A Quantitative Study Determining an Optimal Location for a Company to Place a New Factory Through the Use of the Transportation Algorithm and Excel Solver.

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Abstract

The aim of this study is to determine an optimal new factory location for a company based on the proximity of the new factory's location to its customers and, in turn, reduce the cost related to deliveries. This was carried out using the transportation algorithm via the excel solver tool. This takes into account variables such as distance from customers, weight of the goods, as well as vehicle-based and driver-based costs, in order to determine the most cost effective location of a new factory. The current factory for the company case study is based in Pinetown and Kwa-Zulu Natal in South Africa. The proposed factory locations are Pietermaritzburg, Durban Central or another in Pinetown, all within Kwa-Zulu Natal. Based on the results, the optimal location to establish a new factory would be Pietermaritzburg, KwaZulu Natal. This location combined with the current factory location will generate the lowest cost with regards to vehicle-based and driver-based costs when delivering goods.

Keywords

Transportation, algorithm, excel, solver, location.

Introduction

The location of a business is an important aspect to consider when analysing the idea of setting up a new factory or premises. The factors which can influence the location include the access to market (such as customers), inputs (such as employees, suppliers, and knowledge), accessibility, and costs (McQuaid, et al., 2003). When looking at access to market it is important to take into account the transportation factor when determining location.

Transportation has become an essential activity for most business (Goldsby, et al., 2014). It is an essential activity which provides the economic utilities of place and time. Place being the idea that customers have the product available where they require it and time being that customers have access to the product when they need it (Goldsby, et al., 2014). When looking at these utilities there are costs involved in both. There are three areas of cost in transport, namely, operational cost and freight transportation cost functions, value of time, and external costs (Izadi, et al., 2019). When looking at operational costs in transport in can be separated into two different groups. These groups being vehicle-based cost factors and driver-based cost factors (Izadi, et al., 2019). According to Izadi, et al. (2019), vehicle-based cost consist of fuel and engine oil, truck/trialer lease or purchase, maintence and repairs, fuel tax, insurance premiums, tyres, licensing and permint, and tolls. Driver-based costs include driver wages, benefits and bonuses.

According to Richards (1962) transportation costs can be seen to be made up of two functions, these being weight and distance. It has also been noted that based on this idea that the value of a product at the place of production decreases as the distance from the market increases (Richards, 1962). These points metioned above show a connection in transportation costs and the ditance that a factory may be from customers as well as the weight of the goods being delivered. The problem of determining the most efficient and cost-effective manner used in transporting goods is known as a transportation problem (Yan, 2018).

The objective of this paper is to aid in the decision making process with regards to the location of a new factory. This is to be done through the use of the transportation algorithm and the excel solver tool. This takes into account variables such as distance from customers, weight of the goods, as well as vehicle-based and driver-based costs, in order to determine the most cost effective location of a new factory.

Literature Review

The solutions of optimal transportation and resource allocation is known as transportation theory (Singh, 2015). When finding an optimal solution for a transportation problem, it is important to note that this type of problem falls under the class of linear programming (Mishra, 2017). Linear programming is a mathematical modelling technique used to aid in resource allocation in order to either maximise or minimise a quantity such as profit or cost (Render, et al., 2018). When dealing with linear programming problems, there are three different techniques which can be used, namely, the North-West Corner Method, Least Cost Method, and Vogel's Approximation Method (Singh, 2015). According to Abdelwali, et al. (2019) the transportation problem looks at the optimal way to distribute goods from several sources to several destinations which can be used to minimise cost, distance, and time within the problem.

When solving for a linear programming problem through the three methods mentioned above, the first step is determining an initial basic feasable solution, after which, a test for optimaility is performed and, if not optimal, the method is followed to determine the optimal solution (Mishra, 2017). When looking at problems in the real world that require linear programming, it may become too complex and time consuming to use the above metioned methods. Excel solver is able to solve these larger problems, this is done through the use of a linear programming model (Abdelwali, et al., 2019). The excel solver tool makes use of variables, constraints of these variables, and an objective function which can either be maximised or minimised (Abdelwali, et al., 2019).

When using linear programming, it can be noted that the excel solver tool only gives off an optimal solution for the given senario. When solving transportation problems, all possible senarios should be solved for and compared when deterining the optimal solution (Ghosh, et al., 2020). The transportation problem uses a matrix of rows, representing sources, and coulombs, representing demands, which the algorithms used to solve the problem are based (Ghosh, et al., 2020). When using excel solver to solve a linear programming problem, the input data consists of coefficients, variables, constraints, as well as the optimisation criteria needed for the mathematical model (Šedivý, et al., 2020). The use of constraints within the model allows for the ideal solution to be determined without exceeding the maximum capacity of the sources (Ghazali, et al., 2012). It is common, in any transportation problem, for the constraints to consist of the maximum supply at which the sorces can provides the destinations with, and the required quantity which the destinations need (Azizi, et al., 2015).

In a study conducted by Ghosh, et al. (2020), excel solver is used in the situation of a local paper mill using different transportation models, namely road, train, and a combination of both. Solver is used to determine the most cost effective model in delivering their products through the use of shipping costs. This is an example where different senarios have been modelled and compared through the cost of shipping to minimise the cost of transport. In a second study by Khan (2014), linear programming is used through the use of excel slover to determine the optimal amount of mosquito coils that should be delivered from each warehouse to distributors in order to generate the lowest transportation cost. This is done by using the cost per coil from warehouse to distributors as the fixed varaibles in the model. Both these models have dealt with sorces and desintation which are already set-up and functioning. These have more to do with allocation to minimise the cost.

Methodology

The aim of this study is to determine an optimal new factory location for a company based on the proximity of the new factory's location to its customers and, in turn, the cost related to deliveries. This company produces steel products and has a current capacity of five hundred tons of goods it produces each month. The current factory has eight major customers which it supplies, both in the nearby vicinity and some not. The current factory is based in Pinetown, Kwa-Zulu Natal, South Africa.

It has been determined that there is to be an expected increase in demand within the next few years. The demand from the major customers is expected to increase by double its current amount. This has resulted in the company considering building a second factory, with the same capacity as the first, to cope with the increase in demand with three proposed locations. The proposed locations being Pietermaritzburg, Durban Central or another in Pinetown, all within Kwa-Zulu Natal. This is to be determined through the use of the transportation algorithm through the excel solver tool.

The transportation algorithm deals with the distribution of goods from several suppliers to multiple destinations (Render, et al., 2018). In a paper written by Halawa, et al. (2016) this method is used to find the minimal cost of shipping goods from one place to another, while taking into account the capacity of each supplier as well as the damand of each reciever. Similarly, in this paper the minimal cost is to be determined taking into account the capacity of the factories and the demand of each customer, while making use of the simplex linear programming method in order to gain an optimal display of the real world.

Data Collection

Data that was collected was provided by the branch manager of said company. This data included the eight major customers, the location of these customers, their monthly tonnage orders, and the average cost per kilometre to deliver these goods (at an average load of 7.5 tonnes per load). The cost per kilometre takes into account all vehicle-based costs and driver-based costs. The distance between the factory locations and the customers was identified through the use of a global positioning system (GPS).

Data Analysis

The first step in the data analysis is to determine the cost of delivery per tonne to each customer. This is done by multiplying the cost per kilometre by the distance between the factory and the customer to determine the cost per delivery. From this point the cost of delivery was then divided by the average number of tonnes carried by the truck. In this scenario the cost per kilometre used was R11.21 and the average number of tonnes carried was 7.5 tonnes.

Once these values were determined they were then tabularised as seen in Table 1, in the "Cost per Tonne Table". Inclusive in this table is the demand for each customer as well as the supply capacity of each factory. It is also important to note that the total demand should equal the total supply and if this is not the case, a dummy row or column should be included to account for the lack/excess of demand or supply.

Table 1 – Initial layout

Cost per Tonne Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply (tonnes)
Current Factory	R 5,83	R 92,97	R 96,26	R 90,43	R 93,87	R 340,78	R 12,70	R 17,04	R -	500
Pietermaritzburg	R 87,89	R 9,27	R 177,87	R 3,14	R 9,27	R 249,61	R 97,00	R 98,35	R -	500
Demand (tonnes)	190	80	90	60	110	90	170	150	60	

Assignment Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply (tonnes)
Current Factory										0
Pietermaritzburg										0
Demand (tonnes)	0	0	0	0	0	0	0	0	0	

Total Cost	R -

The formulas that govern the transportation algorithm, as per Render, et al.(2018), are inputted in the "Assignment Table" and in determining "Total Cost" cell. The first formula is the "sum" function which is used to determine the demand for each customer and the supply of each location in the "Assignment Table". These functions perform the addtion of values within the row/column. The "Total Cost" cell contains the "sumproduct" function which is used to multiply the array of data in the "Assignment Table" with the data array in the "Cost per Unit Table" and sums the products together generating a total cost.

The excel solver tool is then used to assign the amount of tonnes each factory should supply each customer. Figure 1 shows a solver parameter form which is filled out in order to generate the assigned tonnages.

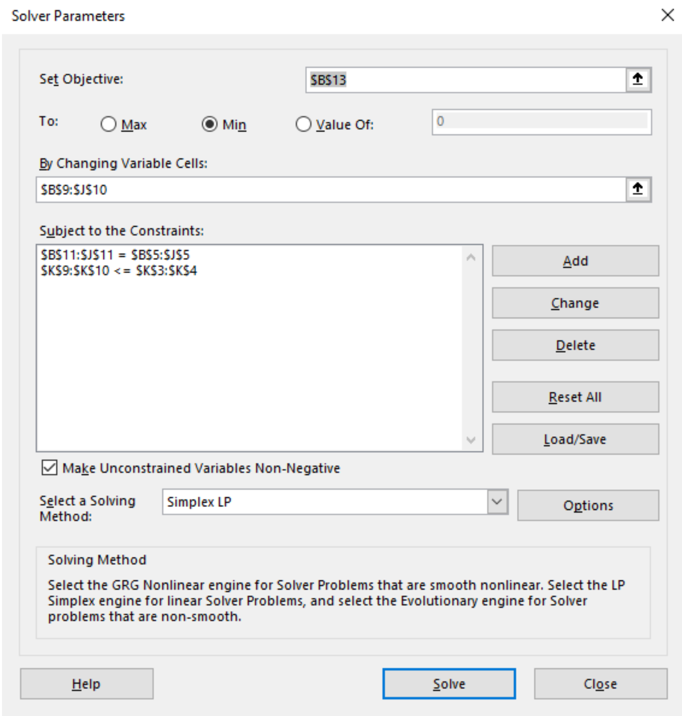

Figure 1 – Solver parameters using excel solver

Within this form the user has set the objective as the "Total Cost" cell and has to select the "Min" radio button as the user is interested in determining the lowest total cost. The "Changing Variable Cells" selected are the values that are to be assigned to the "Assignment Table". The constraints set are that the demands and supply values on the "Assignment Table" are to match those on the "Cost per Unit Table". Lastly the solving method is set to "Simplex LP". The simplex linear programming method, according to Abdelwali, et al. (2019) makes use of the transportation model expressed below.

$$Minimize\ Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}, \qquad j = 1,2, \dots n; i = 1,2, \dots m$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = a_i, \qquad i = 1,2,\dots,m$$
$$\sum_{i=1}^{m} x_{ij} = b_j, \qquad j = 1,2,\dots,n$$
$$x_{ij} \geq 0 \; for \; all \; i \; and \; j.$$

Where:

Z = total transportation cost, time or ton-kilometers.

C_{ij} = unit cost of transport (can be time, money or distance).

X_{ij} = number of units to be transported from source (i) to destination (j).

a_i = sorce availibilities.

b_j = destination requirements.

m = total number of sources.

n = total number of destinations.

Once the solve button is selected the lowest "Total Cost" will be generated with the data provided as seen in Table 2. For this example, "Pietermaritzburg" has been used as the proposed location along with the current factory.

Table 2 – Solution generated through excel solver

Cost per Tonne Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply (tonnes)
Current Factory	R 5,83	R 92,97	R 96,26	R 90,43	R 93,87	R 340,78	R 12,70	R 17,04	R -	500
Pietermaritzburg	R 87,89	R 9,27	R 177,87	R 3,14	R 9,27	R 249,61	R 97,00	R 98,35	R -	500
Demand (tonnes)	190	80	90	60	110	90	170	150	60	

Assignment Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply (tonnes)
Current Factory	190	0	90	0	0	0	170	50	0	500
Pietermaritzburg	0	80	0	60	110	90	0	100	60	500
Demand (tonnes)	190	80	90	60	110	90	170	150	60	

Total Cost	R47 031,70

Once the lowest total cost was identified for the first proposed location, this process was then repeated twice more with the other proposed locations and their relative values being substituted into the "Cost per Tonne Table".

Results

Analysis of the data can be seen in Tables 3, 4 and 5 below. These results show both the lowest total cost that can be attained from each of the combinations of the factory locations, as well as the amount of tonnes each factory should supply each customer with in order to minimize the cost of transporting the steel products. The Cost per Tonne Table (as seen in Table 3, 4 and 5 below) shows the cost of delivery per tonne to each customer from the respective factory locations. The Assignment Table (as seen in Table 3, 4 and 5 below) shows the number of tonnes each factory should supply to each customer.

Table 3 – Current location and Pietermaritzburg

Cost per Tonne Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply (tonnes)
Current Factory	R 5,83	R 92,97	R 96,26	R 90,43	R 93,87	R 340,78	R 12,70	R 17,04	R -	500
Pietermaritzburg	R 87,89	R 9,27	R 177,87	R 3,14	R 9,27	R 249,61	R 97,00	R 98,35	R -	500
Demand (tonnes)	190	80	90	60	110	90	170	150	60	
Assignment Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply (tonnes)
Current Factory	190	0	90	0	0	0	170	50	0	500
Pietermaritzburg	0	80	0	60	110	90	0	100	60	500
Demand (tonnes)	190	80	90	60	110	90	170	150	60	
Total Cost	R47 031,70									

In the above scenario (Table 3) it can be seen that with the current factory and a new factory in Pietermaritzburg, the new factory in Pietermaritzburg would supply majority of the customers with a total cost of R47,031.70.

Table 4 – Current Location and Pinetown

Cost per Tonne Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply
Current Factory	R 5,83	R 92,97	R 96,26	R 90,43	R 93,87	R 340,78	R 12,70	R 17,04	R -	500
Pinetown	R 5,83	R 92,97	R 96,26	R 90,43	R 93,87	R 340,78	R 12,70	R 17,04	R -	500
Demand	190	80	90	60	110	90	170	150	60	
Assignment Table										
Location/Customer	Customer A	Customer B	Customer C	Customer D	Customer E	Customer F	Customer G	Customer H	Dummy	Supply
Current Factory	190	80	90	60	80	0	0	0	0	500
Pinetown	0	0	0	0	30	90	170	150	60	500
Demand	190	80	90	60	110	90	170	150	60	
Total Cost	R 68 345,40									

In Table 4 it can be seen that the number of customers supplied but the current factory and a new factory in Pinetown would be equal with a total cost of R68,345.40.

Table 5 – Current Location and Durban

Cost per Tonne Table										
Location/Customer	Customer A	Customer	Customer	Customer	Customer	Customer	Customer	Customer	Dummy	Supply
Current Factory	R 5,83	R 92,97	R 96,26	R 90,43	R 93,87	R 340,78	R 12,70	R 17,04	R -	500
Durban	R 33,48	R 119,87	R 74,28	R 117,33	R 120,77	R 367,69	R 30,79	R 32,73	R -	500
Demand	190	80	90	60	110	90	170	150	60	
Assignment Table										
Location/Customer	Customer A	Customer	Customer	Customer	Customer	Customer	Customer	Customer	Dummy	Supply
Current Factory	190	80	0	60	80	90	0	0	0	500
DBN	0	0	90	0	30	0	170	150	60	500
Demand	190	80	90	60	110	90	170	150	60	
Total Cost	R 72 603,00									

Table 5 above shows also that the current factory and a new factory in Durban would result in the factories suppling an equal number of customers but with an increased total cost of R72,603.00.

It is important to note that the number of tonnes allocated to the dummy column shows the number of available tonnes the factory can still supply should there be an increase in demand from an existing or new customer. A summary of the total costs can be seen in Table 6 below.

Table 6 – Combination Costs

Combination	Total Cost
Current factory and Pietermaritzburg	R 47 031.70
Current factory and Pinetown	R 68 345.40
Current factory and Durban	R 72 603.00

As per Table 6, above, it can be noted that the combination of the current factory and a second factory in Durban would generate the highest total cost, the current factory and a second factory in Pinetown would generate the second highest total cost, while the current factory and another in Pietermaritzburg would give the lowest total cost.

Conclusion

As mentioned above this study takes into account vehicle-based costs and driver-based costs when looking for the optimal location of a new factory. These, however, are not the only costs that a company should consider when looking at a location. Other costs such as access to suppliers, employees and knowledge should be considered.

Based on the data seen in Table 6, the optimal location to set up a new factory would be in Pietermaritzburg, KwaZulu Natal. This location combined with the current factory location will generate the lowest cost with regards to vehicle-based and driver-based costs when delivering goods as the majority of the customers are based closer to Pietermaritzburg. Due to the nature of this paper, further studies should take into account other cost factors such as location of suppliers, employees and knowledge (such as specialists) in order to gain a better analysis of all costs involved in determining the location of a new factory.

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Biographies

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