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A SUPPLY CHAIN MODEL TO MINIMIZE SHIPMENT COST USING DYNAMIC PROGRAMMING APPROACH

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ABSTRACT

The objective of this research is to develop a supply chain model which incorporates fixed shipment and tariff costs at each stage of the supply chain in order to determine total minimum shipment cost at the end of a planning horizon. While the existing models being expanded in this research use forward recursive method of dynamic programming, the proposed model uses the backward approach which has lower suboptimal costs in between the stages. We observe that though the total minimum cost is the same for both the proposed and the existing model algorithms, the suboptimal costs in the proposed model are lower than the corresponding suboptimal costs in the existing model. This is one of the advantages of the proposed model compared to the existing models since it enhances early detention of unprofitable shipping patterns in the supply chain system. The algorithm of the model also has advantage of batch shipment at certain periods of computation. This assists policy makers to plan for shipment pattern that will reduce transportation cost and maximize profit of the organization.

Keywords: products, supply, consumers, shipment cost, tariff cost.

1.0 INTRODUCTION

A supply chain is a combination of several relevant stakeholders working together to ensure the smooth flow of finished products from manufacturers to retailers and final consumers. Supply chain is defined in [1], as a planning and management process involving the supply of finished products to final consumers. Supply chain will continue to face more risks than any other aspect of business organization because of the direct impact it has on industry's financial performance, [2]. As pointed out in [3], risk assessment and management in a supply chain process is very crucial to the success of any manufacturing company. The various risks that could be encountered in a supply chain process include road accidents, terrorist attacks, climate change and evolution of new products. Efficient management of supply chain can lead to increase in business profits and minimization of production cost, [4].

The process of risk management in supply chains include identifying, assessing and evaluating any possible disruption that could occur during products' shipment to retailers and final consumers with the aim of controlling and reducing their negative impact, [5]. [6] opined that the type of disruption encountered at the logistic level of a supply chain will determine the type of risk management approach to adopt. For example, the COVID-19 pandemic is proof of how unforeseen incidents can disrupt a supply chain.

[7] remarked that mathematical models can be developed and use to reduce problems associated with risk in a supply chain process. In [8], mixed programming and integer programming were used to analyze optimization of supply chain problems. The objectives of these models were to evaluate the degree of effectiveness of the supply chain through the use of mathematical algorithms. In recent times, inventory and their locations have been

incorporated into the mathematical formulation of supply chain models. Such models are reported in [9] and [10] which were formulated with inclusion of disruption factors. Supply chain models which consider several disruption factors are studied in [11]. Impact of disruption on supply chain processes are discussed in [12]. As stated in [13], disruption to supply chain could be caused by extreme weather, earthquake, accidents or strikes by labor union.

A supply chain model which studies how to identify, evaluate and react to risks involved in products' delivery to retailers and final consumers is proposed in [14]. The model was later expanded in [15] in which a resilient factor was incorporated in the already existing models formulations. In [3], the relationship between risk management techniques and uncertainty is studied while the models in [5], [10] and [16] reflect on empirical study of how to sustain logistics in a supply chain system.

The proposed model in this research is meant to correct the shortcomings of existing mathematical models in [2], [8] and [10] which have focused on risk management and sustainability of supply chain systems with the objective of evaluating any possible disruption that could occur during products' shipment without evaluating fixed shipment and tariff costs at each stage of the supply chain. Our proposed supply chain model incorporates fixed shipment and tariff costs at each stage of the supply chain in order to determine total minimum shipment cost at the end of a planning horizon.

The paper is structured as follows: Section 1is the introduction. Section 2 contains the methodology and material, model assumptions, mathematical notations and model description. Sections 3 and 4 contain the model formulation and numerical illustration respectively while Sections 5 and 6 contain the analysis of results and conclusion respectively.

2.0 METHODS AND MATERIAL

Model Assumptions

The following assumptions are considered while formulating the supply chain problem to determine optimal shipment policies.

(a) The number of items to be shipped is known and fixed.
(b) Shipment of a particular brand of product is considered.
(c) Shipment and tariff costs are known and fixed.
(d) Under-shipment is not allowed.

Mathematical Notations

$Q_j =$ number of items in stage j

$k_j =$ fixed shipment cost in stage j

$r_j =$ cost of tariff per item shipped stage j

$l_j =$ number of people recruited in period j

$u_j =$ number of items shipped in an earlier period from stage j.

$n =$ Number of stages

$n-s$ = the general period which has s more periods ahead of it.

$d_{j,n-s} =$ the decision to ship for the first j stages at stage $n-s$.

$c_{j,n-s} =$ the cost of shipment for the first j stages at stage $n-s$.

$q_{jk} =$ number of items shipped from stage j to stage k.

$u_{jk} =$ cost of shipment per item from stage j to stage k.

$v_{jk} =$ is the number of items shipped earlier from stage j to stage k.
$Q_{jk} =$ is the number of items required to be moved from stage j to stage k

Model Description:
Let n be the number of stages or periods in which shipment is planned for in a given establishment. Since the supply chain shipment quantities and their costs vary from period to period, the tariff cost per item per period denoted by r_j will also vary from period to period. The proposed model in this section is formulated based on shipment (v_j) and tariff cost factors in manufacturing industries. The proposed model uses backward recursive approach in dynamic programming while similar dynamic programming models in [17] and [18] use a forward recursive approach. Hence, the proposed shipment model is an extension of [17] and [18] on manpower planning and [8], [2] and and [10] supply chain models which focused on risk management and sustainability of supply chain systems which evaluate shipment cost at each stage of production with the objective of maximizing profit.

In [17] and [18], The function H(z) was used to denote the minimum cost program of an inventory model which has z periods planning horizon. At a given period z, the sub-cost of the first sub-decision is expressed as $k_z + H(z-1)$, where $H(z-1)$ is the preceding period's suboptimal shipment cost. The other sub-costs at period *j* are evaluated using equation (1).

$$c_j = k_j + \sum_{q=j}^{z-1} \sum_{p=q+1}^{z} r_q Q_p + H(j-1), j = 1,2,3,\ldots,z-1 \qquad (1)$$

Hence the suboptimal cost at the last period z is written as

$$H(z) = \min_{1 \le z \le n} \left[\min_{1 \le j < z} \left[k_j + \sum_{q=j}^{z-1} \sum_{p=q+1}^{z} r_q Q_p + H(j-1) \right], k_z + H(z-1) \right] \qquad (2)$$

The backward recursive method in the proposed model is a modified version of Equations (1) and (2). The only difference is that the proposed model requires solving a given dynamic programming problem starting from the last period to the first period in the reverse order of the computational serial number while in [17] and [18] models computation procedure starts from the first period and ends in the last period. The proposed model is applied to the type of problems that make use of Table 1 as follows.

Table 1: Shipment and Tariff costs

Periods	No. of Items Shipped (Q_j)	Fixed Shipment Cost k_j (₦)	Tariff Unit Cost r_j (₦)
1	Q_1	k_1	r_1
2	Q_2	k_2	r_2
3	Q_3	k_3	r_3
$\vdots$	$\vdots$	$\vdots$	$\vdots$
n	Q_n	k_n	r_n

3.0 MODEL FORMULATION
In each period, several decisions are to be made and we seek to obtain the suboptimal decision which gives the minimum shipment cost for the period.

Let $(n-s)$ be the general period when there are s more periods ahead of it. Let $(s+1)$ be the decisions to be made in period $(n-s)$ and they are depicted by $d_{j,n-s} = \{d_{1,n-s}, \quad d_{2,n-s}, \cdots, d_{s+1,n-s}\}$ while their corresponding costs are

$$c_{j,n-s} = \{c_{1,n-s}\,,\ c_{2,n-s}\,,\ c_{3,n-s}\,, \cdots, c_{s+1,n-s}\}. \qquad (3)$$

The suboptimal decision of period $(n-s)$ is depicted by $d_{j^*,n-s}$ which has its corresponding suboptimal cost to be

$$c_{j^*,n-s} = \min_{1\le j\le s+1}\{c_{1,n-s}\,,\ c_{2,n-s}\,, \cdots, c_{s+1,n-s}\} \qquad (4)$$

For $s = 0,1,2,\ldots(n-1)$

Note that $d_{j,n-s}$ simply means the decision j to ship the items for the first j periods at period $(n-s)$ and its corresponding cost is $c_{j,n-s}$

$$c_{j,n-s} = k_{n-s} + Q_{n-s+1}(i_{n-s}) + Q_{n-s+2}2(i_{n-s}) + \cdots + Q_{(n-s)+(j-1)}(j-1)(i_{n-s}) + c_{j^*,n-s+j} \qquad (5)$$

While evaluating equation (5) we should note that

$$c_{j^*,p} = 0, \ \forall \ p > n \qquad (6)$$

The nth period decision is depicted by

$$d_{j,n} = d_{1,n} = d_{1^*,n} \qquad (7)$$

The corresponding cost for Equation (7) is

$$c_{1^*,n} = k_n + c_{j^*,n+1} = k_n \qquad (8)$$

We observe that at the nth period, $s=0$, hence $c_{j^*,n+1} = 0$ from equation (6).

Algorithm of the Proposed DP Model

Step 1: Evaluation of the nth period.
This is the last of the shipment and we are to use equation (8) to evaluate the optimal shipment policy cost, noting that at the nth period, $s=0$ $c_{j^*,n} = k_n + c_{j^*,n+1} = k_n$ and the corresponding optimal decision is $d_{j,n} = d_{1,n} = d_{1^*,n}$ from equation (7)

Step 2: Computations for the other periods, that is $(n-s)th$
We apply equation (5) to evaluate $c_{j,n-s}$, $j = 1,2,\ldots,(s+1)$. For each period $(n-s)$ computation. The suboptimal cost is $c_{j^*,n-s} = \min_{1\le j\le s+1}\{c_{1,n-s}\ ,\ c_{2,n-s}, \cdots, c_{r+1,n-s}\}$ while the corresponding suboptimal decision is $d_{j^*,n-s}$ from equation (4).
Period $(n-s)$ has $(s+1)$ decisions to make and their corresponding costs are as follow:

$$c_{1,n-s} = k_{n-s} + c_{j^*,n-s+1}$$

$$c_{2,n-s} = k_{n-s} + Q_{n-s+1}\ i_{n-s} + c_{j^*,n-s+2}$$

$$c_{3,n-s} = k_{n-s} + Q_{n-s+1}\, i_{n-s} + Q_{n-s+2}\ 2(i_{n-s}) + c_{j^*,n-s+3}$$

$$c_{s,n-s} = k_{n-s} + Q_{n-s+1}\, i_{n-r} + Q_{n-s+2}\, 2(i_{n-s}) + \cdots + Q_{n-1}(s-1)\ (i_{n-s}) + c_{j^*,n}$$

$$c_{s+1,n-s} = k_{n-s} + Q_{n-s+1}\ i_{n-s} + (Q_{n-s+2})2(i_{n-s}) + \cdots + Q_{n-1}(s-1)\ (i_{n-s}) + Q_n(s)(i_{n-s}) + c_{j^*,n+1}$$

Step 3: Evaluate the Overall Policy
The corresponding suboptimal shipment costs are used by a recursive process to obtain the overall optimal shipment policy that will give the minimum total shipment cost of the supply chain system.

Fig. 1 depicts the flow chart of the algorithm of the proposed model.

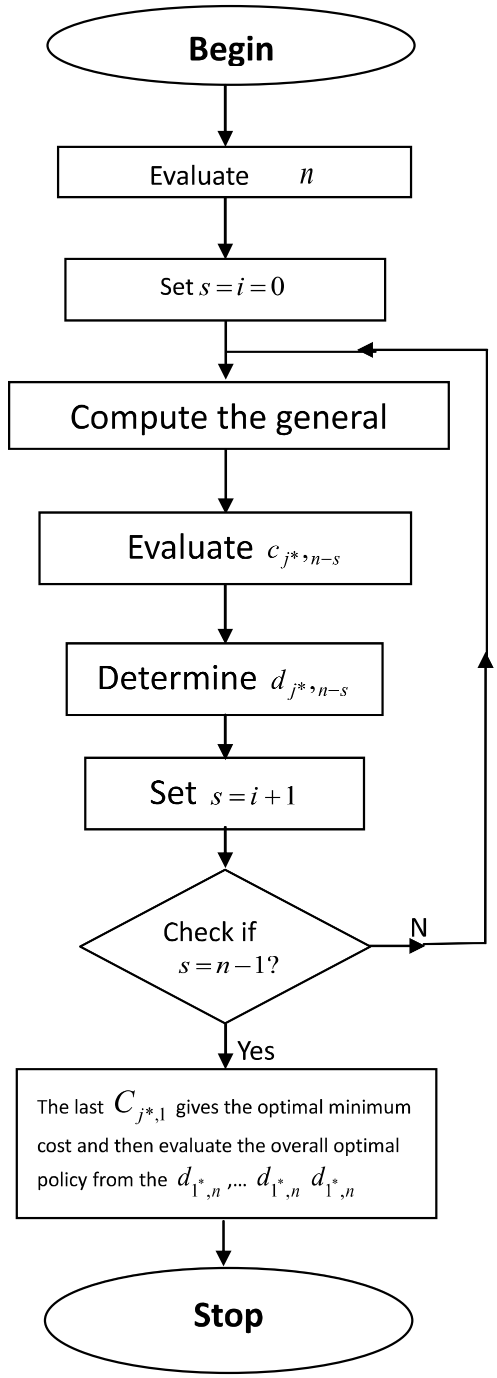

Fig. 1: Model algorithm's flow chart.

4.0 NUMERICAL ILLUSTRATION

The data in Table 2 depicts ABC manufacturing industry with distribution centers spread across many cities in Nigeria. The shipment of finished products is to be carried out periodically in a manner that meets customers/consumers requirement at various destination centers. Given that shipment process attracts additional costs (tariff cost) besides the fixed shipment cost. Determine how the supply of the products to different distribution centers should be maintained throughout the planning horizon of the industry in order to minimize total shipment cost using the data in Table 2.

Table 2: Data of Shipment and Tariff costs.

Year N	No. of items shipped Q	Fixed Shipment Cost (k) (₦)	tariff cost (r) (₦)
1	740	7180	13
2	350	7070	11
3	470	6880	14
4	620	7160	15
5	200	6980	14
6	900	7410	16
7	510	6850	13
8	300	7060	10
9	430	6790	11
10	350	7140	15

Solution by the Proposed DP Model Algorithm

We apply the proposed algorithm in Section 3 to the given numerical example using the data in Table 2 as follows:

The given problem has 10 periods or stages. That is, $n = 10$. At period 10 when $s = 0$

$$c_{1,10} = k_{10} + c_{j^*,11} = 7140 \left(where\ c_{j,11} = 0\right)$$

The suboptimal decision is $d_{1^*,10}$. It implies that 350 units of the items should be shipped in stage 10 to various retailers and consumers centers.

To compute the shipment cost in stage 9 when $s = 1$, using the data in Table 2, we have

$$c_{1,9} = k_9 + c_{j^*,10} = 6790 + 7140 = ₦13930$$

$$c_{2,9} = k_9 + Q_{10}\,\mathrm{r}_9 + c_{j^*,11} = 6790 + 350 \times 11 = 6790 + 3850 = ₦10640$$

The suboptimal shipment cost in stage 9 is ₦10640* which is lower than ₦13930. This suboptimal shipment cost corresponds to the decision $d_{2,9}$ which implies that shipment should be carried out in last two stages starting from stage 9.

In stage 8 when $s = 2$ we have three shipment sub-cost to evaluate:

$$c_{1,8} = k_8 + c_{j^*,9} = N7060 + N10640 = ₦17700$$

$$c_{2,8} = k_8 + Q_9\, r_8 + c_{j^*,10} = N7060 + N430 \times 10 + N7140 = ₦18500$$

$$c_{3,8} = k_8 + Q_9\, s_8 + Q_{10}\, 2(s_8) + c_{j^*,11} = N7060 + N430 \times 10 + N350 \times 2 \times 10 = ₦18360$$

In stage 8, the suboptimal shipment cost is $c_{1*,8} = N17700$ which corresponding to the suboptimal decision = $d_{1^*,8}$

The next stage is stage 7, when $s = 3$, we have four sub-costs to compute corresponding to four sub-decisions. These are:

$$c_{1,7} = k_7 + c_{j^*,8} = N6850 + N17700 = ₦24550$$

$$c_{2,7} = k_7 + Q_8 \; s_7 + c_{j^*,9} = 6850 + 300 \times 13 + 10640 = ₦21390$$

$$c_{3,7} = k_7 + Q_8 \; s_7 + Q_9 \; 2\left(s_7\right) + c_{j^*,10} = N6850 + N30 \times 13 + 430 \times 2 \times 13 + 7140 = ₦29070$$

$$c_{4,7} = k_7 + Q_8 \; s_7 + Q_9 \; 2\left(s_7\right) + Q_{10} 3\left(s_7\right) + c_{j^*,11} = 6850 + 3900 + 11180 + 350 \times 3 \times 13 = ₦35580$$

The shipment suboptimal cost for stage 7 is $c_{2^*,7}$= N21390 which corresponds to the suboptimal decision $d_{2^*,7}$

Computations from stage 6 to stage 1 done by following the same procedure and the results are summarized in Table 3

Table 3: Proposed Algorithm Results' Summary

Year n	10	9	8	7	6	5	4	3	2	1
Compt S/N	1	2	3	4	5	6	7	8	9	10
k_j	7140	6790	7060	6850	7410	6980	7160	6880	7070	7180
r_j	15	11	10	13	16	14	15	14	11	13
Q_j	350	430	300	510	900	200	620	170	350	740
Minimum shipment cost	7140	10640	17700	21390	28800	35780*	38960	45840	51200	57570
Optimum policy	$d_{1^*,10}$	$d_{2^*,9}$	$d_{1^*,8}$	$d_{2^*,7}$	$d_{1^*,6}$	$d_{1^*,5}$	$d_{2^*,4}$	$d_{1^*,3}$	$d_{2^*,2}$	$d_{2^*,1}$

Table 4: Optimal Solution Using Proposed DP Model

Stage	Suboptimal Decision	No. of items	Shipment and tariff Cost (N)
1.	**In period 1 ship for periods 1 & 2**	$Q_1 = 1090$	**7180+13(35) = 11730**
3.	**In period 3 ship for only period 3**	$Q_3 = 470$	**6880**
4.	**In period 4 ship for periods 4 & 5**	$Q_4 = 820$	**7160+15(20) = 10160**
6.	**In period 6 ship for only period 6**	$Q_6 = 900$	7410
7.	**In period 7 ship for periods 7 & 8**	$Q_7 = 810$	**685+13(30) = 10750**
9.	**In period 9 ship for periods 9 & 10**	$Q_9 = 780$	**6790+11(35) = 10640**
		Total = 4870	**Total = ₦57,570**

Table 5: Summary of Results Using Rao's Algorithm

Year n	1	2	3	4	5	6	7	8	9	10
Compt S/N	1	2	3	4	5	6	7	8	9	10
k Q v	7180 740 13.00	7070 350 11.00	6880 470 14.00	7160 620 15.00	6980 200 14.00	7410 900 16.00	6850 510 13.00	7060 300 10.00	6790 430 11.00	7140 350 15.00
	7180*	14250 11730	1861* 19430 23950	25770 27290	32750 2877*	3618* 45350 55770	4303* 44340	50090 4693*	5372* 54390 58110	60060 57570
Minimum costs	7180	11730	18610	25770	28770	36180	43030	4693	53720	57570

5.0 DISCUSION

The given problem has 10 periods or stages. That is, n=10. In period 10, The suboptimal decision is $d_{1^*,10}$. It implies that 350 units of the items should be shipped in stage 10 to various retailers and consumers centers at the cost of N7140. To compute the shipment cost in period 9 when s=1, using the data in Table 2, we have two alternative costs: N13930 and N10640. The suboptimal shipment cost in stage 9 is ₦10640* which is lower than ₦13930. This suboptimal shipment cost corresponds to the decision $d_{2,9}$ which implies that shipment should be carried out in the last two stages starting from stage 9. In stage 8 when s=2, we have three shipment sub-costs: N17700, N18500 and N18360. IN stage 8, the suboptimal shipment cost is $c_{1*,8} = N17700$ which corresponding to the suboptimal decision $= d_{1^*,8}$. The next stage is stage 7, when $s = 3$, we have four sub-costs corresponding to four sub-decisions. These are: N24550, N21390 N29070 and N35580. The shipment suboptimal cost for stage 7 is $c_{2^*,7}$ = N21390 which corresponds to the suboptimal decision $d_{2^*,7}$.

The computation for the remaining stages (i.e stage 6 to stage 1) is done by following the same procedure and the results are summarized in Table 3. In Table 4, the periods that give the optimal shipment cost are periods 1, 3, 4, 6, 7 and 9. That is Q_1=1090, Q_3=470, Q_4=820, Q_6=900, Q_7=810 and Q_9=780. This amounts to the minimum total shipment cost of ₦57,570 and the total number of items shipped is 4870. This shows that shipment is carried out in batches which lead to minimization of total shipment cost. The last rows of Table 3 and Table 5 denote the periodic suboptimal costs of all the stages.

6.0 CONCLUSION

Efficient management of supply chain is very crucial to the financial success of any business organization, [19] and [20]. While the existing models in [2], [17] and [18] use forward recursive method of dynamic programming, the proposed model uses the backward approach which has lower suboptimal costs in between the stages compared to the ones in [17] and [18]. The algorithm of the model has advantage of batch shipment at certain periods of computation. This assists policy makers to plan for shipment patterns that will reduce total shipment cost and maximize the profit of the organization. Many mathematical models have focused on risk management and sustainability of supply chain systems while the proposed model is based on fixed shipment cost and tariff cost at each stage of the supply chain. While existing model use forward recursive method, the proposed model uses backward recursive method of dynamic programming techniques which have lower periodic suboptimal shipment cost in between the stages of the supply chain system. We observe that though the total minimum cost is the same for the two algorithms, the suboptimal costs in the proposed model are lower than the corresponding suboptimal costs in the Rao [17] model as shown in Table 3 and Table 5. This is another advantage of the proposed model compared to the existing models since it enhances early detention of unprofitable shipping patterns in the supply chain system.

The algorithm of the model advocates for batch shipment which could help policy makers to determine the periods in which shipment should be carried out in order to minimize total shipment cost. The limitation of the research is that manual computation will be cumbersome for shipment problems that have large number of periods hence a computer program would be required to obtain the optimal shipment cost of such supply chain problems. This could form a future research direction.

REFERENCES

[1] Nap, I. C. (2018). Studies on Risk Management in the supply chain, Faculty of Mechanical Engineering, Technical University of Cluj-Napoca, pp. 17.

[2] Yang, M., Lim, M.C. Qu, Y. Ni, D. and Xiao, Z. (2023). Supply chain risk management with machine learning technology: A literature review and future research directions, Computer and Industrial Engineering, vol. 175, 108859.

[3] Giuffrida, M. , Jiang, H. and Mangiaracina, R. (2021). Investigating the relationship between uncertainty types and risk management strategies in cross-border e-commerce logistics, The International Journal of Logistics, 32 (4) 1406-1433.

[4] Ogumeyo, S.A., Festus, S.S. Oloda, Jacob, C. Ehiwario and Rosemary, Adigwe (2025). Mathematical Model to Determine Optimum Inventory Level in a Supply Chain System. Earth Journal of Mathematical Sciences, 15(1) 85-103.

[5] Parhi, S., Josh, K., Gunasekaran and Sethuraman, K. (2022). Reflecting on the empirical study of the digitalization initiatives for sustainability on logistics: Cleaner Logistics and supply chain. (4) 100058.

[6] Pooya, A., Mansoori, A., Eshaghnezhad, M., & Ebrahimpour, S. M. (2021). Neutral Network for a Novel Disturbance Optimal Control Model for Inventory and Production Planning in a Four-Echelon Supply Chain with Reverse Logistics. *Neural Processing Letters, 1 – 22.*

[7] Habib, M.S., Lee, Y.H. and Memon, M.S. (2016). Mathematical models in humanitarian supply chain management: A systematic literature review, Hindawi Publishing corporation Mathematical Problems in Engineering . Vol. 2016, ID 3212095.

[8] Nguyen, T.D., Nguyen-Quang, T., Venkatadri , U., Diallo, C., Adams, M. (2021). Mathematical models for fresh fruit supply chain optimization: A review of the literature and emerging trends. Agri-Engineering, vol. 3 pp, 519- 541.

[9] Li, L. (2014). Managing Supply Chain and Logistics: Competitive Strategy for a Sustainable Future. Singapore: World Scientific Publishing Co. Pte. Ltd.

[10] Brandao, M.S. and Godinho-Filho, M. (2022). Multiple supply chain management perspective: a new way to manage global supply chains toward sustainability. Journal of Cleaner Production, vol. 375, 134046.

[11] Jabbarzadeh, A., Aryanezhad, M. B., Aboodi, S. (2011). Designing a Reliable Supply Chain Network with Random Disruption Consideration, Proceedings of the 41st International Conference on Computers & Industrial Engineering, Los Angeles. 429 – 434.

[12] Martha, J. and Vratimos, E.,(2002). Creating a Just-in-Case Supply Chain for the Inevitable Next Disaster, Mercer Management Journal, 14, 70-77.

[13] Simchi-Levi, D., Kaminsky, P. & Simchi-Levi, E. (2000). Designing and Managing the Supply Chain Concepts, Strategies, and Case Studies. United States of America: The McGraw-Hill Companies, Inc.

[14] Shayb, H. (2019). Risk management: identification, evaluation and reaction to risk. Ecomica Magazine, no.1 (107).

[15] Demiralay, E. and Paksoy, T. (2022). Strategy development for supplier selection process with smart and sustainable criteria in fuzzy environment, Journal of Cleaner Logistics and supply chain. No. 5, 100076.

[16] Barojas-Payan, E., Partida, D.S., Flores, J. M., and Romero, D.E., (2019). Mathematical model for locating a pre-positioned warehouse for calculating inventory levels. Journal of disaster research. 14(4) 649-666.

[17] Rao, P.P. (1990). Determination of Optimal Manpower Recruitment Policies Using Dynamic Programming. Journal of Operational Research Society, 41 (10) 983-988.

[18] Ogumyo S.A. (2014). A Ph.D. dissertation submitted Postgraduate School in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Industrial Mathematics. University of Benin, Benin City, Edo State Nigeria.

[19] Dada, M., Petruzzi, Nicholas C., Schwarz, Leroy B. (2007). A Newsvendor's Procurement Problem when Suppliers Are Unreliable, MSOM Winter 9(1) 9-32.

[20] Kersten, W. (2018). Road to a Digitalized Supply Chain Management: Smart and Digital Solutions for Supply Chain Management. Proceedings of the Harmburg International Conference of Logistics (HICL), no, 25.