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.

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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.

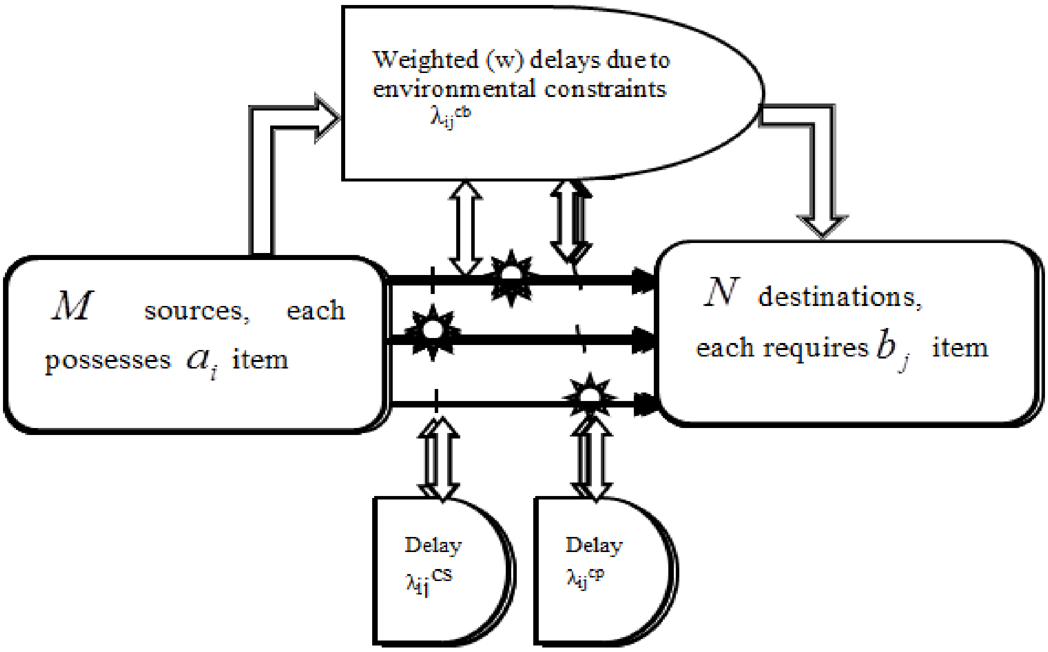

Fig. 1. Transportation Network with Delay Elements

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

$$\sum_{i=1}^{M}\sum_{j=1}^{N} c_{ij} \quad x_{ij} \tag{1}$$

Subject to:

$$\sum_{i=1}^{M} x_{ij} = b_j, \nabla_j \text{ (all demands are met)} \tag{2}$$

$$\sum_{j=1}^{N} x_{ij} = a_i, \nabla_i \text{ (all supplies are used)} \tag{3}$$

$$x_{ij} \succ 0, \nabla_j \tag{4}$$

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 varing proportion and weight, Ws 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):

$$\sum_{i=1}^{M}\sum_{j=1}^{N} (c_{ij} + w_1\lambda_{ij}^{cs} + w_2\lambda_{ij}^{cb} + w_3\lambda_{ij}^{cp}) \; x_{ij} \tag{5}$$

Subject to:

$$\sum_{i=1}^{M} x_{ij} = b_j, \nabla_j \text{ (all demands are met)} \tag{6}$$

$$\sum_{j=1}^{N} x_{ij} = a_i, \nabla_i \text{ (all supplies are used)} \tag{7}$$

$$x_{ij} \succ 0, \nabla_j \tag{8}$$

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

λ_{ij}^{cs} = unit cost of poor security outfit delay of transporting an item from depot i to station j

λ_{ij}^{cb} = unit cost of poor road maintenance delay of transporting an item from depot i to station j

λ_{ij}^{cp} = 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, Ws (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 inadequancy 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:

$$[W]_{3x1} = \begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} = \begin{bmatrix} 0.25 \\ 0.54 \\ 0.21 \end{bmatrix}$$

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 $_{\text{(poor road maintenance/poor security outfit)}}$ = 0.25; weighted $_{\text{(poor climatic condition/poor security outfit)}}$ = 0.54; and weighted $_{\text{(poor security outfit/poor road maintenancey)}}$ = 0.21. These weights, along with the individual cost utilities are taken together or seperately 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 effectivenss 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 chosing 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

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

Table 2 Experts' estimation of unit costs and weights of environmental factors

Depots	Station	Poor security outfit (₦) λ_{ij}^{cs}	Poor road maintenance (₦) λ_{ij}^{cb}	Poor climatic condition (₦) λ_{ij}^{cs}
Ore	Akure	3,200	2,640	2,500
Benin	Akure	3,600	3,300	2,800
Ibadan	Akure	3,900	3,300	2,900
Average cost (₦)		3,633	3,080	2,733
Average distance (km)		154.33	154.33	154.33
Average cost per km (₦/km)		23.54	19.95	17.71
Weighted environmental factor		0.21	0.25	0.54

Table 3 Optimal allocation of petrol under unweighted environmental constraints

Sources/ Depots	Destinations/ Stations	Optimal cost, ₦ (in Nigeria currency) (traditional model)	Optimal cost, ₦ (in Nigeria currency) (new model)	Optimal item allocation (in '000) litres	Optimal distance (in km)	Minimum cost, ₦ of chosen wrong route	Minimum Cost savings, ₦
Aba	Owerri	20,356	20,399	245	102	24,000	3,600
	Port-Harcourt	12,772	12,815	89	64		11,184
	Uyo	20,356	20,399	11	102		3,600
Benin	Abakaliki	49,493	49,536	52	248	64,000	14,463
	Asaba	27,740	27,783	87	139		36,216
	Awka	33,129	33,172	150	166		30,827
Enugu	Umuahia	30,335	30,378	117	152	34,000	3,621
Calabar	Enugu	47,498	47,541	123	238	59,000	11,458
	Uyo	9,978	10,021	123	50		48,978
Gombe	Yola	52,686	52,729	218	264	60,000	7,270

Gusau	Birni-Kebbi	50,092	50,135	88	251	70,000	19,864
	Katsina	41,511	41,554	150	208		28,445
Ibadan	Abeokuta	15,367	15,410	234	77	106,000	90,589
Ilorin	Ibadan	31,732	31,775	87	159	62,000	30, 224
Jos	Abuja	62,465	62,508	200	313	85,000	22,491
	Bauchi	26,343	26,386	212	132		58, 613
	Kano	84,019	84,086	16	421		937
	Lafia	47,498	47,541	139	238		37,458
Kano	Bauchi	64,062	64,062	123	321	88,000	23,894
	Dutse	27,142	27,142	63	136		60,814
	Gusau	64,860	64,905	123	325		23,096
	Kaduna	52,287	52,330	125	262		35,669
	Katsina	34,526	34,569	220	173		53,430
Lagos	Birni-Kebbi	164,845	164,888	136	826	193,000	28,111
	Ibadan	29,337	29,380	16	147		163,619
	Ilorin	61,068	61,111	153	306		131,888
	Makurdi	163,647	163,690	275	820		29,309
	Sokoto	209,548	209,591	59	1,050		-16591
Maiduguri	Damaturu	25,944	25,987	400	130	174,000	148,012
	Gombe	95,993	96,036	246	481		77,963
	Kano	122,536	122,579	72	614		51,420
	Yola	81,624	81,667	27	409		92,332
Makurdi	Abakaliki	53,684	53,727	110	269	206,000	152,272
	Enugu	53,884	53,927	124	270		152,072
	Gudau	152,471	152,471	97	764		53,485
	Kano	151,673	151,716	48	760		54,283
	Lafia	19,957	20,000	150	100		185,999
	Lokoja	63,663	63,706	155	319		142,293
	Maiduguri	186,598	186,641	63	935		19,358
	Sokoto	196,576	196,619	150	985		9,380
Minna	Abuja	23,350	23,393	124	117	59,000	35,606
Mosimi	Abeokuta	12,772	12,815	217	64	16,000	3,184
	Ibadan	15,367	15,410	329	77		589
Ore	Ado Ekiti	27,940	27,983	256	140	39,000	11,016
	Akure	18,360	18,403	234	92		20,596
	Ilorin	38,118	38,161	47	191		838
	Osogbo	23,549	23,592	150	118		15,407
Suleja	Lokoja	27,541	27,584	95	138	35,000	7,415
	Minna	23,350	29,393	250	117		5,606
Yola	Jalingo	28,339	28,382	112	142	81,000	52,617
Atlas-Cove	Ibadan	29,337	29,380	200	147	47,000	17,619
Port-Harcourt	Abakaliki	13,770	13,813	50	69	19,000	5,186
	Yenegoa	8,981	9,024	150	45		9,975
Kaduna	Abuja	35,923	35,966	76	180	67,000	31,033
	Gusau	56,279	52,322	17	282		14,677
	Jos	55,880	55,923	107	280		11,076
Warri	Asaba	17,762	17,805	200	89	21,000	3,194

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

Source/ Depot	Destina-tion/ Station(₦)	Poor security outfit(₦) (1)	Poor road maintenance (₦) (2)	Poor climatic condition (₦) (3)	Relative saving (₦) 1 and 2	Relative saving (₦) 1 and 3	Relative saving (₦) 2 and 3
Aba	Owerri	3,140	3,135	2,669	2,631	2,164	2,160
	Port-Harcourt	10,912	10,909	10,616	10,592	10,300	10,297
	Uyo	3,140	3,135	2,669	2,631	2,164	2,160
Benin	Abakaliki	13,281	13,270	12,135	12,044	10,909	10,898

	Asaba	35,573	35,567	34,931	34,880	34,244	34,237
	Awka	30,050	30,043	29,283	29,222	28,463	28,456
Enugu	Umuahia	10,325	10,315	9,226	9,138	8,049	8,039
Calabar	Enugu	48,775	48,773	48,544	48,525	48,297	48,294
	Uyo	6,009	5,997	4,789	4,692	3,484	3,473
Gombe	Yola	18,667	18,656	17,508	17,415	16,267	16,256
Gusau	Birni-Kebbi	27,461	27,452	26,500	26,423	25,472	25,462
	Katsina	90,252	90,249	89,897	89,868	89,516	89,513
Ibadan	Abeokuta	29,482	29,475	28,747	28,689	27,961	27,954
Ilorin	Ibadan	20,988	20,974	19,542	19,427	17,994	17,981
Jos	Abuja	58,004	57,999	57,395	57,346	56,742	56,736
	Bauchi	-1,100	-1,119	-3,045	-3,200	-5,126	-5,145
	Kano	36,325	36,315	35,226	35,138	34,049	34,039
	Lafia	22,351	22,337	20,868	20,750	19,281	19,267
Kano	Bauchi	60,186	60,180	59,557	59,507	58,885	58,879
	Dutse	21,533	21,519	20,032	19,912	18,425	18,411
	Gusau	34,418	34,406	33,207	33,111	31,912	31,901
	Kaduna	52,619	52,611	51,820	51,756	50,964	50,957
	Katsina	24,072	24,035	20,256	19,952	16,172	16,136
Lagos	Birni-Kebbi	162,936	162,930	162,257	162,203	161,531	161,524
	Ibadan	130,419	130,406	129,006	128,893	127,493	127,479
	Ilorin	25,299	25,263	21,511	21,210	17,457	17,421
	Makurdi	-21,739	-21,785	-26,590	-26,975	-31,780	-31,826
	Sokoto	147,413	147,408	146,813	146,765	146,170	146,164
Maiduguri	Damaturu	75,629	75,608	73,407	73,230	71,029	71,008
	Gombe	48,429	48,402	45,592	45,366	42,557	42,530
	Kano	90,354	90,336	88,465	88,314	86,443	86,425
	Yola	150,986	150,974	149,743	149,645	148,414	148,402
Makurdi	Abakaliki	150,781	150,769	149,534	149,435	148,199	148,187
	Enugu	49,752	49,719	46,223	45,942	42,446	42,412
	Gudau	50,570	50,537	47,059	46,780	43,302	43,268
	Kano	185,549	185,544	185,087	185,050	184,592	184,588
	Lafia	140,760	140,746	139,286	139,169	137,709	137,695
	Lokoja	14,780	14,739	10,460	10,117	5,838	5,797
	Maiduguri	4,555	4,511	4	-358	-4,865	-4,909
	Sokoto	35,072	35,066	34,531	34,488	33,953	33,948
Minna	Abuja	2,912	2,909	2,616	2,592	2,300	2,297
Mosimi	Abeokuta	252	249	-103	-132	-484	-487
	Ibadan	10,368	10,362	9,721	9,670	9,029	9,023
Ore	Ado Ekiti	20,185	20,181	19,760	19,726	19,305	19,301
	Akure	-62	-71	-945	-1,015	-1,889	-1,897
	Ilorin	14,868	14,862	14,323	14,279	13,739	13,734
	Osogbo	6,777	6,771	6,139	6,089	5,457	5,451
Suleja	Lokoja	11,072	11,066	10,531	10,488	9,953	9,948
	Minna	51,959	51,953	51,303	51,251	50,601	50,595
Yola	Jalingo	16,936	16,930	16,257	16,203	15,531	15,524
Atlas-Cove	Ibadan	4,889	4,886	4,570	4,545	4,229	4,226
Port-Harcourt	Abakaliki	9,797	9,795	9,589	9,572	9,366	9,364
	Yenegoa	30,187	30,179	29,356	29,289	28,466	28,458
Kaduna	Abuja	9,327	9,315	8,024	7,920	6,630	6,618
	Gusau	9,736	9,724	8,442	8,339	7,058	7,046
	Jos	2,798	2,794	2,387	2,354	1,947	1,943
Warri	Asaba	3,140	3,135	2,669	2,631	2,164	2,160

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.

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