The Forecasting of Air Transport Passenger Demands in Turkey by using Novel Meta-Heuristic Algorithms. *Concurrency and Computation: Practice and Experience*, 33(16), e6263. <https://doi.org/10.1002/cpe.6263>
- Lin, J., & Cromley, G. (2023). Using the Transportation Problem to Build a Congestion/Threshold Constrained Spatial Accessibility Model. *Journal of transport geography*, 112, 103691.
- Mafimisebi, T. E., Bobola, O. M., & Mafimisebi, O. E. (2013). Fundamentals of Cattle Marketing In Southwest, Nigeria: Analyzing Market Intermediaries, Price Formation and Yield Performance. <https://doi.org/10.22004/ag>.
- Mahmudy, W. F., Widodo, A. W., & Haikal, A. H. (2024). Challenges and Opportunities for Applying Meta-Heuristic Methods in Vehicle Routing Problems: A Review. *Engineering Proceedings*, 63(1), 12. <https://doi.org/10.3390/engproc2024063012>
- Malacký, P., & Madleňák, R. (2023). Transportation Problems and Their Solutions: *Transportation Research Procedia*, 74, 323-329.
- Mohri, S. S., Mohammadi, M., Gendreau, M., Pirayesh, A., Ghasemaghahi, A., & Salehi, V. (2022). Hazardous Material Transportation Problems: A Comprehensive Overview of Models and Solution Approaches. *European Journal of Operational Research*, 302(1), 1-38.
- Moslem, S., Saraji, M. K., Mardani, A., Alkharabsheh, A., Duleba, S., & Esztergár-Kiss, D. (2023). A Systematic Review of Analytic Hierarchy Process Applications to Solve Transportation Problems: from 2003 to 2022. *Ieee Access*, 11, 11973-11990. doi: [10.1109/ACCESS.2023.3234298](https://doi.org/10.1109/ACCESS.2023.3234298) <https://doi.org/10.1109/JSEN.2016.2583382>
- Mubi, A. A., Michika, S. A., & Midau, A. (2013). Cattle Marketing in Mubi Area of Adamawa State, Nigeria. *Agricultural and Biology Journal of North America*, 4(3), 199-198.
- Navarro-Ligero, M. L., Soria-Lara, J. A., & Valenzuela-Montes, L. M. (2019). A Heuristic Approach for Exploring Uncertainties in Transport Planning Research. *Planning Theory & Practice*, 20(4), 537-554. <https://doi.org/10.1080/14649357.2019.1648851>
- Ogumeyo, S. A., & Omole, C. E. O. (2024). Application of Transportation Model to Solve Tankers'-Routing Problem. *Fudma Journal of Sciences*, 8(2), 259-266. <https://doi.org/10.33003/fjs-2024-0802-2352>
- Qiuping, N., Yuanxiang, T., Broumi, S., & Uluçay, V. (2023). A Parametric Neutrosophic Model for the Solid Transportation Problem. *Management Decision*, 61(2), 421-442. <https://doi.org/10.1108/MD-05-2022-0660>
- Sahani, S. K., Shah, B., Kumar, A., & Dubey, R. P. (2024). Study and Analysis of Mathematical Models for Networking Shipping Planning: An Overview of Transportation Problems in Nonlinear Sciences. *Journal of Computational Analysis and Applications*, 33(2).
- Silver, E. A., Victor, R., Vidal, V., & de Werra, D. (1980). A Tutorial on Heuristic Methods. *European Journal of Operational Research*, 5(3), 153-162.
- Singh, B., & Singh, A. (2023). Multi-Index Transportation Problem: An Overview of Its Variants, Solution Techniques and Applications. *Journal Punjab Academy of Sciences*, 23, 164-174.