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# Central Hospital Location and Distribution Planning Using Integrated K-Means and Vehicle Routing Algorithm in the Healthcare Chain

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## ABSTRACT

**A healthcare chain (HC) involves interrelated activities inclusive of medicine manufacturing, storage, and last-mile distribution to drug retailers and users. Major decision-makers in the HC are also interrelated, in which proper management and planning for logistics activities are required to enhance efficiency and effectiveness. In this study, we first investigate the optimal locations of central hospitals using the K-means algorithm at the midstream of the healthcare chain for long-term planning. Next, we assess the distribution plan of medical supplies by integrating the capacitated vehicle routing problem (CVRP) model with a limited time planning horizon, in which the total economic aspect is evaluated for the short-term plan. Then, our integrated framework is applied to a case study of existing hospitals in Thailand to verify and validate model functionalities. We then examine both locational and distribution plans and present our findings using the geographic information system (GIS). The sensitivity analysis is further performed to evaluate the clustering classification scheme for central hospitals and to evaluate the impact on healthcare logistics plans.**

**Keywords***: central hospital, healthcare chain, k-means algorithm, location and distribution, logistics optimization, vehicle routing problem*

## 1. INTRODUCTION

Healthcare Chain Management (HCM) encompasses the planning and design for the efficient and effective flow of various healthcare products, which are inclusive of pharmaceutical products, blood and vaccines, medical equipment, patients, and so on. Managing cold chains with a focus on the healthcare segment is also challenging since regulating temperature becomes one of the key factors that affect healthcare quality control and involves the process of tractability and traceability. Various activities involving the HCM inclusive of manufacturing, storage, and distribution are also challenging due to several uncertain factors that emerged from both the healthcare application and from the logistic operations (Ali and Kannan 2022, Niemsakul *et al.* 2022, Senna *et al.* 2023, Vanbrabant *et al.* 2023). Thus, proper planning and design for the logistics system of HCM can enable efficient and effective storage and distribution activities of temperature-sensitive healthcare products.

The Global Healthcare Cold Chain Logistics Market Report & Forecast (2022) approximates that the HCM logistics market size for temperature-controlled products worldwide will reach US$ 20.3 Billion by 2027, which accounts for around 3.4% of the growth rate. Concerning the worldwide market, the United States is considered the biggest pharmaceutical logistics market followed by China and the group of emerging markets inclusive of middle and low-income countries (Statista, 2023). Additionally, it is expected that increasing demand is prevailing for the healthcare cold chain due also to recent case reports from diseases, which in turn influences the market size. Accordingly, governmental units from many nations aim to enforce effective regulations for the management and planning of temperature-sensitive HCM products.

In Thailand, various practices in the realm of HCM have also been observed to support effective logistics (DKSH 2022). For instance, telehealth or telemedicine has been promoted from 2020 to 2022 by the Ministry of Public Health for Thailand to manage the distribution of health-related services and information via electronic data and telecommunication technologies. In addition, emphasis is also given to the use of technology and innovation to support the development of special storage, handling, and transportation for temperature-sensitive healthcare products in the HCM. Moreover, given that the correct temperature is needed from the manufacturing phase to the point of consumption, the role of dedicated facilities is also essential to support efficient storage and distribution of healthcare products in HCM.

A general structure of the healthcare chain is presented in **Figure 1**, in which the information and physical flow include manufacturers at the upstream, distribution centers and warehouses at the midstream, and hospitals and drug stores at the downstream. Given that operational planning and management for HCM is challenging, we analyze both the location of the central hospital acting as a distribution center and the distribution plan for HCM in this research. Initially, we assess the proper locations of central hospitals using the K-means algorithm at the midstream of the healthcare chain. Next, we assess the distribution plan of medical supplies using the capacitated vehicle routing problem (CVRP) model from the midstream to the hospitals at the downstream process. Then, our integrated framework is verified and validated using a case study of hospitals in Thailand, in which the Geographic Information System (GIS) is applied.

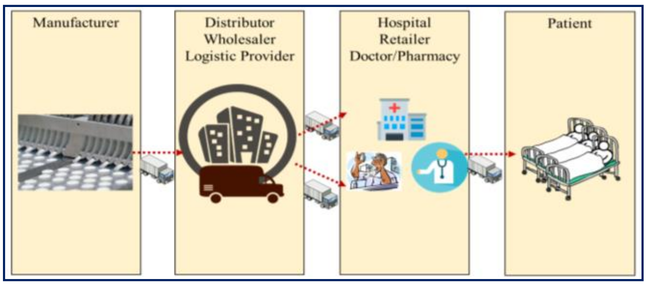

**Figure 1** A supply chain framework of HCM

The less of the paper is organized as follows. We provide an overview of relevant literature for logistics planning of HCM in Section 2. Next, the proposed mathematical model inclusive of both the K-Means algorithm and routing optimization algorithm is presented in Section 3. Then, results and discussion are provided in Section 4. Finally, our research conclusions and future research areas are presented in Section 5.

## 2. LITERATURE REVIEW

### *2.1 Supply Chain Planning and Management*

We next briefly discuss key backgrounds and recent studies in the realm of Logistics and Supply Chain Management (LSCM). LSCM, in particular, involves two interrelated components. That is, supply chain management focuses on a network of activities and key stakeholders involved in the process of transforming raw materials from suppliers to end consumers. Logistic management is a subset of the supply chain, which refers to the processes of acquiring, storing, and delivering resources along the supply chain (Ransikarbum *et al*. 2021, Ransikarbum and Mason 2022, Ransikarbum *et al.* 2023, Nannar *et al.* 2024, Ransikarbum and Pitakaso 2024). Managing both information and physical flow effectively and efficiently is thus needed for the realization of LSCM (Watanabe and Patitad 2022, Watanabe *et al.* 2022). The planning and design for LSCM, in particular, deals with time-phase levels of decision, which can be divided into three phases for strategic-level planning (i.e., long-term phase in years), tactical-level planning (i.e., medium-term phase in months or quarters), and operational-level planning (i.e., short-term phase in days or weeks). According to Biedova and Mahdikhani (2023), dominant themes of future research for LSCM include supply chain integration, risk management, and sustainability.

Concerning network optimization, the evaluation of optimal nodes (i.e., locations) and/or arcs (i.e., distributions) are typically evaluated for the supply chain planning and management of interest applications. Furthermore, operations research and/or optimization methodology typically involves mathematical programming, simulation modeling, and decision analysis techniques to quantitatively investigate the network of LSCM (Wattanasaeng and Ransikarbum 2019, Kumar *et al.* 2020, Chanthakhot and Ransikarbum 2021). While decisions related to optimal locations, assessing sourcing, and deciding storage location are considered a type of strategic decision; multi-period planning, distribution-mode planning, and fleet-size evaluation can be considered a type of tactical decision. Additionally, daily planning (i.e., loading plan) is a type of operational decision. While existing studies in the realm of LSCM are concerned with specific decision categories, integrated decisions among planning categories are called for (Zhang *et al*. 2021, Ali and Kannan 2022). In this research, we focus our study on the integrated strategic-level decision and tactical-level decision, in which both the location analysis and distribution plan of the LSCM are examined.

A digital LSCM is a set of processes that use advanced tools and technologies in the functions of the chain so that better decisions about the key decisions along the LSCM can be justified. Several studies have been proposed with selective technologies and challenges requiring more focus from both researchers and practitioners, such as the realm of risk management for LSCM in the digital age (Ivanov *et al.* 2019, Zekhnini *et al*. 2022), the use of Artificial Intelligence (AI) for LSCM (Ganesh and Kalpana 2022, Sharma *et al.* 2022), and the integration of Machine Learning (ML) and optimization (Oh *et al*. 2019, Yan *et al*. 2022). Additionally, recent studies and experts in the field of LSCM also suggest that existing tools shown to be successful for commercial application of LSCM should be applied and used in other challenging applications, such as humanitarian logistics (Khan *et al.* 2022, Altay *et al.* 2023), service supply chain (Ivanov *et al.* 2022, Nagariya *et al.* 2022, Ramish *et al.* 2022), and healthcare cold chain (Dixit *et al*. 2019, Ali and Kannan 2022, Banik *et al*. 2022, Wahab *et al.* 2023).

## *2.2 Healthcare Chain Management*

The healthcare chain can be considered a specific application of LSCM. One definition of the HCM is proposed by Beaulieu and Bentahar (2021). The authors suggest that HCM is the strategic planning and design of the external LSCM and internal flows, including material, pharmaceutical products, medical supplies, patients, catering, and waste with the sustainable aim of creating value for stakeholders. Additionally, recent applications of model and network analysis in the realm of HCM are recommended in recent literature-review papers (Dixit *et al.* 2019, Marques *et al*. 2020, Beaulieu and Bentahar 2021, Ali and Kannan 2022, Rehman and Ali 2022).

For instance, Dixit *et al*. (2019) propose a literature analysis, or recent papers related to the HCM and suggest certain future research directions related to risk management, waste management, monitoring and tractability, and cold chain management. Beaulieu and Bentahar (2021) suggest that current practices deployed in the HCM lag far behind other applications in the realm of LSCM. The authors further recommend relevant initiatives for making inventory policies, internal flows within the healthcare facility, and external LSCM for the healthcare sector more dynamic and proactive to adapt to the digitalization and evolution of HCM activities. Additionally, Ali and Kannan 2022 evaluate emerging topics for the healthcare supply chain and suggest promising themes involving sustainable operations, circular economy, industry 4.0 technologies, and resilience supply chain aspects. According to the authors, the wildly popular topic for HCM is related to pharmaceutical products and challenges. Concerning the cost components, personal cost and logistics cost are identified as the top two components in the HCM. Rehman and Ali (2022) additionally apply MCDA techniques to evaluate resilience strategies for HCM and suggest that risk awareness and agility, industry 4.0 and multiple sourcing, and logistic operations are key to the success of HCM. Logistical operations for HCM are one of the challenging topics that need to be tackled and planned for in this complex digital age.

Several researchers have proposed studies relevant to the locational analysis of the LSCM for HCM applications (e.g., Şahin *et al*. 2019, Adalı and Tuş 2021, Gul and Guneri 2021, Alkan and Kahraman 2022, Chen *et al*. 2022, Fourie and Grobbelaar 2022, Yazdi *et al.* 2023). According to Gul and Guneri (2021) and Fourie and Grobbelaar (2022), the commonly used methodology for hospital facility location planning falls into the MCDA methodology followed by ML and optimization. In particular, the integrated Analytic Hierarchy Process (AHP) and GIS are found to be the preferred method for selecting a healthcare location. Additionally, the most used criteria are found to be related to the total cost, environment, demand, population, and market competition. For example, Shin *et al*. (2019) apply one of the MCDA techniques called AHP to evaluate proper hospital sites in Turkey with several criteria and sub-criteria. The authors find that demand is the most important criterion. Adalı and Tuş (2021) compare several distance- based MCDA tools to evaluate hospital site selection, in which the market condition is found to be the most important criterion in their study.

Later, researchers applied and took uncertainty into account to assess healthcare facility sites, in which the fuzzy set is found to be the most preferred technique (e.g., Alkan and Kahraman 2022). Recently, other studies have focused on the use of ML-based techniques to investigate hospital site selection problems for HCM (e.g., Almansi *et al.* 2021, Benmoussa *et al.* 2022, Niemsakul *et al*. 2022). For instance, Almansi *et al*. (2021) compare different ML tools inclusive of the Support Vector Machine (SVM), multilayer perception, and linear regression to evaluate suitable hospital locations. Niemsakul *et al*. (2022) also apply the K-means algorithm to assess suitable hospital locations to act as a central hospital in the HCM. The above authors point out that ML techniques are found to be promising approaches to investigating optimal hospital sites for operative health planning. Later, recent studies used integrated approaches to account for both MCDA and ML-based techniques to tackle hospital site location problems. For instance, Benmoussa *et al*. (2022) integrate AHP and random forest techniques to examine the pattern of the hospital site selection. The authors also apply the above-integrated tool to the case study using the GIS platform.

Additionally, the other group of researchers have examined the distribution plan and management issue of HCM (e.g., Agra *et al.* 2019, Gong *et al.* 2020, Zabinsky *et al.* 2020, PG Petroianu *et al.* 2021, Sun *et al.* 2021, and Li *et al.* 2023). For example, Agra *et al*. (2019) present a weekly distribution plan of medical products that optimizes the total number of location visits. The authors integrate inventory capacity, safety stock, and vehicle capacity into their work. Gong *et al*. (2020) proposes a decision-supporting tool for home care scheduling problems by evaluating routing decisions from caregivers to clients. Operating cost is used as the key criterion in their study. Zabinsky *et al.* (2020) proposes a mathematical programming tool to address healthcare scheduling and routing problems. The authors assess transportation routes to pick up medical specimens from clinics and hospitals to a central laboratory under completion time minimization. PG Petroianu *et al.* (2021) propose the decision-aid tool to plan for delivering medical commodities and vaccines to healthcare centers in the HCM. According to the authors, there is a need to also account for intermediary storage decisions of vaccines.

In this paper, our research focus shifts to the integrated approach to tackle both the locational decision at the strategic decision level and the distribution plan at the tactical decision level for HCM. Whereas the locational clustering decision is examined using one of the ML techniques called the K-means algorithm, the distribution and routing plan is sequentially integrated and analyzed using the vehicle routing algorithm. We further discuss existing research gaps as presented in **Table 1** and present our research highlights as follows:

- Prevailing studies are conducted on either the locational planning or distribution planning for the healthcare chain alone. In this research, we investigate the locational data of central hospitals acting as the distribution centers at the midstream of the healthcare chain and later sequentially assess the distribution plan of medical supplies in an integrated way.
- Few studies evaluate integrated planning that accounts for both location and distribution analysis. Our proposed study integrates the machine learning technique (i.e., K-means algorithm) and the

mathematical programming (i.e., CVRP model). That is, the K-means algorithm is applied to assess location clusters in the first phase and then the CVRP model is later used to investigate the distribution planning for HCM in the second phase.

- Rather than using simple case study data, there is a need to call for the use of GIS-based technologies to aid the visualization related to logistics operations. Thus, we incorporate the use of GIS-based QGIS software to illustrate the applicability of the proposed model. Additionally, the sensitivity analysis is conducted to explore the clustering classification scheme for central hospitals.

**Table 1** Recent studies in the realm of HCM

| Study | HCM | | | Methodology | | Case Study |
|---|---|---|---|---|---|---|
| | Location | Distribution | Others | Mathematical Model | Others | |
| Agra *et al.* (2019) | | x | Inventory | Mixed Integer Programming | | Portugal |
| Shin *et al.* (2019) | x | | | MCDA (AHP) | | Hospital site / Turkey |
| Gong *et al.* (2020) | | x | | Metaheuristic Programming | | New York, USA |
| Nikzamir *et al.* (2020) | x | x | Hospital wastes | MILP | Benders Alg. | Iran |
| Zabinsky *et al.* (2020) | | x | Routing / Scheduling | MILP | | Washington, USA |
| Adalı and Tuş (2021) | x | | | Integrated MCDA | | Turkey |
| Almansi *et al.* (2021) | x | | | Integrated ML (SVM, multilayer, regression) | | Palestine |
| PG Petroianu *et al.* (2021) | | x | | VRP | | Washington, USA |
| Alkan and Kahraman 2022 | x | | | MCDA (TOPSIS) | Fuzzy (Uncertainty) | Turkey |
| Benmoussa *et al.* (2022) | x | | | AHP and random forest | GIS | Algeria |
| Das *et al.* (2023) | | x | Cold chain | Metaheuristic Alg. | | India |
| ***This study*** | x | x | *Cluster* | *K-means / CVRP* | *GIS* | *Bangkok, Thailand* |

# 3. RESEARCH METHODOLOGY

## 3.1 Problem Statement

We next discuss the methodology and the problem statement. Our integrated procedure is illustrated with the HCM with a two-echelon chain (i.e., hospital nodes and central distribution center nodes). In particular, the first-phase study involves the evaluation of locational clustering decisions for the group of existing hospitals and potential central distribution centers in the healthcare chain using the K-means clustering method. Next, the second-phase study is to examine the vehicle routing problem to investigate distribution plans from the central distribution centers to associated hospital locations. **Figure 2** illustrates the problem statement in our study.

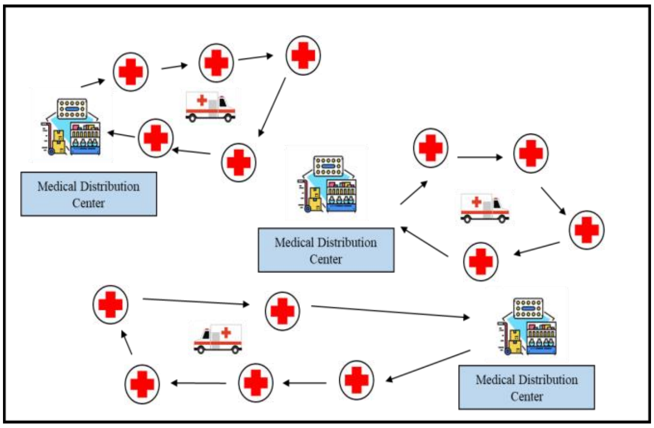

**Figure 2** A schematic illustration of the problem

## 3.2 Methodology Flow

We next present the integrated mathematical model to evaluate both the location and distribution plan for HCM as shown in **Figure 3**. The methodology is sequentially divided into two phases as follows. During the first-phase procedure, the locational data of central hospitals are examined using the K-means algorithm at the midstream of the healthcare chain. The methodology starts with selecting the number of clusters of hospitals. We further conduct the sensitivity analysis to evaluate the proper number of clusters in the study. Next, the initial centroid and distance are assessed to cluster the objects in the proper cluster. Then, the methodology is continued until the termination condition is met.

Then, during the second-phase procedure, the distribution plan of medical supplies is evaluated using the CVRP model. That is, we initially propose the mathematical model to assess the distribution plan for HCM. Then, the model functionality is evaluated, and the case study is applied. We note that the outcome for locations of central hospitals is then later used as an input to the second-phase methodology in this study. We further discuss each particular phase in detail as follows.

## 3.3 Phase I: Location Analysis in HCM

We next discuss the K-means clustering method to examine the cluster classification. That is, the K-means clustering method is a type of unsupervised machine learning algorithm, which can classify various data into $k$ clusters. Additionally, the conventional K-means algorithm will also seek the minimum-sum-of-squares results as illustrated in Equation (1). That is, the algorithm will move $n$

observations, such that they are partitioned into $k$ sets S = {S$_1$, S$_2$, . . . , S$_k$} and the objective of minimizing the sum of squares is reached. The K- means algorithm technique requires the exact value for the cluster number as an input to evaluate the proper classification (Ahmed *et al.* 2020, Lusiantoro *et al.* 2022, Ransikarbum and Madathil 2022, Alvarez-Uribe *et al.* 2023).

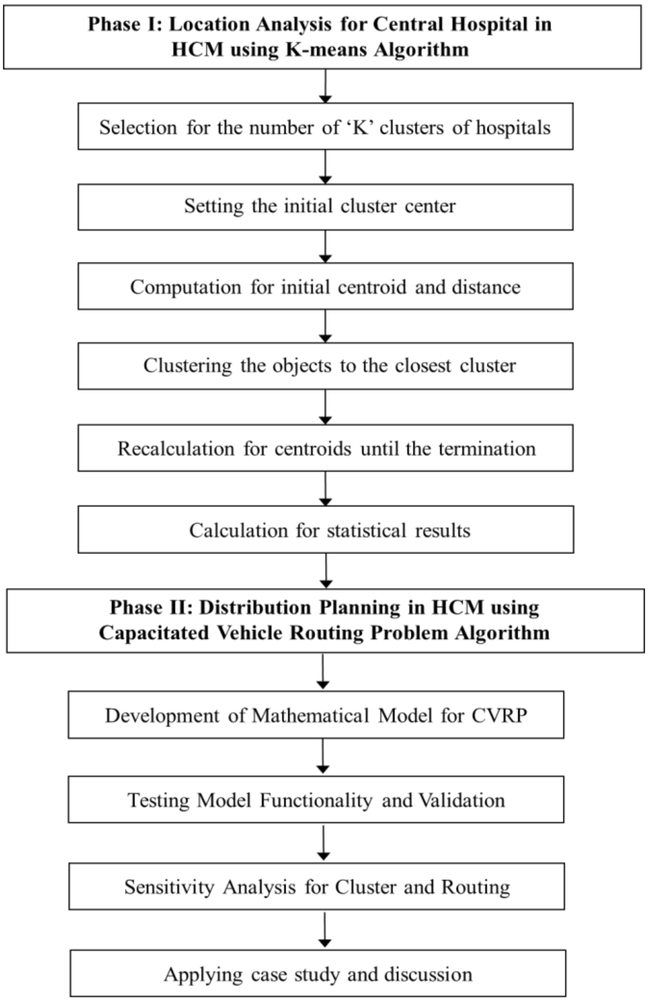

**Figure 3** A high-level methodology to evaluate location and distribution planning for HCM

Next, given the hospital clusters, the rectilinear-distance minimization model is integrated to obtain the proper location of central distribution centers (i.e., central hospitals) in each cluster of analyzed hospitals. The rectilinear-distance minimization model, in particular, aims to evaluate the proper location by minimizing the sum of the absolute difference in respective coordinates based on the rectilinear distance (Celik Turkoglu and Erol Genevois 2020). The rectilinear distance is regarded as a proper measure for travel distances between points via rectilinear aisles in a facility or streets in a city network, which is thus applied and used in our study. The mathematical notations are presented in Equations (2) and (3), in which ($X$ or $x, y$) is the analyzed optimal location, ($P_i$ or $a_i, b_i$) is the present location of the hospital $i$ in each cluster, and $d(X, P_i)$ is the computed rectilinear distance from the central distribution centers (i.e., central hospitals) and the current location of hospitals in a respective cluster.

$$argmin \sum_{i=1}^{k} \sum_{x \in S} \|X - \mu_i\|^2 \quad (1)$$

$$\text{Minimize} \qquad f(X) = \sum_i d(X, P_i) \quad (2)$$

$$f(x, y) = \sum_i |x - a_i| + \sum_i |y - b_i| \quad (3)$$

## *3.4 Phase II: Distribution Plan Analysis in HCM*

We next present the CVRP model with a limited time planning horizon to analyze the distribution plan from a given central distribution center to hospital areas. The CVRP algorithm and its variances have been evaluated, extended, and applied in recent studies (Puchongkawarin and Ransikarbum 2021, Sluijk *et al.* 2022). The mathematical notations are presented below.

### *3.4.1 Mathematical Notation*

Set

| | |
|---|---|
| $G$ | Set of the network or graph of healthcare chain comprising of node $N$ and arc $A$ |
| $N$ | Set of all nodes in the healthcare chain, in which 0 represents the central hospital |
| $A$ | Set of all arcs in the healthcare chain |
| $V$ | Set of the vehicle fleet in the healthcare chain |

Parameter

| | |
|---|---|
| $n$ | Parameter for the total number of nodes in the healthcare chain |
| $m$ | Parameter for the total number of available vehicles/vans at the central hospital |
| $c^f$ | Fixed cost associated with utilizing a particular vehicle |
| $c^v$ | Variable costs associated with delivering healthcare products in the healthcare chain |
| $f^{trans}$ | Fuel consumption rate associated with a type of vehicle |
| $d_{i,j}$ | Parameter for the delivery distance between node *i* and *j*; $(i, j) \in A$ |
| $q_i$ | Parameter for the number of medical supplies to be delivered for each node $i \in N$ |
| $pq_k^{cap}$ | Parameter for the capacity of each vehicle *k* |
| $s_k$ | Parameter for the speed of each vehicle *k* |
| $t^b$ | Parameter for the starting planning time horizon |
| $t^e$ | Parameter for the ending planning time horizon |
| $t_i^s$ | Parameter for service time at each node *i* |
| $t_{i,j}$ | Parameter for the traveling time between node i and j; $(i, j) \in A$ |
| $l$ | Parameter for an arbitrarily large number for model requirement |

Decision Variable

| | |
|---|---|
| $X_{i,j,k}$ | Binary decision variable representing if the transportation occurs between locations *i* and *j* with a vehicle type *k* |
| $Y_{i,j}$ | Continuous decision variable representing for delivery amount of healthcare products from node *i* in an arc $(i, j) \in A$, in which $Y_{i,j}$ is within the capacity limit |
| $V_{i,k}$ | Continuous decision variable representing arrival time at each node *i* of vehicle *k* |

### *3.4.2 Mathematical Model*

We next discuss the mathematical model of the vehicle routing model inclusive of the objective function and key constraint sets. In particular, the total cost minimization is to be obtained, in which both fixed and variable costs of utilizing vehicles and delivering healthcare products through the healthcare chain are investigated and aimed as presented in Equation (4).

Next, the mathematical model's requirements are evaluated with defined constraint sets as follows. The first set of constraints restricts that only one vehicle will go into a particular hospital node per unit time (Equation (5)). The next set of constraints requires that an entering vehicle to a particular hospital node is the same leaving vehicle from the same hospital node (Equation (6)). Additionally, each vehicle that is going out of the central distribution center (i.e., central hospital) must go into each particular hospital in the healthcare chain (Equation (7)). Moreover, the set of constraints in Equations (8) and (9) are combined to calculate the total increasing amount of delivering quantity from hospitals as well as to ensure that the amount up to a particular hospital node in the healthcare chain will not surpass the capacity limit of each vehicle. Equation (10) computes the set of constraints for computing the starting time of the planning horizon for all vehicles. The constraint set in Equation (11) ensures that the latest time for all vehicles is within the planning horizon. The constraint set in Equation (12) computes the time that each vehicle arrives at each node in the network. Last but not least, variable-type constraints for all decision variables are defined as presented in Equations (13) - (15).

$$Minimize Z_1 = \sum_{(0,j)\in A;\, k\in V}^{\sum\sum_{(i,j)\in A;\, k\in V}^{\sum}(c^v d_{i,j}/f^{trans})X_{i,j,k}} c^f X_{i,j,k} \quad (4)$$

$$\sum_{i\in N; i\neq j}\sum_{k\in V} X_{i,j,k} = 1 \quad ;\forall j = 1,\dots,n \quad (5)$$

$$\sum_{i\in N; i\neq j} X_{i,j,k} = \sum_{i\in N; i\neq j} X_{j,i,k} \;;\forall j = 1,\dots,n; k\in V \quad (6)$$

$$\sum_{j\in 1,\dots,n} X_{0,j,k} \leq 1 \quad ;\forall k\in V \quad (7)$$

$$\sum_{(i,j)\in A} Y_{i,j} - \sum_{(j,i)\in A} Y_{j,i} = q_j \;;\forall j = 1,\dots,n \quad (8)$$

$$Y_{i,j} \leq \sum_{k\in V} pq_k^{cap} X_{i,j,k} \;;\forall (i,j)\in A \quad (9)$$

$$V_{i=0,k\in V} = t^b \quad ;\forall k\in V \quad (10)$$

$$V_{i=n+1,k} - V_{o\in N,k} \leq t^e \;;\forall k\in V \quad (11)$$

$$V_{i,k} + t_i^s + t_{i,j} - V_{j,k} \leq l(1 - X_{i,j,k}); \\ ;\forall (i,j)\in A, k\in V \quad (12)$$

$$X_{i,j,k} \in \{0,1\} \;;\forall (i,j)\in A, k\in V \quad (13)$$

$$Y_{i,j} \geq 0 \;;\forall (i,j)\in A \quad (14)$$

$$V_{i,k} \geq 0 \;;\forall i = 1,\dots,n; k\in V \quad (15)$$

# 4. CASE STUDY AND RESULTS

## *4.1 Plan for Long-term Central Hospital Location*

In this section, we present the illustrated case study to plan and manage for long-term locating central distribution center in the HCM. Initially, we collect qualitative and quantitative data for the associated hospitals of the case study. We note that the obtained data are from the open-data source from Thailand's Ministry of Public Health and also from the Digital Government Development Agency (DGDA 2022). That is, there are 10,622 hospitals reported for all the hospitals in Thailand. The most affiliation belongs to the Ministry of Public Health accounting for 99.10% followed by other affiliations representing 0.90%, such as the Bangkok unit, Ministry of Defense, Ministry of Justice, and the Royal Thai Police. Next, we evaluate all the hospitals located in the capital of Thailand, the Bangkok area to scope our study and to verify and validate the model functionalities. The initial analysis shows that there are 99 hospitals in the Bangkok area, where approximately 88% are hospitals affiliated with the Bangkok unit, 5% are hospitals affiliated with the Ministry of Public Health, 4% are hospitals affiliated with the Ministry of Defense, 2% are hospital affiliated with the Royal Thai Police, and 1% from the Ministry of Justice as illustrated in **Figure 4**. We further illustrate data associated with the 99 hospitals in the Bangkok area (the scope of this research's case study) using GIS as shown in **Figure 5**. We further denote latitude and longitude data and provide hospital codes for further analysis as illustrated in **Table 2.**

We next evaluate the parameter *K* representing the cluster number for all planned hospitals. We note that different methods exist to define the cluster number, where the elbow method is applied in this case (Banik *et al.* 2022). In particular, the elbow method is considered a popular graphical procedure, which can be used to visually assess the optimal cluster number. That is, the Within-Cluster Sum of Square (WCSS) representing the sum of the square distance between points in a cluster and the cluster centroid is to be computed and evaluated. In particular, the elbow point with the shifting for the rate of decrease will be selected as shown in **Figure 6**. Thus, as can be seen from the figure, the assessed number of clusters is seven clusters in this case study.

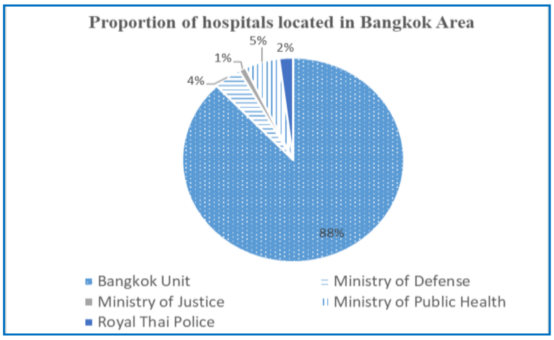

**Figure 4** Hospital proportion located in the Bangkok area for the case study

All the evaluated hospitals are 1classifie4d into different clusters as shown in **Figure 7**, which suggests that hospitals are classified into each cluster based on their locations in the GIS platform.

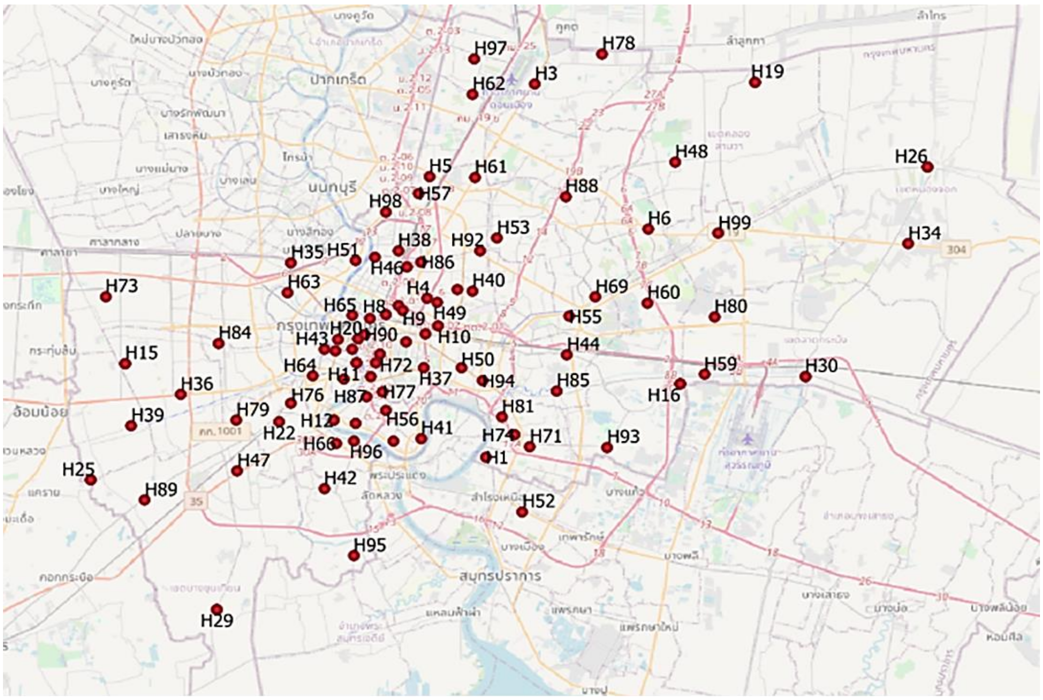

**Figure 5** GIS-based hospital locational data for the case study

**Table 2** Hospital locational data for the case study

| Code | Latitude | Longitude | Code | Latitude | Longitude | Code | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|
| H1 | 13.67027 | 100.58800 | H34 | 13.80702 | 100.84754 | H67 | 13.74923 | 100.55081 |
| H2 | 13.76732 | 100.53416 | H35 | 13.79493 | 100.46814 | H68 | 13.73827 | 100.49957 |
| H3 | 13.90929 | 100.61801 | H36 | 13.71051 | 100.40066 | H69 | 13.77288 | 100.65562 |
| H4 | 13.77195 | 100.55157 | H37 | 13.72767 | 100.54999 | H70 | 13.69182 | 100.50178 |
| H5 | 13.85018 | 100.55313 | H38 | 13.80261 | 100.53469 | H71 | 13.67709 | 100.61345 |
| H6 | 13.81657 | 100.68758 | H39 | 13.69046 | 100.37097 | H72 | 13.73631 | 100.52227 |
| H7 | 13.72219 | 100.51744 | H40 | 13.77681 | 100.57514 | H73 | 13.77327 | 100.35544 |
| H8 | 13.76184 | 100.52643 | H41 | 13.68248 | 100.54806 | H74 | 13.68486 | 100.60557 |
| H9 | 13.76429 | 100.53679 | H42 | 13.65028 | 100.48837 | H75 | 13.75926 | 100.51668 |
| H10 | 13.75450 | 100.55834 | H43 | 13.73940 | 100.48879 | H76 | 13.70581 | 100.46684 |
| H11 | 13.73061 | 100.50843 | H44 | 13.73583 | 100.63742 | H77 | 13.71227 | 100.52467 |
| H12 | 13.69394 | 100.49427 | H45 | 13.79241 | 100.53987 | H78 | 13.92867 | 100.6593 |
| H13 | 13.65567 | 100.34537 | H46 | 13.79861 | 100.51966 | H79 | 13.69478 | 100.46348 |
| H14 | 13.85621 | 100.85910 | H47 | 13.66155 | 100.43505 | H80 | 13.76027 | 100.72684 |
| H15 | 13.73047 | 100.36659 | H48 | 13.85932 | 100.70414 | H81 | 13.69612 | 100.59779 |
| H16 | 13.71722 | 100.70730 | H49 | 13.76972 | 100.55814 | H82 | 13.73978 | 100.50518 |
| H17 | 13.57280 | 100.42277 | H50 | 13.72789 | 100.57294 | H83 | 13.77754 | 100.57024 |
| H18 | 13.72218 | 100.78392 | H51 | 13.79632 | 100.50831 | H84 | 13.74329 | 100.42339 |
| H19 | 13.91053 | 100.75327 | H52 | 13.63549 | 100.61036 | H85 | 13.71288 | 100.63144 |
| H20 | 13.74618 | 100.50953 | H53 | 13.81075 | 100.59968 | H86 | 13.79537 | 100.54884 |
| H21 | 13.74414 | 100.53913 | H54 | 13.68085 | 100.53122 | H87 | 13.70933 | 100.51847 |
| H22 | 13.69291 | 100.46105 | H55 | 13.76041 | 100.63872 | H88 | 13.83725 | 100.63868 |
| H23 | 13.73061 | 100.50843 | H56 | 13.70008 | 100.55566 | H89 | 13.64279 | 100.37785 |
| H24 | 13.69394 | 100.49427 | H57 | 13.83985 | 100.54126 | H90 | 13.74899 | 100.51336 |
| H25 | 13.65567 | 100.34536 | H58 | 13.74577 | 100.49639 | H91 | 13.73077 | 100.52031 |
| H26 | 13.85621 | 100.85910 | H59 | 13.72363 | 100.72234 | H92 | 13.80258 | 100.58423 |
| H27 | 13.73047 | 100.36659 | H60 | 13.76934 | 100.68695 | H93 | 13.67675 | 100.66124 |
| H28 | 13.71722 | 100.70730 | H61 | 13.84901 | 100.58116 | H94 | 13.71915 | 100.53856 |
| H29 | 13.57280 | 100.42279 | H62 | 13.90271 | 100.57937 | H95 | 13.60724 | 100.50567 |
| H30 | 13.72218 | 100.78390 | H63 | 13.77869 | 100.46628 | H96 | 13.68093 | 100.50648 |
| H31 | 13.91053 | 100.75327 | H64 | 13.72231 | 100.48132 | H97 | 13.92545 | 100.58057 |
| H32 | 13.74618 | 100.50953 | H65 | 13.76775 | 100.50589 | H98 | 13.82751 | 100.52363 |
| H33 | 13.72047 | 100.50062 | H66 | 13.67962 | 100.49583 | H99 | 13.81363 | 100.73064 |

Additionally, we further investigate the proper locations of central distribution centers (i.e., central hospitals) in the healthcare chain using the rectilinear-distance location model. That is, the rectilinear distance is illustrated to represent the street way for the delivery route of vehicles in the healthcare chain as presented in **Figure 8.**

Additionally, the sensitivity analysis can be further evaluated to examine parameter uncertainty and the functionality of the evaluated clustering scheme. In our analysis, the parameter *K* is varied from 2 to 10 clusters to further investigate potential policies related to other cluster schemes (e.g., clustering based on the district restrictions, clustering based on the population density, etc.) as presented in **Table 3**.

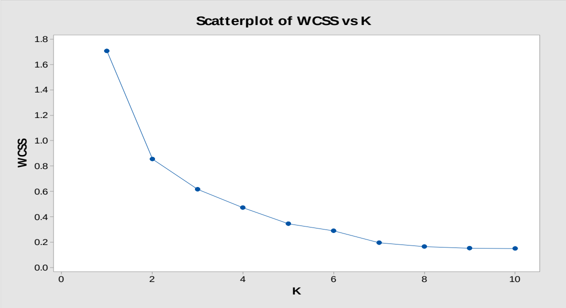

**Figure 6** The elbow method for evaluating hospital cluster number

**Figure 7** Clusters of hospitals in the evaluated case

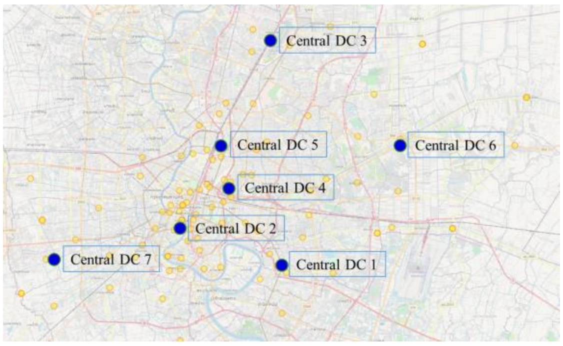

**Figure 8** Locations of central hospitals in the evaluated case

## *4.2 Plan for Short-term Hospital Distribution Plan*

We next illustrate the plan to manage short-term hospital distribution plan in this subsection. Given the long-term plan to suitably locate the central hospital location acting as a distribution center in the HCM, the daily or weekly distribution plan needs to be evaluated next. To exemplify the application of the CVRP model suggested earlier in this study, we further obtain the case study data of distributing medical supplies from the illustrated distribution center company. Collected historical data for locations of distributed hospitals from two selected distribution centers (DCs) are shown in **Table 4**. The average number of daily distributed hospitals from the first and the second central distribution centers are found to be 24 and 18 hospitals, respectively. Other relevant measures are also shown in the table. The analysis of data centrality and dispersion for delivering medical supplies from central distribution centers suggests that the daily plan highly varies for both central DCs. That is, the range of hospitals to be delivered from central DC1 is between 1 and 150 hospitals, whereas the range from central DC2 is between 1 and 105 hospitals. This is expected to be due to the high uncertainty in requesting medical supplies daily in a healthcare chain. Thus, managing to deliver a plan becomes challenging and planning with multiple vehicles using sophisticated tools is clearly needed.

**Table 3** Sensitivity analysis for clustering parameter

| Hospital Code | Parameter 'K' | | | | | | | | Hospital Code | Parameter 'K' | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| H1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | H51 | 2 | 1 | 4 | 4 | 5 | 2 | 2 | 2 |
| H2 | 2 | 1 | 4 | 4 | 5 | 2 | 2 | 2 | H52 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| H3 | 1 | 1 | 4 | 5 | 3 | 3 | 3 | 3 | H53 | 1 | 1 | 4 | 5 | 5 | 5 | 5 | 5 |
| H4 | 2 | 1 | 4 | 4 | 5 | 4 | 4 | 4 | H54 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 |
| H5 | 2 | 1 | 4 | 5 | 5 | 5 | 5 | 5 | H55 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 10 |
| H6 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 10 | H56 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 |
| H7 | 2 | 2 | 2 | 4 | 4 | 2 | 8 | 8 | H57 | 2 | 1 | 4 | 5 | 5 | 5 | 5 | 5 |
| H8 | 2 | 1 | 4 | 4 | 5 | 2 | 2 | 2 | H58 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 |
| H9 | 2 | 1 | 4 | 4 | 5 | 2 | 2 | 2 | H59 | 1 | 3 | 1 | 1 | 1 | 6 | 6 | 10 |
| H10 | 2 | 1 | 4 | 4 | 5 | 4 | 4 | 4 | H60 | 1 | 3 | 1 | 1 | 1 | 6 | 6 | 10 |
| H11 | 2 | 2 | 2 | 4 | 4 | 2 | 8 | 8 | H61 | 1 | 1 | 4 | 5 | 3 | 5 | 5 | 5 |
| H12 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 | H62 | 1 | 1 | 4 | 5 | 3 | 3 | 3 | 3 |
| H13 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H63 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 |
| H14 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 6 | H64 | 2 | 2 | 2 | 4 | 4 | 8 | 8 | 8 |
| H15 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H65 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 |
| H16 | 1 | 3 | 1 | 1 | 1 | 6 | 6 | 10 | H66 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 |
| H17 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H67 | 2 | 1 | 4 | 4 | 5 | 4 | 4 | 4 |
| H18 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 10 | H68 | 2 | 2 | 2 | 4 | 4 | 2 | 8 | 8 |
| H19 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 6 | H69 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 10 |
| H20 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 | H70 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 |
| H21 | 2 | 1 | 4 | 4 | 4 | 2 | 8 | 4 | H71 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| H22 | 2 | 2 | 2 | 2 | 4 | 8 | 9 | 9 | H72 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 |
| H23 | 2 | 2 | 2 | 4 | 4 | 2 | 8 | 8 | H73 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 |
| H24 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 | H74 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| H25 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H75 | 2 | 1 | 4 | 4 | 5 | 2 | 8 | 8 |
| H26 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 6 | H76 | 2 | 2 | 2 | 2 | 4 | 8 | 9 | 9 |
| H27 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H77 | 2 | 2 | 2 | 4 | 4 | 8 | 8 | 9 |
| H28 | 1 | 3 | 1 | 1 | 1 | 6 | 6 | 10 | H78 | 1 | 3 | 3 | 5 | 3 | 3 | 3 | 3 |
| H29 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H79 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 |
| H30 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 10 | H80 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 10 |
| H31 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 6 | H81 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| H32 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 | H82 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 |
| H33 | 2 | 2 | 2 | 4 | 4 | 8 | 8 | 8 | H83 | 2 | 1 | 4 | 4 | 5 | 4 | 4 | 4 |
| H34 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 6 | H84 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 |
| H35 | 2 | 2 | 4 | 4 | 5 | 2 | 2 | 8 | H85 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| H36 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H86 | 2 | 1 | 4 | 4 | 5 | 5 | 2 | 2 |

**Table 3** Sensitivity analysis for clustering parameter (Con’t)

| Hospital Code | Parameter ‘K’ | | | | | | | | Hospital Code | Parameter ‘K’ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2** | **3** | **4** | 2 | **2** | **3** | **4** | 7 | | **2** | **3** | **4** | **5** | **6** | **8** | **9** | **10** |
| H37 | 2 | 1 | 4 | 4 | 4 | 4 | 8 | 4 | H87 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 |
| H38 | 2 | 1 | 4 | 4 | 5 | 5 | 2 | 2 | H88 | 1 | 1 | 4 | 5 | 3 | 5 | 5 | 3 |
| H39 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H89 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 |
| H40 | 2 | 1 | 4 | 4 | 5 | 4 | 4 | 4 | H90 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 |
| H41 | 2 | 2 | 1 | 4 | 4 | 8 | 9 | 9 | H91 | 2 | 2 | 4 | 4 | 4 | 2 | 8 | 8 |
| H42 | 2 | 2 | 2 | 2 | 4 | 8 | 9 | 9 | H92 | 2 | 1 | 4 | 5 | 5 | 5 | 5 | 5 |
| H43 | 2 | 2 | 2 | 4 | 4 | 2 | 8 | 8 | H93 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| H44 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | H94 | 2 | 1 | 1 | 1 | 1 | 4 | 1 | 1 |
| H45 | 2 | 1 | 4 | 4 | 5 | 5 | 2 | 2 | H95 | 2 | 2 | 2 | 2 | 4 | 8 | 9 | 9 |
| H46 | 2 | 1 | 4 | 4 | 5 | 2 | 2 | 2 | H96 | 2 | 2 | 2 | 4 | 4 | 8 | 9 | 9 |
| H47 | 2 | 2 | 2 | 2 | 2 | 7 | 7 | 7 | H97 | 1 | 1 | 4 | 5 | 3 | 3 | 3 | 3 |
| H48 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 6 | H98 | 2 | 1 | 4 | 5 | 5 | 5 | 2 | 5 |
| H49 | 2 | 1 | 4 | 4 | 5 | 4 | 4 | 4 | H99 | 1 | 3 | 3 | 3 | 6 | 6 | 6 | 10 |
| H50 | 2 | 1 | 1 | 4 | 4 | 4 | 4 | 4 | | | | | | | | | |

**Table 4** Hospital drop points for delivering medical supplies from central distribution centers

| Distribution Data | Central DC 1 | Central DC 2 |
|---|---|---|
| Mean | 24 hospitals | 18 hospitals |
| Median | 5 hospitals | 11 hospitals |
| Mode | 1 hospital | 6 hospitals |
| Min | 1 hospital | 1 hospital |
| Max | 150 hospitals | 105 hospitals |
| Standard deviation | 37 hospitals | 19 hospitals |

Additionally, we exemplify the daily operational plan for both selected distribution centers with 16 cases as shown in **Table 5**, in which cases 8 cases (i.e., D-D1 – D-D8) are to illustrate the plan for medical deliveries from the central DC 1 and the other 8 cases (i.e., B-D1 – B-D8) are to plan from the central DC 2, respectively. That is, each central distribution center will collect, transport, and distribute medical supplies daily. For example, Case number 1 (i.e., Case D-D1) shows that there is a requirement for a distribution plan from the Central DC 1 to 19 hospitals, whereas Case number 9 (i.e., Case B-D1) shows that there are 14 hospitals required for the distribution plan. Other case study numbers can be similarly interpreted.

**Table 5** Daily distribution plan for selected hospitals

| Case Number | Case Study | Distributor | Daily Plan | Number of Hospitals |
|---|---|---|---|---|
| No. 1 | Case D-D1 | Central DC 1 | Day 1 | 19 Hospitals |
| No. 2 | Case D-D2 | Central DC 1 | Day 2 | 15 Hospitals |
| No. 3 | Case D-D3 | Central DC 1 | Day 3 | 12 Hospitals |
| No. 4 | Case D-D4 | Central DC 1 | Day 4 | 10 Hospitals |
| No. 5 | Case D-D5 | Central DC 1 | Day 5 | 22 Hospitals |
| No. 6 | Case D-D6 | Central DC 1 | Day 6 | 18 Hospitals |
| No. 7 | Case D-D7 | Central DC 1 | Day 7 | 26 Hospitals |
| No. 8 | Case D-D8 | Central DC 1 | Day 8 | 19 Hospitals |
| No. 9 | Case B-D1 | Central DC 2 | Day 1 | 14 Hospitals |
| No. 10 | Case B-D2 | Central DC 2 | Day 2 | 25 Hospitals |
| No. 11 | Case B-D3 | Central DC 2 | Day 3 | 11 Hospitals |
| No. 12 | Case B-D4 | Central DC 2 | Day 4 | 24 Hospitals |
| No. 13 | Case B-D5 | Central DC 2 | Day 5 | 15 Hospitals |
| No. 14 | Case B-D6 | Central DC 2 | Day 6 | 25 Hospitals |
| No. 15 | Case B-D7 | Central DC 2 | Day 7 | 16 Hospitals |
| No. 16 | Case B-D8 | Central DC 2 | Day 8 | 16 Hospitals |

In the next step, we further analyze the transportation and distribution planning from the first Central DC 1 by applying the proposed CVRP model. Relevant parameters are further set, in which the vehicle speed is set to be 70 kilometers per hour, the starting planning time is 8:00 AM, and the ending planning time is 5:00 PM, respectively. Given the traveling distance between nodes, the respective time between nodes can then be converted and computed. Additionally, the service time is considered negligible, in which the dominant parameter considered in the model is based on the traveling time in this case study. We further assume that the planned capacity of each vehicle for each route is enough to accommodate the medical supplies from the central distribution center to all assigned hospitals due to data limitations. The results for all 8 cases (i.e., Cases D-D1 – D- D8) are shown in **Table 6**, in which details of transportation and distribution planning for each case are mapped to the GIS platform as shown in **Figure 9**. The associated cost, total distance, and delivery plan with associated arrival time at each corresponding node are reported.

Considering the case study D- D1, for example, the results obtained from running the CVRP model show that the total distance to deliver to 19 drop points is found to be 186 kilometers and the delivery plan is from the central DC 1 to respective hospitals and then return to the central DC 1. The driver starts from the central DC1 at 08:00 AM and arrives at the first hospital at 08:33 AM and continues until reaching the last hospital in the route plan at 12:47 PM. Then, the driver returns to the central DC1 at 1:18 PM, respectively. **Figure 9** also further demonstrates the suggested routing plan for each case study from the central DC 1, respectively.

Additionally, the results for the distribution plan obtained from the second Central DC 2 for the other 8 cases (i.e., Cases B-D1 – B-D8) are presented in **Table 7** and the GIS-based results are illustrated in **Figure 10**, respectively. A similar interpretation and discussion can be suggested. For instance, the results show that the total distance to deliver to 14 drop points for the case study B-D1 is found to be 152 kilometers and the delivery plan is from the central DC 2 (08:00 AM) to respective hospitals and then return to the central DC 2 (12:31 PM). The other case studies are also reported to further verify and validate the model functionalities and can be similarly interpreted.

**Table 6** Distribution route planning from the Central DC 1

| **Case Study** | **Total distance** | **Delivery plan (Arrival time)** |
|---|---|---|
| Case D-D1 | 186 kilometers )19 Drops( | *Central DC1 (08:00) –> H7 (08:33) –> H5 (08:44) –> H17 (09:03) –> H9 (09:19) –> H8 (09:39) –> H6 (10:01) –> H4 (10:24) –> H15 (10:42) –> H16 (10:58) –> H14 (11:03) –> H1 (11:15) –> H18 (11:27) –> H12 (11:44) –> H10 (11:55) –> H13 (12:03) –> H11 (12:07) –> H19 (12:13) –> H3 (12:36) –> H2 (12:47) –> Central DC1 (13:18)* |
| Case D-D2 | 202 kilometers )15 Drops( | *Central DC1 (08:00) –> H14 (08:39) –> H2 (08:41) –> H9 (09:15) –> H13 (09:43) –> H6 (09:55) –> H10 (10:09) –> H15 (10:19) –> H7 (10:24) –> H4 (10:30) –> H5 (10:42) –> H8 (10:59) –> H12 (11:26) –> H1 (11:51) –> H11 (12:02) –> H3 (12:25) –> Central DC1 (12:49)* |
| Case D-D3 | 195 kilometers )12 Drops( | *Central DC1 (08:00) –> H3 (08:22) –> H6 (08:41) –> H2 (09:11) –> H9 (09:32) –> H8 (09:47) –> H10 (10:11) –> H11 (10:38) –> H12 (11:03) –> H7 (11:13) –> H4 (11:32) –> H5 (11:58) –> H1 (12:00) –> Central DC1 (12:31)* |
| Case D-D4 | 155 kilometers )10 Drops( | *Central DC1 (08:00) –> H7 (08:22) –> H9 (8:41) –> H2 (09:11) –> H6 (09:37) –> H5 (09:44) –> H10 (09:47) –> H3 (10:05) –> H4 (10:17) –> H8 (10:43) –> H1 (10:45) –> Central DC1 (11:16)* |
| Case D-D5 | 186 kilometers )22 Drops( | *Central DC1 (08:00) –> H14 (08:33) –> H10 (08:44) –> H16 (09:03) –> H9 (09:15) –> H20 (09:21) –> H12 (09:30) –> H8 (09:50) –> H2 (10:12) –> H6 (10:35) –> H3 (10:53) –> H11 (10:56) –> H21 (11:12) –> H4 (11:24) –> H17 (11:41) –> H7 (11:52) –> H18 (11:54) –> H19 (11:56) –> H22 (12:00) –> H5 (12:04) –> H15 (12:09) –> H13 (12:31) –> H1 (12:42) –> Central DC1 (13:15)* |
| Case D-D6 | 207 kilometers )18 Drops( | *Central DC1 (08:00) –> H1 (08:22) –> H13 (08:38) –> H7 (08:54) –> H8 (09:06)–> H12 (09:15) –> H5 (09:45) –> H14 (10:07) –> H17 (10:23) –> H2 (10:33) –> H15 (10:40) –> H3 (10:42) –> H11 (10:47) –> H10 (11:11) –> H16 (11:29) –> H6 (11:57) –> H9 (12:09) –> H18 (12:35) –> H4 (12:38) –> Central DC1 (13:08)* |
| Case D-D7 | 213 kilometers )26 Drops( | *Central DC1 (08:00) –> H22 (08:22) –> H1 (08:42) –> H26 (08:48) –> H18 (08:50) –> H16 (08:53) –> H13 (09:05) –> H10 (09:17) –> H14 (09:31) –> H2 (09:36) –> H20 (09:47) –> H12 (10:03) –> H5 (10:23) –> H4 (10:45) –> H21 (10:48) –> H17 (11:08) –> H8 (11:26) –> H9 (11:44) –> H19 (12:01) –> H6 (12:23) –> H23 (12:35) –> H24 (13:01) –> H3 (13:04) –> H11 (13:14) –> H7 (13:44) –> H15 (13:56) –> H25 (13:59) –> Central DC1 (14:28)* |
| Case D-D8 | 186 kilometers )19 Drops( | *Central DC1 (08:00) –> H18 (08:33) –> H10 (08:44) –> H17 (09:03) –> H5 (09:19) –> H9 (09:39) –> H1 (10:01) –> H14 (10:24) –> H13 (10:42) –> H19 (10:58) –> H15 (11:03) –> H12 (11:15) –> H2 (11:27) –> H4 (11:44) –> H11 (11:55) –> H6 (12:03) –> H8 (12:07) –> H7 (12:13) –> H3 (12:36) –> H16 (12:47) –> Central DC1 (13:18)* |
| Case D-D7 | 213 kilometers )26 Drops( | *Central DC1 (08:00) –> H22 (08:22) –> H1 (08:42) –> H26 (08:48) –> H18 (08:50) –> H16 (08:53) –> H13 (09:05) –> H10 (09:17) –> H14 (09:31) –> H2 (09:36) –> H20 (09:47) –> H12 (10:03) –> H5 (10:23) –> H4 (10:45) –> H21 (10:48) –> H17 (11:08) –> H8 (11:26) –> H9 (11:44) –> H19 (12:01) –> H6 (12:23) –> H23 (12:35) –> H24 (13:01) –> H3 (13:04) –> H11 (13:14) –> H7 (13:44) –> H15 (13:56) –> H25 (13:59) –> Central DC1 (14:28)* |
| Case D-D8 | 186 kilometers )19 Drops( | *Central DC1 (08:00) –> H18 (08:33) –> H10 (08:44) –> H17 (09:03) –> H5 (09:19) –> H9 (09:39) –> H1 (10:01) –> H14 (10:24) –> H13 (10:42) –> H19 (10:58) –> H15 (11:03) –> H12 (11:15) –> H2 (11:27) –> H4 (11:44) –> H11 (11:55) –> H6 (12:03) –> H8 (12:07) –> H7 (12:13) –> H3 (12:36) –> H16 (12:47) –> Central DC1 (13:18)* |

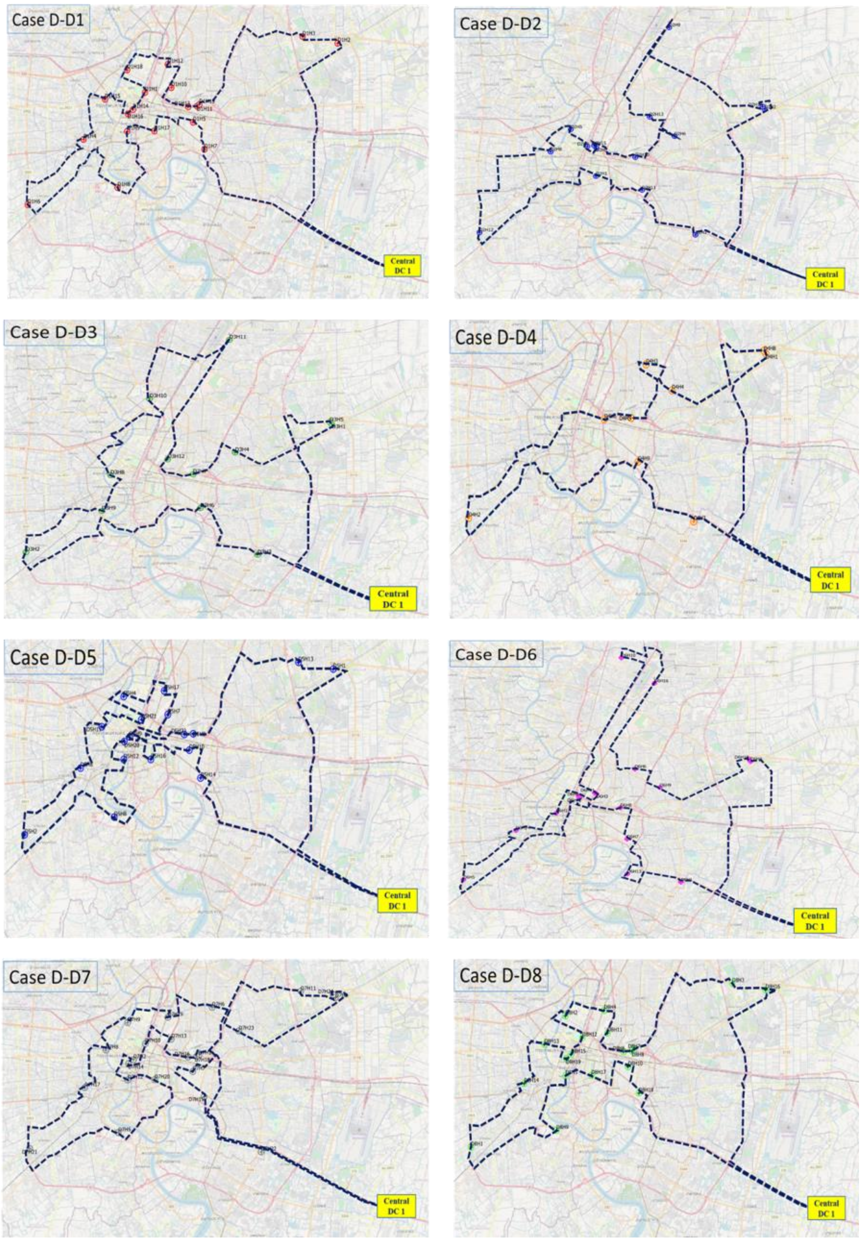

**Figure 9** Results of distribution plan on GIS for each trip from the central DC 1

**Table 7** Distribution route planning from the Central DC 2

| Case Study | Total distance | Delivery plan (Arrival time) |
|---|---|---|
| Case B-D1 | 152 kilometers (14 Drops( | *Central DC2 (08:00) –> H7 (08:14) –> H3 (08:34) –> H10 (08:56) –> H1 (09:09) –> H6 (09:33) –> H14 (09:55) –> H12 (10:09) –> H8 (10:21) –> H11 (10:34) –> H4 (10:45) –> H13 (11:00) –> H5 (11:12) –> H9 (11:43) –> H2 (12:03) –> Central DC2 (12:31)* |
| Case B-D2 | 211 kilometers (25 Drops( | *Central DC2 (08:00) –> H20 (08:17) –> H5 (08:28) –> H18 (08:39) –> H19 (08:47) –> H14 (08:57) –> H3 (09:12) –> H22 (09:18) –> H6 (09:33) –> H1 (09:36) –> H2 (09:53) –> H9 (09;55) –> H13 (10:01) –> H15 (10:09) –> H24 (10:37) –> H17 (10:55) –> H16 (11:14) –> H23 (11:29) –> H12 (11:51) –> H10 (12:10) –> H25 (12:26) –> H4 (12:41) –> H8 (12:58) –> H7 (13:02) –> H11 (13:26) –> H21 (13:31) –> Central DC2 (13:40)* |
| Case B-D3 | 148 kilometers (11 Drops( | *Central DC2 (08:00) –> H10 (08:26) –> H11 (08:54) –> H2 (09:16) –> H3 (09:35) –> H9 (09:54) –> H7 (10:06) –> H1 (10;14) –> H5 (10:27) –> H8 (11:06) –> H4 (11:23) –> H6 (11:49) –> Central DC2 (12:08)* |
| Case B-D4 | 173 kilometers (24 Drops( | *Central DC2 (08:00) –> H16 (08:23) –> H13 (08:35) –> H9 (08:57) –> H11 (09:06) –> H4 (09:29) –> H24 (09:48) –> H7 (10:18) –> H5 (10:40) –> H15 (10:57) –> H23 (11:04) –> H3 (11:08) –> H19 (11:23) –> H6 (11:35) –> H1 (11:37) –> H18 (11:47) –> H20 (12:02) –> H14 (12:04) –> H12 (12:22) –> H10 (12:35) –> H17 (12:43) –> H21 (12:58) –> H22 (13:10) –> H8 (13:20) –> H2 (13:23) –> Central DC2 (12:40)* |
| Case B-D5 | 172 kilometers )15 Drops( | *Central DC2 (08:00) –> H12 (08:14) –> H7 (08:33) –> H14 (08:46) –> H1 (09:08) –> H3 (09:24) –> H4 (09:57) –> H8 (10:11) –> H10 (10:31)–> H9 (10:55) –> H15 (11:29) –> H13 (11:39) –> H5 (11:46) –> H6 (11:55) –> H11 (12:05) –> H2 (12:15) –> Central DC2 (12:39)* |

**Table 7** Distribution route planning from the Central DC 2

| Case Study | Total distance | Delivery plan (Arrival time) |
|---|---|---|
| Case B-D6 | 160 kilometers )25 Drops( | *Central DC2 (08:00) –> H3 (08:22) –> H16 (08:25) –> H4 (08:33) –> H7 (08:38) –> H12 (08:53) –> H24 (09:09) –> H2 (09:20) –> H13 (09:44) –> H15 (10:06) –> H25 (10:10) –> H11 (10:22) –> H20 (10:43) –> H18 (10:50) –> H14 (11:02) –> H10 (11:12) –> H9 (11:16) –> H8 (11:24) –> H23 (11:29) –> H19 (11:51) –> H1 (12:00) –> H22 (12:16) –> H6 (12:18) –> H21 (12:22) –> H5 (12:46) –> H17 (13:06) –> Central DC2 (13:14)* |
| Case B-D6 | 160 kilometers )25 Drops( | *Central DC2 (08:00) –> H3 (08:22) –> H16 (08:25) –> H4 (08:33) –> H7 (08:38) –> H12 (08:53) –> H24 (09:09) –> H2 (09:20) –> H13 (09:44) –> H15 (10:06) –> H25 (10:10) –> H11 (10:22) –> H20 (10:43) –> H18 (10:50) –> H14 (11:02) –> H10 (11:12) –> H9 (11:16) –> H8 (11:24) –> H23 (11:29) –> H19 (11:51) –> H1 (12:00) –> H22 (12:16) –> H6 (12:18) –> H21 (12:22) –> H5 (12:46) –> H17 (13:06) –> Central DC2 (13:14)* |
| Case B-D8 | 153 kilometers )16 Drops( | *Central DC2 (08:00) –> H7 (08:19) –> H8 (08:38) –> H9 (09:07) –> H3 (09:23) –> H2 (09:51) –> H11 (10:03) –> H10 (10:06) –> H14 (10:12) –> H5 (10:32) –> H4 (10:34) –> H16 (10:42) –> H1 (11:06) –> H15 (11:15) –> H13 (11:35) –> H12 (11:45) –> H6 (11:57) –> Central DC2 (12:22)* |

### *4.3 Discussion and Managerial Insights*

There is a need for an analysis of the strategic location of the central distribution center to allocate and stock medical supplies at the strategic level as well as to evaluate the distribution plan for those planned stocks to last-mile demand nodes of hospital areas at the operational level in the HCM. These strategic and operational policies play a key role in evaluating and ensuring the efficiency and effectiveness of the healthcare delivery system in a large and complex network as illustrated in the study. We further note that managerial policies related to HCM also include not only strategic (i.e., long-term planning in years), but also tactical (i.e., medium-term planning in weeks or months) and operational (short-term planning in days) policies. That is, strategic policies may involve healthcare locational decisions, network configuration, and capacity- related investment decisions. Additionally, tactical policies pertain to medical supplier selection, technology assessment, as well as fleet size configuration. Operational policies are related to daily and/ or weekly decisions, such as medical manufacturing plans, delivery plans, and workload plans (Ageron *et al*. 2018, Mathur *et al*. 2018, Karatas *et al*. 2022).

Several studies point out that future research directions are to integrate various analyzing tools to compensate for shortcomings of using a particular tool alone (Ransikarbum *et al*. 2021, Ali and Kannan 2022, Saragih *et al.* 2022, Ransikarbum *et al*. 2023). Thus, integrating multiple mathematical models and the GIS technology platform is one path to further enhance the successful implementation of the HCM. In this study, the clustering analysis for classification of hospital demand areas is conducted at the downstream process of the HCM to assess appropriate locations of central hospitals using the unsupervised machine learning method called K-means clustering method and then later combined with the rectilinear location algorithm during the first phase of the planning. Then, the distribution routing plan is sequentially investigated using the vehicle routing algorithm in an integrated way for the second-phase planning. Other relevant integrated supply chain network design models could also enhance the perspective of simultaneously evaluating both the location and distribution decisions for HCM.

The case studies reported in our study also demonstrate how the integrated mathematical modeling approach can be applied. In the first phase, the parameter $K$ used for the K-means clustering is found to be seven clusters. However, this is clear that other potential policies can be tested to perform locational analysis, such as clustering based on the district restrictions, governmental planning, and expected population density growth due to future urban planning. Additionally, During the second phase, relevant parameters are exemplified, such as the speed limit of each vehicle, the planning horizon, and the time taken for service and delivery between nodes. However, other potential policies can certainly be tested to perform distribution analysis, such as planning with a fleet with varied types of vehicles, varied requirements from different hospitals concerning expected arrival time, and estimating service loading/ unloading time and break time at each location, etc.

## 5. CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

Healthcare chain management is considered an application of a service supply chain system, which is one of the complex applications requiring multifaceted requirements, and the use of quantitative analysis has proven successful for commercial applications. Additionally, managing the healthcare chain also involves interrelated agents inclusive of hospital personnel, regulatory agencies, insurance companies, medical supply units, and logistics providers. Thus, it is not only that economic structure has to be achieved, but also to evaluate key requirements existing in the healthcare chain. Additionally, it is desired that the modeling methodology typically developed and used to assess the industrial and commercial manufacturing domain can be applied to some characteristics of planning the healthcare chain.

This study provides practical research by examining both the long- term and operational- term planning and management of the healthcare chain, in which locational and distribution planning decisions are examined. The integrated mathematical methodology was applied to the regional case studies in Bangkok, Thailand using the integrated K-means with the rectilinear location algorithm as well as the vehicle routing algorithm in a sequential way. The integrated methodological approach is not only called for in the literature, but also can support policy makers to evaluate the impact of setting locations on further planning on distributions of medical supplies. Thus, the collaboration effort among planning staff can be tightened.

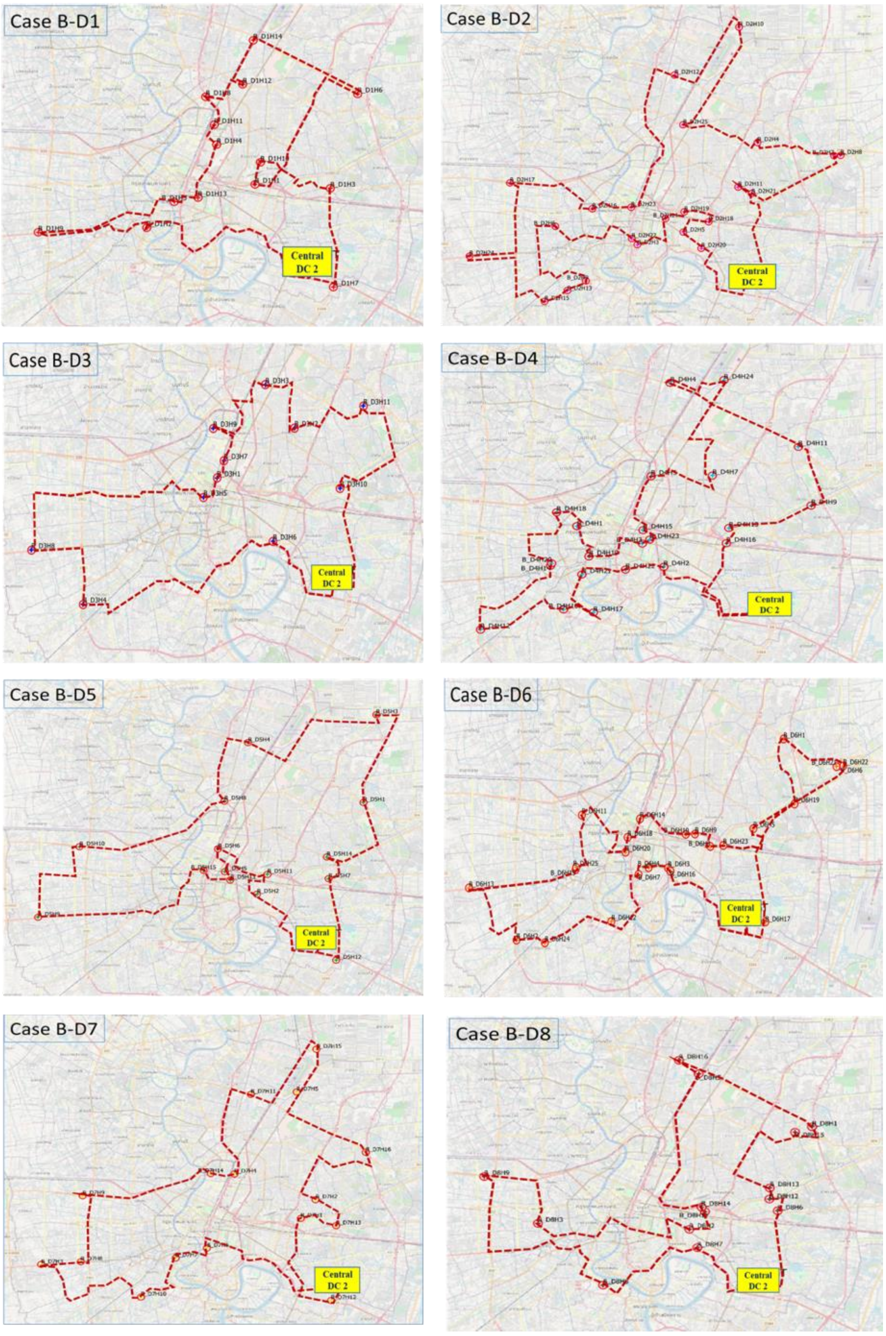

**Figure 10** Results of distribution plan on GIS for each trip from the central DC 2

We note some future research directions as follows. Given that various types of medical supplies exist, in which medical features and requirements are diverse, the multi-commodity model can be further used in this regard. Additionally, the uncertainty of matching supply and demand for the healthcare chain clearly exists due to diverse technologies and types of treatments as well as patients' financial conditions. Thus, it is not only that the sensitivity analysis can be used, but also that the stochastic and robust models can be considered. Finally, healthcare policies and decisions made by one stakeholder often impact the decisions available to other parties. Thus, multi-objective and metaheuristic algorithms could be further used to evaluate the healthcare chain to take into account varied sizes of problem instances and computational time evaluation.

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