Use of Transportation Problem in a water company

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Abstract. Operations Research uses mathematical models to help decision-making in companies. We use linear programming and transportation problem application as a proposal to improve the organisation's resource management based on the availability of vehicles and the fuel costs of equipment in a local water company. This study aims to use the Solver tool to support the cost management decision in the transportation sector of a local water company in Brazil. The results show that the company can reduce fuel costs by adapting and better-targeting vehicles between regions and standardising vehicle categories. The application of Operational Research allows the analysis of how companies manage their resources. Decision-making using Operations Research techniques can contribute to reducing the cost of producing products and make it possible to obtain greater profitability and accuracy in the distribution of resources. We suggest implementing cost management alternatives, making time-based comparations and finding each region's needs for future works.

Keywords: Operational Research, Transportation Problem, Solver.

1 Introduction

Operational Research emerged from the Industrial Revolution, where there is knowledge about the complexity of organisations, where small artisans have become large factories. One factor for this change was the terrific size of the division of labour and the segmentation of managerial responsibilities. However, as complexity and specialisation increased, it became increasingly difficult to manage the resources to carry out the activities efficiently [1].

During World War II, a group of scientists was called to England to study problems related to tactics associated with the country's defence to discuss the effective use of limited resources. Hence, it was possible to allow operational Research to have a formalised first activity. Operational Research is a multidisciplinary science involving exact and applied social sciences knowledge. Thus, they created data-based models that would identify potential problems, simulate and evaluate the results of strategies, and propose alternative decisions [2]. Operational problems focus mainly on finding the optimal cargo route or services needed to minimise cargo transport costs [3].

It is possible to conduct Operational Research, whose objective is to use mathematical, statistical or pre-established algorithms to assist the operation of a system [4]. Linear programming determines and maximises or minimises impacts on the organisation, for example, in profitability or costs; as [5] points out, linear programming solves problems of allocation of limited resources for the performance of activities to ensure maximum efficiency in this allocation, considering the restrictions that the system has.

This study aims to optimise vehicles used in the company to ensure that the demands of its state headquarters are known at the lowest possible cost and that cars are available for the sectors, given the limited amount of equipment in the company. For this, the Solver tool will show the optimal solution for operating vehicles in the case.

2 Theoretical Framework

2.1 Operational Research

Operational Research emerged as the most expressive representative of the approaches focused on decision-making [2]. From the OR, the administrator can make proactive decisions in the different dimensions of the organisation.

An Operational Research study usually has six phases [3]. They formulate the problem, construct the system model, calculate the solution through the model, model and solution testing, and establish solution controls, implementation, and monitoring.

In the first phase, the problem is discussed and defined as what objectives to achieve and the most assertive ways for this to occur, pointing out the system's limitations. In constructing the model, the mathematical model is defined and formed by equations and inequations to determine the problem's objective function and constraints of the problem. The calculation phase uses mathematical techniques considering the availability for calculating the solution. In the test phase of the model, it is performed with empirical data applied to the model. The construction and experimentation of the model and identification of the fundamental parameters for solving the problem. Finally, in the implementation and monitoring phase, the solution will be shown to the administrator, and from the data arranged, make the appropriate decisions to what the model explains.

Operational Research had a significant impact on the efficiency of several organisations. [6] pointed out that Operational Research involves "research on operations". Therefore, it is used for problems in an organisation's activities. The nature of organisations is essentially secondary, and Operational Research can be applied in different areas such as manufacturing, transportation optimisation problems, construction, and financial planning [1].

2.2 Transportation Problem

The transportation problem is commonly used in logistics matters. According to [2], a transport problem aims to reduce transportation costs needed to supply n destinations from different sources (suppliers), considering that the quantities of supply and demand are known. Transportation must be carried out respecting supply limitations and meeting demand [7].

As conceptualised by [8], an objective function makes in its formation use of variable decision elements to elaborate the objective of maximising or minimising the proper mathematical model. Thus, the transportation problem aims to minimise the costs related to the displacement of products as much as possible. According to [2], its objective function can be understood according to The Following Equation 1:

$$Max\ Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}\ X_{ij} \quad (1)$$

Where:
Cij = unit transport cost (R$) from origin i to destination j;
Xij = quantity to be transported from origin i to destination j;
m = set of possible i sources;
i = 1, 2, ..., m;
n = set of possible j targets;
j = 1, 2, ..., n

Since a transport problem can be formulated simply by filling a table, it is not necessary to write a formal mathematical model for the problem [1]. Regarding the analysis method, Table 1 was created in the Solver tool of MS Excel.

It is also important to understand that the transportation problem needs to be analysed from the perspective of some hypotheses pointed out by [1]. This explains the requirement hypothesis: "each origin has a fixed offer of units, in which all this offer has to be distributed to the destinations. (...) Similarly, each destination has a fixed demand for units, and all this demand must be received from the origins." Another hypothesis raised by the authors is that the costs of units from any origin to any destination are directly proportional to the number of units distributed, thus making the cost of distributing the unit cost per unit times the number of units distributed.

Table 1 considers Xn as all unit costs related to the transport into its respective jn. Each source has limited resources, represented in the table as "Total Offers." Each destination has specific needs defined by "Total needs". Thus, we will have the following format for building the problem:

Table 1. Transportation Problem in Excel

	J1	J2	J3		Total Offers
I1	X_{11}	X_{12}	X_{13}	≤	Dpi1
I2	X_{21}	X_{22}	X_{23}	≤	Dpi2
I3	X_{31}	X_{32}	X_{33}	=	Dpi3
Total Needs	Ntj1	Ntj2	Ntj3		

With the data entered in MS Excel, Solver will use the generic Simplex method to solve the proposed transport problem efficiently. In the example of Table 1, it was observed that one of the restrictions (requirements) is in the form of inequalities; for this, the Solver tool will automatically make the addition of slack variables in the problem so that these inequalities can be transformed into equalities, making it possible to perform the simulation. These variables will indicate only possible values not used in availability/needs, then be able to convert the constraints into equality restrictions and perform the simulation necessary to solve the problem.

3 Methodology

3.1 Transportation Problems

More and more computer software is being used to Solve Linear Programming problems. One of the most widely used programs for this purpose is MS Solver, which handles a Microsoft Office Excel add-in offered with the Office suite [9]. This tool, still little known among Operational Search users, helps solve various PL and optimisation problems and aims to assist the administrator in decision-making. It is possible to calculate the results of a formula that uses one or more variables with the Solver enabled [10]. As a complement to the use of Solver, [11] informs that this tool is gaining more and more users because, in addition to the practicality in use, spreadsheets are present practically in all modern companies.

Solver can find an outstanding value for a specific problem. The program rewrites the values in the specified variable cells to produce the expected result in the formula of the objective function. It is, therefore, necessary to apply restrictions to inform the software which variables will interfere with the result.

Based on on-site observation and data collection through the system used by the company, it was verified a high fuel consumption by the vehicles of the agency, in addition to the high variability of cars to perform the activities. Thus, the problem of this study aims to solve the consumption in the supply of the equipment used, ensuring better cost management for the sector and the company.

In partnership with the Transport Sub-management at CAGEPA's administrative headquarters (water company), an improvement in the distribution of vehicles used in its internal activities will be proposed, ensuring full service to the requesting equipment sectors.

Firstly, a survey was applied to the departments to determine each sector's available vehicles. Thus, measuring how many cars each region has and which vehicle model corresponds to that demand is possible. Then, the costs of supplying these vehicles were raised to verify how many and which areas most use them, so it will be possible to measure which vehicles will best suit the site.

After this survey, the problem was formulated according to the available demand and supply of vehicles. The data were inserted into Excel's MS Solver tool, where the results showed the optimal solution for proper transport sector uses to promote the lowest possible cost. We use past data provided by the company to prove that our model works, considering where each region can give up the use of a specific vehicle.

The main objective of this study is to propose improvements in the effective use of the organisation's fleet, allowing the company to have greater control over the demand and use the data presented here to plan its future allocations, avoiding oversizing or lack of sufficient equipment for the company.

3.2 Case Study

CAGEPA is a mixed capital company that plans, executes and operates essential sanitation services in Brazil, comprising all the services responsible for the treatment and distribution of water in the state.

Because it is a company that operates at the state level, it needs massive planning of the resources that have it, one of which is the provision of vehicles to meet the demands of the state, from legal problems to on-site maintenance services. CAGEPA needs equipment to meet the demands and ensure the whole company's activity.

In direct responsibility of the Transport Sub-Management, CAGEPA carries out all necessary procedures for vehicles to be available when requested. Thus, there will always be enough equipment for all sectors of the place to be served.

The organisation aims to plan, execute and operate essential sanitation services throughout the territory of the State of Paraíba, including the capture, adduction, treatment and distribution of water and collection, treatment and final disposal of sewage, commercialised these services and the benefits that directly or indirectly result from their enterprises, as well as any other related or related activities.

It operates in 219 locations, serving an urban population of 2,841.101, where 880 are performed by sewage service. There are 2971 employees divided into 06 (six) regional managers, including The Coastal Regional based in João Pessoa, the Borborema Regional with its head office in Campina Grande, the Brejo Regional, in Guarabira, the Espinharas Regional, which response in Patos, Regional of Rio do Peixe, based in Sousa and the Regional Alto Piranhas, which serves the localities near its head, in Cajazeiras.

CAGEPA needs to use several vehicles to satisfy the necessary demand for its activity. The company's need goes from essential passenger vehicles to specific equipment that can enter hard-to-reach locations, so it is needed to rent trucks, for example. Not only the cost of leasing, but the company is also responsible for the designation of resources for preventive/corrective maintenance and supply of the vehicles used. These values are realistic so that they are used efficiently by each region and that it is sufficient for no vehicle to go unused. For this, it is crucial that the company assertively design its resources to promote the best management of cars according to their organisational needs. To this end, this study aims, through Solver, to help the company promote an optimal solution for allocating the company's fuel costs.

4 Results

4.1 Descriptive Analysis

The total number of vehicles available was verified to find an optimal solution. Due to their data protection, the company could only provide us with accurate data from January 2021. Thus, it was possible to analyse more recent and accurate data about the company's actual vehicle layout. Table 2 refers to the company's current vehicle allocation based on data from January 2021.

As verified, the company has 266 vehicles divided into 5 models, each meeting its specific need. Except for Saveiro and Strada models that participate in the same equipment category, they have the same purpose within the company.

Table 2. Vehicles availability

VEHICLES	REG AP	REG BO	REG BR	REG ES	REG LT	REG RP	Total Offers
(1) DOBLO	2	7	3	2	9	1	24
(2) KA	5	19	9	5	35	3	76
(3) S10	3	19	6	5	25	5	63
(4) SAVEIRO	3	21	7	6	28	6	71
(5) STRADA	4	6	4	6	10	2	32
Total Needs	17	72	29	24	107	17	266

With these data, it was possible to analyse values related to the cost of vehicles concerning fuel consumption in the month studied. For this case, we consider the cost of fuel the cost of the car because it is an expenditure of resources of high variability and cost. For the calculation, an average price was made that each model supplied under its respective regional allocation. The result is in Table 3.

Table 3. Fuel Consumption

	REG AP	REG BO	REG BR	REG ES	REG LT	REG RP
1	R$ 5.891,48	R$ 18.296,9	R$ 7.326,09	R$ 7.149,46	R$ 20.450,6	R$ 2.042,33
2	R$ 14.749,4	R$ 33.331,7	R$ 12.010,3	R$ 8.427,30	R$ 79.463,6	R$ 4.347,36
3	R$ 7.328,88	R$ 49.077,9	R$ 16.996,7	R$ 16.105,5	R$ 52.629,2	R$ 10.998,3
4	R$ 4.768,95	R$ 42.294,4	R$ 19.651,6	R$ 17.513,1	R$ 58.925,1	R$ 12.642,7
5	R$ 4.202,84	R$ 10.007,9	R$ 7.445,96	R$ 12.428,6	R$ 19.807,3	R$ 2.101,00

Table 3 describes the individual cost per consumption, according to one month of vehicles available in the company and the regional ones to which these vehicles are allocated, a total amount of R$: 578,412.85.

Based on these calculations, it was possible to verify how much, on average, a car of a given category consumed fuel in each region, which made the data presented increasingly accurate. According to the values in Table 3, it was possible to notice that different models of vehicles have other average fuel consumption, considering that there are diverse offers and demands of use in each location.

Thus, this study aims to find a solution to measure the company's minimum cost (in supplies) based on the availability of current vehicles through the Solver package to find the expected result.

4.2 Exploratory Analysis

To elaborate the problem, we use the sum of all unit costs of each vehicle concerning the quantity available. Then, a new table was built, and the variables were inserted. Considering the data in Table 3, the objective function will be described as follows:

$$Min\ Z = 2945.74X\_{11} + 2613.85\ X\_{12} + 2442.03\ X\_{13} + 3574.73\ X\_{14} + 2272.28\ X\_{15} + 2042{,}33\ X\_{16} + 2949.89\ X\_{21} + 1754.30\ X\_{22} + 1334.47\ X\_{23} + 1685.45\ X\_{24} + 2270.38\ X\_{25} + 144\ 9.11\ X\_{26} + 2442.96\ X\_{31} + 2583.04\ X\_{32} + 2832.79\ X\_{33} + 3221.11\ X\_{34} + 2132.79\ X\_{35} + 21\ 99.66\ X\_{36} + 1589.65\ X\_{41} + 2014.02\ X\_{42} + 2807.37\ X\_{43} + 2918.84\ X\_{44} + 2104.46\ X\_{45} + 2107.128\ X\_{46} + 1050.71\ X\_{51} + 1667.99\ X\_{52} + 1861.49\ X\_{53} + 2071.44\ X\_{54} + 1980.72\ X\_{55} + 1050.49\ X\_{56} \quad (2)$$

As the literature shows, transportation problems are subject to restrictions, such as financial restrictions on capacity or the number of resources. For this case, the constraints will take place in the number of resources shown in the following formulas:

$$R1\ (Doblo): X\_{11} + X\_{12} + X\_{13} + X\_{14} + X\_{15} + X\_{16} = 24 \quad (3)$$

$$R2\ (KA): X\_{21} + X\_{22} + X\_{23} + X\_{24} + X\_{25} + X\_{26} = 76 \quad (4)$$

$$R3\ (S10): X\_{31} + X\_{32} + X\_{33} + X\_{34} + X\_{35} + X\_{36} = 63 \quad (5)$$

$$R4\ (Saveiro): X\_{41} + X\_{42} + X\_{43} + X\_{44} + X\_{45} + X\_{46} = 71 \quad (6)$$

$$R5\ (Strada): X\_{51} + X\_{52} + X\_{53} + X\_{54} + X\_{55} + X\_{56} = 32 \quad (7)$$

$$R6\ (AP): X\_{11} + X\_{21} + X\_{31} + X\_{41} + X\_{51} = 17 \quad (8)$$

$$R7\ (BO): X\_{12} + X\_{22} + X\_{32} + X\_{42} + X\_{52} = 72 \quad (9)$$

$$R8\ (BR): X\_{13} + X\_{23} + X\_{33} + X\_{43} + X\_{53} = 29 \quad (10)$$

$$R9\ (ES): X\_{14} + X\_{24} + X\_{34} + X\_{44} + X\_{54} = 24 \quad (11)$$

$$R10\ (LT): X\_{15} + X\_{25} + X\_{35} + X\_{45} + X\_{55} = 107 \quad (12)$$

$$R11\ (RP): X\_{16} + X\_{26} + X\_{36} + X\_{46} + X\_{56} = 17 \quad (13)$$

After performing simulations, it was possible to observe a significant reduction in the company's costs if it adopted the "Strada" model as the category standard in its use, as shown in Table 4.

It is also considered that the entire model supply would be standardised with the model analysed in Table 4. The fuel cost would significantly reduce the costs in the organisation. Considering the amount spent by the company in January (R$: 578,412.85) in analysis with the value obtained by the new solver simulation (R$: 465,467.67), it would be possible to reduce the organisation's costs by more than R$ 110,000.00 using the suggested model. When linear programming is carried out on the Solver, considering all vehicles, it is noted that some localities will not have specific models of vehicles that previously served the region.

Table 4. Optimal Solution

VEHICLES	REG AP	REG BO	REG BR	REG ES	REG LT	REG RP	Total	Total Offers
DOBLO	0	0	0	0	24	0	24	24
KA	0	23	29	24	0	0	76	76
S10	0	0	0	0	63	0	63	63
SAVEIRO	17	49	0	0	20	17	103	103
STRADA	17	72	29	24	107	17	CT	R$ 465.467,67
Total	17	72	29	24	107	17		
Total Needs	17	72	29	24	107	17		

The software finds the best distribution of vehicles based on total cost reduction and not specifically for each type of vehicle used. Therefore, the software allows the analysis of some reports generated automatically by the software for the manager to understand the results obtained. They are the response report, the sensitivity report and the limit report. In this analysis, it will be possible to identify changes in the optimal solution that may imply adaptation and cost management improvements.

5 Considerations

The relevance of Operational Research leads to reflect applicability in companies. Operational Research is of great help in the decision-making process, considering which items can be best allocated and how much cost will be in this allocation.

This case aimed to use a mathematical function to minimise fuel costs and vehicle allocation in a company operating in Paraíba, Brazil.

Through the data obtained in the organisation and linear programming study from the Solver tool, it was possible to identify potential items that can be modified and better allocated to reduce company costs concerning supplies. The Solver presented an optimal solution for reducing the company's costs, where it was noticeable to identify possible factors that could lead the company to have high costs. The data showed that a standardisation of a vehicle model used by the company can reduce the fuel cost by more than R$ 100,000.00 that the company currently has.

Based on the analysis performed by the software, added to the problem presented, it was considered that the management of the company's fuel costs is carried out inanely, making it necessary to expenditure beyond what is required for the fulfilment of the activities. As seen, using Solver allowed better management of CAGEPA's fuel costs, ensuring the company allocates its resources better, converting them into improvements for the organisation itself.

It was also possible to remodel the types of equipment used. Based on the analysis performed, it is possible to make changes in the current scenario of vehicle layout since the adaptation to the proposed model significantly reduces the fuel costs of the sector. In this way, CAGEPA can ensure better efficiency of its equipment, lowering costs and standardising its fleet with measures proposed by the solver tool.

As a proposal for future studies, is to make time-based comparations, such as the behaviour of fuel prices, to test the volatility of the company's demands or if there is an increase or reduction in the number of vehicles available by the organisation. Using the same tool to work on the company's transport designation is also interesting, obtaining accurate data on demand for vehicles required. Finally, it is also essential that the company makes new simulations as the data changes so that the sector can assertively monitor the need and better management of its resources.

The manager can embrace this model seeking to understand how to use a specific type of vehicle in each region. For example, a Strada can be used when they need to transport some equipment, while they should not transport only a server. The model does not consider the needs of each specific region because this was not the study's objective. We found a fuel reduction and structural modification proposal in all the areas.

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