AHP Analysis of Critical Environmental Factors under Transportation Model for Attainment of Optimal System Performance: A Case Study of Nigerian Petroleum Industry

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Abstract

Consideration of environmental factors are critical in determining the effectiveness of the transportation system. Critical factors - road safety and security were earlier addressed. The outcome is yet a mirage without due consideration of the climate/weather change as a salient environmental factor leading to delay in transportation process. A sustainable transportation model under consideration of weighted loss cost function from the influence of the environmental factors was formulated and analysed using Analytic Hierarchy Process (AHP). Contrast was made using cost saving paradigm between the old and the new models for the case study of gasoline transportation schedule of the Nigerian petroleum industry. The results showed a clear variation in the two models in term of higher flexibility and cost saving. The findings showed that the new model possessed wide range of system’s operation cost savings in contrast with static cost nature of the traditional transportation model.

Indexing terms/Keywords: Environment, AHP, Sustainability, Criticality, Transportation, Model, Optimality.

Subject Classification: Operations Research/Stochastic Process

Type (Method/Approach): Transportation System Modelling and Optimisation

Supporting Agencies: Partly supported by the Management of the Federal University of Technology, Akure, Nigeria

Language: English

Date of Submission: 2018-02-12
Date of Acceptance: 2018-04-10
Date of Publication: 2018-04-30

Volume: 01 Issue: 01
Journal: MATLAB Journal
Website: https://purkh.com

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Introduction

Transportation algorithmic tool is found to be more efficient than the linear programming based simplex method [1,2], and is a special case of linear programming model [3,4]. Transportation model algorithms have been applied in electronic computers for minimizing time and cost of locating processing units [5,6]. In transportation model total supplied are presumed as equal to total demanded. This balanced condition is rare in practical sense [1,7,8]. The approach can give a good idea of how best the cost of transportation can be minimized in the heterogeneous network flow problems [9]. In the past studies, there were evidence of considering the delays due to bad road and security check-point [10,11]. Many of the assumptions made in the traditional model need to be relaxed to find application in a changing environment [12,13]. In some environment, there are evidence of poor road maintenance, poor security outfit, and unstable climatic condition which are inimical to smooth transportation process. Consideration of the stated environmental factors in the new model will enable realisation of moderate cost of transportation and price of goods. The new transportation model provided in this study will take care of the environmental constraints which many of the previous studies neglected. Analytic Hierarchy Process (AHP) [14] will be utilised in formulating weighted loss cost function by taking care of changing impacts of the environmental conditions.

Materials and Methods

In the traditional transportation model, there are $M$ sources and $N$ destinations. Each source ($i$) possesses $a_i$ item, and each destination ($j$) requires $b_j$ item. The problem is how the item be distributed from the source to the destination such that the cost of transportation is minimized. Diagrammatic representation of the transportation problem is shown in Fig. 1. In this figure, traditional (conventional) transportation representation is modified to reflect environmental constraints-poor road maintenance, poor climatic condition and poor security outfit, which can result to delays of goods/services along the transportation network.

The mathematical statement of the traditional transportation problem (without delay elements) is [1], Minimize (sum of transportation cost):

![Fig. 1. Transportation Network with Delay Elements](image-url)
\[
\sum_{i=1}^{M} \sum_{j=1}^{N} c_{ij} x_{ij} \quad (1)
\]

Subject to:
\[
\sum_{i=1}^{M} x_{ij} = b_j, \quad \forall j \quad (2)
\]
\[
\sum_{j=1}^{N} x_{ij} = a_i, \quad \forall i \quad (3)
\]
\[
x_{ij} \geq 0, \quad \forall i, \forall j \quad (4)
\]

Where,
- \(x_{ij}\) = the amount of item transported from depot \(i\) to station \(j\)
- \(c_{ij}\) = unit cost of transporting an item from depot \(i\) to station \(j\)

The environmental or delay elements (poor road maintenance, poor climatic condition and poor security outfit) can occur at any time with varying proportion and weight, \(W_s\) designated as: equally severe, 1; moderately severe, 2; or strongly severe, 3. Mathematical formulation of the new transportation problem under the consideration of environmental factors is presented thus:

Minimize (sum of transportation cost):
\[
\sum_{i=1}^{M} \sum_{j=1}^{N} (c_{ij} + w_1 \lambda_{ij}^{se} + w_2 \lambda_{ij}^{rm} + w_3 \lambda_{ij}^{cl}) x_{ij} \quad (5)
\]

Subject to:
\[
\sum_{i=1}^{M} x_{ij} = b_j, \quad \forall j \quad (6)
\]
\[
\sum_{j=1}^{N} x_{ij} = a_i, \quad \forall i \quad (7)
\]
\[
x_{ij} \geq 0, \quad \forall i, \forall j \quad (8)
\]

Where,
- \(x_{ij}\) = the amount of item transported from depot \(i\) to station \(j\)
- \(c_{ij}\) = unit cost of transporting an item from depot \(i\) to station \(j\)
- \(\lambda_{ij}^{se}\) = unit cost of poor security outfit delay of transporting an item from depot \(i\) to station \(j\)
- \(\lambda_{ij}^{rm}\) = unit cost of poor road maintenance delay of transporting an item from depot \(i\) to station \(j\)
- \(\lambda_{ij}^{cl}\) = unit cost of poor climatic condition delay of transporting an item from depot \(i\) to station \(j\)
- \(w_1\) = weighted poor security outfit vectorial relationship factor
- \(w_2\) = weighted poor road maintenance vectorial relationship factor
- \(w_3\) = weighted poor climatic condition vectorial relationship factor

The weighted parameters, \(W_s\) (\(w_1\), \(w_2\), \(w_3\),..., \(w_n\)) were evaluated using Analytic Hierarchy Process (AHP). The primary function of AHP is to help management set priorities and make adaptive decisions in complex situations. The AHP is able to handle both qualitative and quantitative decision-making scenarios. The relative or specific weights of the incidental insecurity parameters were estimated using AHP as demonstrated by Finnie et al. [14]. In this process, any entry in the matrix will take the integer value of 1-5. Therefore, comparison of the two attributes (poor road maintenance, poor climatic condition, or poor security outfit) will take any of the following values: equally severe, 1; moderately severe, 2; strongly severe, 3; very strongly severe, 4; and extremely severe, 5.

The model is tested using Nigerian petroleum industry as a case study. Data were obtained from a number of dependent and independent marketers sprang up across the country [16]. Petroleum products are mostly
manufactured in the country’s refineries located in Port-Harcourt, Warri and Kaduna cities. Piping systems of different capacities were used to facilitate distribution of petroleum products, through effective pumping, to twenty two (22) major oil depots spread across the country [16]. The major marketers loaded petroleum products from the depots in tankers, and transported them to their respective 37 retail stations. End-users buy the products from the stations based on pump price. Petroleum distribution inadequacy had led to demand bottleneck and high pump price. Data, including transportation cost per litre and road distances from depots to stations (Table 1), were extracted from identified petroleum related publications including bulletin, annual reports and journals [16-18]. The cost of transportation between the depots was estimated by calculating the average cost per kilometre (km) for selected depots from the average distances to the stations [19]. The expert data were analysed using AHP [14]. Based on expert opinion the average costs per km of delays, due to poor road maintenance, poor climatic condition and poor security outfit are presented in Table 2. The expert opinion showed that three attributes of environmental constraints (poor road maintenance, poor climatic condition, or poor security outfit) have the following relationships: poor climatic condition is equally severe over poor security outfit; poor road maintenance is strongly severe over poor climatic condition; and poor road maintenance is moderately severe over poor security outfit. The order of the three attributes is: 1) poor road maintenance; 2) poor climatic condition; and 3) poor security outfit. The 3 x 3 eigenvalue matrix for the preferences stated above takes the following form:

\[
[A]_{3x3} = \begin{bmatrix}
1.0 & a_{12} & a_{13} \\
a_{21} & 1.0 & a_{23} \\
a_{31} & a_{32} & 1.0
\end{bmatrix}
\]

Here \(a_{12}\) refers to comparing bad road over poor weather. Similarly, \(a_{32}\) refers to comparing security check-point over poor weather. Based on the preferences of the attributes, the pair-wise comparison of the attributes would be as follows:

\[
\begin{bmatrix}
1.0 & 0.5 & 1.5 \\
2.0 & 1.0 & 3.0 \\
1.5 & 0.25 & 1.0
\end{bmatrix}
\]

The normalized matrix is determined by dividing the values in each column by the sum of the column:

\[
\begin{bmatrix}
0.22 & 0.29 & 0.23 \\
0.44 & 0.57 & 0.62 \\
0.33 & 0.14 & 0.15
\end{bmatrix}
\]

Now, the eigenvector is formed as the average of each normalized row:

\[
[W]_{3x1} = \begin{bmatrix}
0.25 \\
0.54 \\
0.21
\end{bmatrix}
\]

Finally, the eigenvector is the weights of the three attributes where the weights of all the attributes sum up to 1. The different weights are: weighted (poor road maintenance/poor security outfit) = 0.25; weighted (poor climatic condition/poor security outfit) = 0.54; and weighted (poor security outfit/poor road maintenance) = 0.21. These weights, along with the individual cost utilities are taken together or separately for calculating unit transportation cost (Table 2). This will lead to six cost savings of transportation from which optimal saving(s) is selected based on environmental condition(s) (Table 4). A computer software (using Microsoft Visual Basic 6.0 compiler) was developed for the new model for easy application in industries over traditional algorithms [15]. The most paramount hypothesis is to test null hypothesis that there is a significant difference between the cost of transportation using old and new methods. The alternative hypothesis is that there is no significant difference between the two approach.

Results and Discussion

Table 1 shows the cost of transporting a litre of petrol from the selected depots to station in Akure city, Nigeria, with the average distances (in km) apart. The cost of transportation to other depots was estimated from the product of average cost per km and the distance apart. The results obtained from application of traditional and new transportation problem to the distribution of petrol from 22 depots to 37 stations in Nigerian cities are shown in Table 3 with details of cost savings under unit weight of environmental factors,
while that of the cost savings from the new model under varying weights are detailed in Table 4. The results from the new model generally showed that there were appreciable transportation cost savings over traditional approach (Tables 3 and 4). This was an indicator of outstanding effectiveness of the new model in supplying petrol from available 22 depots to the 37 stations in major cities of Nigeria at reduced cost over the minimum cost of choosing a wrong route (Table 3). Explicitly, cost savings, ranging from 4 % to 86 % were achieved with the application of new model over unplanned choice of routes, and ... over the traditional approach. This showed an improvement in cost estimation accuracy over the traditional approach. The results from the new approach (Table 4) produced six different ranges of cost savings depending on the magnitude of delays by the environmental conditions. This indicated an outstanding flexibility in determining the cost of transportation. The savings (Table 4) were slightly lower or higher in varying proportions to the results presented in Table 3 under unit weight of delay elements. This flexibility in cost savings realisable from the new model is an indication of robustness in term of accuracy in determining possible ranges in prices of petrol with respect to changing environmental conditions.

**Table 1** Estimation of transportation cost of petrol

<table>
<thead>
<tr>
<th>Depots</th>
<th>Station</th>
<th>Cost of transportation per litre (₦ / litre)</th>
<th>Cost of transporting 33,000 litres (₦)</th>
<th>Distance in km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore</td>
<td>Akure</td>
<td>0.80</td>
<td>26,400</td>
<td>92</td>
</tr>
<tr>
<td>Benin</td>
<td>Akure</td>
<td>1.00</td>
<td>33,000</td>
<td>171</td>
</tr>
<tr>
<td>Ibadan</td>
<td>Akure</td>
<td>1.00</td>
<td>33,000</td>
<td>200</td>
</tr>
<tr>
<td>Average cost, and distance</td>
<td></td>
<td>30,800</td>
<td>154.33</td>
<td></td>
</tr>
<tr>
<td>Average cost per km (₦/km)</td>
<td></td>
<td>199.57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2** Experts’ estimation of unit costs and weights of environmental factors

<table>
<thead>
<tr>
<th>Depots</th>
<th>Station</th>
<th>Poor security outfit (₦) $c^s_{ij}$</th>
<th>Poor road maintenance (₦) $c^b_{ij}$</th>
<th>Poor climatic condition (₦) $c^c_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore</td>
<td>Akure</td>
<td>3,200</td>
<td>2,640</td>
<td>2,500</td>
</tr>
<tr>
<td>Benin</td>
<td>Akure</td>
<td>3,600</td>
<td>3,300</td>
<td>2,800</td>
</tr>
<tr>
<td>Ibadan</td>
<td>Akure</td>
<td>3,900</td>
<td>3,300</td>
<td>2,900</td>
</tr>
<tr>
<td>Average cost (₦)</td>
<td></td>
<td>3,633</td>
<td>3,080</td>
<td>2,733</td>
</tr>
<tr>
<td>Average distance (km)</td>
<td></td>
<td>154.33</td>
<td>154.33</td>
<td>154.33</td>
</tr>
<tr>
<td>Average cost per km (₦/km)</td>
<td></td>
<td>23.54</td>
<td>19.95</td>
<td>17.71</td>
</tr>
<tr>
<td>Weighted environmental factor</td>
<td></td>
<td>0.21</td>
<td>0.25</td>
<td>0.54</td>
</tr>
</tbody>
</table>

**Table 3** Optimal allocation of petrol under unweighted environmental constraints

<table>
<thead>
<tr>
<th>Sources/Depots</th>
<th>Destination/ Stations</th>
<th>Optimal cost, ₦ (in Nigeria currency) (traditional model)</th>
<th>Optimal cost, ₦ (in Nigeria currency) (new model)</th>
<th>Optimal item allocation (in ’000) litres</th>
<th>Optimal distance (in km)</th>
<th>Minimum cost, ₦ of chosen wrong route</th>
<th>Minimum Cost savings, ₦</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aba</td>
<td>Owerri</td>
<td>20,356</td>
<td>20,399</td>
<td>245</td>
<td>102</td>
<td>24,000</td>
<td>3,600</td>
</tr>
<tr>
<td></td>
<td>Port-Harcourt</td>
<td>12,772</td>
<td>12,815</td>
<td>89</td>
<td>64</td>
<td>11,184</td>
<td>11,184</td>
</tr>
<tr>
<td>Benin</td>
<td>Uyo</td>
<td>20,356</td>
<td>20,399</td>
<td>11</td>
<td>102</td>
<td>3,600</td>
<td>3,600</td>
</tr>
<tr>
<td>Abakaliki</td>
<td>Umuahia</td>
<td>49,493</td>
<td>49,536</td>
<td>52</td>
<td>248</td>
<td>64,000</td>
<td>14,463</td>
</tr>
<tr>
<td>Asaba</td>
<td>Enugu</td>
<td>27,740</td>
<td>27,783</td>
<td>87</td>
<td>139</td>
<td>36,216</td>
<td>36,216</td>
</tr>
<tr>
<td>Awka</td>
<td>Enugu</td>
<td>33,129</td>
<td>33,172</td>
<td>150</td>
<td>166</td>
<td>30,827</td>
<td>30,827</td>
</tr>
<tr>
<td>Enugu</td>
<td>Umuahia</td>
<td>30,335</td>
<td>30,378</td>
<td>117</td>
<td>152</td>
<td>34,000</td>
<td>3,621</td>
</tr>
<tr>
<td>Calabar</td>
<td>Emu</td>
<td>47,498</td>
<td>47,541</td>
<td>123</td>
<td>238</td>
<td>59,000</td>
<td>11,458</td>
</tr>
<tr>
<td>Uyo</td>
<td>Enugu</td>
<td>9,978</td>
<td>10,021</td>
<td>123</td>
<td>50</td>
<td>48,978</td>
<td>48,978</td>
</tr>
<tr>
<td>Gombe</td>
<td>Yola</td>
<td>52,686</td>
<td>52,729</td>
<td>218</td>
<td>264</td>
<td>60,000</td>
<td>7,270</td>
</tr>
<tr>
<td>Source/Depot</td>
<td>Destinations/Station (N)</td>
<td>Poor security outfit (N) (1)</td>
<td>Poor road maintenance (N) (2)</td>
<td>Poor climatic condition (N) (3)</td>
<td>Relative saving (N) 1 and 2</td>
<td>Relative saving (N) 1 and 3</td>
<td>Relative saving (N) 2 and 3</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------</td>
<td>-----------------------------</td>
<td>-------------------------------</td>
<td>-------------------------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>Aba</td>
<td>Owerni</td>
<td>3,140</td>
<td>3,135</td>
<td>2,669</td>
<td>2,631</td>
<td>2,164</td>
<td>2,160</td>
</tr>
<tr>
<td></td>
<td>Port-Harcourt</td>
<td>10,912</td>
<td>10,909</td>
<td>10,616</td>
<td>10,592</td>
<td>10,300</td>
<td>10,297</td>
</tr>
<tr>
<td>Uyo</td>
<td></td>
<td>3,140</td>
<td>3,135</td>
<td>2,669</td>
<td>2,631</td>
<td>2,164</td>
<td>2,160</td>
</tr>
<tr>
<td>Benin</td>
<td>Abakaliki</td>
<td>13,281</td>
<td>13,270</td>
<td>12,135</td>
<td>12,044</td>
<td>10,909</td>
<td>10,898</td>
</tr>
</tbody>
</table>

**Table 4:** Savings along the routes using the new (weighted) transportation model
Conclusions

A new transportation algorithm was developed by taking into consideration some critical environmental factors that can impede free flow of vehicles on the established road networks. The traditional transportation model was modified to have a realistic outlook by integrating into it the weighted environmental factors (poor road maintenance, poor climatic condition and poor security outfit) that can bring delays during.
transportation process under Analytic Hierarchy Process (AHP) platform. Transportation problem of Nigerian petroleum product (petrol) distribution among existing depots and stations under the stated environmental threats was solved using the newly developed algorithms on the platform of computer package developed using Microsoft Visual Basic (VB 6.0) integrated development environment (compiler). It can be concluded from the results that the flexibility in savings obtained from the new model was an indication of accuracy of determining possible ranges in prices of petrol with respect to changing environmental conditions as compared to the rigid pricing outcome obtainable from the traditional approach. The findings will help the petroleum industry in determining the best and appropriate pump price of petrol which will be fair to customers, retailers, dealers, and the producers based on prevailing environmental conditions.

Conflicts of Interest

There are no conflicts of interests.

Funding Statement

Author was partly supported by the Management of the Federal University of Technology Akure (FUTA), Nigeria through provision of laboratory facilities and other logistics for the successful execution of the study.

References


