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Dynamic Multiple Depots Vehicle Routing in the Physical Internet context

Anirut Kantasa-ard.* Tarik Chargui.* Abdelghani Bekrar.*
Abdessamad Ait El Cadi.* Yves Sallez.*

* LAMIH, UMR CNRS 8201, Polytechnic University of Hauts-de-France
Le Mont Houy, 59313, UPHF, Valenciennes, France
(e-mail: Anirut.Kantasa-Ard@etu.uphf.fr,{Tarik.Chargui, Abdelghani.Bekrar, Abdessamad.AitElCadi, Yves.Sallez}@uphf.fr)

Abstract: This paper proposes Dynamic Multiple Depots Vehicle Routing (DMDVR) to explore the feasible solution of routing transportation between PI-hubs and retailers in the same cluster. The routing solution in this research is constructed by the daily forecasting demand of a commodity crop, Pineapple, from Thailand's northern region. Each route is composed of a starting hub, the number of retailers, and an ending hub. The authors propose Mixed Integer Linear Programming (MILP) to construct the routes considering inventory and truck capacity constraints. Besides, another solution method is proposed by using a heuristic method named "Iterated Random Heuristic". The empirical results are evaluated by using the total distribution cost and computational time. The routing transportation of this research is based on the daily delivery transportation from PI-hubs to retailers. The results show that Iterated Random Heuristic with Nearest Neighbor Search generates near-optimal solutions within a short computational time.

Keywords: Physical Internet, Multiple depots, Forecasting demand, Distribution, Heuristic, Mathematical programming

1. INTRODUCTION

The supply chain structure recently is more complicated with many stakeholders: suppliers, distributors, and customers. However, the connection links are limited, and customers can request their products only from their partner distributors (Waller, Johnson and Davis, 1999). One of the interesting solutions to reduce stakeholder connectivity problems in the classical supply chain is the Physical Internet. Physical Internet (PI) is a new paradigm to improve the global supply chain's potential to be higher via implementing the decentralized connection links between the supply and demand side (Montreuil, Meller and Ballot, 2013). PI allows customers, which are retailers or wholesalers, to stock products in any place in the network. Also, this paradigm provides multi-sourcing options for on-demand orders (Yang, Pan and Ballot, 2017). It means that customers can request their products from various distributors in the network, and each distributor can share its inventory with the others. The distributor or open logistics center in the Physical Internet context is the combination between a warehouse and a distribution center denoted "open PI-hub" (Montreuil, Ballot and Fontane, 2012).

To optimize the distribution cost in the decentralized connection between suppliers and customers via open PI-hubs, it is essential to focus on routing construction. Suppliers and distributors can control their distribution costs if they have good solutions to distribute products even from plants to distributors or from distributors to customers. The authors in (Pan *et al.*, 2019) proposed the Collaborative Vehicle Routing Problem (CVRP) idea to optimize the profit of transportation for many delivery orders with some collaborative carriers in the network. Also, the authors (Caballini *et al.*, 2017) proposed the approach of road transportation between various networks in the Physical Internet context. The objective is to minimize total cost and reduce the empty truck when transporting from supplier nodes to customer nodes. The authors (Darvish, Larrain and Coelho, 2016) proposed the PI-hub shared network concept to reduce the total logistics cost; Production cost, Inventory cost, and Transportation cost by using Mixed Integer Linear Programming (MILP) model. In the last example, the authors (Pal and Kant, 2016) proposed a mechanism for decreasing empty miles of the truck and the carbon footprint in the fresh food distribution network between the first-mile distributors and the last-mile distributors. These works focus on the optimization solution of goods transportation from origin supplier nodes to destination customer nodes in the network. However, the solution for goods transportation would be more complex if the number of PI-hubs and customers are large. It is also more complicated to construct routing between several PI-hubs and customers.

One example research proposes the idea to reduce the size of the transportation problem in the Physical Internet context. Authors (Kantasa-Ard *et al.*, 2019) proposed a dynamic clustering method to group the number of PI-hubs in the same area and assign retailers into each hub's group based on the daily forecasting demand of the agricultural products. However, there are still some aspects of routing construction between hubs and retailers required to study more details.

Therefore, there are two main contributions proposed in this paper. Firstly, the approach of transportation routing between PI-hubs and retailers inside each cluster is proposed based on

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the concept of the Multiple Depots Vehicle Routing Problem (MDVRP) by using MILP model. Secondly, the authors propose another solution by implementing the heuristic concept which is called "Iterated Random Heuristic" (IRH) to construct the route with less computational time. Besides, this heuristic method has improved the performance of the selection process by using Nearest Neighbor Search (NNS). Then, we compare the results between these two models via total distribution cost and computational time. The customer demand used in this experiment comes from the daily forecasting demand of a commodity crop in the Thailand's northern region (Kantasa-ard *et al.*, 2020). Also, this research focuses only on the delivery part from PI-hubs to retailers.

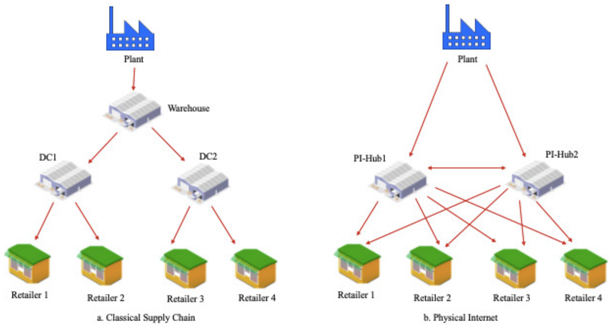
The remainder of this paper is organized as follows. Section 2 presents the literature review of the distribution concept between classical supply chain and Physical Internet and vehicle routing problem. Section 3 introduces the problem statement and assumptions about the problem. Section 4 presents the implementation of MILP and heuristic models to solve the problem of vehicle routing. Section 5 shows the comparison results between MILP and heuristic models via total distribution cost and computational time. Section 6 concludes the work and provides future research directions.

2. LITERATURE REVIEW

In this section, the concept of distribution in the supply chain and vehicle routing problem is presented with more details. The first part mentions the ideas of distribution that are established in the classical supply chain. Also, the authors will benchmark these ideas with the Physical Internet context. For the second part, the Multiple Depot Vehicle Routing Problem (MDVRP) concept is proposed.

2.1 The concept of distribution in the supply chain

The distribution flow of goods always begins from the customer demand, both from actual demand and forecasting demand. Since the suppliers receive total demands from their customers, they will fabricate and deliver finished goods to their customers via distributors' hierarchical structure (Waller, Johnson and Davis, 1999). Moreover, each distributor manages its stock and does not share it with other distributors (Chopra, 2003). It means that each distributor will replenish its stock by requesting from suppliers directly. In contrast, when we consider the interconnectivity concept in the Physical Internet, we can find that all open PI-hubs in this context can share their stocks and means of transport. Also, each customer can request products from various hubs in the network (Yang, Pan and Ballot, 2017). There is an example of distribution flow between the classical supply chain and Physical Internet, as shown in figure 1. For the dimension of routing transportation, it will be presented in the next section.



a. Classical Supply Chain

b. Physical Internet

Fig.1. The distribution flow in the Classical Supply Chain and Physical Internet

2.2 Vehicle Routing Problem (VRP)

Several variants were implemented in the concept of Vehicle Routing Problem (VRP) to find the optimal solution of goods transportation in the classical supply chain, especially the MDVRP concept. The Multiple Depot Vehicle Routing Problem (MDVRP) concept is similar to the vehicle routing problem with a single depot. However, it focuses on more than one depot in the network (Montoya-Torres *et al.*, 2015). The objective is to optimize the routing construction and transportation cost of each depot based on customer demand. The authors (Kek, Cheu and Meng, 2008) proposed a Mixed Integer Programming (MIP) and a branch-and-bound method to find the optimal solution of routing transportation with the fixed and flexible fleets. For the flexible fleet case, they proposed that the starting depot and ending depot can be different points based on customer demand and travel time constraints. The authors (Cornillier, Boctor and Renaud, 2012) proposed the MILP model to define the set of feasible trips to deliver petroleum products from many depots to many petroleum stations with maximum net revenue. These two works are examples of MDVRP implementation. However, the following examples performed the experiment with less depots and faced the problem of imbalance vehicle in each depot. Also, they fixed the position of the ending depot even though the ending depot can be different from the starting depot in some cases.

MDVRP is not only implemented in the classical supply chain, but it is also implemented in the context of the Physical Internet. The authors (Ben Mohamed *et al.*, 2017), for instance, implemented this concept to find the feasible solution to the operational urban transportation problem. This paper focused on picked-up and delivery operations among distribution centers, PI-hubs, and pickup-delivery points in the network. However, each truck was forced to return to the initial hub.

Regarding this paper's problem statement, the concept of MDVRP is useful to find the near-optimal solution of goods transportation between PI-hubs and retailers in the same network. In this paper, the authors assume that each hub would be the starting depot for all trucks. Also, the ending depot should be selected based on the closest distance from the last customer in a route. Finally, the authors summarize the distribution concept between the classical supply chain and Physical Internet as shown in table 1.

Table 1: The Distribution Concept Between Classical & PI

Relevant perspective	Classical Supply Chain	PI Supply Chain
Distribution concept	Hierarchical delivery from plant to end customers (Waller, Johnson and Davis, 1999)	Interconnected for all parties (Yang, Pan and Ballot, 2017)
Distribution flow between distributors and plants	Each distributor loads its products from a fixed plant (Chopra, 2003)	Each distributor can load its products from different plants independently (Montreuil, Ballot and Fontane, 2012)
The interconnectivity between distributors	Each distributor manages its stock and does not share with other distributors (Chopra, 2003)	All distributors share their stocks and support each other (Yang, Pan and Ballot, 2017)
The relation between customers and distributors	One customer can receive products only from his partner distributors (Waller, Johnson and Davis, 1999)	One customer can receive products from different distributors in the network (Pal and Kant, 2016; Pan *et al.*, 2017; Yang, Pan and Ballot, 2017)
MDVRP implementation between distributors and end-customers	There are several implemented in many cases of MDVRP (Kek, Cheu and Meng, 2008; Cornillier, Boctor and Renaud, 2012; Montoya-Torres *et al.*, 2015; Montoya-Torres, Muñoz-Villamizar and Vega-Mejía., 2016)	There are a few cases implemented in MDVP (Ben Mohamed *et al.*, 2017).

3. PROBLEM STATEMENT AND ASSUMPTIONS

As mentioned previously in the introduction, this research's problem statement is how to construct the set of feasible transportation routes between PI-hubs and retailers inside each cluster or area. This statement aims to minimize total distribution costs in the set of feasible routes based on retailer demands and stock levels at each hub. Also, we would like to reduce empty trips from PI-hubs to retailers, as shown in figure 1.

Besides, four main assumptions are provided to support the problem statement and research objectives.

- Firstly, the retailer's stocks can be fulfilled by different PI-hubs in the cluster.
- Secondly, the demands of retailers in this experiment are predicted from the historical demands. In this case, the historical demands are initiated from the inventory data of one harvest commodity crop (OAE Thailand, 2019).
- Thirdly, all PI-hubs can share their means of transportation (trucks, drivers) among them based on the number of PI-hubs and retailers.
- Fourthly, each hub should have at least one truck at the end of the day because the hub can continue loading goods for delivery the next day.

We investigate the routing problem via MILP and heuristic models regarding the problem statement and assumptions. The details of each method are proposed in the methodology section.

4. METHODOLOGY

This section comprises three main methods: Preparing a dataset of PI-hubs and retailers, Formulating the problem with Mixed Integer Linear Programming (MILP) model, and Proposing another solution with Iterated Random Heuristic. The details are mentioned below.

4.1 Preparing dataset of PI-hubs and retailers

The forecasting demand proposed in (Kantasa-ard *et al.*, 2020) generates the prediction of retailer demand. In this experiment, the authors focus on the retailer demand of one commodity crop from the Thailand's northern region. Besides, the inventory level of each PI-hub is from the total demand from all retailers in the cluster. There are two criteria for the number of hubs and retailers using in this experiment based on our assumption: Case 1 with 3 hubs and 6 retailers, Case 2 with 6 hubs and 12 retailers. The hub positions are randomly generated from the main cities' position in Thailand's northern region via Google maps. Also, the retailer positions are randomly chosen from the actual position of mini stores in the same region.

4.2 Formulating the problem with Mixed Integer Linear Programming (MILP) model

After retailer demands and hubs' inventories are generated, the problem of routing transportation is formulated as a MILP model. This model is inspired from MDVRP in (Montoya-Torres *et al.*, 2015) and (Montoya-Torres, Muñoz-Villamizar and Vega-Mejía., 2016) to solve the routing transportation problem between PI-hubs and retailers. There are two different points between inspired models and this model. Firstly, this model does not force a truck to return to the initial hub after finishing all deliveries. Secondly, this model does not consider only truck capacity, it also considers the inventory level at each hub. This problem is defined over a graph G = (V, A) where V is nodes: hub and retailer nodes and A is the set of arcs between nodes. The following mathematical model is used:

Notations:

- H : number of PI-hubs
- R : number of retailers
- K : number of trucks
- d_{ij} : distance matrix from retailer i to retailer j
- p_{hi} : distance matrix from hub h to retailer i
- S_h : inventory level at hub h
- D_i : demand at retailer i
- T_k : capacity of truck k

Decision Variables:

- Y_{hik} : 1, if vehicle k goes from hub h to retailer i. 0, otherwise
- X_{ijk} : 1, if vehicle k goes from retailer i to retailer j. 0, otherwise
- Z_{ihk} : 1, if vehicle k goes from retailer i to hub h. 0 , otherwise

$$Min \sum_{h=1}^{H}\sum_{i=1}^{R}\sum_{k=1}^{K} p_{hi} * Y_{hik} + \sum_{i=1}^{R}\sum_{j=1}^{R}\sum_{k=1}^{K} d_{ij} * X_{ijk}$$

$$+ \sum_{h=1}^{H}\sum_{i=1}^{R}\sum_{k=1}^{K} p_{hi} * Z_{ihk} \qquad (1)$$

Subject to:

$$\mathrm{R} * \sum_{h=1}^{H}\sum_{i=1}^{R} Y_{hik} \geq \sum_{i=1}^{R}\sum_{j=1}^{R} X_{ijk}, \forall k \in \{1, \ldots, K\} \qquad (2)$$

$$\mathrm{R} * \sum_{h=1}^{H}\sum_{i=1}^{R} Z_{ihk} \geq \sum_{i=1}^{R}\sum_{j=1}^{R} X_{ijk}, \forall k \in \{1, \ldots, K\} \qquad (3)$$

$$\sum_{h=1}^{H}\sum_{k=1}^{K} Y_{hik} + \sum_{j=1}^{R}\sum_{k=1}^{K} X_{jik} = 1 , \forall i \in \{1, \ldots, R\} \qquad (4)$$

$$\sum_{h=1}^{H} Y_{hik} + \sum_{j=1}^{R} X_{jik} = \sum_{h=1}^{H} Z_{ihk} + \sum_{j=1}^{R} X_{ijk},$$

$$\forall k \in \{1, \ldots, K\}, \forall i \in \{1, \ldots, R\} \qquad (5)$$

$$X_{iik} = 0 , \forall k \in \{1, \ldots, K\}, \forall i \in \{1, \ldots, R\} \qquad (6)$$

$$U_i - U_j + R * X_{ijk} \leq \mathrm{R}\text{-}1, \forall k \in \{1, \ldots, K\}, \forall i, j \in \{1, \ldots, R\} \qquad (7)$$

$$\left(\sum_{i=1}^{R}\sum_{h=1}^{H} D_i * Y_{hik}\right) + \left(\sum_{i=1}^{R}\sum_{j=1}^{R} D_j * X_{ijk}\right) \leq T_k,$$

$$\forall k \in \{1, \ldots, K\} \qquad (8)$$

$$\left(\sum_{i=1}^{R} D_i * Y_{hik}\right) + \left(\sum_{i=1}^{R}\sum_{j=1}^{R} D_j * X_{ijk}\right) \leq S_h,$$

$$\forall k \in \{1, \ldots, K\}, \forall h \in \{1, \ldots, H\} \qquad (9)$$

In the MILP model, equation (1) represents the objective function; it minimizes the total distance from the hub to retailer, retailer to retailer, and retailer back to the hub. Equations (2) and (3) denote that every route should start and finish at a hub. The starting hub and ending hub can be the same different hubs. Equation (4) denotes that all retailers must be visited exactly once. Also, equation (5) presents the equity of flow in and flow out transportation between hubs and retailers. Equation (6) states that the route should not be itself. Equation (7) eliminates sub tours in each route. Also, equation (8) denotes that all retailer demands should respect truck capacity. Furthermore, equation (9) denotes that each hub's inventory level should cover retailer demands in a route. This model is validated via IBM CPLEX (Version 12.8) on a CPU Intel Core i5.

However, when we consider the MILP model, we find that the model will be more complicated if we consider more constraints based on equations (1) - (9). Besides, if the number of hubs and retailers inside the cluster is large, it will take additional computational time to define the optimal solution, as shown in table 3. Therefore, the authors propose another solution method using Iterated Random Heuristic. The details of this method are described in the next section.

4.3 Proposing the solution with Iterated Random Heuristic (IRH)

In this section, the set of feasible routes is constructed using a heuristic method called "Iterated Random Heuristic". The set of routes will support the daily demand of all retailers. Each route is composed of the starting hub, list of retailers, and the ending hub. Besides, the list of retailers in each route is based on the inventory level at the starting hub and truck capacity. A truck will start from the starting hub and be managed by external carriers. Therefore, one solution set will have more than one route due to the number of retailers in the area. For constructing the initial solution, the authors will create a solution based on random selection. It means that the starting hub, list of retailers, and ending hub are randomly chosen by respecting the constraints. The flow chart of the Iterated Random Heuristic is shown in figure 3.

However, there are still some problems with the retailer and ending hub selection. For example, one retailer's total distance to other retailers and the last retailer to the ending hub is too long. Then, the authors investigate to improve the selection process by implementing the Nearest Neighbour Search (NNS). The NNS will select the next node based on the previous node's shortest distance (Du and He, 2012). In this experiment, the authors implement NNS to select the retailer nodes and end hub nodes based on the previous node's shortest distance. For the starting node, it is still random. The example of the set of feasible routes is represented in figure 2. The list of PI-hubs contains H1, H2, and H3. These hubs can be both the starting hub and the ending hub. Also, the list of retailers contains R1, R2, R3, R4, and R5. There are two routes in this solution; H1-R3-R4-H2 is the first route (blue colour), H3-R2-R1-R5-H2 is the second route (red line). Each truck is assigned to each route. Because of the investigation of the routing problem via MILP and heuristic models, these models' results are demonstrated in the result analysis section.

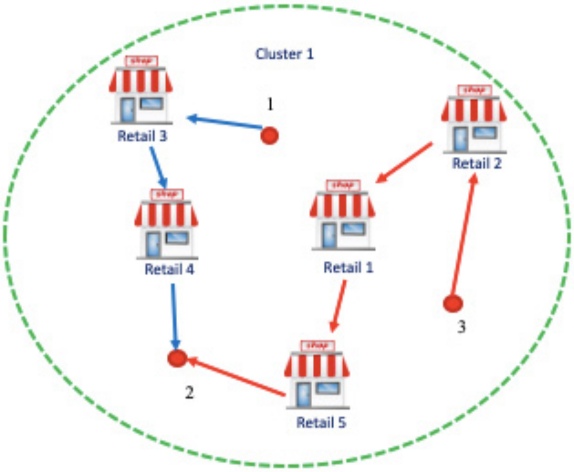


Fig.2.An illustrative example of the set of feasible routes

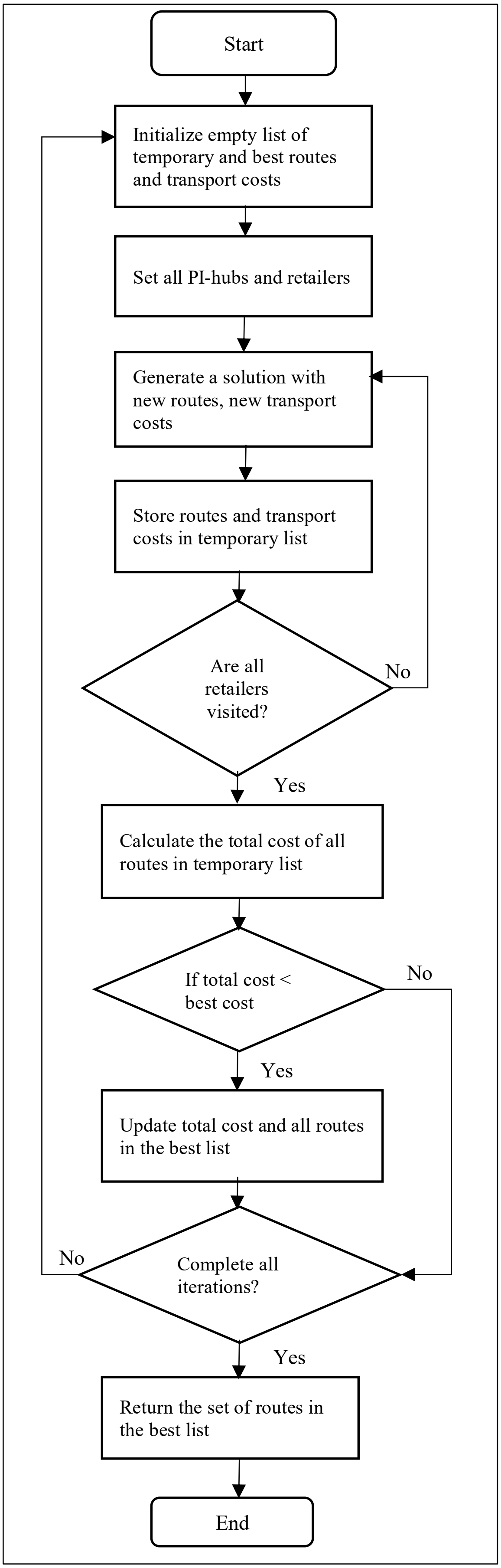


Fig.3.The flow chart of Iterated Random Heuristic

5. RESULTS ANALYSIS

In this section, the total distribution cost and computational time are the main indicators of these models. The total distribution cost is the combination between transportation cost and fixed truck cost. The transportation cost is calculated from the minimum distance from PI-hubs to retailers, retailers to retailers, and retailers to PI-hubs. The unit transportation cost is equal to 2.0 (monetary unit) per full truckload per kilometer (Yang, Pan and Ballot, 2015). We assume that the unit transportation cost from PI-hubs to retailers and from retailers to retailers are the same. The fixed truck cost is also calculated by the multiplication between the number of trucks in each solution and the unit fixed truck cost. The unit fixed truck cost is assumed to be 300 (monetary unit) per truck. Also, each truck's capacity is equal 50.5 tons (Office of Highways Traffic Weight Control, 2014). The results of total distribution cost and computational time are represented in Tables 2-3. There are two scenario cases; 1: 3 hubs and 6 retailers, 2: 6 hubs and 12 retailers. The abbreviation of IRH is from Iterated Random Heuristic, and IRH-NNS is from Iterated Random Heuristic with Nearest Neighbor Search.

Table 2: The result comparison between each hidden layer in this condition

Case	**Total Distribution Cost**				
	MILP	***10 iterations***		***20 iterations***	
		IRH	***IRH-NNS***	***IRH***	***IRH-NNS***
1	1377.88	1493.86	1563.48	1580.82	1608.28
2	3439.04	3869.68	3523.38	3958.63	3450.37

Table 3: The computational time between MILP and IRH

Case	**Computational Time (seconds)**				
	MILP	***10 iterations***		***20 iterations***	
		IRH	***IRH-NNS***	***IRH***	***IRH-NNS***
1	0.68	0.023	0.05	0.053	0.092
2	7.64	0.047	0.182	0.09	0.383

When we consider the total distribution cost in Table 2, we can find that the total cost of IRH and IRH-NNS is similar even though IRH generates a lower cost in the first case with an 8%-13% gap optimal point. While in the second case, with the higher number of hubs and retailers, IRH-NNS provides a lower cost than IRH and closer to the optimal value. The %gap deviation is decreased to 2%-7% from the optimal value. When we consider with the computational time in table 3, it shows that MILP takes higher computational times than IRH and IRH-NNS, even though the computational times gap is lower. Since MILP is time-consuming for instances with large amounts of PI-hubs and retailers, IRH-NNS will be used to construct feasible routes when the number of PI-hubs and retailers is large. Besides, it takes less computational time than the MILP method. Moreover, MILP and heuristics provide good performance in both cases, for the small network (case 1), and the large network (case 2).

6. CONCLUSION

In this paper, the Iterated Random Heuristic with Nearest Neighbor Search (IRH-NNS) provides a feasible solution with near-optimal value. If the number of PI-hubs and retailers are large, IRH-NNS can be a good option to construct the initial solution for the set of routes. However, this model still requires improving more performance by implementing relevant metaheuristics to get a better set of feasible routes with smaller trucks. According to the Physical Internet context, all retailers can request their goods from different PI-hubs. In addition, all PI-hubs can share their vehicles based on PI-hubs' location and driving periods. This perspective makes goods transportation more flexible and adaptable than the classical supply chain network. Each business unit can implement this perspective to improve its transportation planning. It is essential to mention that the presented results are given as a validation of the MILP and heuristics. Further extensive experiments are needed to assess both classical and PI supply chain networks. Also, this model can be extended to solve the problem by considering the transportation time and product type constraints.

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