

TRANSPORTATION PROBLEM

A Case Study of Unilorin Water
Enterprise(UWE)

BY

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CERTIFICATION

This is to certify that this project work was carried out by **UDO, Uduak David** with matriculation number **17/56EB094** and approved as meeting the requirement for the award of the Bachelor of Science (B.Sc.) degree of the Department of Mathematics, Faculty of Physical Sciences, University of Ilorin, Ilorin, Nigeria.

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DEDICATION

This is dedicated to God Almighty, my creator, my strong pillar, my source of inspiration, wisdom, knowledge, and comprehension. He has been the source of my strength throughout this program, and I have soared only on his wings.

I also dedicate this work to my father, Apostle David Udosen, who has always encouraged me and ensured that I give it everything I have to finish what I started. Aduragbemi Olorunyomi; my buddy turned sister, thank you for everything you do for me. And to my friends, course-mate, family, and well-wishers; my love for you all is immeasurable. God's blessings on you all.

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All praises, adoration and glorification are for Almighty God.

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I also want to thank the Manager of Unilorin Water Enterprise (UWE) for providing the data for the study.

ABSTRACT

This study takes into account the proposed transportation model of manufacturing goods to consumers (key distributors).

This transportation model will be useful for Unilorin Water Enterprise logistics managers in making strategic decisions regarding the optimal allocation of products from four storehouses; factory, consultancy, business school, and UITH, to various customers (key distributors) at the lowest transportation cost.

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Chapter 1

GENERAL INTRODUCTION

1.1 Introduction

The **Transportation Problem (TP)** is the overall term for a wide range of issues in which transportation is required. The following are the general parameters of Transportation Problem:

- (A) **Resources:** These are the elements that can be moved from one location to another. Goods, machinery, tools, people, and cargo are examples of discrete resources; continuous resources include energy, liquids, and money..
- (B) **Locations:** Point of delivery, recollection depots, nodes, railway stations, bus terminals, loading ports, seaports, airports, refueling depots, and schools are all examples of locations.
- (C) **Transportation Modes:** Transportation modes are methods of delivering resources to certain areas. Water, space, air, road, train, and

cable are used as forms of transportation. The infrastructure, capacity, schedules, activities, and rules varies depending on the mode of transportation. Ships, planes, trucks, trains, pipelines, motorcycles, and other forms of movement are examples.

1.2 Definition of Terms

1. **Destination:** It is the location to which shipments are transported.
2. **Unit Transportation Cost:** It is the cost of transporting one unit of the consignment from an origin to a destination.
3. **Feasible Solution:** A solution that satisfies the row and column sum restrictions and also the none-negatively restrictions is a feasible solution.
4. **Basic Feasible Solution:** A feasible solution of $(m \times n)$ transportation problem is said to be basic feasible solution when the total number of allocations is equal to $(m + n - 1)$.
5. **Optimal Solution:** A feasible solution is said to be optimal solution when the total transportation cost will be the minimum cost.
6. **Degenerate & Non-degenerate Basic Feasible Solution:** A Basic Feasible Solution to the $m \times n$ transportation problem that contains exactly $m + n - 1$ allocation in independent position is called non-degenerate basic feasible solution.

1.3 Types of Transportation Problem

There are basically two (2) types of transportation problem:

1. Balanced Transportation Problem
2. Unbalanced Transportation Problem

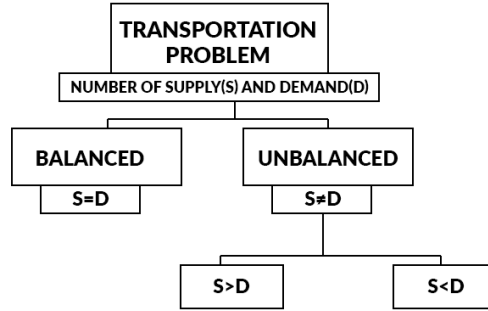


Figure 1.1: Types of Transportation Problem

1.4 Model of A Transportation Problem

The transportation problem model is defined by

$$\text{Minimize } Z = \sum_{i=1}^m X_{ij} C_{ij} \quad (1.1)$$

$$\sum_{j=1}^n X_{ij} \leq a_i \quad , \quad i = 1, 2, 3, \dots, m \quad (\text{Demand Constraint}) \quad (1.2)$$

$$\sum_{i=1}^m X_{ij} \geq b_j \quad , \quad j = 1, 2, 3, \dots, n \quad (\text{Supply constraint}) \quad (1.3)$$

$$X_{ij} \geq 0, 1, 2, 3, \dots, n \quad (1.4)$$

This is a Linear Program with $m \cdot n$ decision variables, $m + n$ functional constants, and $m \cdot n$ non-negative constraints. Where

n is the number of destination

m is the number of resources

a_i is the capacity of i source

b_j is the demand of j th destination

C_{ij} is the unit transportation cost between i th source and j th destination (in naira or as a distance in Kilometers, miles, etc.). While X_{ij} is the size of material transported between i th source and j th destination (in tons, pounds, liters etc.).

A transportation problem is said to be unbalanced if and only if

$$\sum_{i=1}^m a_i \neq \sum_{j=1}^n b_j \quad (1.5)$$

There are two cases:

Case (1)

$$\sum_{i=1}^m a_i \geq \sum_{j=1}^n b_j \quad (1.6)$$

Case (2)

$$\sum_{i=1}^m a_i \leq \sum_{j=1}^n b_j \quad (1.7)$$

To balance the Transportation Problem, introduce a dummy origin or source in the transportation table with a zero cost. The availability at the origin is

$$\sum_{i=1}^m a_i - \sum_{j=1}^n b_j = 0 \quad (1.8)$$

1.5 Tableau And Network Representation

The transportation problem is illustrated with the model of a linear program and it appears in a network and tableau form

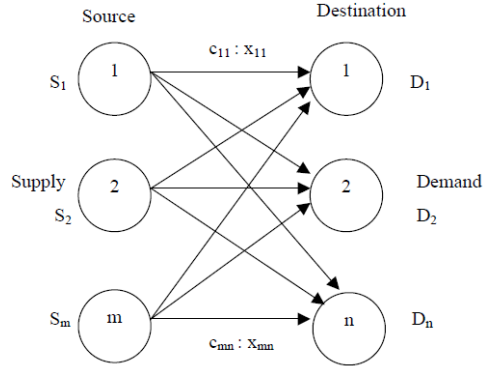


Figure 1.2: The Transportation Network

Plants \ Destination							Supply quantity
	D_1	D_2	D_3		D_{n-1}	D_n	
S_1	x_{11}	x_{12}	x_{13}	...	$x_{1,n-1}$	$x_{1,n}$	s_1
S_2	x_{21}	x_{22}	x_{23}	...	$x_{2,n-1}$	$x_{2,n}$	s_2
S_3	x_{31}	x_{32}	x_{33}	...	$x_{3,n-1}$	$x_{3,n}$	s_3
	\cdot	\cdot	\cdot		\cdot	\cdot	\cdot
	\cdot	\cdot	\cdot		\cdot	\cdot	\cdot
	\cdot	\cdot	\cdot		\cdot	\cdot	\cdot
S_{m-1}	$x_{m-1,1}$	$x_{m-1,2}$	$x_{m-1,3}$...	$x_{m-1,n-1}$	$x_{m-1,n}$	s_{m-1}
S_m	$x_{m,1}$	$x_{m,2}$	$x_{m,3}$...	$x_{m,n-1}$	$x_{m,n}$	s_m
Demand quantity	d_1	d_2	d_3	...	d_{n-1}	d_n	

Figure 1.3: The Transportation Tableau

1.6 Flowchart Solution of the Transportation Problem

- the problem is formulated as a transportation model
- is the transportation model balanced?
- if yes, got next step, add dummy to the rows or column
- determine initial basic solution
- go to next step if the solution is optimized else go to fourth step
- using the optimal solution, calculate the total transportation cost

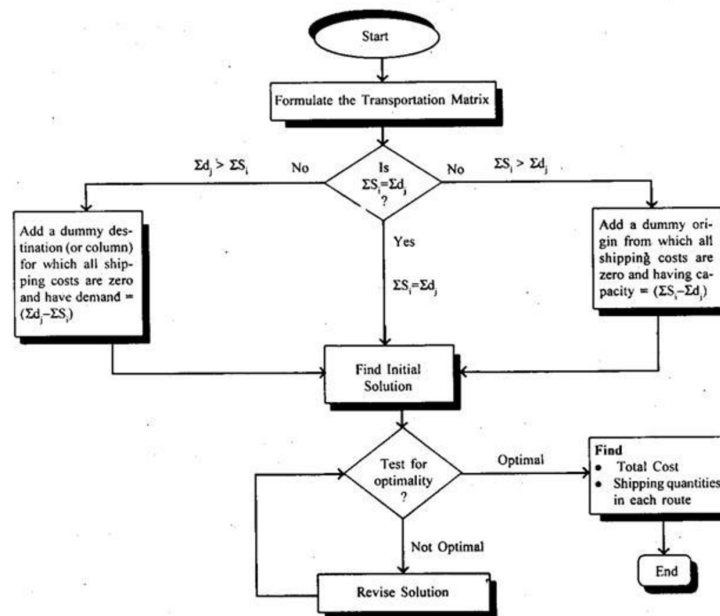


Figure 1.4: Flowchart of Transportation Solution

1.7 Background of Study

1.7.1 Company Profile

The Unilorin Water Enterprise began operations on September 23, 2013, with the promise of producing sparkling clean water for the use of members of the university community and beyond. The Unilorin Water Enterprise is open from Mondays through Saturdays.

1.7.2 Company Brand

On March 4, 2014, the National Agency for Food and Drug Administration and Control (NAFDAC) approved Unilorin Water Enterprise (UWE) by assigning product registration numbers to the two water brands. Unilorin table water 50cl and 75cl bottles with registration number (1-2090L) and Unilorin Pure water with registration number (1-2049L).

1.7.3 Process of Production

The factory manufactures and packages the product in a calm and sanitary atmosphere; the company has five sedimentation tanks connected to a particular borehole, huwa-san, sand filter, carbon filter, and four treated water tanks. The business has a micro filter reserve osmosis, treated water tank, ultra violet sterilizer, and washing, filling, and capping equipment for sachet water, and an automatic packaging machine for bottle water.

1.7.4 Storehouses

The warehouse in the senior staff quarters store house stores raw materials, semi-finished items, and completed goods. This final goods and services are provided on time and at a low cost. There are only three registered transporters in charge of loading, packing, unloading, and moving finished items from the manufacturing warehouse to the distributors.

1.7.5 Distributions

Finished goods are sold directly to registered distributors. The distributors are the primary agents who distribute to retailers; the university of Ilorin water company produces on a huge scale and has over 70 distributors on and off campus. The firm produces about 4000 bags of sachet water, 500 packs of 50cl Unilorin table water, and 1000 packs of 75cl table water.

1.8 Problem Statement

The project will attempt to resolve the challenge of determining the ideal transportation plan that will reduce the overall cost of transporting products from the major production locations to the many important distributors in Ilorin who are geographically dispersed.

1.9 Aim and Objectives

The Aim of the study is to develop a transportation model of Unilorin Water Enterprise . The objectives were to:

- (i) develop a model of distribution of Unilorin Water Enterprise (UWE) products as a transportation problem .
- (ii) minimize the transportation cost.
- (iii) maximize the profit.

Chapter 2

LITERATURE REVIEW

The transportation problem (TP) is an important Linear Programming (LP) model that arises in several context and has deservingly received much attention in literature.

The transportation problem is probably the most important special linear transportation problem in terms of relative frequency with which it appears in the applications and also in the simplicity of the procedure developed for its solution. The following features of the transportation problem are considered to be most important.

The transportation problem were the earliest class of Linear Programs discovered to have totally unimodular matrices and integrand extreme points resulting in considerable simplification of the Simplex method.

The study of the transportation problems laid the foundation for further

theoretical and algorithmic development of the minimal cost network flow problems.

The transportation problem was formalized by the French mathematician Monges (1781). Major advances were made in the field during World War II by the Soviet/Russian mathematician and Economist Leonid Kantorovich. Consequently, the problem as it is now stated is sometimes known as the Monge-Kantorovich transportation problem. Kantorovich (1942) published a paper on continuous version of the problem and later with Gavurian, and applied study of the capacitated transportation problem Kantorovich et al (1949).

Many scientific disciplines have contributed toward analysing problems associated with the transportation problem, including operation research, Economics, Engineering, Geographic Information Science and Geography. It is explored extensively in the Mathematical Programming and Engineering literatures. Sometimes referred to as the facility location and allocation problem, the transportation optimization problem can be modelled as a large-scale mixed integer linear programming problem.

The origin of transportation was first presented by Hitchcock (1941) also presented a study entitled '*The Distribution of a product from several sources to numerous locations*', this presentation is considered to be transportation problems. Koopmans (1947), presented an independent study, not related to Hitchcock's and called "*Optimum utilization of the transportation sys-*

tem". These two contributions helped in the development of transportation methods which involve a number of shopping sources and a number of destination. The transportation problem, received this named because many of its applications involve determining how to optimally transport goods.

Chapter 3

METHODOLOGY

3.1 Introduction

This chapter reviews the proposed solution methodology and approach for handling transportation problem in Unilorin Water Enterprise . The transportation problem seeks to minimize the total shipping cost of transporting goods from m origins (each with a supply s_i) to n destinations (each with a demand d_j) when the unit shipping cost from an origin i , to a destination j , is C_{ij} .

3.2 Mathematical Formulation

Supposed a company has m warehouses and n retail outlets. A single product is to be shipped from the warehouse to the outlets. Each warehouse has a given level of supply, and each outlet has a given level of demand. We are also given the transportation cost between every pair of warehouse and outlet,

and these cost are assumed to be linear. More explicitly, the assumptions are

- the total supply of products from warehouse $i = a$, where $i = 1, 2, 3, \dots, m$
- the total demand of the products at the outlet $j = b$, where $j = 1, 2, 3, \dots, n$
- the cost of sending one unit of the product from warehouse i to outlet j is equal to C_{ij} , where $i = 1, 2, 3, \dots, m$ and $j = 1, 2, 3, \dots, n$. The total cost of a shipment is linear in size of shipment.

3.3 Solution of A Transportation Problem

Solving the Transportation Problem:- There are three popular methods to finding an initial basic feasible solution and they include:

- (1) Northwest Corner Rule
- (2) Least Cost Method
- (3) Vogel Approximation Method

Northwest Corner Rule(NCR)

In this method, allocation of quantities being transported from source to some destination must start from the upper most left hand cell that is the Northwest Corner of the table. The steps include:

- (a) Make allocation in the northwest (upper left) corner of the transportation problem table. Compare the supply of plant 1 say S_1 with the demand at the warehouse or destination 1 say d_1 . Then,
 - (i) If $d_1 < S_1$ i.e If the amount required at d_1 is less than the number of units available at S_1 , set x_{11} equal to d_1 , find the balance supply and demand and proceed horizontally.
 - (ii) If $d_1 = S_1$, set x_{11} equal to d_1 , balance supply and demand and proceed diagonally. Remember to make a zero allocation to the least cost cell in S_1/d_1 .
 - (iii) If $d_1 > S_1$, set x_{11} equal to S_1 , balance demand and supply and proceed vertically.
- (b) Continue with *itotiii*, step by step away from the upper left corner until you reach a value in the South-East corner.
- (c) calculate the total transportation cost.

This method does not take into account the transportation cost and hence may not yield a good initial basic feasible solution.

Least Cost Method (LCM)

The Least Cost Method is also called the Matrix Minimum Method, is a method of finding an initial basic feasible solution where allocation of resources begins from the least cost. The steps includes:

1. Determine the cell having the least transportation cost (C_{ij})

2. Allocate as much as possible to this least cost
3. If there's a tie in least cost, select the cell having the greatest least cost.
4. Delete the row or column which has been exhausted
5. Select the next least cost and allocate as much as possible
6. Continue this manner till all row and column requirements are met.

The Vogel Approximation Method(VAM)

This procedure is an iterative method of finding an initial basic feasible solution. It is an improved version of the least cost method. The steps include:

1. Find the difference between the least cost and next least cost of each row and column(This difference is the row or column penalty).
2. Select the row or column with the biggest penalty
3. In case of a tie in penalty, select the row or column with the greatest least cost
4. Make allocation as much as possible to the cell in that row/column
5. Delete the column or row that has been completely exhausted.
6. Repeat steps 1 to 5 until all allocation are made

3.3.1 Numerical Illustration

Consider A company which has 3 production facilities S_1, S_2 and S_3 with production capacity of 7, 9 and 18 units (in 100's) per week of a product, respectively. These units are to be shipped to 4 warehouses D_1, D_2, D_3 and D_4 with requirement of 5, 8, 7 and 14 units (in 100's) per week, respectively. The transportation costs (in rupees) per units between factories to warehouse are given in the table below

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10	7
S_2	70	30	40	60	9
S_3	40	8	70	20	18
Demand	5	8	7	14	34

To find an initial basic feasible solution for the given transportation problem. Using the three method.

3.3.2 METHOD 1: Using North West Corner

TOTAL number of supply constraints: 3

TOTAL number of demand constraints: 4

Problem Table is

	D_1	D_2	D_3	D_4	Capacity
--	-------	-------	-------	-------	----------

S_1	19	30	50	10	7
S_2	70	30	40	60	9
S_3	40	8	70	20	18
Demand	5	8	7	14	34

The rim values for $S_1 = 7$ and $D_1 = 5$ are compared

The smaller of the two i.e $\min(7, 5) = 5$ is assigned to $S_1 D_1$.

This meets the complete demand of D_1 and leaves $7 - 5 = 2$ units with S_1 .

Table-1

	D_1	D_2	D_3	D_4	Capacity
S_1	19(5)	30	50	10	2
S_2	70	30	40	60	9
S_3	40	8	70	20	18
Demand	0	8	7	14	

The rim values for $S_1 = 2$ and $D_2 = 8$ are compared.

The smaller of the two i.e $\min(2, 8) = 2$ is assigned to $S_1 D_2$

Table-2

	D_1	D_2	D_3	D_4	Capacity
S_1	19(5)	30(2)	50	10	0
S_2	70	30	40	60	9
S_3	40	8	70	20	18
Demand	0	6	7	14	

The rim value for $S_2 = 9$ and $D_2 = 6$ are compared

The smaller of the two i.e $\min(9, 6) = 6$ is assigned to S_2D_2 .

This exhausts the capacity of S_1 and leaves $8 - 2 = 6$ units with D_2

Table-3

	D_1	D_2	D_3	D_4	Capacity
S_1	19(5)	30(2)	50	10	0
S_2	70	30(6)	40	60	3
S_3	40	8	70	20	18
Demand	0	0	7	14	

The rim values for $S_2 = 3$ and $D_3 = 7$ are compared.

The smaller of the two i.e $\min(3, 7) = 3$ is assigned to S_2D_3 . This exhausts the capacity of S_2 and leaves $7 - 3 = 4$ units with D_3

Table-4

	D_1	D_2	D_3	D_4	Capacity
S_1	19(5)	30(2)	50	10	0
S_2	70	30(6)	40(3)	60	0
S_3	40	8	70	20	18
Demand	0	0	4	14	

The rim values for $S_3 = 18$ and $D_3 = 4$ are compared

This smaller of the two i.e $\min(18, 4) = 4$ is assigned to S_3D_3

This meets the complete demands of D_3 and leaves $18 - 4 = 14$ units with S_3 .

Table-5

	D_1	D_2	D_3	D_4	Capacity
S_1	19(5)	30(2)	50	10	0
S_2	70	30(6)	40(3)	60	0
S_3	40	8	70(4)	20	14
Demand	0	0	0	14	

The rim values for $S_3 = 14$ and $D_4 = 14$ are compared.

The smaller of the two i.e $\min(14, 14) = 14$ is assigned to S_3D_4

Table-6

	D_1	D_2	D_3	D_4	Capacity
S_1	19(5)	30(2)	50	10	0
S_2	70	30(6)	40(3)	60	0
S_3	40	8	70(4)	20(14)	0
Demand	0	0	0	0	

Initial feasible solution is

	D_1	D_2	D_3	D_4	Capacity
S_1	19(5)	30(2)	50	10	7
S_2	70	30(6)	40(3)	60	9
S_3	40	8	70(4)	20(14)	18
Demand	5	8	7	14	

The minimum total transportation cost

$$19 \times 5 + 30 \times 2 + 30 \times 6 + 40 \times 3 + 70 \times 4 + 20 \times 14 = 1015$$

Here, the number of allocated cells = 6 is equal to

$$m + n - 1 = 3 + 4 - 1 = 6$$

\therefore This solution is non-degenerate

3.3.3 METHOD 2: Using Least Cost Method to find solution

TOTAL number of supply constraints: 3

TOTAL number of demand constraints: 4

Problem Table is

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10	7
S_2	70	30	40	60	9
S_3	40	8	70	20	18
Demand	5	8	7	14	

The smallest transportation cost is 8 in cell S_3D_2

The allocation to this cell is $\min(18, 8) = 8$

This satisfies the entire demand of D_2 and leaves $18 - 8 = 10$ units with S_3

Table-1

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10	7
S_2	70	30	40	60	9
S_3	40	8(8)	70	20	10
Demand	5	0	7	14	

The smallest transportation cost is 10 in cell S_1D_4

The allocation to this is $\min(7, 14) = 7$

The exhausts the capacity of S_1 and leaves $14 - 7 = 7$ units with D_4

Table-2

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10(7)	0
S_2	70	30	40	60	9
S_3	40	8(8)	70	20	10
Demand	5	0	7	7	

The smallest transportation cost is 20 in cell S_3D_4

The allocation of the cell is $\min(10, 7) = 7$

This satisfies the entire demand of D_4 and leaves $10 - 7 = 3$ units with S_3

Table-3

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10(7)	0
S_2	70	30	40	60	9
S_3	40	8(8)	70	20(7)	3
Demand	5	0	7	0	

The smallest transportation cost is 40 in cell S_2D_3

The allocation to this cell is $\min(9, 7) = 7$

This satisfies the entire demand of D_3 and leaves $9 - 7 = 2$ units with S_2

Table-4

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10(7)	0
S_2	70	30	40(7)	60	2
S_3	40	8(8)	70	20(7)	3
Demand	5	0	0	0	

The smallest transportation cost is 40 in cell S_3D_1

The allocation to this cell is $\min(3, 5) = 3$

This exhausts the capacity of S_3 and leaves $5 - 2 = 2$ units with D_1

Table-5

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10(7)	0
S_2	70	30	40(7)	60	2
S_3	40(3)	8(8)	70	20(7)	0
Demand	2	0	0	0	

The smallest transportation cost is 70 in cell S_2D_1

The allocation to this cell is $\min(2, 2) = 2$

Table-6

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10(7)	0
S_2	70(2)	30	40(7)	60	0
S_3	40(3)	8(8)	70	20(7)	0
Demand	0	0	0	0	

Initial feasible solution is

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10(7)	7
S_2	70(2)	30	40(7)	60	9
S_3	40(3)	8(8)	70	20(7)	18
Demand	5	8	7	14	

The minimum total transportation cost

$$10 \times 7 + 70 \times 2 + 40 \times 3 + 8 \times 8 + 20 \times 7 = 814$$

Here, the number of allocated cells = 6 is equal to

$$m + n - 1 = 3 + 4 - 1 = 6$$

\therefore This solution is non-degenerate

3.3.4 METHOD 3: Using Vogel's Approximation Method to find solution

TOTAL number of supply constraints: 3

TOTAL number of demand constraints: 4

Problem Table is

	D_1	D_2	D_3	D_4	Capacity
S_1	19	30	50	10	7
S_2	70	30	40	60	9
S_3	40	8	70	20	18
Demand	5	8	7	14	

Table-1

	D_1	D_2	D_3	D_4	Capacity	Row Penalty
S_1	19	30	50	10	7	9=19-10
S_2	70	30	40	60	9	10 = 40-30
S_3	40	8	70	20	18	12 = 20-8
Demand	5	8	7	14		
Column Penalty	21 = 40-19	22=30-8	10=50-40	10=20-10		

The maximum penalty, 22 occur in column D_2

The minimum C_{ij} in this column is $C_{32} = 8$

The maximum allocation in this cell is $\min(18, 8) = 8$

It satisfy demand of D_2 and adjust the supply of S_3 from 18 to 10 ($18 - 8 = 10$).

Table-2

	D_1	D_2	D_3	D_4	Capacity	Row Penalty
S_1	19	30	50	10	7	$9=19-10$
S_2	70	30	40	60	9	$20 = 60-40$
S_3	40	8(8)	70	20	10	$20 = 40-20$
Demand	5	0	7	14		
Column Penalty	$21 = 40-19$	–	$10=50-40$	$10=20-10$		

The maximum penalty, 21, occur in column D_1

The minimum C_{ij} in this column is $C_{11} = 19$

The maximum allocation in this cell is $\min(7, 5) = 5$

It satisfy demand of D_1 and adjust the supply of S_1 from 7 to 2 ($7 - 5 = 2$)

Table-3

	D_1	D_2	D_3	D_4	Capacity	Row Penalty
S_1	19(5)	30	50	10	2	$40=50-10$
S_2	70	30	40	60	9	$20 = 60-40$
S_3	40	8(8)	70	20	10	$50 = 70-20$
Demand	0	0	7	14		
Column Penalty	—	—	$10=50-40$	$10=20-10$		

The maximum penalty, 50 occurs in row S_3

The minimum C_{ij} in this row is $C_{34} = 20$

The maximum allocation in this cell is $\min(10, 14) = 10$

It satisfy supply of S_3 and adjust the demand of D_4 from 14 to 4 ($14-10 = 4$).

Table-4

	D_1	D_2	D_3	D_4	Capacity	Row Penalty
S_1	19(5)	30	50	10	2	40=50-10
S_2	70	30	40	60	9	20 = 60-40
S_3	40	8(8)	70	20(10)	0	–
Demand	0	0	7	4		
Column Penalty	–	–	10=50-40	50=60-10		

The maximum penalty, 50, occurs in column D_4

The minimum C_{ij} in this column is $C_{14} = 10$

The maximum allocation in this cell is $\min(2, 4) = 2$

It satisfy supply of S_1 and adjust the demand of D_4 from 4 to 2 ($4 - 2 = 2$).

Table-5

	D_1	D_2	D_3	D_4	Capacity	Row Penalty
S_1	19(5)	30	50	10(2)	0	–
S_2	70	30	40	60	9	20 = 60-40
S_3	40	8(8)	70	20(10)	0	–
Demand	0	0	7	2		
Column Penalty	–	–	40	60		

The maximum penalty, 60, occurs in column D_4

the minimum C_{ij} in this column is $C_{24} = 60$

The maximum allocation in this cell is $\min(9, 2) = 2$

It satisfy demand of D_4 and adjust the supply of S_2 from 9 to 7 ($9 - 2 = 7$)

Table-6

	D_1	D_2	D_3	D_4	Capacity	Row Penalty
S_1	19(5)	30	50	10(2)	0	—
S_2	70	30	40	60(2)	7	40
S_3	40	8(8)	70	20(10)	0	—
Demand	0	0	7	0		
Column Penalty	—	—	40	—		

The maximum penalty, 40, occurs in row S_2

The minimum C_{ij} in this row is $C_{23} = 40$

The maximum allocation in this cell is $\min(7, 7) = 7$

It satisfy supply of S_2 and demand of D_3

Initial feasible solution is

	D_1	D_2	D_3	D_4	Capacity	Row Penalty
S_1	19(5)	30	50	10(2)	7	9 9 40 40 - -
S_2	70	30	40	60(2)	9	10 20 20 20 20 40
S_3	40	8(8)	70	20(10)	18	12 20 50 - - -
Demand	5	8	7	14		
	21	22	10	10		
	21	—	10	10		
	—	—	10	10		
	—	—	10	50		
	—	—	40	60		
	—	—	40	—		

The minimum total transportation cost

$$19 \times 5 + 10 \times 2 + 40 \times 7 + 60 \times 2 + 8 \times 8 + 20 \times 10 = 779$$

Here, the number of allocated cells = 6 is equal to

$$m + n - 1 = 3 + 4 - 1 = 6$$

\therefore This solution is non-degenerate

Chapter 4

DATA COLLECTION AND ANALYSIS

4.1 Data Collection

The table below displays a weekly balanced transportation problem data from Unilorin Water Enterprise's storehouses: Factory, Consultancy, Business School, and UITH, each. This problem's demand and supply capacity are provided as 400, 150, 100, 200 and 250, 200, 150, 250 (in packs per week), respectively. The transportation costs in naira between factories to warehouses are given per week.

This study covers data collection from the month of September - October, 2021.

4.2 Analysis

	W_1	W_2	W_3	W_4	Supply Capacity Availability
Factory	5	6	5	7	400
Consultancy	2	2	3	3	150
Business School	5	4	4	3	100
Uith	13	12	15	12	200
Demand	250	200	150	250	

To find an initial basic feasible solution for the given transportation problem using the three method. Representing the stores as S_1, S_2, S_3, S_4 .

4.2.1 METHOD 1: Using North West Corner

TOTAL number of supply constraints: 4

TOTAL number of demand constraints: 4

	W_1	W_2	W_3	W_4	Supply
S_1	5	6	5	7	400
S_2	2	2	3	3	150
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	250	200	150	250	

The rim values for $S_1 = 400$ and $W_1 = 250$ are compared

The smaller of the two i.e $\min(400, 250) = 250$ is assigned to S_1W_1

This meets the complete demand of W_1 and leaves $400 - 250 = 150$ units with S_1

Table-1

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6	5	7	150
S_2	2	2	3	3	150
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	0	200	150	250	

The rim values for $S_1 = 150$ and $W_2 = 200$ are compared

The smaller of the two i.e $\min(150, 200) = 150$ is assigned to S_1W_2

This exhausts the capacity of S_1 and leaves $200 - 150 = 50$ units with W_2

Table-2

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6(150)	5	7	0
S_2	2	2	3	3	150
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	0	50	150	250	

The rim values for $S_2 = 150$ and $W_2 = 50$ are compared

The smaller of the two i.e $\min(150, 50) = 50$ is assigned to S_2W_2

This meets the complete demand of W_2 and leaves $150 - 50 = 100$ units with S_2

Table-3

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6(150)	5	7	0
S_2	2	2(50)	3	3	100
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	0	0	150	250	

The rim values for $S_2 = 100$ and $W_3 = 150$ are compared

The smaller of the two i.e $\min(100, 150) = 100$ is assigned to S_2W_3

This exhausts the capacity of S_2 and leaves $150 - 100 = 50$ units with W_3

Table-4

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6(150)	5	7	0
S_2	2	2(50)	3(100)	3	0
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	0	0	50	250	

The rim values for $S_3 = 100$ and $W_3 = 50$ are compared

The smaller of the two i.e $\min(100, 50) = 50$ is assigned to S_3W_3

This meets the complete demand of W_3 and leaves $100 - 50 = 50$ units with S_3

Table-5

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6(150)	5	7	0
S_2	2	2(50)	3(100)	3	0
S_3	5	4	4(50)	3	50
S_4	13	12	15	12	200
Demand	0	0	0	250	

The rim values for $S_3 = 50$ and $W_4 = 250$ are compared

The smaller of the two i.e $\min(50, 250) = 50$ is assigned to S_3W_4

This exhausts the capacity of S_3 and leaves $250 - 50 = 200$ units with W_4

Table-6

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6(150)	5	7	0
S_2	2	2(50)	3(100)	3	0
S_3	5	4	4(50)	3(50)	0
S_4	13	12	15	12	200
Demand	0	0	0	200	

The rim values for $S_4 = 200$ and $W_4 = 200$ are compared

The smaller of the two i.e $\min(200, 200) = 200$ is assigned to S_4W_4

Table-7

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6(150)	5	7	0
S_2	2	2(50)	3(100)	3	0
S_3	5	4	4(50)	3(50)	0
S_4	13	12	15	12(200)	0
Demand	0	0	0	0	

Initial feasible solution is

	W_1	W_2	W_3	W_4	Supply
S_1	5(250)	6(150)	5	7	400
S_2	2	2(50)	3(100)	3	150
S_3	5	4	4(50)	3(50)	100
S_4	13	12	15	12(200)	200
Demand	250	200	150	250	

The minimum total transportation cost

$$5 \times 250 + 6 \times 150 + 2 \times 50 + 3 \times 100 + 4 \times 50 + 3 \times 50 + 12 \times 200 = 5300$$

Here, the number of allocated cells = 7 is equal to $m + n - 1 = 4 + 4 - 1 = 7$

\therefore the solution is non-degenerate.

4.3 METHOD 2: Using Least Cost

TOTAL number of supply constraints: 4

TOTAL number of demand constraints: 4

Problem Table is

	W_1	W_2	W_3	W_4	Supply
S_1	5	6	5	7	400
S_2	2	2	3	3	150
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	250	200	150	250	

The smallest transportation cost is 2 in cell S_2W_1

The allocation to this cell is $\min(150, 250) = 150$

This exhausts the capacity of S_2 and leaves $250 - 150 = 100$ units with W_1

Table-1

	W_1	W_2	W_3	W_4	Supply
S_1	5	6	5	7	400
S_2	2(150)	2	3	3	0
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	100	200	150	250	

The smallest transportation cost is 3 in cell S_3W_4

The allocation to this cell is $\min(100, 250) = 100$

This exhausts the capacity of S_3 and leaves $250 - 100 = 150$ units with W_4

Table-2

	W_1	W_2	W_3	W_4	Supply
S_1	5	6	5	7	400
S_2	2(150)	2	3	3	0
S_3	5	4	4	3(100)	0
S_4	13	12	15	12	200
Demand	100	200	150	150	

The smallest transportation cost is 5 in cell S_1W_3

The allocation to this cell is $\min(400, 150) = 150$

This satisfies the entire demand of W_3 and leaves $400 - 150 = 250$ units with S_1

Table-3

	W_1	W_2	W_3	W_4	Supply
S_1	5	6	5(150)	7	250
S_2	2(150)	2	3	3	0
S_3	5	4	4	3(100)	0
S_4	13	12	15	12	200
Demand	100	200	0	150	

The smallest transportation cost is 5 in cell S_1W_1

The allocation to this cell is $\min(250, 100) = 100$

This satisfies the entire demand of W_1 and leaves $250 - 100 = 150$ units with S_1

Table-4

	W_1	W_2	W_3	W_4	Supply
S_1	5(100)	6	5(150)	7	150
S_2	2(150)	2	3	3	0
S_3	5	4	4	3(100)	0
S_4	13	12	15	12	200
Demand	0	200	0	150	

The smallest transportation cost is 6 in cell S_1W_2

The allocation to this cell is $\min(150, 200) = 150$

This exhausts the capacity of S_1 and leaves $200 - 150 = 50$ units with W_2

Table-5

	W_1	W_2	W_3	W_4	Supply
S_1	5(100)	6(150)	5(150)	7	0
S_2	2(150)	2	3	3	0
S_3	5	4	4	3(100)	0
S_4	13	12	15	12	200
Demand	0	50	0	150	

The smallest transportation cost is 12 in cell S_4W_4

The allocation to this cell is $\min(200, 150) = 150$

This satisfies the entire demand of W_4 and leaves $200 - 150 = 50$ units with S_4

Table-6

	W_1	W_2	W_3	W_4	Supply
S_1	5(100)	6(150)	5(150)	7	0
S_2	2(150)	2	3	3	0
S_3	5	4	4	3(100)	0
S_4	13	12	15	12(150)	50
Demand	0	50	0	0	

The smallest transportation cost is 12 in cell S_4W_2

The allocation to this cell is $\min(50, 50) = 50$

Table-7

	W_1	W_2	W_3	W_4	Supply
S_1	5(100)	6(150)	5(150)	7	0
S_2	2(150)	2	3	3	0
S_3	5	4	4	3(100)	0
S_4	13	12(50)	15	12(150)	0
Demand	0	0	0	0	

Initial Feasible solution is

	W_1	W_2	W_3	W_4	Supply
S_1	5(100)	6(150)	5(150)	7	400
S_2	2(150)	2	3	3	150
S_3	5	4	4	3(100)	100
S_4	13	12(50)	15	12(150)	200
Demand	250	200	150	250	

The minimum total transportation cost

$$5 \times 100 + 6 \times 150 + 5 \times 150 + 2 \times 150 + 3 \times 100 + 12 \times 50 + 12 \times 150 = 5150$$

Here, the number of allocated cells = 7 is equal to

$$m + n - 1 = 4 + 4 - 1 = 7$$

\therefore this solution is non-degenerate.

4.4 METHOD 3: Finding Solution using Vogel's Approximation(VAM)

TOTAL number of supply constraints: 4

TOTAL number of demand constraints: 4

Problem Table is

	W_1	W_2	W_3	W_4	Supply
S_1	5	6	5	7	400
S_2	2	2	3	3	150
S_3	5	4	4	3	100
S_4	13	12	15	12	200
Demand	250	200	150	250	

Table-1

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5	6	5	7	400	0=5-5
S_2	2	2	3	3	150	0=2-2
S_3	5	4	4	3	100	1=4-3
S_4	13	12	15	12	200	0=12-12
Demand	250	200	150	250		
Column Penalty	3=5-2	2=4-2	1=4-3	0=3-3		

The maximum penalty, 3, occur in column W_1

The minimum C_{ij} in this column is $C_{21} = 2$

The maximum allocation in this cell is $\min(150, 250) = 150$

It satisfy demand of S_2 and adjust the demand of W_3 from 250 to 100
($250 - 150 = 100$).

Table-2

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5	6	5	7	400	0=5-5
S_2	2(150)	2	3	3	0	—
S_3	5	4	4	3	100	1=4-3
S_4	13	12	15	12	200	0=12-12
Demand	100	200	150	250		
Column Penalty	0=5-5	2=6-4	1=5-4	4=7-3		

The maximum penalty, 4, occur in column W_4

The minimum C_{ij} in this column is $C_{34} = 3$

The maximum allocation in this cell is $\min(100, 250) = 100$

It satisfy supply of S_3 and adjust the demand of W_4 from 250 to 150 ($250 - 100 = 150$).

Table-3

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5	6	5	7	400	0=5-5
S_2	2(150)	2	3	3	0	–
S_3	5	4	4	3(100)	0	–
S_4	13	12	15	12	200	0=12-12
Demand	100	200	150	150		
Column Penalty	8=13-5	6=12-6	10=15-5	5=12-7		

The maximum penalty, 10, occur in column W_3

The minimum C_{ij} in this column is $C_{13} = 5$

The maximum allocation in this cell is $\min(400, 150) = 150$

It satisfy demand of W_3 and adjust the supply of S_1 from 400 to 250 ($400 - 150 = 250$).

Table-4

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5	6	5(150)	7	250	1=6-5
S_2	2(150)	2	3	3	0	–
S_3	5	4	4	3(100)	0	–
S_4	13	12	15	12	200	0=12-12
Demand	100	200	0	150		
Column Penalty	8=13-5	6=12-6	–	5=12-7		

The maximum penalty, 8, occur in column W_1

The minimum C_{ij} in this column is $C_{11} = 5$

The maximum allocation in this cell is $\min(250, 100) = 100$

It satisfy demand of W_1 and adjust the supply of S_1 from 250 to 150 ($250 - 100 = 150$).

Table-5

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5(100)	6	5(150)	7	150	1=7-6
S_2	2(150)	2	3	3	0	–
S_3	5	4	4	3(100)	0	–
S_4	13	12	15	12	200	0=12-12
Demand	0	200	0	150		
Column Penalty	–	6=12-6	–	5=12-7		

The maximum penalty, 6, occur in column W_2

The minimum C_{ij} in this column is $C_{12} = 6$

The maximum allocation in this cell is $\min(150, 200) = 150$

It satisfy supply of S_1 and adjust the demand of W_2 from 200 to 50 ($200 - 150 = 50$).

Table-6

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5(100)	6(150)	5(150)	7	0	—
S_2	2(150)	2	3	3	0	—
S_3	5	4	4	3(100)	0	—
S_4	13	12	15	12	200	0=12-12
Demand	0	50	0	150		
Column Penalty	—	12	—	12		

The maximum penalty, 12, occur in column W_4

The minimum C_{ij} in this column is $C_{44} = 12$

The maximum allocation in this cell is $\min(200, 150) = 150$

It satisfy demand of W_4 and adjust the supply of S_2 from 200 to 50 ($200 - 150 = 50$).

Table-7

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5(100)	6(150)	5(150)	7	0	—
S_2	2(150)	2	3	3	0	—
S_3	5	4	4	3(100)	0	—
S_4	13	12	15	12(150)	50	12
Demand	0	50	0	0		
Column Penalty	—	12	—	—		

The maximum penalty, 12, occur in column S_4

The minimum C_{ij} in this column is $C_{42} = 12$

The maximum allocation in this cell is $\min(50, 50) = 50$

It satisfy supply of S_4 and adjust the demand of W_2 .

Initial feasible solution is

	W_1	W_2	W_3	W_4	Capacity	Row Penalty
S_1	5(100)	6(150)	5(150)	7	400	0 0 0 1 1 – –
S_2	2(150)	2	3	3	150	0 – – – – – –
S_3	5	4	4	3(100)	100	1 1 – – – – –
S_4	13	12(50)	15	12(150)	200	0 0 0 0 0 0 12
Demand	250	200	150	250		
	3	2	1	0		
	0	2	1	4		
	8	6	10	5		
	8	6	–	5		
	–	6	–	5		
	–	12	–	12		
	–	12	–	–		

The minimum total transportation cost

$$5 \times 100 + 6 \times 150 + 5 \times 150 + 2 \times 150 + 3 \times 100 + 12 \times 50 + 12 \times 150 = 5150$$

Here the number of allocated cells = 7 is equal to

$$m + n - 1 = 4 + 4 - 1 = 7$$

\therefore this solution is non-degenerate.

Chapter 5

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

Transportation costs are a significant component of every company's overall cost structure. The company (Unilorin Water Enterprise) may quickly and efficiently organize its transportation by using this mathematical model (the Transportation Model). such that it not only saves money on transportation but also saves time by identifying products and services at the right place and correct time.

5.2 CONCLUSION

The Northwest Corner Cell Method, Least Cost Method, and Vogel's Approximation approaches are used to discover the initial basic workable solution

to a transportation problem. Vogel's approximation approach is an upgrade on the Least Cost Cell method that yields a better result. The Northwest Corner Cell approach is the simplest but most inefficient since it does not account for the cost of transportation for all conceivable alternative routes. Because costs are included for allocation, the Least Cost method is preferable to the Northwest Corner Cell method.

5.3 RECOMMENDATION

Based on the study findings, I recommend that Unilorin Water Enterprise's management seek the incorporation of mathematical models or theories into their operations as a necessary tool for decision making, not only in the area of logistics (the transportation problem), but also in production and administration.

This study used mathematical techniques to solve management difficulties and make best decisions in a timely manner. If the University of Ilorin Water Enterprise used the suggested transportation model, it would help them plan out their transportation schedule more efficiently and at a lower cost. This strategy may be used to any transportation challenge

REFERENCES

- ALFRED ASASE THESIS. (n.d.). Retrieved from
<https://www.coursehero.com/file/66599684/ALFRED-ASASE-THESISdocx/>
- Badra, N. M. (2007). *Sensitivity analysis of transportation problems*. Journal of Applied Sciences Research, 3(8), 668-675.
- Boah, D. K., Adu, I. K., & Eduafo, S. (2015). *Optimal transportation schedule for a lumber company in Ghana*. International Journal of Computing and Optimization, 2, 47-52.
- Chanas, S., & Kuchta, D. (1996). *A concept of the optimal solution of the transportation problem*. <https://www.ijmttjournal.org> international journal of mathematics friends and Technology IJMTT. - Google Zoeken. (n.d.). Retrieved from
<https://www.ijmttjournal.org+international+journal+of+mathematics+friends+and+Technology+IJMTT>.
- Hitchcock, F. L. (1941). *The Distribution of a Product from Several Sources to Numerous Locations*, Journal of Mathematics and Physics, 20, pp. 224- 230.

Kantorovich, L. (1942). *The translocation of masses*, Academic Science, 37, pp. 199–201.

Shah, P. N. (n.d.). *Transportation problem using north-west corner method calculator*. Retrieved from
<https://cbom.atozmath.com/CBOM/Transportation.aspx?q=nwcm>

Koopmans, T. C. (1947). *Optimum Utilization of Transportation System*, Proceedings of International Statistics Conference, Washington, D. C.

University Of Ilorin Water Enterprises - Ilorin - Ngads: Nigeria free Classified and Business Directory. Retrieved from
<https://ngads.com.ng/item/university-of-ilorin-water-enterprises-212514.html>