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MINIMISATION OF TRANSPORTATION COST AND EFFICIENT ASSIGNMENT OF ENGINEERS IN AN INDUSTRY

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ABSTRACT

Operations Research deals with implementing analytical techniques for optimal decision making. This discipline essentially breaks down a given situation into components of mathematical analysis, thereby effectively providing means to overcome hurdles in businesses. Knowledge, innovations and technology are constantly changing. The process of decision making, over the years has upgraded and hence in today's social and business environment, this has become a complex task due to little or no precedents. In order to address the broader tactical and strategic issues effectively and provide sound leadership in the global business environment, an understanding of the use of quantitative methods to decision-making is essential for managers to effectively decide upon business issues. Operations research approach helps in the comparison of all possible courses of actions with respect to their potential outcomes thereby, aiding to the decision-maker's judgement.

This research paper drawn upon field research highlights the application of transportation methods in operations research to solve a technical challenge in 'Sigma Diesel Ltd. - Kirloskar Generators Authorised Service Dealer - KOEL CARE CENTRE', a dealer of Kirloskar Generators in Visakhapatnam, Andhra Pradesh. This paper understands the application of transportation and assignment problems in real life situations, by practically implementing them and analysing their significance. Implementing Vogel's approximation method and modified distribution method of transportation problem, the aim is to minimise the total transportation cost borne in transportation of spare parts from the company's warehouses to the intended workshops in various destinations. The Hungarian method of assignment problem will be practically implemented to effectively assign engineers throughout the city of Visakhapatnam in order to reduce time and distance during routine maintenance visits.

INTRODUCTION

The diesel generator market in India is expected to grow at a CAGR of more than 3% over the period of 2020-2025. Increase in demand for uninterrupted and reliable power supply and increasing growth in the healthcare industry fuels this growth. The 21st century is a time where electricity is a lifeline. Continuous supply of power 24/7 is vital to any household or fixed establishment today. The generator manufacturing industry in India has been flourishing by fulfilling this vital necessity. The generator market follows a two-tier distribution system covering generator suppliers and dealers. A generator dealer is the primary point of contact for the customer or end user. The dealer performs tasks that include installation and periodic maintenance of generators, ensuring that generators run without any hitches.

Kirloskar Generators, the major player in the industry runs on the same model. The dealers of Kirloskar Generators are referred to as 'KOEL CARE'. KOEL CARE Service network has over 425 dedicated Service outlets with over 6000 Service Engineers across the nation serving customers 24x7 and 'Sigma Diesel Ltd. -

Kirloskar Generators Authorised Service Dealer - KOEL CARE CENTRE', is one of these KOEL CARE centres. It is based in Visakhapatnam and looks after the regions of Visakhapatnam, Vizianagaram, Srikakulam and Tuni, providing warranty service, maintenance service, and genuine spare parts.

With the help of semi structured data collected from the company, this research paper aims to reduce the transportation cost of the company in delivering spare parts and engine oil to its workshops in Visakhapatnam, Vizianagaram, Srikakulam and Tuni. The study of transportation problem helps to identify optimal transportation routes along with units of commodity to be shipped in order to minimize total transportation cost. The transportation problem represents a particular type of linear programming problem used for allocating resources in an optimal way; it is a highly useful tool for managers and supply chain engineers for optimizing costs. The sources of supply are production facilities, warehouses, or supply centres, each having a certain amount of commodity to supply. The destinations are consumption facilities, warehouses or demand centres each having a certain amount of requirement (or demand) of the commodity. The problem is to be solved using Vogel's approximation method and modified distribution method of transportation problem to ensure the most optimal solution is reached at.

This paper also aims to tackle the assignment problem faced by the company. An assignment, similar to transportation model is a form of Linear Programming model will be used to allocate particular areas to engineers in order to reduce time, distance and cost. Sigma Diesel Ltd. has 20 service engineers out of which 12 engineers are given the responsibility of going for routine maintenance service in Visakhapatnam, the schedule of which is always pre-planned and is known before-hand. The task is to effectively assign these engineers to different locations in the city of Visakhapatnam such that the distance and time taken to reach the destination is minimized. The assignment is to be done in such a way that the areas assigned is closest to the engineer's residence in order to reach on time and reduce the distance to reach the service location, thereby ensuring punctual service helping in reduction of customer complaints and also saving costs on account of company's expenditure on fuel for the engineers to travel. To ensure this, the Hungarian method of solving assignment problems shall be used.

The implications of the results derived would lead to reduction of cost and risk in the supply chain, thereby increasing efficiency of the company. The purpose of this study is to determine the industry's functioning from a practical perspective and suggest improvements in the existing supply chain management thereby understanding the applications of knowledge gained in the discipline of operations research. To analyse and determine feasible approaches, a number of research papers on transportation and assignment problems in Operations Research were thoroughly studied and referred to.

LITERATURE REVIEW:

The aptness of solving methods depends upon the selection of the method as emphasised in 'An Assignment Problem and Its Application in Education Domain: A Review and Potential Path' by Syakinah Faudzi, Syariza Abdul-Rahman and Rosshairy Abd Rahman. It is very important to select the right approaches in solving the problem in order to obtain an optimal or nearest optimal solution depending on the complexity of the problem. The assignment problem remains as a puzzle in the future as its flexibility in diverse applications that can be applied into real-world situations.

Another paper that was referred to was 'The Assignment Problem in Human Resource Project Management under Uncertainty by Helena Gaspars-Wieloch'. According to it, when considering new innovative projects or when the projects are performed in very turbulent times, the parameter assessment converts into more complex. The Assignment Problem model, with deterministic parameters can be easily solved, but it is apposite for standard projects in a quiet environment.

'Review article: Applications of Operational Research to the Transportation Problems in Developing Countries: A Review' by S. Datta reflects about the useful OR studies to help developing countries in distribution, technology, management and infrastructure issues. The paper emphasises that standard problems are easy to solve but few broad considerations the discipline needs to encompass that involves a realistic assessment of constraints and creative use of innovative methods. It is hoped that the transportation methods improve further to address the problems of developing countries with more efficiency.

Considerable number of methods have been used for solving assignment problems in the paper, A Comparative Analysis of Assignment Problem by Shweta Singh, G.C.Dubey, Rajesh Shrivastava. Comparisons were made between various methods where in the conclusion states that among them the Hungarian Method that works on the basis of matrix reduction is more convenient.

'An Analytical Solution of Transportation Problem from Modified Distribution (MODI) Approach' by Prof. Vipin Jain, Dr. Puneeth Sethi, Dr. Rajiv Verma, Dr. Satyendra Arya and Dr. Chanchal Chawla solves a transportation problem in the IT industry, implementing the Modified Distribution method. The researchers, based on widespread study arrive at an optimal solution through the use of Vogel's Approximation Method as the technique decreases unpredictability and provides a straightforward solution to the problem stated in the paper. The VAM techniques are used for adjusted cases with exception of task issues.

In another paper, 'Operations Research for Transportation and Sustainable Development' by Jesica de Armas, Helena Ramalhinho, Eduardo Lalla-Ruiz, Belen Melian-Batista and Marcos Moreno-Vega deals with mathematical programming techniques, especially the application of transportation techniques for promoting a sustainable environment, eliminating wastage through multi objective approaches.

'Production and inter-facility transportation scheduling for a process industry' studies the issue of coordinating between interfacility transportation schedules by formulating the data into a mixed integer programming model, highlighting the general relationships between the scheduling decisions of production and transportation and the choice of mode of transportation yielding significant savings in cost.

RESEARCH OBJECTIVES

- To develop an optimal transportation schedule that results in minimum total transportation cost, thereby understanding the practical implementation of Transportation methods.
- To effectively assign engineers with areas for routine maintenance visits, thereby reducing time and distance and improving efficiency, thereby providing a feasible solution through the knowledge of the Hungarian method of solving an assignment problem.

RESEARCH METHODOLOGY

The study is based on both Primary and Secondary sources.

1. Primary sources were collected through some interviews with a simple questionnaire, the data collected was agreed upon to be confidential as per the privacy policy of the company.
2. Secondary data was collected from the administrative office of Sigma Diesel Ltd. – Kirloskar Generators Authorised Dealer – KOEL CARE CENTRE.

TRANSPORTATION MODEL:

The transportation problem is a special type of linear programming problem where the objective consists in minimizing transportation cost of a given commodity from a number of sources or origins to a number of destinations. Each source has a limited supply while each destination has a demand to be satisfied. This assumption that there is no leeway in the volumes to be sent or received indicates that there needs to be a balance between the total supply from all sources and the total demand at all destinations.

Mathematical Statement of Cost Minimizing Transportation Problem:

$$\text{Minimize } z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$$

subject to

$$\sum_{j=1}^{n} x_{ij} = a_i, \; i = 1,2,\ldots,m \; ; \; \sum_{i=1}^{m} x_{ij} = b_j, \; j = 1,2,\ldots,n$$

$x_{ij} \geq 0$, for all i and j

where m is the number of supply points and n is the number of demand points. The production capacity of the ith plant is a_i and the number of units required at the jth destination is b_j .The transportation cost of one unit from the ith plant to the jth destination is c_{ij} and x_{ij} is the number of units shipped from the ith plant to jth destination.

Transportation problems can be solved with the help of North-west corner method, Least Cost method or Vogel's approximation method. The reason Vogel's approximation method is being chosen to solve the problem is because in this method, an allocation is made on the basis of the opportunity (or penalty or extra) cost that would have been incurred if the allocation in certain cells with minimum unit transportation cost was missed. Under this method, allocations are made in such a way that the penalty cost is minimized. An initial solution obtained by using this method is nearer to the optimal solution or is the optimal solution itself. Vogel's approximation method assists us in reaching the initial basic feasible solution.

The steps involved in Vogel's approximation method are:

1. Calculate the penalties for each row and each column by taking the difference between the two successive least cost in that row or column.
2. Select the row or column with the largest penalty.
3. In the selected row or column, allocate the maximum feasible quantity to the cell with the minimum cost.
4. Eliminate the row or column where all the allocations are made.
5. Write the reduced transportation table and repeat the steps until all the allocations are made.

The Modified distribution method, known as MODI method or (u-v) method is used in order to fetch an optimum solution to a transportation method. It provides a computational scheme that reduces complexity, considerable time savings over other methods for solving transportation methods.

The steps involved in this method are:

1. Determine an initial basic solution using Northwest corner method, Matrix minimum method or Vogel approximation method. As mentioned earlier, Vogel approximation method will be implemented here.
2. Determine the values of dual variables u_i and v_j, using $c_{ij} = u_i + v_j$

3. Compute opportunity cost, $\Delta_{ij} = c_{ij} - (u_i + v_j)$.
4. Check the sign of each opportunity cost. If the opportunity costs of all unoccupied cells are either positive or zero, then the given solution is optimal. However, if one or more unoccupied cells have negative opportunity cost, then the given solution is not optimal and further minimisation of transportation cost is possible.
5. Select the unoccupied cell with the smallest negative opportunity cost as the cell which is to be included in the next solution and draw a closed loop. It is to be noted that the right angle turn in the loop is permitted by occupied cells and at the original unoccupied cell.
6. Assign alternate positive and negative signs at the unoccupied cells on the corner points of the closed path with a positive sign at the cell which is under evaluation.
7. Determine the maximum number of units that should be allocated to this unoccupied cell. The smallest value with negative sign on the closed loop indicates the number of units that can be transported to the entering cell.
8. Add this quantity to all cells on the corner points of the loop marked with positive signs and subtract from these cells marked with negative signs. An unoccupied cell becomes occupied.
9. Repeat the entire procedure until an optimal solution is obtained.

This method of transportation problem helps to attain optimality, thereby effectively reducing cost of transportation and potentially improving the supply chain management. To ensure accuracy in results, TORA software has been used to solve the transportation problem.

HUNGARIAN METHOD OF SOLVING ASSIGNMENT PROBLEM:

An assignment problem is a special type of linear programming problem where the objective function is to minimize the cost or time of completing a particular number of jobs by a particular number of persons. The jobs are to be assigned such that only one person is assigned to cater to one task. This method was developed by D. Konig, a Hungarian mathematician and hence, it is known as the Hungarian method of assignment problem. The problem of personnel-assignment in order to attain efficiency and minimize wastage of time, money and distance can be solved with the help of Hungarian method of assignment.

The steps involved in solving the assignment problem faced in this paper are as follows.

1. In a given problem, if the number of rows is not equal to the number of columns and vice versa, then add a dummy row or a dummy column. The assignment costs for dummy cells are always assigned as zero.
2. Reduce the matrix by selecting the smallest element in each row and subtract from other elements in that row.
3. Reduce the matrix by selecting the smallest element in each column and subtract from other elements in that column.
4. Draw minimum number of lines to cover all zeros.
5. Optimality test: If number of lines drawn = order of matrix, then optimally is reached, then proceed to step 7. If optimally is not reached, then go to step 6.
6. Select the smallest element of the whole matrix, which is not covered by lines. Subtract this smallest element with all other remaining elements that are not covered by lines and add the element at the intersection of lines. Leave the elements covered by single lines as it is. Now repeat steps 4 and 5.
7. Take any row or column which has a single zero and block it by drawing a square. Strike off the remaining zeros, if any, in that row and column. Repeat the process until all the assignments have been made.

8. Write down the assignment results and find the minimum cost/time.

This research paper effectively makes use of the steps above to determine an optimal assignment schedule for the company. With the help of Microsoft excel, basic calculations were made to ensure accuracy and simplicity while solving the assignment problem.

ANALYSIS AND FINDINGS

The data collected from Sigma Diesel Ltd. – Kirloskar Generators Authorised Dealer – KOEL CARE CENTRE was complex to decipher. For simplicity in analysis, the data has been cut down to fit the format of our knowledge. As mentioned earlier, the data was agreed to be confidential as per the privacy policy of the company.

An approach to minimise total transportation cost of spare parts:

Sigma Diesel Ltd. – Kirloskar Generators Authorised Dealer – KOEL CARE CENTRE receives spare parts from the main factory of Kirloskar generators in Pune. From the workshop in Visakhapatnam, the spare parts are transported to districts of Vizianagaram, Srikakulam and Tuni. The company has 2 warehouses located in Visakhapatnam, where from, the spare parts will be transported to these three locations.

Few assumptions were made beforehand to fit the data into the transportation problem.

1. Demand is assumed to be equal to supply.
2. Transportation is always through road.

The unit cost table derived is as follows.

	Visakhapatnam	Srikakulam	Tuni	Supply (no. of units)
Warehouse 1	50	100	70	170
Warehouse 2	30	80	80	180
Demand (no. of units)	150	90	110	350

Here, the unit cost is in the form of Indian rupees.

Calculation of initial basic solution through Vogel's approximation method and with the help of Modified distribution method with the help of TORA software has been derived and shown below.

TRANSPORTATION MODEL

TORA Optimization System, Windows®-version 1.00
Copyright © 2000-2002 Hamdy A. Taha. All Rights Reserved
Monday, September 20, 2021 18:16

TRANSPORTATION TABLEAU - (Vogel's Method)

Title: Tranportation model of Sigma Diesel Ltd. --(minimum cost)

Steps for generating transportation tableaus:
1. (Optional step) Initialize ONE of the simplex multiplier (u1, u2, ..., v1, v2 ...) to zero value (default u1 = 0)
2. Click (in any order) the cells defining the change-of-basis loop (if corret, cell changes color)
3. Click command button NEXT ITERATION (or ALL ITERATIONS) -- This step may be executed without Step 2

Initialize u or v: u1=0

Next Iteration | All Iterations | Write to Printer

Iter 1	ObjVal =	20600.00	D1	D2	D3	Supply
	Name		Vizianagaram	Srikakulam	Tuni	
			v1=50.00	v2=100.00	v3=70.00	
S1	Warehouse 1	u1=0.00	50.00	100.00	70.00	
				60	110	170
			0.00	0.00	0.00	
S2	Warehouse 2	u2=-20.00	30.00	80.00	80.00	
			150	30		180
			0.00	0.00	-30.00	
	Demand		150	90	110	

Here, it can be clearly seen that the rim requirement of m+n-1 being equal to the number of allocations, where m is the number of origins and n is the number of destinations is met aptly as in this case m is 2 and n is 3. There are 4 positive independent allocations and, 2+3-1=4. It can be said that the solution obtained is not degenerate.

The TORA Software for computing transportation problem has effectively helped in attaining an optimal solution. The output summary of the final solution obtained to this transportation model is shown below.

TRANSPORTATION MODEL

TORA Optimization System, Windows®-version 1.00
Copyright © 2000-2002 Hamdy A. Taha. All Rights Reserved
Monday, September 20, 2021 18:18

TRANSPORTATION MODEL OUTPUT SUMMARY

Title: Tranportation model of Sigma Diesel Ltd.
Final Iteration No.: 1
Objective Value (minimum cost) =20600.00

Next Iteration | All Iterations | Write to Printer

From	To	Amt Shipped	Obj Coeff	Obj Contrib
S1: Warehouse 1	D2: Srikakulam	60	100.00	6000.00
S1: Warehouse 1	D3: Tuni	110	70.00	7700.00
S2: Warehouse 2	D1: Vizianagaram	150	30.00	4500.00
S2: Warehouse 2	D2: Srikakulam	30	80.00	2400.00

The minimum transportation cost derived is Rs. 20,600.

This can be achieved if the above schedule is followed. Following this can lead to cost reduction and can in turn increase profits. However, the aptness in the findings derived from transportation methods and their implementation cannot be ascertained in a practical environment, depending on the data, the constraints of the environment an organisation and other factors affecting the data. In this case, the number of origins and destinations are quite low and most constraints were taken into consideration. So, it is expected for the optimal result to be similar while implementation by the company.

Assignment Problem faced by the administration of the company:

Sigma Diesel Ltd. – Kirloskar Generators Authorised Dealer – KOEL CARE CENTRE has 20 engineers in Visakhapatnam out of which 12 engineers are allocated to routine service rounds and the remaining 8 are allocated to work in the workshop in Visakhapatnam. When an engineer assigned with routine servicing is on leave, then he is replaced by a workshop engineer for that day.

The city of Visakhapatnam has been broken down into 10 sectors for ease in assignment.

Sector	Area
A	Madhurwada
B	Pendurthi
C	Gajuwaka
D	Tagarpuvalsa
E	Anandapuram
F	Seethamdhara
G	MVP
H	Waltair
I	Old town
J	Gyanapuram

The 12 engineers are to be allocated on the basis of time taken to reach each sector. The engineers are to be assigned a sector accordingly, which minimises the time to reach the destination, thereby reducing the company's expenditure on fuel to provide the engineers for transportation. The 12 routine service engineers are to start from their respective houses for servicing. The time taken to reach each of these areas from their houses has been recorded in the table below. Time is taken in minutes. With the help of the Hungarian method of transportation problem, an optimum assignment schedule can be prepared and effective assignments can be made that would be beneficial for the company in saving time and costs.

The engineers and sectors are arranged in a matrix with rows being engineers, columns being sectors, and entries being the time taken to reach these sectors. Time is taken in minutes.

Engineer/Sector	A	B	C	D	E	F	G	H	I	J
1	10	75	60	30	40	30	30	40	80	90
2	30	70	30	30	60	30	15	10	30	40
3	70	110	60	60	75	40	45	30	60	35
4	35	80	45	40	90	40	10	15	30	40
5	120	60	45	140	160	60	75	60	75	60
6	150	60	20	120	140	70	65	60	65	35
7	120	40	30	150	170	120	60	40	45	30
8	15	60	120	20	40	25	25	30	40	60
9	140	70	60	60	80	40	35	20	10	20
10	30	75	60	60	80	15	15	10	15	20
11	35	45	50	70	90	30	25	20	30	10
12	75	120	120	60	80	30	25	20	15	30

We have 12 engineers and 10 sectors. The problem is unbalanced since the number of rows are not equal to the number of columns. Hence, dummy columns D1, D2 will be added to make the problem balanced.

After solving the problem with the help of excel according to the steps involved in the procedure of the Hungarian method, the following assignments have been derived.

Engineer/Sector	A	B	C	D	E	F	G	H	I	J	D1	D2
1	0	55	60	10	~~0~~	25	30	40	90	100	20	20
2	10	40	20	0	10	15	5	~~0~~	30	40	10	10
3	40	70	40	20	15	15	25	10	50	25	0	~~0~~
4	15	50	35	10	40	25	0	5	30	40	10	10
5	90	20	25	100	100	35	55	40	65	50	~~0~~	0
6	120	20	0	80	80	45	45	40	55	25	~~0~~	~~0~~
7	90	0	10	110	110	95	40	20	35	20	~~0~~	~~0~~
8	5	40	120	~~0~~	0	20	25	30	50	70	20	20
9	110	30	40	20	20	15	15	~~0~~	0	10	~~0~~	~~0~~
10	10	45	50	30	30	0	5	~~0~~	15	20	10	10
11	5	5	30	30	30	5	5	~~0~~	20	0	~~0~~	~~0~~
12	45	80	100	20	20	5	5	0	5	20	~~0~~	~~0~~

Clearly, each row and column has only one allocation.

The following is the assignment schedule obtained by performing the Hungarian method of Assignment problem. The allocated cells are matched with the rows and columns to derive the schedule.

Engineer	Sector	Area	Time (minutes)
1	A	Madhurwada	10
2	D	Tagarapuvalsa	30
3	D1	-	-
4	G	MVP	10
5	D2	-	-
6	C	Gajuwaka	20
7	B	Pendurthi	40
8	E	Anandapuram	40
9	I	Old Town	10
10	F	Seethamdhara	15
11	J	Gyanapuram	10
12	H	Waltair	20

The assignment schedule obtained allocates each engineer to each sector in such a way that the time taken to reach the areas in their respective sectors is minimized. Following the above assignment schedule will help the company in a significant way in bringing down chaos and improving their already exceptional customer service to a higher level by enabling engineers to reach on time, not overburdening them and thereby also achieving economy of operations along with good and on-time customer service.

CONCLUSION

This paper sees the implementation of Vogel's approximation method and Modified distribution method to tackle the supply chain problem in Sigma Diesel Ltd. – Kirloskar Generators Authorised Dealer – KOEL CARE CENTRE, thereby, providing a solution that lowers total transportation cost than what it is currently and eradicating chaos in assigning engineers for routine maintenance service.

The data received was complex, it was fitted to the transportation framework. According to the analysis mentioned in the research paper, the company has further possibility of cutting down costs. The solution derived is optimal, however, the company has several other complex constraints to consider while following its existing transportation method. Hence, it cannot be argued that the solution proposed is optimal and that what the company currently follows is not.

The assignment problem of the company solved in this paper through the Hungarian method of solving assignment problem provides a systematic and an organised framework based on which the company can reduce customer complaints by ensuring that engineers reach on time and the distance is minimized, being beneficial for the company which in turn can reduce costs.

This research paper has helped in attaining a practical perspective of the corporate world, where in real life the concepts of operations research can be implemented. Though the discipline helps companies to minimise their costs and effectively assign jobs, there are instances when companies may not be able to follow the delivered results in practicality to an extent, which results in solutions that are not very optimal as per the discipline but optimal as per the constraints and situation faced in reality.

Hence, this research paper proposes an optimal solution to the problems of Sigma Diesel Ltd. – Kirloskar Generators Authorised Dealer – KOEL CARE CENTRE in the area of transportation and assignment. Another interesting conclusion to this paper would be that the solutions rendered by the discipline of operations research have more scope of improvement to take into consideration all constraints and limitations.

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