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BLOCKCHAIN TECHNOLOGY AND MITIGATING BULLWHIP EFFECT IN SUPPLY CHAINS WITH UNCERTAIN MARKETS: A HORIZONTAL LAYER PRODUCT DISTRIBUTION STRATEGY

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Abstract. Product distribution in supply chain management has been hotly debated during the last decade. However, during COVID-19, many supply chains suffered from sudden changes in local market demands. Such changes cause a bullwhip effect throughout a supply chain, making it unable to respond rapidly. This research develops a new model for distributing products in the food chain using real urban and geographical data of blockchain technology. The aim is to re-adjust the product distribution plans by using a horizontal layer product distribution readjustment strategy while local markets confront sudden market changes. To address the problem, a heuristic was proposed and coded by Python based on the *largest density-distance* rule. Then, to evaluate the performance of the proposed method, the schedules are assessed with some metrics gathered in the literature. For this purpose, a Full Factorial design of experiments is generated by Python. Moreover, the outcomes are compared with those gained from short-traveling time and greedy loading-based heuristics. The results showed that using the horizontal layer product distribution readjustment strategy for modifying the initial schedules could prevent lost sales in all studied cases. Besides, by responding to sudden market demand changes rapidly, which subsequently prevents lost sales, more profits were gained in 58.3% of the studied cases. In addition, in 61.11% of studied cases, the proposed method was faster than other studied heuristics in terms of computational time.

Mathematics Subject Classification. 90-10.

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1. Introduction

The question of how to mitigate lost sales resulting from sudden changes in market demand is a significant concern within supply chain management. Fluctuations in product demand are commonplace in the market, yet they can occasionally inflict irreparable damage on supply chains. Consequently, the discussion surrounding the distribution of products in response to market changes has garnered considerable attention in recent literature [10, 38, 40]. Nonetheless, there remains a gap in this field. Traditionally, most product distribution problems have centered on delivery time [3, 24].

Keywords. Supply chain management, real-time scheduling, blockchain, product distribution, density-distance rule.

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During the last two decades, scientists focused on two main strategies to reduce the bullwhip effect during wavy market demands. The first is the adoption of emerging technologies such as the Internet of Things (IoT) has surged in recent years, contributing to more precise product distribution [25, 27]. However, there are still numerous factors continue to introduce uncertainty in distribution planning. in this regard, Delfani *et al.* [5] have demonstrated that employing fuzzy optimization can yield more robust results in product distribution by accounting for these uncertainties. Moreover, radio frequency identification (RFID) now plays a pivotal role in enhancing supply chain operations, thereby positively impacting overall performance [1].

On another front, leveraging chain information technologies like blockchain has shown promise in expediting and refining information transfer [31]. Yet, during sudden shifts in market demand that precipitate the bullwhip effect, the time interval and magnitude of demand fluctuations along the supply chain become critical. Consequently, this article endeavors to utilize horizontal blockchain within intermediary layers of the supply chain to recalibrate the distribution of goods, aiming to minimize the time spent within the supply chain amidst demand surges.

This research tries to answer the following question: how using a re-adjust product distribution plan could help prevent lost sales during rapid market demand changes? For this purpose, in this research, a new product dispatching and distribution method will be proposed that will focus on using the capacity of other distributors at the same horizontal level to fulfill the product shortages of any local market that encounters with a sudden increase in product demand.

The organization of the remainder of the research will proceed as the following: (i) a number of opted references ill be selected and reviewed to find out the challenges of market demand fluctuations and also drivers of effective planning to mitigate their adverse effects on a supply chain. (ii) in continuation the problem will be formulated as a mathematical programming method. (iii) Following that, a new method will be proposed to determining the best production distribution using the horizontal layer product distribution readjustment strategy. (iv) Finally, in Section 4.5, the proposed method will be verified using solving a number of case studies.

2. Literature review

2.1. Market demand uncertainty and bullwhip effect

Several items exist that can be considered as reasons for demand fluctuations in a market which cause the market demands to be uncertain [30, 45]. Regardless of its roots, market demand fluctuations can increase the market demand uncertainty [7, 23, 36], which consequently may yield to bullwhip effect [4, 9, 44]. Besides, manufacturing systems are uncertain in their nature as they are affected by many uncertain factors which increase the level of internal risks for them [4]. Phenomena such as machine failures, special sales orders, and similar items can be the main reasons for increasing uncertainty in supply chains [46].

Market uncertainty is paid attention to by offering three main strategies by scientists. While some tried to improve the product demand forecasting accuracy in their target markets [13, 18, 19, 35, 43]; others tried to find ways to respond to the customer's demand fluctuations rapidly [2, 42]. In addition, inventory management and deciding on optimal safety level is the third strategy generally used by supply chain owners to stay away from bullwhip adverse effects [28, 32, 37, 47].

There are also other ways that can be classified as subsidiary strategies to mitigate the chance of confronting with bullwhip effect in supply chains. Improving collaborations with retailers [16,33,47] and topology in designing supply chains are among these types of strategies [13]. Outsourcing is another strategy that is proposed to overcome capacity limitations when a supply chain is suddenly confronted with sudden changes in market demands [8, 39].

The bullwhip effect plays a domino in a supply chain and may cause disruptions throughout the supply chain, from supplier selection [11, 17] to product after-sale services [21]. Providing a practical framework for managers enables them to develop a sustainable supply chain by quantifying managers' risk perceptions and applying these perceptions to supply chain strategies (Sato *et al.* 2020). Figure 1 indicates the main causes and effects of supply chains.

Hemant *et al.* [12] provided directions for considering the most influencing enablers that can act as critical factors in the successful implementation of Collaborative Planning, Forecasting, and Replenishment (CPFR). Achieving better supply chain resilience capability plays an important mediating role between supply chain risks and resilience, while the relationships depend on the performance of seven mitigating strategies. For this purpose, Um and Han [39] explored the relationships between global supply chain risks, supply chain resilience, and mitigating strategies. Proposing a framework for managing pharmaceutical supply chain uncertainty and risk [41] showed that supply chain integration capability is an effective risk management tool for mitigating supply chain uncertainty and risk. Transportation and logistics are two vital sectors that can be effectively used in preventing the bullwhip effect in supply chains. During the last few years, many research projects have been carried out to enhance the performance of transportation systems [20, 29]. Although many references proposed methods to overcome the bullwhip effect by improving transportation planning [2,26]; however, product dispatching re-adjustment has not been developed yet. As a result, in the following section, a new method will be proposed to mitigate the adverse impact of bullwhip effect using product distribution readjustment strategy.

2.2. Novelties and contribution of the research

To answer the aforementioned questions, this research will propose a new strategy called the horizontal layer product distribution readjustment strategy that can switch the vertical bullwhip effect into the horizontal bullwhip effect to respond rapidly to market demand changes. In order to make the results more realistic, a mathematical model will be developed using real geographical data and population factors. Malaysia will be considered as the place to conduct the research.

3. Materials and methods

In this research, a 3-phase framework will be proposed to mitigate the bullwhip effect in supply chains using a new method. The framework consisted of 3 phases and works based on data analytics, modeling, and a heuristic. Figure 2 shows the flowchart of the research methodology. In the initial phase, a field study will be used to gather customer factors information. Then, different areas of the country will be considered on the map of the country (Malaysia) according to the customers and geographical information (Phase 1). In continuation, a mathematical model will be developed using the geographical model and customer information (Phase 2). Then in Phase 3, a new method will be proposed for mitigating the bullwhip effect in supply chains with uncertain markets and coded with a new heuristic that works based on the horizontal layer product distribution readjustment strategy (Phase 3).

In continuation, each of the steps will be explained in detail.

3.1. Customer and geographical analysis (Phase 1)

3.1.1. Identify influential market factors in product distribution in a supply chain

As the beginning step, finding the factors influencing food distribution in a food supply chain is necessary. These factors will then be used for developing the heuristic for product distribution based on the market needs.

Features can be extracted using the following sources:

1. Literature review
2. Interview with the experts

The literature review indicated that the following features are significant in the food delivery pattern.

In addition, several university experts and also experts in the industry were interviewed. It is tried to use a wide range of experts to make us consider the features as much as possible. Figure 3 indicates the factors influencing chocolate distribution in Malaysia.

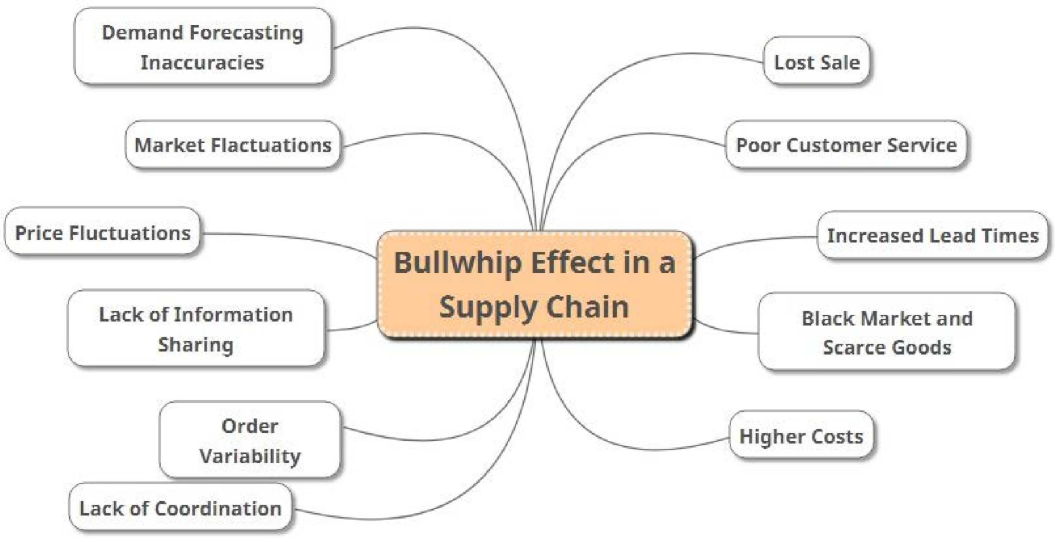

FIGURE 1. Main causes and effects of supply chains.

TABLE 1. The population and distance data of capital cities in the states and federal territories of Malaysia.

Row	State	Capital	Distance	Population
1	Selangor	Shah Alam	23.58	6569500
2	Sabah	Kota Kinabalu	1621.98	3907500
3	Johor	Johor Bahru	295.61	3776600
4	Sarawak	Kuching	974.49	2828700
5	Perak	Ipoh	175.51	2518600
6	Kedah	Alor Setar	362	2193900
7	Kelantan	Kota Bharu	334.61	1904900
8	Penang	George Town	293.45	1783600
9	WP Kuala Lumpur	Kuala Lumpur	0	1773900
10	Pahang	Kuantan	194.57	1682200
11	Terengganu	Kuala Terengganu	287.5	1259000
12	Negeri Sembilan	Seremban	54.51	1135900
13	Melaka	Malacca City	121.36	936900
14	Perlis	Kangar	402.38	255000
15	W.P. Labuan	W.P. Labuan	1518.56	99600
Total Population				32,625,800

– *Statistical Population and Data Gathering.* In order to collect sufficient information from the society, the number of responders in the statistical society must be determined using the Cochran formula for limited communities will be used to determine the sample size, which is as follows [34]:

$$n = \frac{z_{\frac{\alpha}{2}}^2 \cdot p \cdot q + e^2}{\frac{Z_{\frac{\alpha}{2}}^2 \cdot p \cdot q}{N} + e^2} = \frac{(1.96)^2 \cdot (0.5) \cdot (0.5) + (0.05)^2}{\frac{(1.96)^2 \cdot (0.5) \cdot (0.5)}{4{,}587{,}000} + (0.05)^2} = 169.06 \cong 170 \tag{1}$$

TABLE 2. Sorted states and federal territories of Malaysia based on population.

Row	State	Capital	Distance	Population	Geographical location
5	Perak	Ipoh	175.51	2518600	North (West Malaysia)
6	Kedah	Alor Setar	362	2193900	North (West Malaysia)
7	Kelantan	Kota Bharu	334.61	1904900	North (West Malaysia)
14	Perlis	Kangar	402.38	255000	North (West Malaysia)
8	Penang	George Town	293.45	1783600	Right (West Malaysia)
11	Terengganu	Kuala Terengganu	287.5	1259000	Right (West Malaysia)
1	Selangor	Shah Alam	23.58	6569500	Mid (West Malaysia)
9	W.P. KualaLumpur	Kuala Lumpur	0	1773900	Mid (West Malaysia)
10	Pahang	Kuantan	194.57	1682200	Mid (West Malaysia)
12	Negeri Sembilan	Seremban	54.51	1135900	Mid (West Malaysia)
13	Melaka	Malacca City	121.36	936900	South (West Malaysia)
3	Johor	Johor Bahru	295.61	3776600	South (West Malaysia)
2	Sabah	Kota Kinabalu	1621.98	3907500	East Malaysia
4	Sarawak	Kuching	974.49	2828700	East Malaysia
15	W.P. Labuan	W.P. Labuan	1518.56	99600	East Malaysia

here, N is the size of the total number of people in the market in Malaysia. P is the portion of that desire to use the Chocolate (whether people desire to use Chocolate or not); n is the size of the statistical society; e is the tolerable error (0.05) and z is the standard value of the normal distribution.

In order to gather the required data, the following steps have been carried out:

Data in the verified websites: the information about destinations of cities, populations, age, gender, possible transportation system, and diabetes rate can be gathered from verified websites such as governmental or university websites.

Questionnaire: according to equation (1), the questionnaire will be distributed to 170 customers. Some information such as taste, health awareness, education, and brand popularity is asked. This information helps the sales department anticipate the product demand in each area.

3.1.2. Geographical information analysis

In this research, a food supply chain that produces various types of chocolates is considered. The company contains its main manufacturing plant, which is located in Kuala Lumpur, the capital of Malaysia, and 5 main wholesalers on the left island (also known as a West Malaysia that includes WP Kuala Lumpur, Selangor, Pahang, Negeri Sembilan, Melaka, Johor, Perak, Kelantan, Penang, Terengganu, Perlis, and Kedah) and right island (also known as an East Malaysia that includes Sabah, Sarawak, and WP Labuan) of Malaysia as shown in Figure 4.

The population data for Malaysians based on states and federal territories will be utilized as the data in this section. The population data was taken from the Statistics webpage. Additionally, data on travel distances between state capital cities is taken from the distance calculator website. All distances are measured from Kuala Lumpur, the place where the main factory is located (Tab. 1).

The top managers of the supply chain divided the country into four main areas according to the geographical distribution of population, namely the north, middle, right, and south areas of the Western Malaysia Island as well as the Eastern Malaysia Island, where each of the four main areas has the main wholesaler. Table 2 indicates the areas and states inside each.

Figures 5 and 6 indicate the designed supply chain on the map. This map will be used for mathematical modeling.

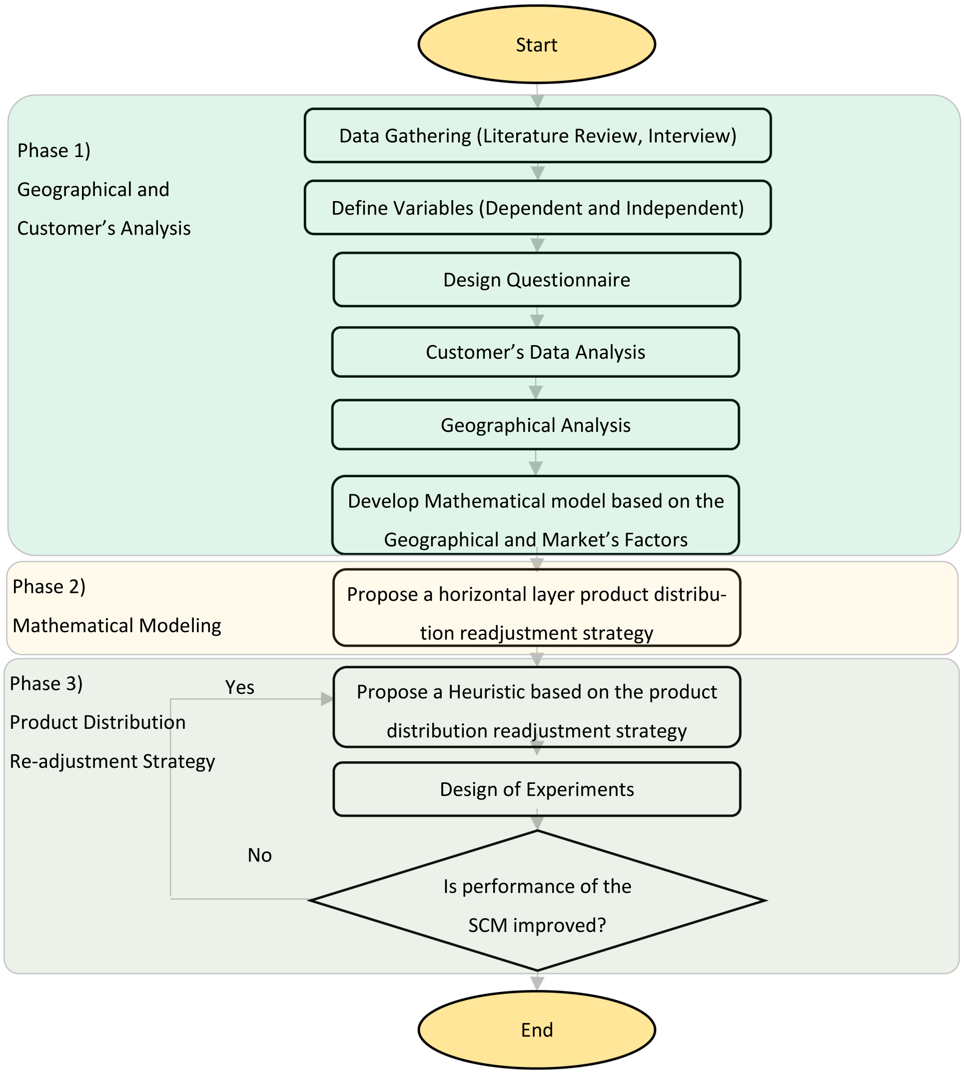

FIGURE 2. Flowchart of the research methodology.

3.2. A new non-linear integer programming model for scheduling product distribution in the designed supply chain (Phase 2)

In this section, a new mathematical model will be developed based on the customer's demand and determined geographical areas. The aim is to determine the best product scheduling for each market, while the objective is to maximize the profit of the supply chain. For this purpose, a three layers supply chain model will be developed. In order to get the best production plan, a nonlinear integer programming model will be developed. The model will then (next section) be solved by Scipy optimization in Python.

3.2.1. Model assumptions

In order to make a practical model that is formulated based on the geographical and population facts and also availabilities of the studied supply chain, a number of assumptions will be considered as follows:

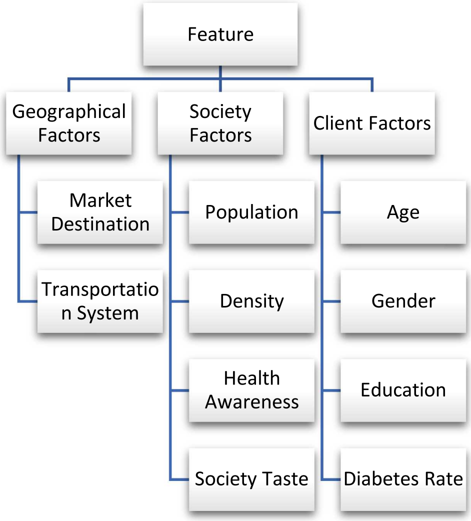

FIGURE 3. Independent factors that can influence food delivery in an area.

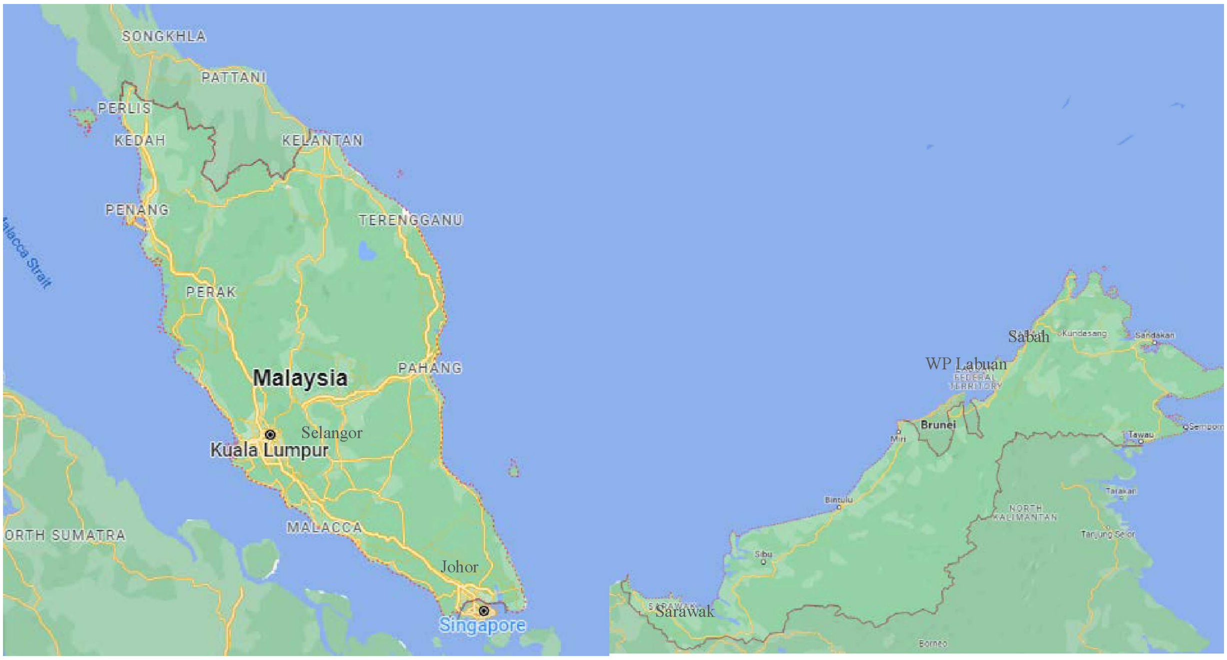

FIGURE 4. Map of Malaysia (West and East Islands).

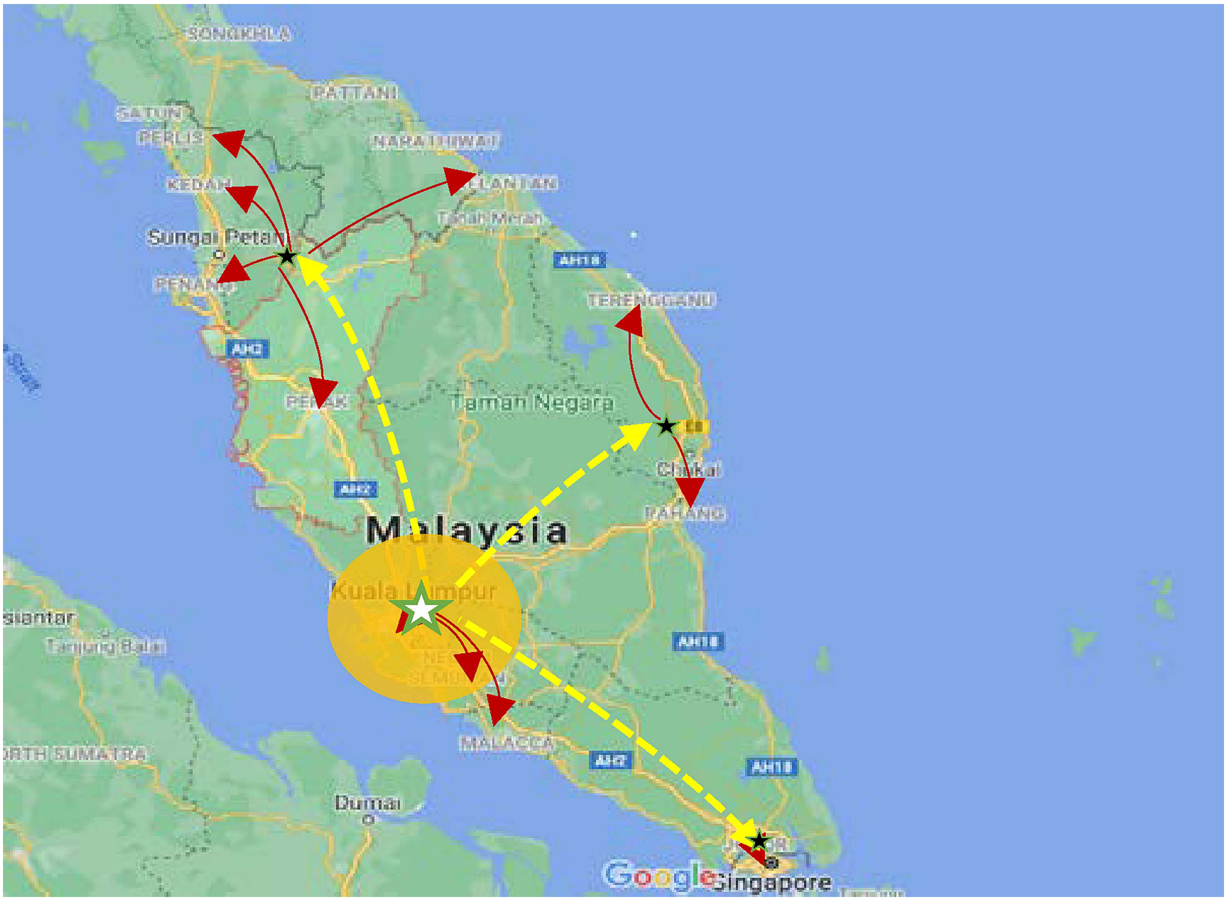

FIGURE 5. The designed supply chain, including the main factory and wholesaler center points for each region in the West Island of Malaysia Mad Ali *et al.* [22].

1- Malaysia is a country with two main islands which are separated by part of the South China Sea. As a result, in order to design supply chain networks, Malaysia will be considered as west and east islands where the west island will be divided into 4 main areas (as shown in Tab. 2). Each of the areas should have at least one wholesaler.
2- The inventory at the first scheduling period is considered zero.
3- Each retailer has specific demand that is forecasted in advance and will be considered as input of the model.
4- The state of unsatisfied demands during a period is *lost sales* which will be happened if end users purchase another chocolate brand because they cannot find the brand of the studied supply chain. Using the proposed heuristic in this research, the lost sale should be zero.
5- The transportation system of the studied supply chain contains heavy trucks (10 tons) that are usually used for farther distances (transporting products from the main factory to the wholesalers) and light trucks (5 tons) that are mostly used for shorter distances (distributing products from wholesalers to retailers).

3.2.2. Indexes

- i: $Number\ of\ Products$
- j: $Wholesaler\ Counter$
- k: $Retailer\ Counter$

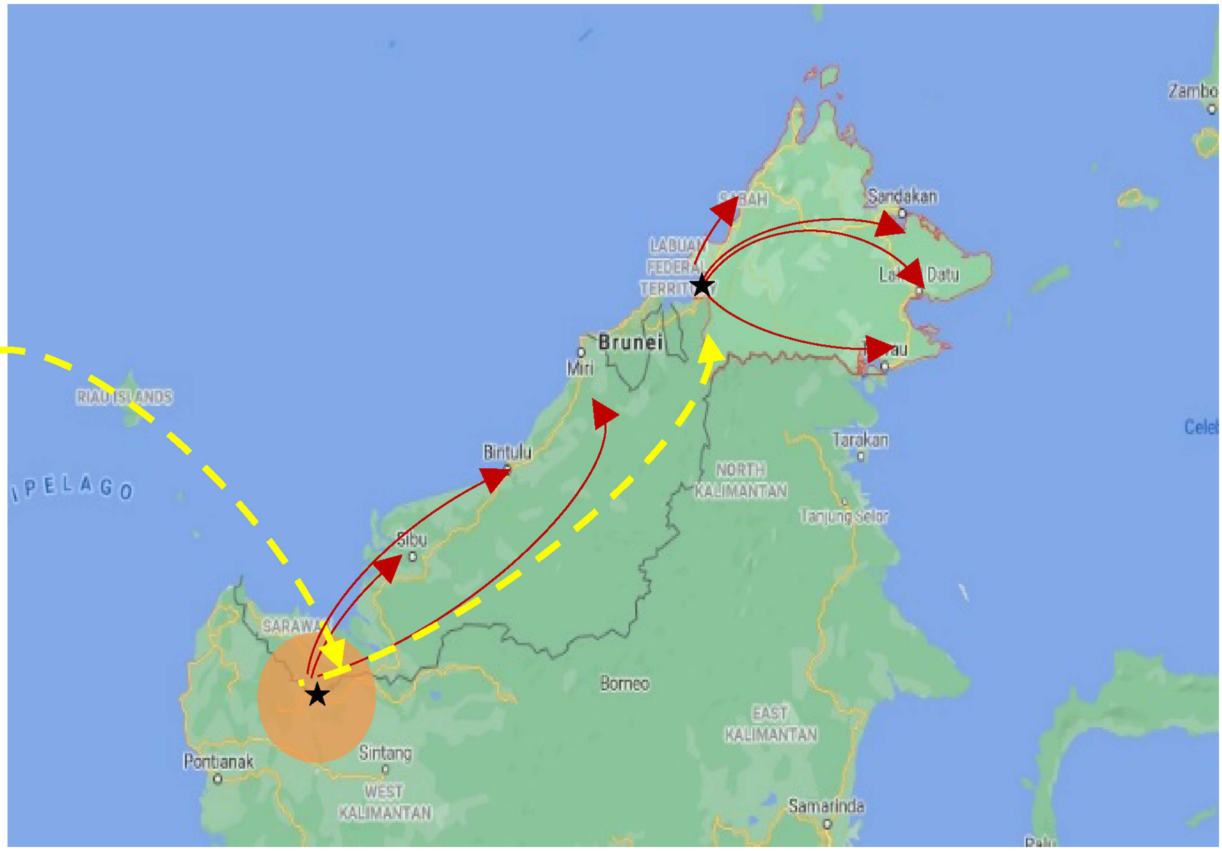

FIGURE 6. The designed supply chain, including the main factory and wholesaler center points for each region in the East Island of Malaysia Mad Ali *et al.* [22].

- s: *Region Counter*
- e: *Truck type counter*
- t: *Production Period*

3.2.3. Parameters

- $d_{i,t,k} = Demand\ of\ product\ type\ i\ that\ is\ requested\ by\ retailor\ k\ in\ period\ t$
- $C = Capacity\ of\ the\ factory\ in\ producing\ chocklate\ (per\ gram)\ in\ each\ period$
- $P_i = Profit\ of\ selling\ one\ product\ type\ i$
- $LW_j = whether\ the\ wholsaler\ j\ is\ located\ in\ the\ West\ Malaysia\ (Binary\ Matrix)$
- $RW_j = whether\ the\ wholsaler\ j\ is\ located\ in\ the\ East\ Malaysia\ (Binary\ Matrix)$
- $F_j = Distance\ of\ wholesaler\ s\ in\ the\ left\ from\ the\ Main\ Factory\ Per\ KM$
- $F_j^{'} = Distance\ of\ wholesaler\ s\ in\ the\ right\ island\ from\ the\ Kuching\ Port\ Per\ KM$
- $M_{k,j} = Distance\ of\ retailer\ k\ from\ the\ wholesaler\ j\ per\ KM$
- $L = Fixed\ distance\ for\ ship\ travel\ across\ ocean\ to\ transfer\ products\ from\ West\ Malaysia\ to\ West\ Malaysia\ (From\ Kuala\ Lumpur\ to\ Kuching)$
- $FL = cost\ of\ transferring\ one\ unit\ of\ product\ by\ ship\ for\ each\ KM$
- $N_{j,k} = whether\ Wholesaler\ j\ can\ send\ product\ to\ retiler\ k\ (a\ binary\ matrix)$
- $Cap_e = capacity\ of\ each\ truck\ type\ e$

- $QRL_o = Initial\ Number\ of\ 5\ ton\ trucks\ in\ the\ West\ Malaysia\ at\ the\ begining$
- $QRR_o = Initial\ Number\ of\ 5\ ton\ trucks\ in\ the\ East\ Malaysia\ at\ the\ begining$
- $QWL_o = Initial\ Number\ of\ 10\ ton\ trucks\ in\ the\ West\ Malaysia\ at\ the\ begining$
- $QWR_o = Initial\ Number\ of\ 10\ ton\ trucks\ in\ the\ East\ Malaysia\ at\ the\ begining$
- $WP_i = Weight\ of\ each\ product\ type\ i\ per\ gram$
- $TC = Transferring\ cost\ for\ each\ Kilometer$
- $FC = Fixed\ transfer\ cost\ for\ each\ travel\ of\ a\ truck$
- $CR_1 = Cost\ of\ renting\ a\ 5\ ton\ truck\ per\ travel$
- $CR_2 = Cost\ of\ renting\ a\ 10\ ton\ truck\ per\ travel$

3.2.4. Variables

- $X_{i,k,t} = Number\ of\ products\ of\ type\ i\ that\ is\ received\ by\ retailer\ k\ during\ period\ t\ (Integer)$
- $Y_{i,s,t} = Number\ of\ products\ of\ type\ i\ that\ is\ received\ by\ wholsaler\ s\ during\ period\ t\ (Integer)$
- $LS_{i,s,t} = Number\ of\ lost\ sale\ products\ of\ type\ i\ in\ market\ s\ in\ period\ t\ (Integer)$
- $QRL_{j,t} = Number\ of\ 5\ ton\ trucks\ required\ for\ distributing\ products\ fromthe\ wholesaler\ j\ to\ all\ retailers\ in\ West\ Malaysia\ in\ period\ t\ (Integer)$
- $QRR_{j,t} = Number\ of\ 5\ ton\ trucks\ required\ for\ distributing\ products\ from\ the\ wholesaler\ j\ to\ all\ retailers\ in\ East\ Malaysia\ in\ period\ t\ (Integer)$
- $QWL_{j,t} = Number\ of\ 10\ ton\ trucks\ required\ for\ distributing\ products\ from\ factory\ to\ the\ wholesaler\ j\ in\ West\ Malaysia\ in\ period\ t\ (Integer)$
- $QWR_{j,t} = Number\ of\ 10\ ton\ trucks\ required\ for\ distributing\ products\ from\ factory\ to\ the\ wholesaler\ j\ in\ East\ Malaysia\ in\ period\ t\ (Integer)$
- $RL_t = Number\ of\ rented\ 5\ ton\ trucks\ for\ the\ West\ Malaysia\ during\ period\ t\ (Integer)$
- $RR_t = Number\ of\ rented\ 5\ ton\ trucks\ for\ the\ East\ Malaysia\ during\ period\ t\ (Integer)$
- $WRL_t = Number\ of\ rented\ 10\ ton\ trucks\ for\ the\text{West}\ Malaysia\ during\ period\ t\ (Integer)$
- $WRR_t = Number\ of\ rented\ 10\ ton\ trucks\ for\ the\ East\ Malaysia\ during\ period\ t\ (Integer$

3.2.5. Mathematical model

$$
\begin{aligned}
&Maximize\ Z\colon \left(\sum_t^T \sum_i^I \sum_k^K P_i \cdot X_{i,k,t}\right) - \left(\sum_t^T \sum_j^J (TC \cdot F_j + FC) \cdot \left[QRL_{j,t} + RL_t\right] \cdot LW_j\right) \qquad (2)\\
&- \left(\sum_t^T \sum_i^I \sum_{k \in RW_k}^K (\mathrm{WP_i} \cdot X_{i,k,t}) \cdot L \cdot FL + \sum_t^T \sum_j^J \left(TC \cdot F_j' + FC\right) \cdot \left[QRR_{j,t} + RR_t\right] \cdot RW_j\right)\\
&- \left(\sum_t^T \sum_j^J \sum_k^K (TC \cdot M_{k,j} + FC) \cdot \left[QWL_{j,t} + WRL_t\right] \cdot N_{j,k}\right)\\
&- \left(\sum_t^T \sum_j^J \sum_k^K (TC \cdot M_{k,j} + FC) \cdot \left[QWR_{j,t} + WRR_t\right] \cdot N_{j,k}\right)\\
&- \left(\sum_t^T CR_1 \cdot [RR_t + RL_t]\right) - \left(\sum_t^T CR_2 \cdot [WRL_t + WRR_t]\right)\\
&S.t:
\end{aligned}
$$

$$X_{i,k,t} \leq d_{i,t,k}; \quad \forall t,i,k \tag{3}$$

$$\sum_{s}^{S} Y_{i,s,t} \leq \sum_{k}^{K} d_{i,t,k}; \quad \forall i,t \tag{4}$$

$$\sum_{k}^{K} X_{i,k,t} \leq Y_{i,s,t}; \quad \forall t,i,s \tag{5}$$

$$\sum_{i}^{I} \sum_{s}^{S} Y_{i,s,t} \leq C; \quad \forall t \tag{6}$$

$$LS_{i,s,t} = \sum_{k}^{K} (d_{i,t,k} - X_{i,k,t}); \quad \forall t,s,i \tag{7}$$

$$QRL_{k,t} = \frac{\sum_{i}^{I} (WP_i \cdot X_{i,k,t} \cdot LW_j)}{Cap_e}; \quad \forall t,k,e = 1 \tag{8}$$

$$QRR_{k,t} = \frac{\sum_{i}^{I} (WP_i \cdot X_{i,k,t} \cdot RW_j)}{Cap_e}; \quad \forall t,k,e = 1 \tag{9}$$

$$QWL_{k,t} = \frac{\sum_{i}^{I} (WP_i \cdot Y_{i,s,t} \cdot N_{j,k})}{Cap_e}; \quad \forall t,k,e = 2 \tag{10}$$

$$QWR_{k,t} = \frac{\sum_{i}^{I} (WP_i \cdot Y_{i,s,t} \cdot N_{j,k})}{Cap_e}; \quad \forall t,k,e = 2 \tag{11}$$

$$RL_t = \sum_{k}^{K} (QRL_{k,t} - QRL_o); \quad \forall t \tag{12}$$

$$RR_t = \sum_{k}^{K} (QRR_{R,t} - QRR_o); \quad \forall t \tag{13}$$

$$WRL_t = \sum_{k}^{K} (QWL_{k,t} - QWL_o); \quad \forall t \tag{14}$$

$$WRR_t = \sum_{k}^{K} (QWR_{R,t} - QWR_o); \quad \forall t \tag{15}$$

$$X_{i,k,t}; Y_{i,s,t}; LS_{i,s,t}; QRL_{j,t}; QRR_{j,t}; QWL_{j,t}; QRL_{j,t}; RL_t; RR_t; WRL_t; WRR_t : Integer \tag{16}$$

The objective function's first mathematical expression shows the profit the designed supply chain can get by selling various product types in different markets. The next expression shows the transportation cost from the main factory to the designed wholesalers on the West Malaysia of the country. The next expression calculates the transportation cost from the main factory to Sarawak Port in the East Malaysia (the first part of the expression) and then product distribution to the wholesalers' centers according to their needs (the second part of the mathematical expression). The third expression indicates the transporting cost of the products from their wholesalers' center point to the related retailers. Since there is only one wholesaler located in each region, that wholesaler is responsible for covering all retailers in the region. For this purpose, the $N_{j,k}$ matrix is used to show that verified retailers receive products from a regional wholesaler. The fourth expression calculates the fees of renting trucks for using external transportation services in a period if required.

The first set of constraints ensures that each retailer will receive the products based on its demand (Eq. 3). The second series of constraints are set to show that the amount of all products distributed to the different retailers will not exceed the company's capacity (Eq. 4). The third set of constraints can calculate the amount of the lost sale of each product type if any. The fourth and fifth series of constraints are used to determine the number of trucks required for the wholesalers in the West and East Malaysia in a period, respectively (Eqs. 7 and 8). The 6th and seventh series of constraints are used to determine the number of external trucks required to be rented for West and East Malaysia in a period (Eqs. 14 and 15). The last series of constraints are used to show the domain of the variables (Eq. 16).

3.3. Reasons to choose a heuristic method to solve the developed model

After developing the mathematical model for distributing the products in the designed supply chain, a solving method must be proposed. Generally, optimizing methods are used for solving a mathematical model. However, while a model is too complex, optimizing methods are not capable of solving it. In such conditions, the optimizing solving methods must be replaced with heuristics and meta-heuristics.

Several reasons exist for the developed mathematical model to be considered as an Np-hard model and use a heuristic algorithm for it:

1- In the model, several nonlinear constraints are available. Such non-linearity in constraints causes the model to be too complex to be solved by solvers [6, 14, 15].
2- The method that is used by Delgoshaei *et al.* [8] for calculating several feasible and non-feasible essential solutions in a linear mathematical model shows that by increasing the dimension of the model, its complexity of will increase drastically. It means that for medium and large-scale problems, the number of basic solutions will be so high that it would be too time-consuming for an optimizer to solve the model (Tab. A.1, Appendix).

Therefore, it is better to use a heuristic method than a classic optimizer. As a result, a new heuristic will be designed in the next section using Python for the developed model.

4. A horizontal layer product distribution readjustment strategy for mitigating bullwhip effect in supply chains with uncertain markets (Phase 3)

In this section, the proposed Horizontal Layer Product Distribution Readjustment Strategy for mitigating the bullwhip effect in supply chains will be explained in detail. To clarify the proposed method, Figure 7 is provided which indicates the schematic graphical view of the supply chain. Based on this figure, products will be distributed from a main manufacturing plant to the wholesalers and then to the retailers accordingly. A horizontal layer product distribution readjustment is a product exchange between wholesalers (as the 2nd level of the supply chain) or between retailers (as the 3rd level of the supply chain) while confronting a sudden market demand increase. Using this strategy, a retailer will receive products from other retailers located in the same or the nearest market (county or state) with extra products. While all retailers in a market face the same sudden increase in market demands, the product exchange between wholesalers might be applied. Such a strategy will

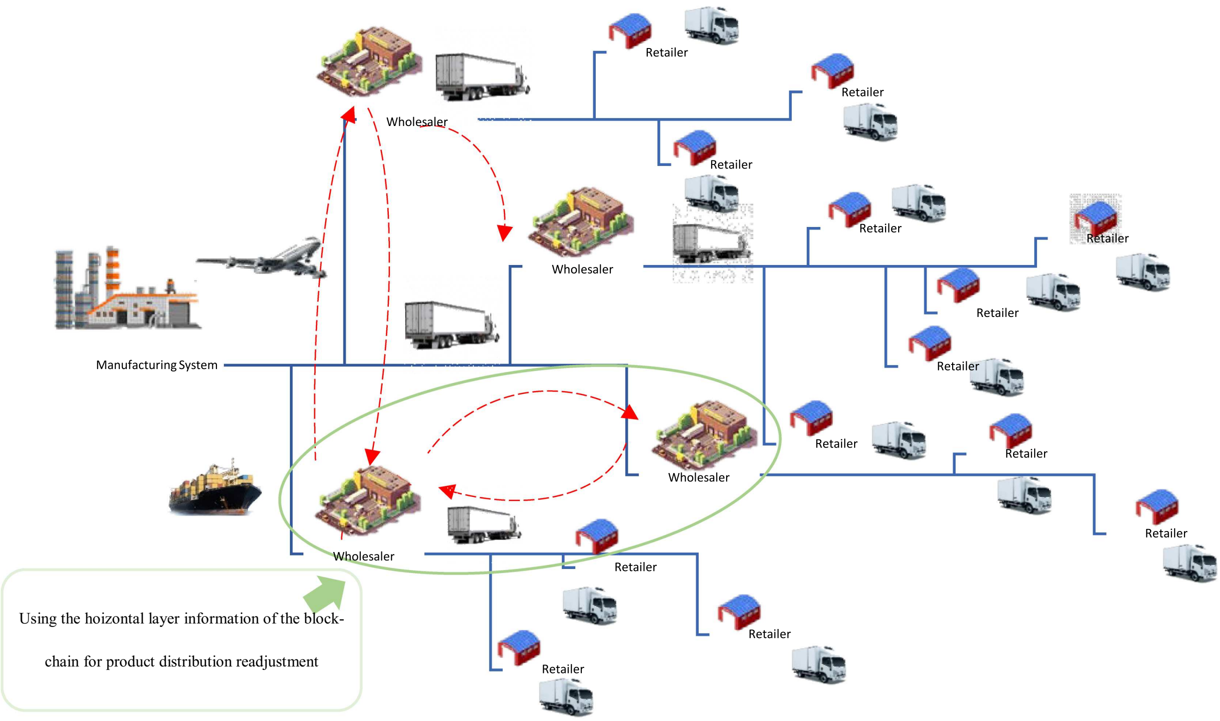

FIGURE 7. Graphical view of the using the horizontal layer information of the blockchain technology for the Product distribution readjustment.

prevent the bullwhip effect throughout the supply chain. For this purpose, using the information on geographical and urban factors that are presented in Figure 3, a new Nonlinear mixed integer programming model will be developed. The aim is to maximize profit where horizontal layer readjustment is applied. A heuristic will then be proposed to solve the model.

The benefits of using the proposed method in this research will be as follow:

- To modify the product distribution schedules based on sudden market changes
- To smoothen the bullwhip effect of market changes using horizontal layer product distribution readjustment
- To schedule product distribution using real geographical and urban features

4.1. Python

This research used Python to code the proposed coding solution algorithm.

Python is one of the most frequently used software with a powerful engine for calculating mathematical equations and models.

Python has many applications. Jupyter is a handy platform for coding algorithms, as each line of scripts can be executed separately, and the results can be seen.

4.2. Libraries to be used by Python

- import NumPy as np: To perform mathematical functions including arrays, linear algebra, and metrics.
- from scipy.optimize import minimize: To perform optimization functions.
- import math: Access to the mathematical functions specified by the C standard is provided by this module.
- import time: To calculate the solving time.

– import matplotlib.pyplot as plt: To draw bar charts and trend lines.

4.3. The engine of the proposed heuristic

The products will be delivered to the retailers based on their profit and size in the proposed heuristic. With this strategy, those products that have more profit will be planned to send first. This procedure will be continued until all products are transported, or the capacity of the main manufacturer is full.

X = min (demand of the retailer and remaining capacity of the main factory)

$$X_{i,k,t} = \min\left(d_{i,k,t} - \left[C - \sum_{k=1}^{k-1} X_{i,k,t}\right]\right) \quad \forall i,t. \tag{17}$$

If a retailer cannot receive the required amount of products, it will be considered a lost sale:

$$LS_{i,k,t} = d_{i,k,t} - X_{i,k,t}; \quad \forall i,t. \tag{18}$$

Then, the values for the products that must be transported from the main factory to the wholesaler's center points will be calculated:

$$Y_{i,s,t} = \min\left(\sum_{i=1}^{I}\sum_{k=1}^{k} X_{i,k,t}\right) \quad \forall s,t. \tag{19}$$

The transportation process from the main factory to the wholesalers' center points and then to the retailers will be done according to the capacity of the trucks:

$$\text{Number of the required trucks for a wholesaler} = \sum_{i=1}^{I}\sum_{k=1}^{k} X_{i,k,t} \cdot WS_i/Cap(2) \tag{20}$$

$$\text{Number of the required trucks for a wholesaler} = \sum_{i=1}^{I} X_{i,k,t} \cdot WS_i/Cap(1). \tag{21}$$

4.4. Verifying and validating the solution algorithm

In order to verify the performance of the proposed solution algorithm in stage 4 of the proposed framework, the following steps will be carried out sequentially:

1. The proposed solving heuristic method will be applied to several experiments designed by the Taguchi method (DOE).
2. The outcomes experiments solved by the proposed heuristic algorithm in the previous step are then measured by some indicators such as Solving Time and Lost Sale Rate.
3. The outcomes of the experiments solved by the proposed heuristic algorithm are then compared with two other heuristic algorithms.

4.4.1. Processing machine

In this research, a personal Laptop with the following information is used:

– CPU: Intel Core i7
– VGA: 4 GB
– RAM: 8 GB
– Windows: 10 Enterprise

4.4.2. Results of using the proposed heuristic for the designed supply chain

In this section, the proposed method is used for scheduling the supply chain for 2 periods. After solving the problem for the designed supply chain, the following results are gained:

Y= [[[349 385 161 71 286 413]
[320 366 192 83 331 359]
[356 355 138 74 292 336]
[300 422 165 88 337 372]]

[[289 357 164 78 304 369]
[326 356 169 75 279 343]
[300 387 132 96 288 407]
[307 340 170 76 297 353]]]

X = [[[91 97 63 98 72 59 85 91 78 83 78 71 87 50 86 63 77 97 92 56 91]
[94 56 93 77 95 99 55 58 59 95 97 83 100 79 61 91 74 59 67 83 76]
[77 81 99 99 75 51 58 91 80 78 60 74 71 76 79 66 68 71 70 75 52]
[50 80 82 88 88 92 79 91 72 100 65 88 89 68 83 97 67 88 54 98 65]]

[[69 60 82 78 59 83 72 92 51 89 75 78 77 75 98 54 57 93 59 79 81]
[92 57 78 99 64 84 55 75 78 99 70 75 64 54 86 75 76 84 53 57 73]
[82 63 85 70 64 69 74 87 93 80 52 96 53 54 97 84 95 99 81 56 76]
[99 90 63 55 65 54 94 70 57 75 95 76 89 87 52 69 59 84 72 84 54]]]

LS [[[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0], [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]]]
QRL = [[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1], [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]]
QWL [[1 1 1 1 1 1], [1 1 1 1 1 1]]

The following matrixes show the required light and heavy trucks in each period's West and East Malaysia. For example, the required 10-ton truck for the West Malaysia in period 1 is 3.

WRL = [3. 3.]

For example, the required 10-ton truck for the East Malaysia in period 0 is 1.

WRR = [1. 1.]

For example, the required 5-ton truck for the West Malaysia in period 1 is 10.

WRR = [10. 10.]

For example, the required 5-ton truck for the East Malaysia in period 1 is 6.

WRR = [6. 6.]

The objective function, which shows the profit of the designed supply chain after decreasing the transportation system, will be as follows:

OFV $[2.08170e+05 - 2.52654e+03 - 5.91000e+03 - 5.60000e+01]$
Sum OFV = 199677.46.

In the above matrix, the first array shows the profit of selling products; the second array shows the transferring cost from the main factory to the wholesalers along with the shipping cost across the sea (for the wholesalers on the East Malaysia), the third array shows the transferring costs from each wholesaler to the retailer and the fourth array shows the truck rental fees.

The algorithm was capable of solving the model in less than 1.5 s.

— 1.417 s —

Figures 8 and 9 show the volume of products distributed to the wholesalers, respectively.

Figure 10 compares the number of product demands, distributed products, and lost sales for each retailer for product 1 in the production periods.

Figure 10 shows that by using the proposed method, the amount of sudden changes in each of the local markets have been supplied by other neighbor distributors in the same layer, and therefore the lost demand has not been observed in any of the two periods.

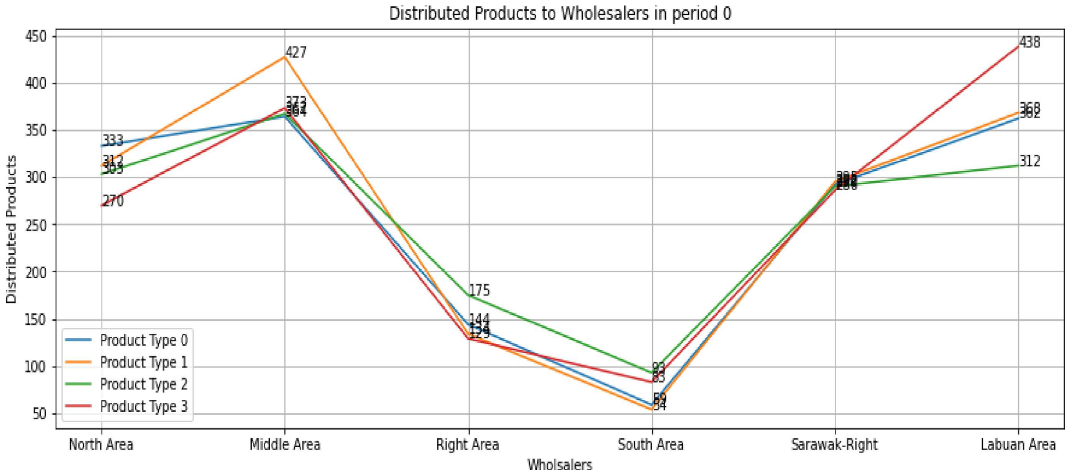

FIGURE 8. Distributed products to wholesalers in Period 0.

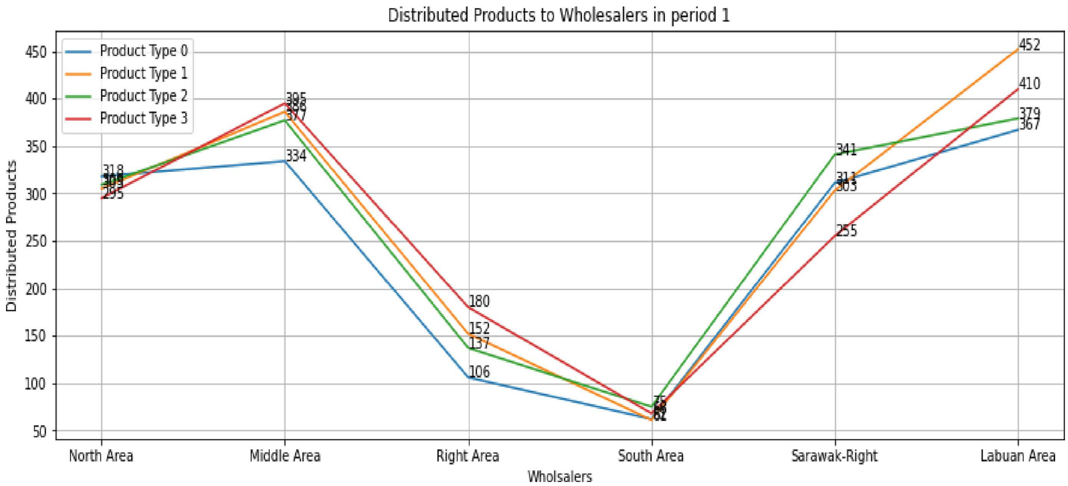

FIGURE 9. Distributed products to wholesalers in Period 1.

4.4.3. Solving case studies

After proposing the heuristic method, the method's performance must be evaluated. For this purpose, the method should be examined in various conditions. For this purpose, several experiments will be designed on small, medium, and large scales. A full factorial method is used using the pyDOE2 library in Python.

In a full factorial design, several factors will be entered. Then for each factor, several levels will be considered. Consequently, the m^n case studies will be designed by a full factorial method.

Libraries required for the Design of Experiments

- import numpy as np
- import pandas as pd
- import pyDOE
- import pyDOE2
- import diversipy

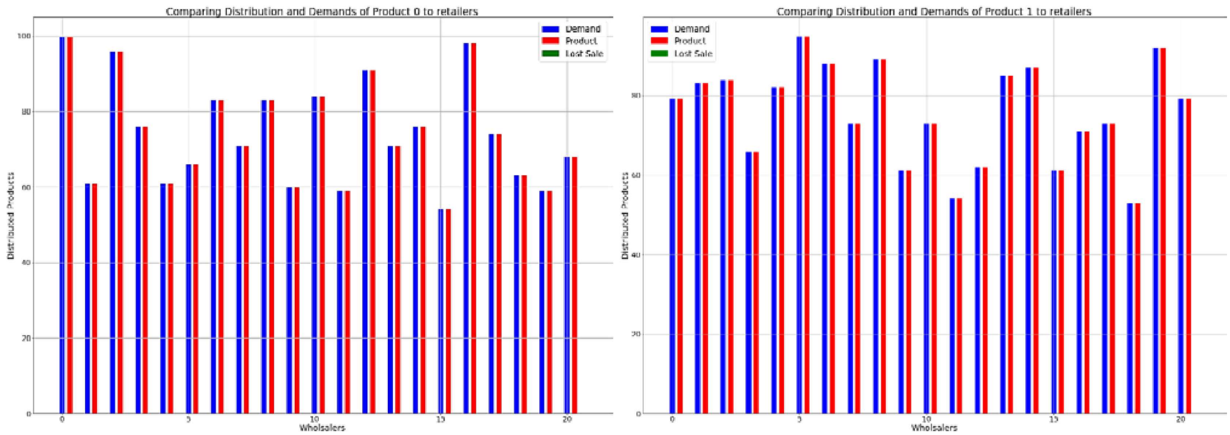

FIGURE 10. Comparing distribution and demands of the first product to retailers in Periods 1 and 2.

– from doepy import build

In this research, the number of products, retailers, and light and heavy trucks will be considered the DOE factors (4 factors). Then for each factor, 2 or 3 levels are taken into account as follows:

– build.build_full_fact
– 'Product Type':[3,5,10],
– 'Retailers':[20, 50, 200],
– 'Light Trcuk Capacity':[5000,6000],
– 'Heavy Truck Capacity':[10000,20000]

After running the method, Python offered 35 experiments with different levels. Table A.2 in the appendix shows the designed experiments.

4.5. Solving case studies of the full factorial designed case studies

Table 3 shows the results of solving the designed case studies with the proposed heuristic.

4.6. Compare scenarios of normal product distribution *vs.* horizontal layer product distribution re-adjustment strategy in supply chains

In this section, two possible scenarios for product distribution in a supply chain will be compared. In the first scenario, data for the transportation of products using routine procedures will be considered. In the second scenario, product distribution plans will be adjusted using a horizontal layer product distribution re-adjustment strategy when the supply chain encounters a sudden increase in market demand for certain products during specific periods. The rest of the input data will remain the same. Table 4 indicates the results obtained in terms of the amount of lost sales for both scenarios.

Table 4 presents data comparing the total lost sales observed using two different scenarios of normal product distribution and using the proposed horizontal layer product distribution re-adjustment strategy. Each row corresponds to a specific case with the lost sale that was presented in Table 3, with associated values for both methods and the calculated percentage improvement achieved by the alternative method. The outcomes showed that (Fig. 11) the horizontal layer product distribution re-adjustment method shows lower observed lost sales compared to the normal product distribution method, with improvement percentages ranging from 3.2% to 16.2%. This suggests that the alternative method tends to provide more favorable outcomes in terms of mitigating lost sales across the various cases analyzed.

Table 3. The outcomes of solving the full factorial case studies using the proposed heuristic methods.

Case	Product type	Factory capacity	Retailers	Light truck	Heavy truck	Proposed heuristic			
						Successfully solved	OFV	LS	Solving time
1	3	10000	20	5000	10000	✓	134378.46	0	1.028
2	3	10000	20	6000	20000	✓	134276.46	0	1.365
3	3	10000	50	5000	20000	✓	322669.46	2711	0.970
4	3	10000	200	6000	10000	✓	465270.46	70518	2.039
5	3	20000	20	5000	20000	✓	171709.46	0	1.139
6	3	20000	50	6000	10000	✓	393777.46	0	1.396
7	3	20000	200	5000	10000	✓	896749.46	49656	2.301
8	3	20000	200	6000	20000	✓	1044072.46	49960	2.023
9	3	50000	20	6000	10000	✓	172387.46	0	0.98
10	3	50000	50	5000	10000	✓	448867.46	0	1.112
11	3	50000	50	6000	20000	✓	236616.46	0	0.793
12	3	50000	200	5000	20000	✓	1761334.46	0	2.519
13	5	10000	20	5000	20000	✓	359811.46	0	0.884
14	5	10000	50	6000	10000	✓	494819.46	17773	1.037
15	5	10000	200	5000	10000	✓	425270.46	128903	2.11
16	5	10000	200	6000	20000	✓	465270.46	129223	2.276
17	5	20000	20	6000	10000	✓	316731.46	0	0.779
18	5	20000	50	5000	10000	✓	777412.46	0	0.954
19	5	20000	50	6000	20000	✓	632643.46	0	0.869
20	5	20000	200	5000	20000	✓	918880.46	109662	2.098
21	5	50000	20	5000	10000	✓	300342.46	0	0.687
22	5	50000	20	6000	20000	✓	239791.46	0	1.025
23	5	50000	50	5000	20000	✓	898698.46	0	1.006
24	5	50000	200	6000	10000	✓	2524454.27	50644	1.836
25	10	10000	20	6000	10000	✓	515376.46	0	0.951
26	10	10000	50	5000	10000	✓	1463783.46	0	1.045
27	10	10000	50	6000	20000	✓	1323473.46	0	1.018
28	10	10000	200	5000	20000	✓	505270.46	282979	2.020
29	10	20000	20	5000	10000	✓	594830.46	0	0.825
30	10	20000	20	6000	20000	✓	540324.46	0	0.941
31	10	20000	50	5000	20000	✓	975677.46	34599	0.968
32	10	20000	200	6000	10000	✓	1055182.46	262013	2.067
33	10	50000	20	5000	20000	✓	602225.46	0	0.889
34	10	50000	50	6000	10000	✓	1227239.46	0	0.8624
35	10	50000	200	5000	10000	✓	2518693.27	201126	2.478
36	10	50000	200	6000	20000	✓	2196113.46	200548	2.186

TABLE 4. Compare the results of normal product distribution *vs.* horizontal layer product distribution re-adjustment.

Case	Total lost sale observed in normal distribution	Total lost sales observed using the horizontal layer product distribution re-adjustment	Improvement %
3	3104	2711	14.5
4	72774	70518	3.2
7	56309	49656	13.4
8	58153	49960	16.4
14	20101	17773	13.1
15	146820	128903	13.9
16	148353	129228	14.8
20	127098	109662	15.9
24	58848	50644	16.2
28	315238	282979	11.4
31	37747	34599	9.1
32	301838	262013	15.2
35	219830	201126	9.3
36	224613	200548	12.0

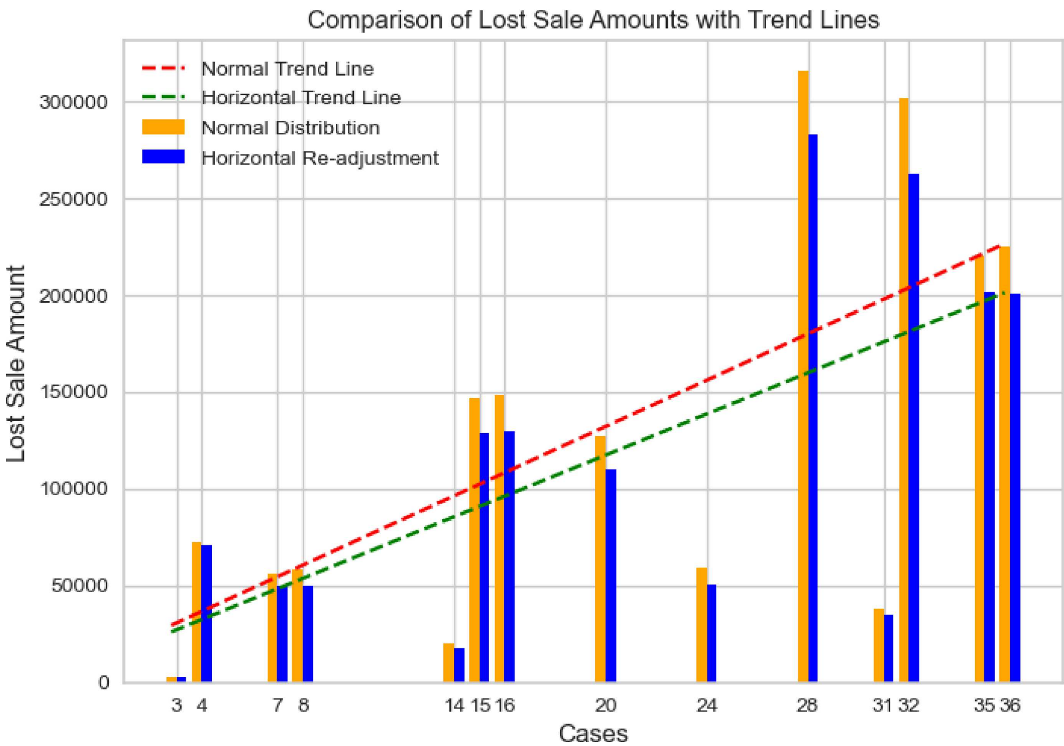

FIGURE 11. Lost sale values for normal distribution *vs.* horizontal layer readjustment strategy.

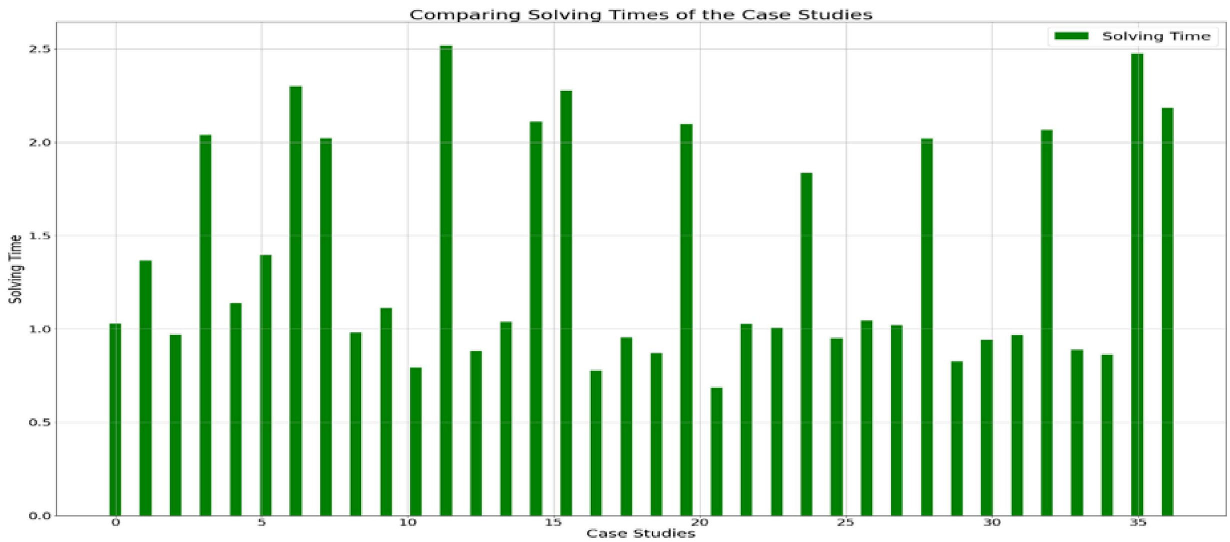

FIGURE 12. Solving time for the studied cases using the proposed heuristic method.

4.7. Measuring the performance of the proposed method

4.7.1. Validating index

Validating index is developed to indicate the ability to solve all cases designed by the Full Factorial Method. This index shows whether the proposed heuristic is strong enough to solve all studied cases designed by the Full Factorial method. The outcomes showed that the proposed heuristic can solve all the case studies designed by the Full Factorial Method.

$$Validating \cdot Index = \frac{Number\ of\ Solved\ Cases\ without\ error}{Number\ of\ Orthogonal\ Designed\ Cases} \cdot 100 = \frac{36}{36} \cdot 100 = 100\%. \quad (22)$$

4.7.2. Solving time

The solving time index is a measuring index to check the computing time to solve a problem. The outcomes of measuring the solving time for the studied cases show that the proposed heuristic can solve each problem in less than 3 seconds, which is reasonable. Figure 12 shows the solving time for the studied cases using the proposed heuristic method.

4.7.3. Quality of the solutions

In order to evaluate the quality of the solutions gained by the proposed heuristic, the outcomes of the solved case studies designed by the Full Factorial method will be compared with a Random Search Heuristic and Forward Serial Programming (Tab. 5).

Figure 13 shows that for 58.3% of the cases, the proposed algorithm could provide solutions with a higher objective function. Moreover, the proposed heuristic is faster than the Random Search Heuristic and Forward Serial Programming methods in 61.11% of the studied cases (Fig. 14).

Therefore, the proposed heuristic can be considered a reliable and fast method to solve the developed mathematical model of the designed supply.

Table 5. Results of the proposed heuristic, random search heuristic and forward serial programming.

Case	Proposed heuristic			Random search heuristic			Forward serial programming		
	OFV	LS	Solving time	OFV	LS	Solving time	OFV	LS	Solving time
1	191967	0	1.008	153741	0	2.215	155127	0	0.725
2	183272	0	0.925	174426	0	1.271	148505	0	0.767
3	486093	2146	1.061	347405	2146	1.105	449843	2146	1.433
4	385270	70003	2.34	265270	70003	1.789	365270	70003	2.292
5	115569	0	0.821	115569	0	1.193	183420	0	0.973
6	331719	0	1.155	472835	0	1.067	461843	0	1.101
7	905294	50051	2.157	809940	50051	2.312	889482	50051	2.368
8	775427	50264	2.544	782257	50264	2.175	823766	50264	2.474
9	140244	0	0.853	133989	0	3.513	143761	0	0.817
10	526622	0	0.75	466592	0	1.353	480072	0	1.25
11	458242	0	1.12	547793	0	1.352	442771	0	1.256
12	1859621	0	2.011	1500976	0	3.101	1859788	0	2.915
13	297524	0	0.68	257739	0	0.93	298315	0	0.884
14	359447	17119	1.319	284623	17119	2.815	290711	17119	1.431
15	465270	129407	2.083	245270	129407	2.561	385270	129407	1.974
16	405270	130817	2.165	275270	130817	4.717	265270	130817	2.116
17	337988	0	2.204	236724	0	1.369	215860	0	1.368
18	669038	0	0.801	707363	0	3.585	782393	0	2.113
19	709133	0	1.218	702553	0	5.777	640837	0	1.954
20	1035936	110852	1.929	861248	110852	2.101	575622	110852	2.049
21	271995	0	0.295	345946	0	1.041	345946	0	1.041
22	245278	0	0.765	223025	0	0.978	295873	0	1.135
23	792907	0	0.941	846004	0	2.096	714986	0	1.966
24	1776643	50134	2.423	1686555	50134	3.156	1572766	50134	2.995
25	490440	0	1.106	564405	0	2.149	614195	0	1.645
26	1234128	0	0.797	1359403	0	1.868	1295340	0	0.883
27	1303414	0	0.979	1530799	0	1.323	1458890	0	1.31
28	505270	280858	1.904	275270	280858	2.372	245270	280858	2.025
29	551454	0	1.128	513356	0	1.67	511775	0	1.583
30	579390	0	1.164	605487	0	2.551	559164	0	1.418
31	975677	34599	1.331	736278	35477	4.812	946102	35477	0.986
32	985270	259494	2.535	811359	259494	3.244	543902	259494	2.33
33	569967	0	0.859	608121	0	2.434	492461	0	1.032
34	1503733	0	1	1464942	0	1.009	1481091	0	0.941
35	2632429	197062	2.422	1758444	197062	3.402	1746579	197062	1.809
36	2413710	200431	1.933	1872570	200431	2.812	1855001	200431	1.616

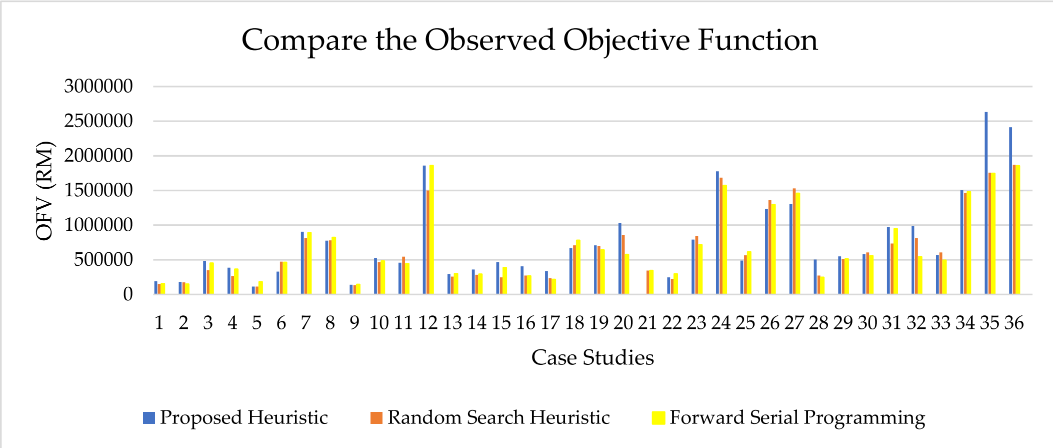

FIGURE 13. Comparing the Objective Function Values (OFV) of the proposed heuristic, random search heuristic and forward serial programming.

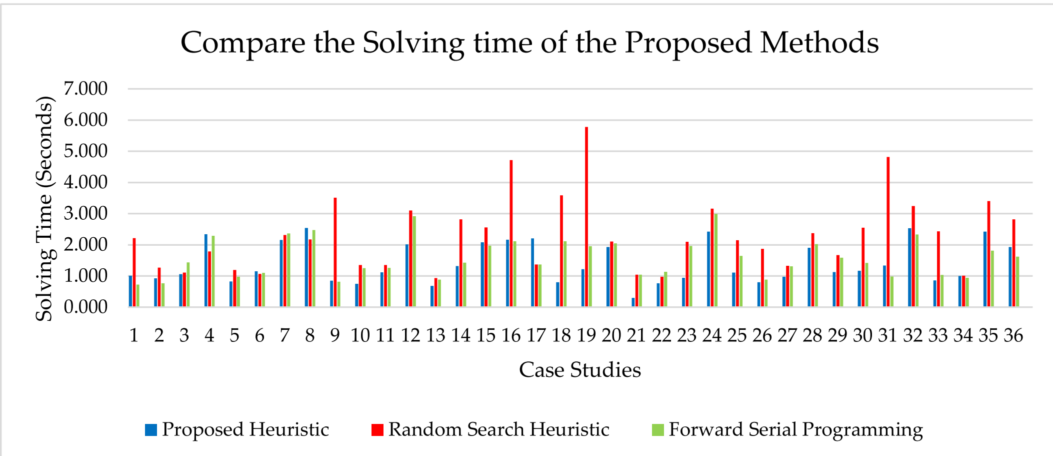

FIGURE 14. Comparing the solving time of the proposed heuristic, random search heuristic and forward serial programming.

4.8. Implications of the study based on results

The findings of this research have the potential to enhance logistics and transportation strategies when a supply chain encounters sudden changes in demand within submarkets. The primary solution discussed in this research involves implementing a temporary and short-term strategy to redistribute products within a layer of the supply chain. This approach can prove useful in preventing time wastage and mitigating the bullwhip effect.

To achieve this objective, a novel product distribution approach employing horizontal layering throughout the supply chain was introduced in this study. This method circumvents the need for transportation between wholesalers and the main plants of a supply chain, which typically involves longer distances, by optimizing local distribution among regional wholesalers. This approach has the potential to significantly reduce transportation costs during emergency situations triggered by sudden market changes.

The results indicate that in the examined scenarios, adopting a transitory supply strategy through local distributors in alternative markets leads to a reduction in lost demand ranging from 3.2% to 16.2% compared to the conventional product distribution mode. Consequently, when confronted with rapid and unforeseen changes in local market demand, adjusting product distribution plans is recommended. This strategy effectively mitigates the bullwhip effect by minimizing order shipping delays that propagate through the entire supply chain and result in lost orders.

5. Conclusions

In this research, a nonlinear integer programming method is developed to address the bullwhip effect in supply chains. Using the blockchain technology concepts, a horizontal layer product distribution readjustment is proposed for reducing the transportation time inside a supply chain. For this purpose, a new mathematical model was developed where constraints were set according to the real data gained from the society, geographical and urban features in Malaysia.

The developed model could determine the best amount of product that must be transferred to each wholesaler and the distributed products to each retailer according to the designed supply chain, which is designed according to the geographical and population features.

It was shown that the standard optimization methods could not solve the developed model in Np-hard. For this purpose, a heuristic algorithm is proposed and coded by Python to solve the model in the next phase.

Then, due to the complexity of the developed model, a heuristic was proposed and coded by Python, which was worked based on the maximum profit and minimum distance from retailers. The method is designed to transfer the products inside a layer (wholesalers or retailers) while sudden changes in a local market are seen. In order to evaluate the performance of the proposed method, its outcomes are compared with two other heuristics, which were Random Search-based and Forward Serial Programming-based heuristics. For this purpose, a Full Factorial design of experiments is generated by Python. After solving the designed case studies by the mentioned DOE method, the outcomes were compared in terms of the solving time and quality of the solutions.

The outcomes show that in 5.3% of the studied cases, the proposed heuristic could provide better-quality solutions than the 2 other heuristics and therefore is recognized as the better method. Moreover, in 61.11% of the studied cases, the proposed method could solve a problem faster than the other 2 heuristics, and consequently, it was recognized as the faster method.

Further expanding the model by considering fuzzy systems in machine learning to consider the uncertainty of factors in clustering the wholesalers' center points while clustering country regions is recommended.

Acknowledgements

The authors would like to thank anonymous reviewers and the editor for their positive comments.

Appendix A.

Table A.1. Dimensions of the variables and constraints of the developed mathematical model.

Item	Definition	Domain	Results
Variables	$X_{i,k,t}$	i, k, t	3 * 21 * 2
	$Y_{i,s,t}$	i, s, t	3 * 6 * 2
	$LS_{i,s,t}$	i, s, t	3 * 6 * 2
	$QRL_{j,t}$	j, t	6 * 2
	$QRR_{j,t}$	j, t	6 * 2
	RL_t	t	2
	RR_t	t	2
	WRL_t	t	2
	WRR_t	t	2
Constraints	$X_{i,k,t} \leq d_{i,t,k};\quad \forall t,i,k$	i, t, k	3 * 21 * 2
	$\sum_{s}^{S} Y_{i,s,t} \leq \sum_{k}^{K} d_{i,t,k};\quad \forall i,t$	i, t	3 * 2
	$\sum_{k}^{K} X_{i,k,t} \leq Y_{i,s,t};\quad \forall t,i,s$	i, t, s	3 * 6 * 2
	$\sum_{i}^{I}\sum_{s}^{S} Y_{i,s,t} \leq C;\quad \forall t$	t	2
	$LS_{i,s,t} = \sum_{k}^{K} (d_{i,t,k} - X_{i,k,t});\quad \forall t,s,i$	i, t, s	3 * 6 * 2
	$QRL_{k,t} = \frac{\sum_i^I (WP_i \cdot X_{i,k,t} \cdot LW_j)}{Cap_e};\quad \forall t,k,e = 1$	t, k, 1	2 * 21 *1
	$QRR_{k,t} = \frac{\sum_i^I (WP_i \cdot X_{i,k,t} \cdot RW_j)}{Cap_e}; \forall t,k,e = 1$	t, k, 1	2 * 21 * 1
	$QWL_{k,t} = \frac{\sum_i^I (WP_i \cdot Y_{i,s,t} \cdot N_{j,k})}{Cap_e}; \forall t,k,e = 2$	t, k, 1	2 * 21 * 1
	$QWR_{k,t} = \frac{\sum_i^I (WP_i . Y_{i,s,t} \cdot N_{j,k})}{Cap_e};\quad \forall t,k,e = 2$	t, k, 1	2 * 21 * 1
	$RL_t = \sum_{k}^{K} (QRL_{k,t} - QRL_o);\quad \forall t$	t	2
	$RR_t = \sum_{k}^{K} (QRR_{R,t} - QRR_o);\quad \forall t$	t	2
	$WRL_t = \sum_{k}^{K} (QWL_{k,t} - QWL_o);\quad \forall t$	t	2
	$WRR_t = \sum_{k}^{K} (QWR_{R,t} - QWR_o);\quad \forall t$	t	2

Table A.2. Experiments that are designed by the full factorial method.

Case	Product type	Factory capacity	Retailers	Light truck	Heavy truck
0	3	10000	20	5000	10000
1	3	10000	20	6000	20000
2	3	10000	50	5000	20000
3	3	10000	200	6000	10000
4	3	20000	20	5000	20000
5	3	20000	50	6000	10000
6	3	20000	200	5000	10000
7	3	20000	200	6000	20000
8	3	50000	20	6000	10000
9	3	50000	50	5000	10000
10	3	50000	50	6000	20000
11	3	50000	200	5000	20000
12	5	10000	20	5000	20000
13	5	10000	50	6000	10000
14	5	10000	200	5000	10000
15	5	10000	200	6000	20000
16	5	20000	20	6000	10000
17	5	20000	50	5000	10000
18	5	20000	50	6000	20000
19	5	20000	200	5000	20000
20	5	50000	20	5000	10000
21	5	50000	20	6000	20000
22	5	50000	50	5000	20000
23	5	50000	200	6000	10000
24	10	10000	20	6000	10000
25	10	10000	50	5000	10000
26	10	10000	50	6000	20000
27	10	10000	200	5000	20000
28	10	20000	20	5000	10000
29	10	20000	20	6000	20000
30	10	20000	50	5000	20000
31	10	20000	200	6000	10000
32	10	50000	20	5000	20000
33	10	50000	50	6000	10000
34	10	50000	200	5000	10000
35	10	50000	200	6000	20000

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