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Development of Two-Stage Transportation Problem Model with Fixed Cost for Opening the Distribution Centers

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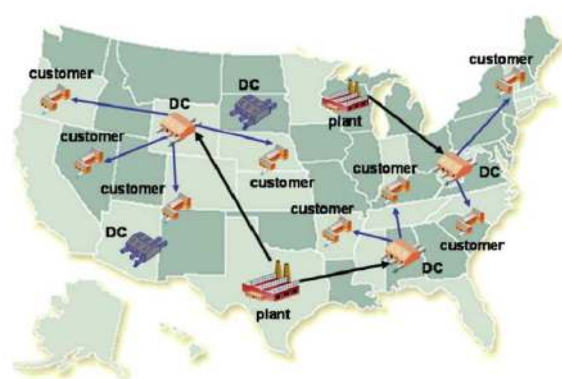
Abstract. *The Two-Stage Transportation Problem (TSTP) is a model of product transportation in the supply chain. The transportation starts from the factory to customers through a distribution center (DC), which considers the fixed cost of opening a DC, the transportation cost per unit from a certain factory to a certain DC, and the transportation cost per unit from a certain DC to certain customers. This study develops a model by allowing direct delivery from the factory to the customer. From the numerical example given, the proposed model that allows direct delivery from the factory to a customer could result in a total distribution cost that is minimized to the initial model. Both models were compared with calculation using Lingo 19.0. The model developed is expected to provide options and consideration for the management to determine the right distribution and logistics strategy for their products.*

Keywords: *direct delivery, distribution cost, distribution strategy, supply chain, two-step transportation problem*

I. INTRODUCTION

The supply chain indicates the stream of materials beyond various facilities, beginning with input materials and finishing with end products being shipped to end customers. The multi-stage distribution problem is a specific problem for companies with supply chain networks (Jawahar & Balaji, 2009). The Two-Stage Transportation Problem (TSTP) implicates a network of products transportation from the factory to the customer through a distribution center (DC) or warehouse and the illustration could be seen in Figure 1.

A company may have problems with opening or operating a DC. DC is generally a storage facility that has the capacity or no capacity. The transportation problem is a basic network problem that is quite well known and the goal is to find a method to deliver similar products from origin points to destination points to get minimized total costs. In applications, the transportation problem is expanded to meet some other additional constraints or is carried out in some phases (Gen et al., 2006).



Source: Gen et al. (2006)

Figure 1. Two-stage transportation network illustration

Many factors affect the efficiency of the logistics system; one of that factors is to determine the amount and location of good DC to open so that the customer demand could be met with minimum costs of opening DC and transportation costs. Most companies have problems with limited capital for opening and operating a DC. Thus, the number of DC that could be opened is an important consideration in this development research.

Marín & Pelegrín (1997) made a research that manufacturers and DCs have no limits in capacity and there are fixed costs related to opening DCs and the amount of DC opened is determined earlier and fixed. To solve a TSTP of

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this type, they used a Lagrangean decomposition and a branch-and-bound technique that satisfy the consideration in transportation problems.

Marín (2007) investigated the uncapacitated problem when producers and DCs were charged a fixed cost and proposed a mixed-integer programming model to solve the problem. Pirkul & Jayaraman (1998) consider multiple commodities and plants for a facility location problem with capacity consideration provide a mixed-integer programming model formulation, and propose a heuristic method with the Lagrangian relaxation consideration. The next study considers the purchase of materials and presents a solution based on the heuristic approach that utilizes a relaxation of Lagrangian (Jayaraman & Pirkul, 2001).

Amiri (2006) proposes different variants that allow the use of multiple levels of plant and DC capacity and construct a heuristic approach with Lagrangian relaxation. Another research on a two-level optimization problem builds distribution network planning and proposes a model of two-level mixed-integer from the problem. Determination of the delivery from DC to customer and supply from producer to DC using a solution approach in metaheuristic combines evolutionary algorithm to control DC supply and optimization method (Calvete et al., 2014).

Antony Arokia Durai Raj & Rajendran (2012) consider the problem using two scenarios: the fixed costs associated with the route in the first scenario, and for the second scenario adds cost for opening the DC beside cost for transport per unit. A genetic algorithm (GA) is developed for a TSTP and also presented a set of 20 examples. TSTP with Fixed Costs (TSTP-FC) with the route from producer to the customer is solved using a different genetic algorithm using different genetic algorithm (Jawahar & Balaji, 2009). Case resolution in the first scenario using a hybrid algorithm that combines a steady-state GA with a Local Search (LS) procedure (P. C. Pop et al., 2017).

An approach of multi-start Iterated Local Search (ILS) was developed to minimize distribution costs of TSTP-FC, with the main solution, using local search procedures to improve exploration, perturbation mechanisms, and neighborhood operators to diversify the search and also present a soft computational approach to solve TSTP-FC associated with routes in optimization problems in the framework of GA (Cosma et al., 2019; Cosma et al., 2020).

The next research proposes a different approach, an effective hybrid GA to solve TSTP-FC. The results are compared with existing solution approaches on 150 benchmark instances and 50 new randomly generated instances of larger size (Cosma, Pop, & Sabo, 2020).

Pop et al. (2016) describe a novel hybrid heuristic approach using a GA based on encoding individual hash tables with a robust LS procedure. Cosma et al. (2018) propose an efficient Hybrid ILS which builds on the initial solution while using LS procedures aiming to improve exploration and for search diversification purposes, neighborhood structure is used.

Model of the TSTP-FC where consider two types of fixed costs: one for opening distribution centers and the other related to routes between producers and DCs and between DCs and retailers (Hong et al., 2018). Another version of TSTP with one factory considers reducing greenhouse gas emissions as an environmental impact. This research is to deal with practical applications that occur in the public sector (Santibanez-Gonzalez et al., 2011).

Some of the implementations of TSTP are being used for the distribution of fertilizer in Central Sulawesi province. The developed model is not use fixed costs to open a distribution center and is completed with Lingo software (Aida & Rahmanda, 2020). Another TSTP for soft drink products and the Mixed-Integer Linear Programming (MILP) model created is for multiple products with a fixed cost to open a DC, and a DC only serves one retailer (Fatma & Manurung, 2021).

This research explains the network design problem of a supply chain, the fixed cost TSTP to open DC, which could be seen as a development of the classic transportation problem. The objectives considered in the transportation problem are to determine the DCs to be opened and to identify and select the route from the producer through the selected DCs to be opened to the customer that meets the producer's capacity constraints and the DCs to meet the customer's specific demands under minimal total distribution costs.

The mathematical model of this problem is used in research Gen et al. (2006), Antony Arokia Durai Raj & Rajendran (2012), and (Cosma, Danciulescu, et al., 2019). This research aims to develop a mathematical model of the problem by allowing direct delivery from the factory or producer to the customer (without going through DC).

II. RESEARCH METHOD

This section described a mathematical model for the development of a fixed-cost, TSTP for opening a DC that allows direct delivery from the factory to the customer, without going through the DC:

Index:

p = amount of factories

q = amount of DC

r = amount of customers

i = factories, where i ∈ {$1, \dots, p$}

j = DC, where j ∈ {$1, \dots, q$}

k = customers, where k ∈ {1, . . ., r}

Parameters:

w = maximum amount of DC that could be opened

D_k = demand of customer k

S_i = capacity of factory i

Q_j = capacity of distribution center j, where j ∈ {1, . . ., q}

F_j = fixed cost to open DC j

c_{ij} = transportation cost per unit from factory i to DC j

c_{jk} = transportation cost per unit from DC j to customer k

c_{ik} = transportation cost per unit from factory i to customer k

Decision variables:

x_{ij} = amount of units delivered from factory i to DC j

x_{jk} = amount of units delivered from DC j to customer k

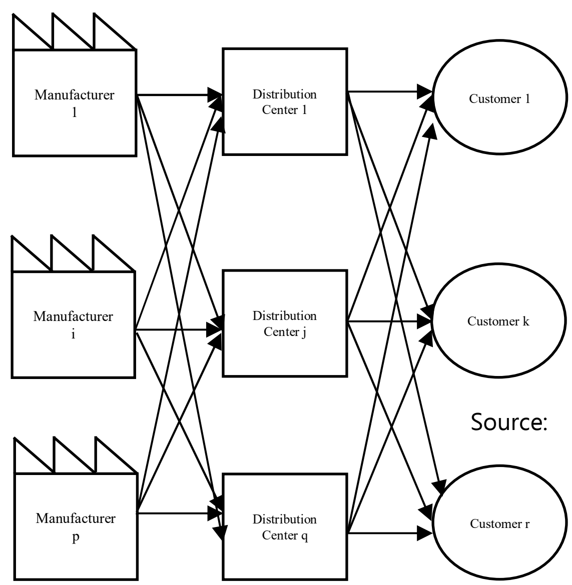
x_{ik} = amount of units delivered from factory i to customer k

Z_j = 1 if DC j opened and 0 if not

Given a factory p set, DC q set, and customer r set with the following: every factory i have supply capacity Si, every distribution center j has capacity Qj and every customer k has demand Dk. Every factory could deliver to any distribution center q at the cost of transportation per unit cij from factory i to DC j. Each distribution center could deliver to any customer r at the cost of transportation per unit cjk from DC j to customer k. Every factory is allowed to deliver directly to any customer k with transportation costs per unit cik from factory i to customer k. There is a fixed cost for opening a distribution center, as well as a limit on the number of DCs allowed to open.

The purpose of the TSTP-FC for opening a DC is to determine the DC and the route that is opened and the appropriate number of deliveries on that route, so that customer demand could be met, all delivery constraints are met, and the total distribution costs could be minimized. The illustration of the problem of TSTP-FC for opening a DC could be seen in Figure 2.

The illustration of a TSTP-FC to open a DC by allowing direct delivery from the factory to the consumer can be seen in Figure 3.



Source: Cosma, Danciulescu, et al. (2019)

Figure 2. A TSTP-FC for opening a DC

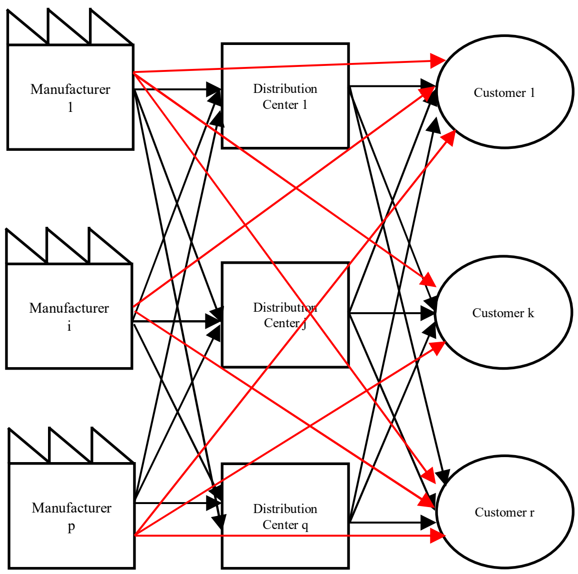


Figure 3. A TSTP-FC for opening a DC that allows direct delivery from the factory to the customer

Objective function:

$$\text{Minimize } \sum_{i=1}^{p}\sum_{j=1}^{q} c_{ij}x_{ij} + \sum_{j=1}^{q}\sum_{k=1}^{r} c_{jk}x_{jk} + \sum_{i=1}^{p}\sum_{k=1}^{r} c_{ik}x_{ik} + \sum_{j=1}^{q} F_j Z_j \qquad (1)$$

Constraints:

$$\sum_{j=1}^{q} x_{ij} + \sum_{k=1}^{r} x_{ik} \leq S_i, \quad \forall i \in \{1,\dots,p\} \qquad (2)$$
$$\sum_{j=1}^{q} x_{jk} + \sum_{i=1}^{p} x_{ik} \geq D_k, \quad \forall k \in \{1,\dots,r\} \qquad (3)$$
$$\sum_{k=1}^{r} x_{jk} \leq Q_j Z_j, \quad \forall j \in \{1,\dots,q\} \qquad (4)$$
$$\sum_{j=1}^{q} Z_j \leq w \qquad (5)$$
$$\sum_{i=1}^{p} x_{ij} = \sum_{k=1}^{r} x_{jk}, \quad \forall j \in \{1,\dots,q\} \qquad (6)$$
$$x_{ij} \geq 0, \quad \forall i \in \{1,\dots,p\}, \forall j \in \{1,\dots,q\} \qquad (7)$$
$$x_{jk} \geq 0, \quad \forall j \in \{1,\dots,q\}, \forall k \in \{1,\dots,r\} \qquad (8)$$
$$Z_j \in \{0,1\}, \quad \forall j \in \{1,\dots,q\} \qquad (9)$$
$$x_{ik} \geq 0, \quad \forall i \in \{1,\dots,p\}, \forall k \in \{1,\dots,r\} \qquad (10)$$

Equation (1) explains about an objective function that minimizes the total distribution cost involving transportation costs per unit and fixed costs for opening a distribution center. Constraint in equation (2) ensures that the quantity sent to DC and customers from every factory does not exceed the available capacity. Constraint in equation (3) ensures that the total deliveries received from factories and DCs by every customer have met their demand.

Constraint (4) ensures that the amount sent out of every DC does not exceed the available capacity. Constraint (5) limits the amount of distribution centers that could be opened. Constraint (6) is a flow conservation condition and ensures that the units received by DC from the factory and the units delivered from the distribution center to customers are the same. Constraints (7) to (10) ensure non-negative decision variables.

Further testing would be carried out on the initial model and the development model on given numerical examples. Tests were carried out with the help of Lingo 19.0 software. Numerical examples are given for 2 factories (p = 2), 4 distribution centers (q = 4), and 5 customers (r = 5).

III. Result and Discussion

Testing of the initial model and development model would be carried out using 3 numerical examples.

Numerical example 1

The numerical example used for testing: capacities of factories 1 and 2 are 90000 and 75000 units, respectively, while the maximum number of DC opened is 3 DC. Table 1 is the transportation cost per unit from factory i to DC j, while Table 2 is the transportation cost from DC j to customer k. Table 3 is the transportation cost from factory i to customer k.

The capacity of DC and the amount of fixed costs to open DC could be seen in Table 4 and customer demand for k could be seen in Table 5.

Furthermore, the numerical data would be processed using Lingo 19.0 software for both models, the initial model used in the study of Gen et al. (2006), Antony Arokia Durai Raj & Rajendran (2012), and (Cosma, Danciulescu, et al., 2019). Model development is carried out by allowing direct delivery from the factory to the customer.

The initial model solves as could be seen in table 6. The total distribution cost resulting from this model is 10,200,000. The number of DC opened is 3 pieces: DC 2, DC 3, and DC 4. Factory 1 delivered products to DC 2, 3, and 4 for 14,000; 46,000; and 30,000 units, respectively, while factory 2 sent products only to DC 2 for 26,000 units.

DC 2 delivers products to customers 1, 2, and 4 respectively 30,000; 8,000; and 2;000 units. DC 3 delivered products to customers 2, 3, and 5 in the amount of 15,000; 15,000; and 16,000 units, respectively. DC 4 only delivered 30,000 units of product to customer 4.

Table 1. Transportation cost per unit from factory i to DC j for numerical example 1

Factory	DC 1	DC 2	DC 3	DC 4
Factory 1	90	66	50	52
Factory 2	80	70	64	66

Table 2. Transportation cost per unit from DC j to customer k for numerical example 1

DC	Customer				
	1	2	3	4	5
DC 1	30	72	66	38	58
DC 2	16	40	70	26	40
DC 3	76	24	30	28	14
DC 4	70	86	78	54	90

Table 3. Transportation cost per unit from factory i to customer k for numerical example 1

Factory	Customer				
	1	2	3	4	5
Factory 1	140	160	110	84	162
Factory 2	150	124	142	126	120

Table 4. Fixed cost to open DC and DC capacity

	DC 1	DC 2	DC 3	DC 4
Fixed Cost	25,000	28,000	30,000	32,000
Capacity	35,000	40,000	46,000	50,000

Table 5. Customer Demand

Customer	Demand
1	30,000
2	23,000
3	15,000
4	32,000
5	16,000

Table 6. The final solution of the initial model for numerical example 1

	DC 1	DC 2	DC 3	DC 4
Factory 1	0	14,000	46,000	30,000
Factory 2	0	26,000	0	0

DC	Customer				
	1	2	3	4	5
DC 1	0	0	0	0	0
DC 2	30,000	8,000	0	2,000	0
DC 3	0	15,000	15,000	0	16,000
DC 4	0	0	0	30,000	0

Table 7. The final solution of the developed model for numerical example 1

	DC 1	DC 2	DC 3	DC 4
Factory 1	0	4,000	46,000	0
Factory 2	0	26,000	0	0

DC	Customer				
	1	2	3	4	5
DC 1	0	0	0	0	0
DC 2	30,000	0	0	0	0
DC 3	0	23,000	7,000	0	16,000
DC 4	0	0	0	0	0

Factory	Customer				
	1	2	3	4	5
Factory 1	0	0	8,000	32,000	0
Factory 2	0	0	0	0	0

The model developed by allowing direct delivery from factory i to customers k solves as could be seen in Table 7. The total distribution cost resulting from this model is 9,476,000. The number of DC opened is only 2 (DC 2 and DC 3).

DC 2 delivered 3,000; 7,000; and 16,000 units of product to customers 2, 3, and 5, respectively. Direct shipments from the factory were carried out from factory 1 to customers 3 and 4 of 8,000 and 32,000 units, respectively.

The calculation results of this numerical example show that the model developed by allowing direct delivery from the factory to the customer provides a lower total distribution cost of 724,000 or 7.1%.

Numerical example 2

Numerical example 2 is carried out in numerical example 1 above, by changing the capacity of factories 1 and 2 to 75,000 and 90,000 units, respectively. In the additional scenario, the initial model solves as could be seen in Table 8. The total distribution cost resulting from this model is 10,270,000. The number of DC opened is 3 (DC 2, DC 3, and DC 4).

Factory 1 delivered products to DC 3 and 4 of 45,000 and 30,000 units, respectively, while factory 2 sent products to DC 2 and DC 3 of 40,000 and 1,000 units, respectively. DC 2 delivers products to consumers 1, 2, and 4 of 30,000; 8,000; and 2,000 units, respectively. DC 3 delivered products to consumers 2, 3, and 5 in the amount of 15,000; 15000; and 16,000 units, respectively. DC 4 only delivered 30,000 units of product to consumer 4.

The development of the model solves as could be seen in Table 9. The total distribution cost resulting from this model is 9,578,000. The number of DC opened is 2 pieces, DC 2 and DC 3.

Factory 1 only delivered products to DC 3 of 45,000 units, while factory 2 delivered products to DC 2 and DC 3 of 40,000 and 1,000 units, respectively. DC 2 delivers products to consumers 1, 2, and 4 of 30,000; 8,000; and 2,000 units, respectively. DC 3 delivered products to consumers 2, 3, and 5 in the amount of 15,000; 15,000; and 16,000 units, respectively. Direct delivery is only made by factory 1 to consumer 4 of 30,000 units.

The development of the model results in a total distribution cost that is cheaper than the initial model, with a difference of 692,000 or 6.74%. The additional scenario produces a solution that is almost similar between the initial model and the development model which allows direct delivery from the factory to the consumer. The only difference is how factory 1 sends products to consumers 4. In the initial model solution, factory 1 delivers 30,000 units of product to customer 4 via DC 4, while in the development model, direct shipments from factory 1 to customer 4 are 30,000 units.

In this numerical example, it would be seen that the difference in distribution costs of the two models of 692,000 is obtained from calculating the difference in distribution costs on the difference for the solutions of the two models. In the initial model solution, factory 1 deliver 30000 units of product to customer 4 via DC 4, so the distribution costs are distribution costs from factory 1 to DC 4 + distribution costs from DC 4 to customer 4 + fixed costs to open DC 4 = [(52 x 30,000) + (54 x 30,000) + 32,000] = 3,212,000.

In the development of the model, direct delivery from factory 1 to consumer 4 is 30,000 units, so the distribution costs are only distribution costs from factory 1 to consumer 4 of 84 x 30,000 = 2,520,000. The difference in distribution costs of the two models becomes 3,212,000 – 2,520,000 = 692,000. From this numerical example, it is hoped that it will be easy to see the difference between the two models.

Table 8. The final solution of the initial model for numerical example 2

	DC 1	DC 2	DC 3	DC 4
Factory 1	0	0	45,000	30,000
Factory 2	0	40,000	1,000	0

DC	Customer				
	1	2	3	4	5
DC 1	0	0	0	0	0
DC 2	30,000	8,000	0	2,000	0
DC 3	0	15,000	15,000	0	16,000
DC 4	0	0	0	30,000	0

Table 9. The final solution of the developed model for numerical example 2

	DC 1	DC 2	DC 3	DC 4
Factory 1	0	0	45,000	0
Factory 2	0	40,000	1,000	0

DC	Customer				
	1	2	3	4	5
DC 1	0	0	0	0	0
DC 2	30,000	8,000	0	2,000	0
DC 3	0	15,000	15,000	0	16,000
DC 4	0	0	0	0	0

Factory	Customer				
	1	2	3	4	5
Factory 1	0	0	0	30,000	0
Factory 2	0	0	0	0	0

Numerical example 3

Numerical example 3 still uses numerical example 1 above, by changing the transportation cost per unit from factory i to DC j and changing the transportation cost from factory i to customer k as shown in Table 10 and Table 11. Following the data provided, the initial model solves as could be seen in Table 12. The total distribution cost generated from this model is 7,529,000. The number of DC opened is 3 (DC 1, DC 2, and DC 3)

Factory 1 delivers products to DC 2 and 3 in the amount of 40,000 and 46,000 units, respectively, while factory 2 delivers products to DC 1 only in the amount of 30,000 units. DC 1 delivered 30,000 units of product to consumer 4, while DC 2 sent products to consumer 1, 2, and 4 of 30,000; 8,000; and 2,000 units, respectively. For DC 3, it sends products to consumers 2, 3, and 5 in the amount of 15,000; 15,000; and 16,000 units, respectively.

Table 10. Transportation cost per unit from factory i to DC j for numerical example 3

	DC 1	DC 2	DC 3	DC 4
Factory 1	50	46	30	32
Factory 2	40	50	44	46

Table 11. Transportation cost per unit from factory i to customer k for numerical example 3

Factory	Customer				
	1	2	3	4	5
Factory 1	80	110	105	74	90
Factory 2	100	114	120	96	78

Table 12. The final solution of the initial model for numerical example 3

	DC 1	DC 2	DC 3	DC 4
Factory 1	0	40,000	46,000	0
Factory 2	30,000	0	0	0

DC	Customer				
	1	2	3	4	5
DC 1	0	0	0	30,000	0
DC 2	30,000	8,000	0	2,000	0
DC 3	0	15,000	15,000	0	16,000
DC 4	0	0	0	0	0

Table 13. The final solution of the developed model for numerical example 3

	DC 1	DC 2	DC 3	DC 4
Factory 1	0	22,000	46,000	0
Factory 2	0	18,000	0	0

DC	Customer				
	1	2	3	4	5
DC 1	0	0	0	0	0
DC 2	30,000	0	0	10,000	0
DC 3	0	23,000	15,000	0	8,000
DC 4	0	0	0	0	0

Factory	Customer				
	1	2	3	4	5
Factory 1	0	0	0	22,000	0
Factory 2	0	0	0	0	8,000

The development of the model solves as could be seen in Table 13. The total distribution cost generated from this model is 7,546,000. The number of DC opened is 2 DC, DC 2, and DC 3. Factory 1 delivered 22,000 and 46,000 units of product to DC 2 and DC 3, respectively, while factory 2 only delivered 18,000 units of product to DC 2. DC 2 delivered 30,000 and 10,000 units of product to consumers 1 and 4, respectively. DC 3 delivered products to consumers 2, 3, and 5 in the amount of 23,000; 15,000; and 8,000 units, respectively. Direct shipments were made by factory 1 to consumer 4 of 22,000 units and by factory 2 to consumer 5 of 8,000 units. In this numerical example 3, the initial model produces a total distribution cost that is cheaper than the model development, with a difference of 17,000.

At this time, TSTP is still very much solved using the initial model. The model development carried out by allowing direct delivery from the factory to the consumer will certainly add options for management in determining an efficient strategy for a distribution problem.

IV. CONCLUSION

The calculation results in the numerical example above show that the development of a model that allows direct delivery from factory i to customers k could result in a lower total distribution cost than the initial model, which does not allow direct delivery.

The difference in distribution costs for the two models could be easily seen from numerical example 2. The consideration is which one is cheaper between distribution costs in the initial model and distribution costs in model development.

Distribution costs in the initial model are distribution costs from factory to DC + distribution costs DC to consumers + fixed costs to open DC, while distribution costs in model development are distribution costs from factories to consumers.

However, in other cases as in numerical example 3 shows that the initial model might produce a total distribution cost that is cheaper than the model development carried out. Therefore, it is hoped that this research can be used as a consideration in determining a distribution plan.

The direct delivery strategy from factory i to customer k is expected to be an option for management in conducting distribution network analysis and of course, it could be a consideration in determining the right distribution strategy for a product.

Further research could be carried out to develop the model, which considers multiple products due to the large number of companies that have several product variants in their distribution network.

REFERENCES

Aida, F. N., & Rahmanda, W. (2020). Analisis Biaya Transportasi Distribusi Pupuk Menggunakan Software Lingo. *Jurnal Rekayasa Sistem Industri*, *5*(2), 135. https://doi.org/10.33884/jrsi.v5i2.1930

Amiri, A. (2006). Designing a distribution network in a supply chain system: Formulation and efficient solution procedure. *European Journal of Operational Research*, *171*(2), 567–576. https://doi.org/10.1016/j.ejor.2004.09.018

Antony Arokia Durai Raj, K., & Rajendran, C. (2012). A genetic algorithm for solving the fixed-charge transportation model: Two-stage problem. *Computers and Operations Research*, *39*(9), 2016–2032. https://doi.org/10.1016/j.cor.2011.09.020

Calvete, H. I., Galé, C., & Iranzo, J. A. (2014). Planning of a decentralized distribution network using bilevel optimization. *Omega (United Kingdom)*, *49*, 30–41. https://doi.org/10.1016/j.omega.2014.05.004

Cosma, O., B, P. P., Oliviu, M., & Zelina, I. (2018). *A Hybrid Iterated Local Search for Solving a Particular Two-Stage Fixed-Charge Transportation Problem* (Vol. 1). Springer International Publishing. https://doi.org/10.1007/978-3-319-92639-1

Cosma, O., Danciulescu, D., & Pop, P. C. (2019). On the Two-Stage Transportation Problem with Fixed Charge for Opening the Distribution Centers. *IEEE Access*, *7*, 113684–113698. https://doi.org/10.1109/ACCESS.2019.2936095

Cosma, O., Pop, P. C., & Sabo, C. (2020). An efficient hybrid genetic approach for solving the two-stage supply chain network design problem with fixed costs. *Mathematics*, *8*(5). https://doi.org/10.3390/MATH8050712

Cosma, O., Pop, P. C., & Sitar, C. P. (2019). An efficient iterated local search heuristic algorithm for the two-stage fixed-charge transportation problem. *Carpathian Journal of Mathematics*, *35*(2), 153–164. https://doi.org/10.37193/cjm.2019.02.04

Cosma, O., Pop, P., & Zelina, I. (2020). An Efficient Soft Computing Approach for Solving the Two-Stage Transportation Problem with Fixed Costs. *Advances in Intelligent Systems and Computing*, *950*, 523–532. https://doi.org/10.1007/978-3-030-20055-8_50

Del R. Santibanez-Gonzalez, E., Mateus, G. R., & Luna, H. P. (2011). Solving a public sector sustainable supply chain problem: A genetic algorithm approach. *Proceedings of the 2011 International Conference on Artificial Intelligence, ICAI 2011*, *2*, 507–512.

Fatma, E., & Manurung, S. (2021). Optimasi Biaya Distribusi Multi-eselon untuk Multi-produk menggunakan Mix Integer Linier Programming Optimization of Multi-echelon Distribution Costs for Multi- products using Mix Integer Linear Programming. *Jurnal Manajemen Transportasi & Logistik*, *08*(01), 75–82.

Gen, M., Altiparmak, F., & Lin, L. (2006). A genetic algorithm for two-stage transportation problem using priority-based encoding. *OR Spectrum*, *28*(3), 337–354. https://doi.org/10.1007/s00291-005-0029-9

Hong, J., Diabat, A., Panicker, V. V., & Rajagopalan, S. (2018). A two-stage supply chain problem with fixed costs: An ant colony optimization approach. *International Journal of Production Economics*, *204*, 214–226. https://doi.org/10.1016/j.ijpe.2018.07.019

Jawahar, N., & Balaji, A. N. (2009). A genetic algorithm for the two-stage supply chain distribution problem associated with a fixed charge. In *European Journal of Operational Research* (Vol. 194, Issue 2). Elsevier B.V. https://doi.org/10.1016/j.ejor.2007.12.005

Jayaraman, V., & Pirkul, H. (2001). Planning and coordination of production and distribution facilities for multiple commodities. *European Journal of Operational Research*, *133*(2), 394–408. https://doi.org/10.1016/S0377-2217(00)00033-3

Marín, A. (2007). Lower bounds for the two-stage uncapacitated facility location problem. *European Journal of Operational Research*, *179*(3), 1126–1142. https://doi.org/10.1016/j.ejor.2005.04.052

Marín, A., & Pelegrín, B. (1997). A branch-and-bound algorithm for the transportation problem with location of p transshipment points. *Computers and Operations Research*, *24*(7), 659–678. https://doi.org/10.1016/S0305-0548(96)00078-0

Pirkul, H., & Jayaraman, V. (1998). a Multi-Commodity , Multi-Plant , Capacitated Facility Location Problem : Formulation and. *Computers and Operations Research*, *25*(10), 869–878.

Pop, P. C., Sabo, C., Biesinger, B., Hu, B., & Raidl, G. R. (2017). Solving the two-stage fixed-charge transportation problem with a hybrid genetic algorithm. *Carpathian Journal of Mathematics*, *33*(3), 364–370. https://doi.org/10.37193/cjm.2017.03.11

Pop, P., Matei, O., Sitar, C. P., & Zelina, I. (2016). A hybrid based genetic algorithm for solving a capacitated fixed-charge transportation problem. *Carpathian Journal of Mathematics*, *32*(2), 225–232. https://doi.org/10.37193/cjm.2016.02.10