TRANSPORT TECHNOLOGIES

Vol. 5, No. 1, 2024

Harrison Obiora Amuji [1], **Donatus Eberechukwu Onwuegbuchunam*** [1], **Kenneth Okechukwu Okeke** [1], **John Folayan Ojutalayo** [2], **Christy Chidiebere Nwachi** [1], **Abdulmalik Muhammad Mustapha** [3]
1. Federal University of Technology Owerri
Main Campus, Ihiagwa, P.M.B 1526, Owerri, Imo State, Nigeria

2. Federal College of Fisheries and Marine Technology
2, Wilmot Point Road, Victoria Island, Lagos, Nigeria

3. Ibrahim Badamasi Babangida University
Minna Road, Lapai 911101, Niger State, Nigeria

https://doi.org/10.23939/tt2024.01.053

SHAPLEY VALUE COST ALLOCATION MODEL FOR MULTIMODAL FREIGHT TRANSPORT CARRIERS

Summary. *The downstream petroleum products distribution is beset with significant challenges due to ageing pipeline infrastructure, pipeline vandalism and other logistical constraints. These challenges have given rise to soaring pump prices of premium motor spirit (PMS), product shortages and unavailability across some locations in Nigeria. Thus, deploying alternative transport modes for PMS distribution is explored to improve product distribution efficiency. The decision to combine inland waterway transport (instead of pipeline network) and road transport modes would activate the intrinsic advantages inherent in the multimodal transport system. However, the efficiency outcome of using multi-modes may be eroded if the multimodal transport operators compete (instead of collaborating) in service provisions. This research investigated cost efficiency in cooperative collaboration among multimodal transport carriers. We proposed collaboration among six multimodal transport operators. The aim of encouraging such a large-scale coalition (S) is the expectation that costs emanating from their joint operation would be reduced. We applied the Shapley value cost allocation method to distribute the costs of operation and profit to the collaborators. After the analysis, we observed that the unit cost for coalition S1 was reduced by N17.16 (5.10 %) million naira. Similarly, we observed respective reductions in unit costs for coalitions S2, …, S10. We observed a reduction in cost by N107.84 million naira, which represents a 6.15 % reduction in total unit cost for the multimodal transportation carriers. Thus, the observed cost efficiency represents savings due to distribution chain efficiency if the multimodal transport carriers collaborate to improve product availability. Working as a coalition would offset PMS pump price variation attributable to distribution chain inefficiency.*

Keywords*: Shapley value; cost allocation; multimodal freight transport; petroleum products distribution; carrier collaboration, Game theory.*

1. INTRODUCTION

Shippers and carriers will continue to explore ways to reduce operational costs and improve transportation chain performance. One such way is to deploy alternative transport modes for cargo distribution. Use of multimodal transport can guarantee cost savings given the comparative cost advantage

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* *Corresponding author. E-mail: don@futo.edu.ng*

specific to the modes. However, the expected cost savings may be eroded through wasteful competition if multimodal transport carriers operating in close proximity, compete against each other instead of collaborating. Collaboration encourages competitive advantage, reduction of transport operation costs, and supply chain efficiency. It eliminates competition among the collaborators as each collaborator will specialize on a given part and share in the profit the collaboration brings to all parties involved. In the market of petroleum product transportation in Nigeria, it has been observed that there is competition among the carriers involved in the haulage of products from one location to the other. Each carrier adopts the best strategy to dominate or even dislodge other competitors from the business. This kind of confrontational competition among the parties concerned brings us to competitive game theory; hence, we bring in the theory of the game to obtain the best out of the proposed collaboration among the petroleum products transport carriers. It should be noted that cost reduction in this collaboration is achieved through expected reductions in less than full load trips, underutilization of transport capacities of individual carriers and activation of intrinsic gains associated with mode-specific specialization in large-volume transportation of products. Though a petroleum equalization fund was introduced to cushion the effect of variation in petrol prices, supply chain costs and other constraints continue to manifest in pump price variations (nationwide) and product supply shortages in remote customer locations. This paper is focused on the horizontal collaboration (see [1]) among petroleum product transportation carriers using inland waterway transport and road tankers for the distribution of refined petrol (Premium Motor Spirit or PMS) in Nigeria. The study seeks to find how collaboration could bring about cost savings for the collaborators and increase the efficiency in the distribution chain of petroleum products in Nigeria. It is envisaged that once destructive competition is removed and cooperation among the collaborators realised – there will be a multiplier effect of uninterrupted supply and stability of the product prices, which will positively impact the public welfare. Achieving cost efficiency in the distribution chain through carriers' collaboration will also reflect positively on the shippers who double as the marketers.

This cost reduction achieved by switching to inland waterway and road transport modes is a gain to the collaborators (coalition). The gains from the cost reduction as a result of combining their fleet of ships, barges and road tanker trucks in a multimodal setting are shared by the coalition. This study aims to determine the potential for cost efficiency by multimodal transport carriers working as a coalition in petroleum product distribution. We organize this paper into five sections to enhance its coherence. Section one treats the introduction; section two treats the literature review; section three treats materials and methods; section four treats data presentation and analysis; section five treats discussions.

2. LITERATURE REVIEW

Competition among producers, marketers, shippers, airliners and transporters creates unhealthy rivalry, especially in the transport and logistics industry. The distribution from the shippers to the consumers via the carriers involves lots of competition, where each party works assiduously to maximize profit. This scenario can be understood better as a competitive game theory where each player brings out their best strategy to outweigh the other. However, there is a need for collaboration to create a conducive environment, which will favor each participant to avoid the problem of sub-optimization and hence improve global efficiency in the distribution chain. It brings us to cooperative game theory, where each participant works to promote a common goal and share the profit or cost savings accruing to the grand coalition. Some researchers [1] worked on the benefit of horizontal cooperation in transportation and logistics. Their findings show that participants build the system and create a conducive atmosphere that benefits all and sundry, including the market environment. Other researchers [2] have studied horizontal cooperation between transporters at the level of tactical planning of supply chain distribution. They inferred that the purpose of collaboration is to create a conducive market for the producer, the distributors and the buyers. The study's purpose was to determine the relationship between the shipper and the carriers who distribute goods between different customer locations. The researchers proposed and adopted the cooperative game theory method for sharing accrued profit for the operators. They adopted the Shapley value for fair sharing of profit (cost savings) of the grand coalition between the carriers. The validity of the collaboration was conducted using the super-additivity property of the game theory, and the result revealed that each carrier's profit is significant and that the partnership improves the customer service rate. Authors [3] investigated interaction, cooperation and alliances among carriers in a maritime transportation network. The alliance formation was centered on liner shipping. The essence was to create a large-scale transportation network system for carriers in cooperation and, hence, optimize the allocation of scarce resources for the benefit of all carriers. The authors proposed game theory as a guide for equitable sharing of accruals from such alliances. Each carrier receives profit according to its contribution to the grand coalition. The result from their method is encouraging and can help carriers to form a strong and sustainable coalition. In a related study, [4] developed a model for an efficient distribution system. The authors proposed a multi-period and multi-commodity distribution (re)planning problem for a multi-stage centralized upstream network with structure dynamics. The complex model was developed by modelling the supply chain as a non-stationary dynamic system with linear programming (LP); then, researchers transformed the LP model to a maxima flow problem by removing the demand constraints. This problem became a multi-objective optimization problem that accommodates various objectives of the distribution functions. The authors noted that the structure dynamics allow different execution techniques and offer suggestions on re-planning if there is any obstruction. Researchers [5] noted that freight consolidation is essential because of the perceived competitive advantage and efficiency of multimodal transportation. This collaboration is a horizontal cooperation among partners involved in the multimodal transport chain. The benefit or cost emanating from this collaboration is shared among the participants. The author noted that some of the literature in this area excluded multimodal freight transport operations. In this case, application in the unimodal transport case is much easier. The author compared three different allocation models – the proportional allocation model, the decomposition model and the Shapley value method. The result indicated a preference for the Shapley method. Again, [6] observed that transport plays a pivotal role in the future industry supply chain. Though more manufacturers are shipping in the same market region, collaboration between two or more of these is rare. Of late, there has been a discovery of cost-saving and delivery time reduction through transportation alliances. Their study was centered on cooperation of four companies through transportation collaboration. This scenario saves costs and creates a conducive environment for everyone in the market. Also, the authors proposed a cost-sharing formula based on the Shapley value.

But [7] developed a modification into the Shapley value to accommodate the interest of the partners, who had been competing with one another before collaboration. They observed that the Shapley value resulting from cooperative game theory was applied to share profit among five cargo importers, but the sharing formula was not fair to some importers. Applying an original form of the Shapley value did not favor the highest importers, while the lowest importers have a reasonable chunk of the profit. Then, the complaint of the highest importer led to the modification to arrive at a model that shares the profit in an equitable form that reflects the capacity and contribution of each importer; otherwise, the cooperation may not be sustained. But [8] defined cooperative game theory as the characteristic function of an n-person cooperative game, which has a set C of players (referred to as a grand coalition). It attributes the maximum value v(S) to each subset S of C, which coalition S can guarantee to itself by coordinating its members' strategies, despite what the other players do. Other researchers [9] have studied the problem of calculating the cost of servicing each location in terms of transportation by one vehicle. They noted that the problem was formally given by the traveling salesperson game (TSG). It is a cooperative general utility game where agents correspond to places in a travelling salesperson problem (TSP). The authors established the relationship between the dynamic programming model and the Shapley value because of the exponential increase in the dimension of the resulting problem. They used sampling-based procedures to calculate the Shapley value. They used the Shapley value method to develop six proxies, which were easy to compute using a computer program. Concerning the cost allocation for less-than-truckload collaboration among perishable product retailers, researchers [10] studied this problem. The relevant costs included variable transportation costs, set transportation costs, and decay loss of perishable products. The authors applied the Cooperative game theory to study the cost allocation problem. The result revealed that the simple cost allocation scheme and the Shapley value operate better with the percentage of allocations lying in the core. Similarly, [11] applied a two-echelon inventory location and routing problem (2E-CILRP) model to minimize logistics cost, emissions and accident rate to integrate an optimization approach for improving the urban transportation system. The results showed that the developed approach can significantly reduce accident rates, emissions levels, and logistics costs caused by transportation in the cities. Regarding the cost and savings over the multimodal freight transport system, authors [12] examined sea-rail multimodal freight transport settings operating on vessels and rail freight wagons with different sizes and shapes. Three types of cost allocation models were analyzed in this study, namely the mechanism of proportional allocation, method of decomposition, and Shapley value for the uniform volumes of freight transport. The results showed that all participants had higher cost savings after applying the Shapley value method for combined freight transport. Paper [13] examined the Shapley value-based cost allocation in transportation operations involving drones and trucks. This method focuses on minimizing the total cost of serving all customers concerning the capacity and synchronization constraints. The cost-sharing and contribution of each truck and drone to serving the customers showed significant potential to enhance the performance of network transportation through optimized routes and minimized costs.

3. MATERIALS/METHODS AND PROBLEM DESCRIPTION/GRAND COALITION

3.1. Materials / Methods

A game is an activity between two or more rational players with moves (strategies) at the end in which one suffers a loss and the other gains some reward (see [14]). This kind of game is called a competitive or zero-sum game and has been observed in the transportation and physical distribution sectors. It is an antagonistic game theory which sees the opponent as an enemy in the business. But here, we are proposing a cooperative game theory where each player collaborates for the overall good of the players, the economy and hitch-free distribution where each player shares in the profit such collaboration brings to the partners (see [3]). This kind of game theory encourages competitive advantage and eliminates unfair competition that could destroy some participants. A fair and acceptable method of (payoff) profit or cost distribution called the Shapley value is proposed to get the reward according to contribution to the collaborative business. The Shapley value has three necessary properties, namely (i) anonymity (the costs allocated to a particular location are dependent only on the impact they have on the entire costs); (ii) efficiency (the entire costs of serving all N locations are allocated); and (iii) strong monotonicity (if the total coalition costs are reduced, then the allocation to all locations participating in that coalition is either reduced or not increased), see [15]. In a collaborative study, authors [2] observed that the Shapley value provides a unique distribution of a total excess produced by the coalition of all players in any cooperative game with three essential features, these are:

- fairness for any joint problem because players in the game can reject any unfair outcome in many ways.
- uniqueness: the players prefer to receive a unique imputation. It does not allow other solutions from being potentially better or ignored. The Shapley value prevents players from regretting the solution they have made and reduces the need for long bargaining and negotiation.
- implementation: the Shapley value is quite achievable because it is determined by a standard formula. It does not need any linear programs to be solved. The Shapley value has been applied in many cooperative game applications in economics, management and computing.

In a cooperative game theory, the imputation must be rational for the cooperation to exist. According to [8], an assumption in an n-person game with characteristic function *v*(S), which is defined for all coalitions S, is a vector $x = (x_1, x_2, ..., x_n)$ satisfying:

(i) $x_1 + x_2 + x_3 + x_4 + x_5 = v(N)$, where N is the set of all players;

(ii) $x_i \geq v(i)$ for *i* = 1, 2,…, *n*.

and if the conditions (i) – (ii) can be formulated as follows:

(a) $x_A + x_B + x_C + x_D + x_E = v\{A, B, C, D, E\}$;

(b) $x_A \geq v(A); x_B \geq v(B); x_C \geq v(C); x_D \geq v(D); x_E \geq v(E)$.

We say that an imputation $x=(x_1,x_2,...,x_n)$ is rational for coalition S if the sum of payments it generates for all its members is larger or equal to *v*(S). Therefore, if a certain imputation $x=(x_1,x_2,...,x_n)$ does not satisfy the condition stated in "a and b" for some coalition S, it will have no monetary interest in participating in such a share of benefit. Therefore, the set of all assumptions, which are reasonable for all coalitions S, is called the *core* of the game; hence, in this kind of problem, the natural candidate for the solution is the Shapley value $(x^*=x=(x_A{}^*,x_B{}^*,x_C{}^*,x_D{}^*,x_E{}^*))$.

Also, according to [16], a cooperative game with transferable utility is a pair (N, v), where:

- N is a finite set of players, indexed by i;
- v: 2N ↦ R is the function assigning a real-valued payment *v*(S) to each coalition S ⊆ N with *v*(∅) = 0.

Let |S| be the number of members in coalition S, and N \ {k} be the set N except element k. In a coalition game, an assumption (labeled x) is a vector of players' benefits. Each element x_i of this vector marks the share of the grand coalition's payment that a player i ∈ N obtains.

The Shapley value is the most efficient cost allocation method. It is based on highly complex game theory [11]. The Shapley value allocates the weighted average of each participating operator in all sub-coalitions to the coalition. The Shapely-based cost distributed to the *i*th partner is calculated mathematically as:

$$c_i=\sum\nolimits_{S\subseteq N\setminus\{k\}}\frac{(|S|-1)!(|N|-|S|)!}{|N|!}\left[c(S\cup i)-c(S)\right], \tag{1}$$

where number of all participants in the sub-coalitions is | . | (see [12]). The Shapley value technique is obtained from the axioms of dummy, player, symmetry, efficiency axiom and additivity (see [17]). The Shapley value is very useful in the transport collaboration.

Hence, we adopted equation (1) for the calculation of new cost and write the model as:

$$Z_k(N,v)-C_i=y_i, \tag{2}$$

where $Z_k(N,v)$ – is the initial total cost; C_i – is the new cost; |*S*| is the number of ships/self-propelled barges and road tankers in the coalition; |*N*| is the grand coalition, that is the total number of ship/barges and road tankers in coalition; $\frac{1}{N!}\sum\nolimits_{S\subseteq N\setminus\{i\}}(|S|-1)!(|N|-|S|)!$ is the weight of gain $(w_i),[v(S\cup\{i\}-v(S)]$ is the marginal cost; y_i – is the savings of ith partner due to the formation of the coalition.

Equation (2) can be written as:

$$Z_k(N,v)=C_i+y_i, \tag{3}$$

$$\frac{y_i}{Z_k(N,v)}\cdot 100=\mathit{percentage\ savings\ for\ i^{th}\ partner}. \tag{4}$$

3.2. Problem Description and Grand Coalition

Petroleum products, specifically the premium motor spirit distribution in Nigeria, have continued to face significant challenges resulting from poor infrastructure – ageing pipeline infrastructure and pipeline vandalism. The major independent marketers who import and distribute the products have had to resort to road transport and sea transport (inland waterway) modes to distribute products to customers in specific locations in Nigeria. It has come at great cost to the marketers and their consumers despite the price equalization policy of the Federal Government of Nigeria. In this light, we propose a model that can help collaborating product carriers or transporters to share costs evenly. That would benefit them and improve cost efficiency in the distribution network. In the proposed coalition, we consider the shippers (who import petroleum and store temporarily in tank farms at jetties located in offshore locations) and the carriers who then distribute the products inland to customers at specific locations in Nigeria see Table 1 (grand coalition).

Table 1

Distribution of Petroleum Product Shippers and Multi-modal Transport Carriers

S/NO	Product Marketers: Importers & shippers	Product Carriers: Barge/ Road Tanker Operators
i.	ABZ Inc.	JULA Marine
ii.	Capitol Oil	TON shipping
iii.	Impire Energie	NEPCO Marine
iv.	RenOil	JUHE Transport
v.	StarEnergie	AZB Petroleum
vi.	Matric Oil	TSLL Transport

Source: Author, field study

Two modes of transportation (Inland waterways and Road transport) for product distribution are considered here. Therefore, we model cooperative collaboration among inland waterway and road transport carriers transporting products from tank farms to depots and gas stations in a multimodal transport setting, see Fig. 1.

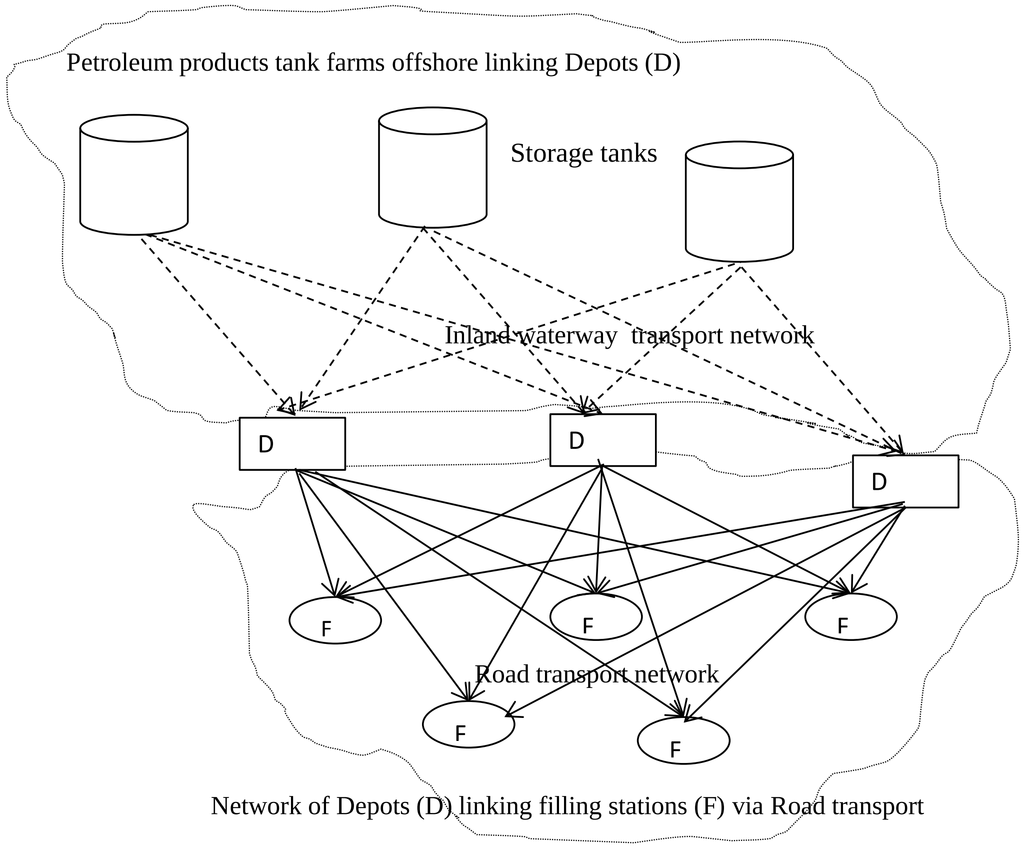

Fig. 1. Petroleum products distribution network of tank farms, Depots (D) and filling stations (F) in multimodal transport setting

It is expected that there will be shared responsibilities among the carriers, deploying ships and tankers in the transport and distribution chain. The share of responsibilities extends to the share of cost and profit. Therefore, cooperative games [18] provide a mathematical model for solving this decision problem. Specifically, six transport providers, grand coalition |N| (see column 2 of Table 1), collaborated to supply and distribute PMS across stated locations in Nigeria (see column 1 of Table 2); the areas of coverage were represented by S1, … , S10. Each coverage area is of different sizes (legs) depending on the distance to be covered in the product distribution. These legs are the number of operators in each coalition |S| (see column 4 of Table 2) (Number of operators). We can observe that the number of operators on one row could differ from the other row depending on the distance covered by each coalition. It is shown in columns 2 and 3 of Table 4, where the coalition |S| with different sizes and grand coalition |N=6| were presented.

4. DATA PROCESSING AND ANALYSIS

4.1. Data Processing

The data for the study, Tariffs per Sea-Road transport routes (in Naira) for 250,000 litres of fuel barges and road tankers, is presented in Table 2, and calculation of sum of savings for each coalition is presented in Table 3.

Table 2

Tariffs per Sea (Inland Waterway)- Road transport routes (in Nigeria) for 250.000 Liters fuel tankers/barges

S_i	Origin – Destination (O-D)	Multimodal freight transport route from terminal – terminal	Multimodal transport providers	Number of operators	Unit Cost(m)	Frequency	Unit Cost(m)	Frequency	Unit Cost(m)	Frequency	Unit Cost(m)	Frequency	Unit Cost(m)	Frequency	Total Cost (m)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S1	Apapa – Aba	Apapa + I + Port-Harcourt + +R + +Aba	JULA, NEPCO, JUHE, TSLL	4	270	3	22	7	22	12	22.5	8			336.5
S2	Apapa – Akwa Ibom	Apapa + I + +Akwa Ibom	TON, AZB, JUHE	3	271	2	22	9	22	13					315
S3	Apapa – Enugu	Apapa + I + +Port-Harcourt + +R+ Aba + +R + Enugu	TON, TSLL, JUHE, NEPCO	4	271	3	23	6	22.6	8	22.8	14			339.4
S4	Calabar – Enugu	Calabar + I + Akwa-Ibom + +R + Aba + +R + Enugu	NEPCO, AZB, TSLL	3	22	4	22	7	22.6	12					66.6
S5	Calabar – Aba	Calabar + I + +Akwa- Ibom + +R + Aba	NEPCO, TSLL	2	22.7	5	23	9							45.7
S6	Port-Harcourt – Aba	Port-Harcourt + +R + Aba	JUHE, AZB, NEPCO	3	22.2	10	22	12	22.5	14					66.7

Table continuation 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
S7	Apapa-Abakiliki	Apapa + I + Cross-River + +R + Abakiliki	JULA, TSLL, JUHEL, AZB, TSL	5	270	3	22	10	22.3	8	22.6	7	22.8	12	359.7
S8	Calabar – Awka	Calabar + R + Aba + R + +Owerri + R + +Awka	TON, NEPCO, JUHEL, AZB	4	22.3	5	22	15	22.3	12	22.4	7			89
S9	Calabar – Owerri	Calabar + R + Aba + R + +Owerri	TSLL, NEPCO, AZB	3	22.4	6	23	9	22.7	12					68.1
S10	Port-Harcourt – Onitsha	Port Harcourt + +I + Warri + I + +Onitsha	TSLL, JUHEL, NEPCO	3	22.3	9	22	10	22.3	13					66.6
I: Inland Waterway Transport; R: Road transport															

4.2. Data Analysis

Results of computation of cost savings accruing from carriers' collaboration are presented in Table 3.

Table 3

Results of calculation of sum of savings for each coalition

S_i	Total unit cost per coalition (A)	Unit cost per coalition (B)	Difference between A and B (C = A – B)	Weight of profit (w_i) per coalition (D)	Savings per leg of the coalition (E)
1	2	3	4	5	6
S1	336.5	270	66.5	0.017	1.1305
	336.5	22	314.5	0.017	5.3465
	336.5	22	314.5	0.017	5.3465
	336.5	22.5	314	0.017	5.338
Total					17.1615
S2	315	271	44	0.017	0.748
	315	22	293	0.017	4.981
	315	22	293	0.017	4.981
Total					10.71
S3	339.4	271	68.4	0.017	1.1628
	339.4	23	316.4	0.017	5.3788
	339.4	22.6	316.8	0.017	5.3856
	339.4	22.8	316.6	0.017	5.3822
Total					17.3094
S4	66.6	22	44.6	0.017	0.7582
	66.6	22	44.6	0.017	0.7582
	66.6	22.6	44	0.017	0.748
Total					2.2644
S5	45.7	22.7	23	0.033	0.759
	45.7	23	22.7	0.033	0.7491
Total					1.5081
S6	66.7	22.2	44.5	0.017	0.7565
	66.7	22	44.7	0.017	0.7599
	66.7	22.5	44.2	0.017	0.7514
Total					2.2678

Table continuation 3

1	2	3	4	5	6
S7	359.7	270	89.7	0.033	2.9601
	359.7	22	337.7	0.033	11.1441
	359.7	22.3	337.4	0.033	11.1342
	359.7	22.6	337.1	0.033	11.1243
	359.7	22.8	336.9	0.033	11.1177
Total					47.4804
S8	89	22.3	66.7	0.017	1.1339
	89	22	67	0.017	1.139
	89	22.3	66.7	0.017	1.1339
	89	22.4	66.6	0.017	1.1322
Total					4.539
S9	68.1	22.4	45.7	0.017	0.7769
	68.1	23	45.1	0.017	0.7667
	68.1	22.7	45.4	0.017	0.7718
Total					2.3154
S10	66.9	22.3	44.6	0.017	0.7582
	66.9	22	44.9	0.017	0.7633
	66.9	22.3	44.6	0.017	0.7582
Total					2.2797

The total sum of all the savings per legs in each coalition yield the savings per coalition (*Si*). It is presented in column 6 of Table 4.

Table 4

Calculation of New Unit Cost and Savings using the Shapley value Method

S_i	Unit Cost	Number of operators |S| for each route from terminal to terminal	Total number of operators |N| in grand coalition	$\frac{(\lvert S\rvert-1)!(\lvert N\rvert-\lvert S\rvert)!}{\lvert N\rvert!}$	$\sum_{\forall i} y_i$	Savings (%)	New Cost
S1	336.5	4	6	0.017	17.16	5.10	319.34
S2	315	3	6	0.017	10.71	3.40	304.29
S3	339.4	3	6	0.017	17.31	5.10	322.09
S4	66.6	3	6	0.017	2.26	3.39	64.34
S5	45.7	2	6	0.033	1.51	3.30	44.19
S6	66.7	3	6	0.017	2.27	3.40	64.43
S7	359.7	5	6	0.033	47.48	13.20	312.22
S8	89	4	6	0.017	4.54	5.10	84.46
S9	68.1	3	6	0.017	2.32	3.41	65.78
S10	66.6	3	6	0.017	2.28	3.42	64.32
Total	1753.3	–	–	–	107.84	6.15	1645.46

4.3. Interpretation of results

The Shapley value method of cost allocation is interested in reducing unit cost resulting from adding or increasing the total cost by adding one unit more of the product or transportation cost. From the analysis in Table 4, we observed that the unit cost for S1 was reduced by 17.16 million. Note that S1, as a unit in the coalition, has four legs (collaborating transport organizations), and after the business over the period, they made some gains, which led to the reduction of cost by 5.10 %. Similarly, S2, ..., S10 had their respective cost reduction, as shown in Table 4. We computed savings for each coalition using equation (2) (column 5 of Table 4). Also, percentage savings were computed using equation (4) and the new cost was computed using equation (1). We observed that the total unit cost was reduced as a result of the collaboration by 6.15 % [(1753.3–1645.46)/1753.3×100 = 6.15 %] on average, thereby giving the collaborators a total savings of 107.84 million naira.

5. CONCLUSIONS

In this paper, we carried out a study on the collaboration of six transportation organizations involved in the shipping and distributing of petroleum products. This kind of collaboration is encouraged instead of a competitive game where each participant in the industry tries to out-compete the other to take advantage of it. We proposed collaboration among six transport organizations to encourage a large-scale coalition with the expectation of sharing costs and benefits. This kind of coalition is called a cooperative game, where each participant contributes to the growth and efficient running of the business and shares in the proceeds from such collaboration. It has been found that such collaboration enhances harmony among the collaborators. The ripple effect of it is that it leads to a reduction in unit costs, creates avenues for continued supply and maintains stability in the prices of the product. The popular method adopted in sharing duties and profit with the collaborators is the Shapley value method of cost and profit allocation. This study adopted it because of its advantages over proportional and decomposition methods of cost allocation. We found that the set of all imputations is rational for all coalitions; hence, S is called the *core* of the game, and members were happy to participate in the coalition because there is a profit in doing that. We observed that there was a reduction in the cost by N107.84 million, which represents a 6.15 % cost reduction for the multimodal transportation carriers. This amount is the profit they made by cooperating in fuel supply and distribution. The most profits came from improving the stowage factor through full utilization of available transport vehicles, route maximization and haulage of large volumes of petrol. The collaboration is a huge success and is recommended to carriers involved in petroleum product distribution in a multimodal freight transport system.

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Received 26.03.2024; Accepted in revised form 24.04.2024.

МОДЕЛЬ РОЗПОДІЛУ ВИТРАТ ШЕПЛІ ДЛЯ МУЛЬТИМОДАЛЬНИХ ВАНТАЖНИХ ПЕРЕВІЗНИКІВ

Анотація. *Розподіл нафтопродуктів у секторі переробки та збуту стикається зі значними проблемами через старіння трубопровідної інфраструктури, вандалізм на трубопроводах та інші логістичні обмеження. Ці проблеми призвели до стрімкого зростання цін на пальне, дефіциту та недоступності продукту в деяких регіонах Нігерії. Зважаючи на це, використання альтернативних видів транспорту для розподілу нафтопродуктів вивчають з метою підвищення ефективності розподілу цієї продукції. Рішення поєднати внутрішній водний транспорт (замість трубопровідної мережі) та автомобільний транспорт активізує переваги, притаманні мультимодальній транспортній системі. Однак ефективність використання мультимодальних перевезень може знизитись, якщо оператори мультимодальних перевезень будуть конкурувати (замість того, щоб співпрацювати) у наданні послуг. У статті досліджено економічну ефективність кооперативної співпраці між мультимодальними перевізниками. Розглянуто співпрацю між шістьма операторами мультимодальних перевезень. Метою заохочення такої масштабної коаліції (S) є очікування, що витрати, які виникають в результаті їхньої спільної діяльності, будуть зменшені. Застосовано метод розподілу вартісних витрат Шеплі для розподілу операційних витрат і прибутку між учасниками коаліції. Результати аналізу показали, що витрати на одиницю продукції для коаліції S1 зменшилися на 17,16 (5,10 %) млн. найр. Аналогічно, спостерігається відповідне зниження питомих витрат для коаліцій S2, ..., S10. Відбулося зниження витрат на 107,84 млн найр, що становить 6,15 % зниження загальних витрат на одиницю продукції для мультимодальних перевізників. Отже, спостережувана економічна ефективність є економією завдяки ефективності ланцюга розподілу, якщо мультимодальні транспортні перевізники співпрацюють для покращення доступності продукції. Робота в коаліції компенсує коливання цін на пальне, спричинене неефективністю ланцюга розподілу*

Ключові слова: *показник Шеплі; розподіл витрат; мультимодальні вантажні перевезення; дистрибуція нафтопродуктів; співпраця перевізників; теорія ігор.*