A Biobjective Hub Location Model with Consideration of Congestion for Railway Transportation Planning

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***Abstract*—Transportation planning is highly essential and important, especially for railway systems. In this paper, we propose an optimization model to determine optimal station locations in a rail network. The objective is to minimize the total transportation cost, which is composed of operation costs and fixed costs. Congestion of the system is considered as the second objective, which is to minimize the longest travel time that a passenger spends on the trip. The problem is formulated as a multi-objective programming model and solved by the ε-constraint method. A case study of railway transportation is presented. By using the proposed optimization model, we are able to obtain all non-dominated solution points, which provides alternatives for decision-makers. The results are beneficial and support decision-making in railway transportation planning.**

***Keywords*—hub location, railway, transportation planning, optimization, congestion**

I. Introduction

Hub location models have been applied to solve many transportation network problems to transfer commodities between an Origin-Destination (OD) pair through hub-and-spoke systems. Instead of transferring commodities directly from an origin to a destination, we can transfer them through hubs as shown in Fig. 1. Flows are collected from origin *i* through hub *k*, transferred via hubs, and distributed from hub *l* to the destination node *j*. By transferring through a hub, flows are combined at the hub facilities and the total transportation cost is saved by taking advantage of economies of scale. Several applications of hub location models have been studied to solve various problems such as airline networks [1–3], telecommunication systems [4], postal services [5], emergency services [6, 7], logistics distribution [8, 9], transportation management [10–12], etc.

The Hub Location Problem (HLP) is generally classified into different types. The main two types are single allocation and multiple allocation. In a single allocation, each non-hub node must be allocated to only one hub. While in a multiple allocation, each non-hub node can be allocated to more than one hub. If the hub capacity is considered, it is called the capacitated HLP [13], otherwise it is called the uncapacitated HLP [14]. HPL is also categorized by its objective. Three main problems are the hub median problem, hub center problem, and hub covering problem [15]. For the hub median problem, the objective is to minimize the total time (or distance) between all origin-destination pairs. For the hub center problem, the objective is to minimize the maximum travel time (or distance) between any origin-destination pair. For the hub covering problem, the objective is to maximize the covered demand (or number of passengers). If the number of hubs is predetermined, namely *p*, the problems can be called *p*-HLP such as the capacitated single allocation *p*-hub median problem. For more details about HLPs [16, 17].

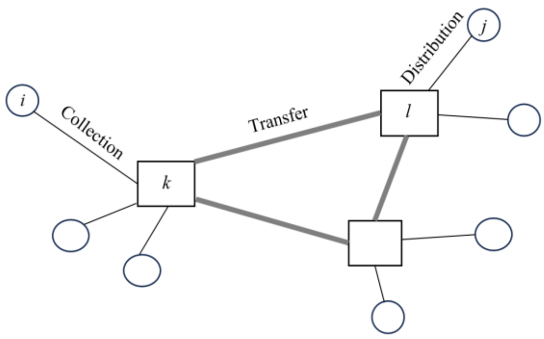

Fig. 1. Hub location model.

In this paper, we consider the extension of the single allocation hub median problem, where two objectives are optimized simultaneously. The first objective is to minimize the total transportation cost, which is composed

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of two parts: operation cost and fixed cost. The optimal number of hubs and their locations are the important decision variables. In this case, the decision-makers have to decide whether to establish more hubs to take advantage of the large volume of passengers or face high system operation costs. Most transportation system models only focus on cost. However, another important factor is service. So, we consider the travel time a passenger has to spend on the transportation system. The second objective is to minimize the maximum travel time of a passenger in the system. The proposed model is applied to solve a railway transportation case study. The results show the advantages of the proposed hub location model in terms of a managerial point of view. The main contributions of this paper are:

- We propose a biobjective hub location model, which simultaneously considers both important factors: the total transportation cost (operation cost and fixed cost) and the maximum travel time (traveling time and waiting time).
- The proposed model is able to organize congestion in two aspects: minimizing the maximum travel time of a passenger and limiting the hub capacity at stations.
- By solving the problem by using the ε-constraint method, we obtain all non-dominated solution points. Each solution provides an alternative, which is significantly valuable to decision-makers.

The rest of the paper is organized as follows. In Section II, we briefly review the related literature on transportation hub location models. Section III describes the biobjective programming model that we propose along with the selected solution method, the ε-constraint method. A small-sized and medium-sized problem case studies of railway transportation systems are presented in Section IV. Finally, a conclusion and future research directions are provided in Section V.

II. Literature Review

In this section, we briefly review related works on hub location models for transportation systems, which have widely been studied in the field of hub location networks. Various types of formulations, models, and solution methods have been proposed by many researchers. A well-known first mathematical formulation of HLP was introduced as a quadratic integer programming model by O'Kelly [18]. Later, Campbell [19] proposed multiple mathematical formulations for HLPs as integer programming models for classical facility location problems: the hub median problem, hub center problem, and hub covering problem. After that, many attempts at different extensions and solution approaches have been studied.

Transportation network design is a challenge since it involves many factors and requires a high investment cost of infrastructure. Hub location models have been applied to design complex transportation systems. The most common objective for transportation network design is minimizing total transportation costs. Cunha and Silva [20] solved the problem of HLP for trucking companies to determine the number of consolidation terminals (hubs). The objective was to minimize the total cost, which was composed of fixed and variable costs. A Genetic Algorithm (GA) was developed to solve the problem. Zhou *et al*. [21] considered the HLP for container shipping in inland waterways to determine an optimal hub location, feeder port allocation, and fleet deployment. The objective was to minimize the total cost of ships, transportation, and transshipment. A math-heuristic based on a GA was developed to solve the problem. Li *et al*. [22] designed a hybrid hub network of road-rail intermodal transportation for express delivery using a mixed integer programming model. The objective was to minimize the total construction cost and the total operation cost. A heuristic based on a greedy algorithm was developed to solve the problem. Chanta and Sangsawang [23] investigated the optimal station location in a rail transportation network using a two-stage optimization model. The candidate stations were selected in the first stage by considering partial coverage, and then in the second stage, an optimal number of stations and locations was determined by maximizing passenger transportation cost savings.

Recently, some researchers have paid attention to customer services such as service level, satisfaction, travel time, delay, and congestion. Jayaswal and Vidyarthi [24] studied HLP for a logistics service provider, where the provider had two classes of shipments. The objective was to minimize the total cost, where different service levels were considered as constraints. They developed a cutting plane algorithm to solve the problem. Kanai *et al*. [25] considered an algorithm for optimal delay management, where dissatisfaction of all passengers in the whole network was set as a criterion for making a decision. The objective was to minimize passengers' dissatisfaction. To solve the problem, they developed an algorithm with a combination of simulation and optimization, which consisted of a train traffic simulator and the passenger flow. Droes and Rietveld [26] examined the effect of congestion on accessing a railway network. They found that the number of access nodes, station capacity, and road congestion had an effect on accessibility. So, they suggested a trade-off policy between congestion and urbanization.

Since transportation network design involves many factors, some researchers work on a biobjective model. Demir *et al.* [27] introduced a biobjective multiple allocation HLP model with the objectives to minimize the total transportation cost and the maximum travel time required for routing. The non-dominated sorting genetic algorithm (NSGA-II) was developed to solve the problem. Kahag *et al.* [28] addressed the congestion issues in the HLP. The model was formulated as a constrained biobjective optimization model to minimize the total costs as well as minimizing the total system time. Alumur *et al.* [29] modeled congestion at hubs as a service time limit, where the service time composed of travel time on the hub network included the handling and delay times caused by congestion at hubs. The objective was to minimize the congestion level and ready time, where the sum of transportation and opening costs was constrained at the optimal value using a lexicographical method. Karimi-Mamaghan *et al.* [30] studied a single allocation multi-commodity HLP under congestion using a queuing system. The objective was to minimize the total transportation costs while minimizing the maximum transportation time between each OD pair. They developed a solution approach to solving the problem, which combined NSGA-II, *k*-means clustering, and an iterative Local Search Algorithm (ILS). Rahimi *et al*. [31] presented a biobjective model for a multi-modal HLP under uncertainty congestion in the hubs. The objective was to minimize total transportation cost as well as minimize the maximum transportation time between each OD pair. They developed a Differential Evolution (DE) to solve the problem.

Although hub location models have been applied to solve many transportation network problems, there are still a few studies on the case of rail transportation network systems. Moreover, most previous works ignored important factors such as travel time, delay time, and congestion at stations. In this paper, we propose a biobjective programming model for determining the optimal location and allocation for railway stations. The proposed model is able to minimize the total transportation cost as well as system congestion. The first objective is to minimize the total transportation cost, while the second objective is to minimize the maximum travel time from traveling between OD pairs. The travel time is composed of the traveling time from node-to-hub, hub-to-hub, hub-to-node, and delay time at hubs. Since the problem is formulated as a biobjective mixed integer programming model, we implement the ε-constraint method for solving the problem [32].

III. MATERIALS AND METHODS

A. The Proposed Biobjective Programming Model

We propose a Biobjective Capacitated Single Allocation Hub Location Problem (BCSAHLP). The model belongs to the hub median location problems with fixed establishment cost, where the number of hubs in this problem is not determined. The objective is to minimize the total transportation costs, which are composed of the sum of the total travel cost (distance) of the flows in the system plus the established cost of hubs. All OD pairs must be fully connected. The origin and destination can be allocated to one hub. All hubs have limited capacity. The first hub median problem is quadratic [18]. The later versions are linear, but they are still difficult to solve with the decision variables of size $O(N^4)$ [19, 28–31]. The proposed model is developed based on the work of Ernst and Krishnamoorthy [33] with the decision variables of size $O(N^3)$.

Given *n* existing stations (nodes), the overall goal is to make the following decisions: (i) identify the stations that will serve as hubs, that is, the stations at which the hubs will be located; (ii) assign the remaining stations to the hubs once they have been located; and (iii) determine the amount of flow that will be routed from each station to a hub. These decisions are evaluated by two objective functions and it is of interest to compute the decisions that yield the smallest values of these two objectives.

The model assumptions are as follows:

- The set of nodes in the network is given.
- The number of hubs is not predetermined.
- Flows have to be routed through at least one hub.
- Single allocation is allowed or each node can only connect to one hub.
- The discount factors are applied if a passenger travels via a hub.
- All hubs are capacitated.
- The demand is constant.
- There is only one type of flow.
- The transportation cost is composed of the traveling cost (associated with distance) and the fixed cost (hub establishment).

We provide a mixed integer linear programming model, whose details are presented as follows.

Notations and indices

n = number of station locations

i, j, k, l $\in \{1,2,\ldots, n\}$, where i and j denote nodes, and k and l denote hubs

Parameters

C_{ij} = transportation cost from node i to node j

F_k = fixed cost of establishing hub k

W_{ij} = amount of flow from node i to node j

O_i = total amount of flow originating at node i, where $O_i = \sum_{j=1}^{n} W_{ij}$

D_j = total amount of flow to node j, where $D_j = \sum_{i=1}^{n} W_{ij}$

χ = discount factor for collection cost (non-hub to hub)

δ = discount factor for distribution cost (hub to non-hub)

α = discount factor for transhipment cost between hub links (hub to hub)

β = discount factor for traveling time between a hub links (hub to hub)

t_{ij} = traveling time from node i to node j

H_k = maximum capacity of hub k

Decision Variables

X_{ik} = 1 if node i is assigned to a hub located at node k, = 0 otherwise

X_{kk} = 1 if node k is a hub, = 0 otherwise

Y^i_{kl} = total amount of flow that is routed from node i through hubs k and l

Mathematical Model: M1

Minimize $Z_1 = \sum_{i=1}^{n}\sum_{k=1}^{n} C_{ik}X_{ik}(\chi O_i + \delta D_i) + \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} \alpha C_{kl}Y_{kl}^{i} + \sum_{k=1}^{n} F_k X_{kk}$ (1)

Minimize $Z_2 = \max_{i,j,k,l \in R} \{t_{ik}X_{ik} + t_{lj}X_{lj} + (s_k + \beta t_{kl} + s_j)Y_{kl}^{i}\}$ (2)

Subject to

$$\sum_{k=1}^{n} X_{ik} = 1 \quad \forall i \quad (3)$$

$$X_{ik} \le X_{kk} \quad \forall i,k \quad (4)$$

$$\sum_{l=1}^{n} Y_{kl}^{i} - \sum_{l=1}^{n} Y_{lk}^{i} = O_i X_{ik} - \sum_{j=1}^{n} W_{ij} X_{jk} \quad \forall i,k \quad (5)$$

$$\sum_{i=1}^{n} (O_i + D_i) X_{ik} \le H_k X_{kk} \quad \forall k \quad (6)$$

$$Y_{kl}^{i} \ge 0 \quad \forall i,k,l \quad (7)$$

$$X_{ik} \in \{0,1\} \quad \forall i,k \quad (8)$$

The first objective in Eq. (1) is to minimize the total transportation cost, which is composed of two types of costs: the variable cost C_{ik} and the fixed cost F_k. The variable cost is associated with travelled distance and consists of three components, which are the collection cost represented by χ, the distribution cost represented by δ, and the transfer cost between hub arcs represented by α. The fixed cost is the cost of establishing hubs. The second objective in Eq. (2) is to minimize the maximum travel time of a passenger in the system, where R is the set of all feasible routes. The travel time is composed of the traveling time from origin to destination including delay time at hubs. Note that the traveling time is associated with a distance traveling through hubs gets a discount factor β. Constraint (3) ensures that each node is allocated to exactly one location. Constraint (4) assigns the flow to a hub after the hub has been located. Constraint (5) is the flow balance equation. Constraint (6) restricts the amount of arriving flow from a node to a capacitated hub. Constraints (7) and (8) are the non-negativity and binary requirements, respectively.

Since the second objective (Z_2) is not a linear function and makes this model a min-max problem, we reformulate this objective into a linear function by introducing an auxiliary variable T, where T is the maximum travel time between each OD pair. The problem is reformulated as below.

Mathematical Model: M2

Minimize $Z_1 = \sum_{i=1}^{n}\sum_{k=1}^{n} C_{ik}X_{ik}(\chi O_i + \delta D_i) + \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} \alpha C_{kl}Y_{kl}^{i} + \sum_{k=1}^{n} F_k X_{kk}$

Minimize $Z_2 = T$ (9)

Subject to

$$t_{ik}X_{ik} + t_{lj}X_{lj} + (s_k + \beta t_{kl} + s_j)Y_{kl}^{i} \le T \quad \forall i,k,l,j \quad (10)$$

Constraints (3)–(8)

B. The ε-Constraint Method

In order to solve multiobjective programming problems, we need a specific solution method. Generally, in an optimization model, we only have a single objective, whether to minimize or maximize. However, in a multiobjective model, more than one objective has to be considered at the same time. The exact solution methods for multiobjective problems are the weighted-sum method, ε-constraint method, lexicographical method, weighted metric method, etc. [32].

In this study, we implement the ε-constraint method for solving our problem, since it is powerful and known to be able to find all points in the Pareto set of the biobjective problem [34]. The biobjective problem is reformulated as a single objective model, while all objectives but one are moved to the constraints and bound by ε values. In our problem, we choose to minimize Z_1 and bound Z_2 at the acceptable value of ε. So, we have one objective (Z_1), which is to minimize the total transportation cost and the second objective (Z_2) is bounded at ε value as shown in Constraint (11). The rest of the system constraints remain the same as Constraints (3)–(8), (10). The original problem is reformulated into the ε-constraint form as the following.

Mathematical Model: M3

Minimize $Z_1 = \sum_{i=1}^{n}\sum_{k=1}^{n} C_{ik}X_{ik}(\chi O_i + \delta D_i) + \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} \alpha C_{kl}Y_{kl}^{i} + \sum_{k=1}^{n} F_k X_{kk}$

Subject to

$$T \le \varepsilon \quad (11)$$

Constraints (3)–(8), (10)

To solve the problem, we first have to find the range of the ε value. Note that these two objectives are in conflict, which means the best solution of the Z_1 (minimum) will give the worst value of Z_2 (upper bound). To find the upper bound of Z_2, we solve problem (M2) only with a single objective (Z_1) in Eq. (1), which is to minimize the total transportation cost subject to Constraints (3)–(8), (10). Then we obtain the value of the T, which is the upper bound of the ε value. To find the lower bound of Z_2, we solve the problem (M2) only with a single objective (Z_2) in Eq. (9), which is to minimize the maximum travel time subject to Constraints (3)–(8), (10). Then we obtain the value of the T, which is the lower bound of the ε value. To get the optimal solution points of the proposed biobjective model, we solve the reformulated problem in ε-constraint form (M3) by varying the ε value from its lower bound to its upper bound.

IV. Result and Discussion

In this section, we apply our proposed biobjective model to solve a railway transportation network problem. To see the performance of the model, we test the proposed model with two case studies: one with a small-sized data set and another one with a medium-sized data set. Our case study is the northern railway line with the distance of 751 kilometers routed from Bangkok to Chiang Mai, Thailand. There is a total of 130 train stations. Note that we excluded the small stations that have very small numbers of passengers and no potential to be a hub. So, for a medium sized data set, only 54 stations are considered. For a small sized data set, we use the short section of the north railway line routed from Bangkok to Ayutthaya. The demand is represented by the number of passengers at each station and is assumed to originate at the stations. The station capacity is set at two different levels. For the low level, the capacity is set according to actual number of passengers. For the high level, the capacity is set at 10 times of the low level.

The reformulated proposed model in the ε-constraint form (M3) is implemented in OPL (Optimization Programming Language) 12.7 and all experiments are solved by using an Intel Core i5-2410M CPU 2.3 GHz with 6 GB of RAM.

A. Railway Case Study with A Small Data Set

The small case study is based on a section of the north railway line from Bangkok to Ayutthaya, Thailand. There are 10 existing candidate stations in this section (n = 10). The transportation cost is associated with the travel distance. The discount factors (χ, δ, α, β) are fixed as (3, 2, 0.4, 0.5). The fixed cost refers to the cost of hub implementation, which is set to be the same for all hubs. We conducted two experiments with different hub capacities. Note that each hub has a different capacity based on the size of the stations. In the first experiment, the hub capacity is fixed at a high level, and at a low level in the second experiment.

The results of the first experiment with high capacity are shown in Table I. For each Pareto point, we report the maximum travel time (Z_2), the minimum total cost (Z_1), and the open hub sets. The running times are from 1.18 s to 1.84 s. The model shows efficient performance by obtaining the Pareto points to a small-sized problem in a few seconds. To minimize the total transportation cost, only one hub is suggested to open (hub set = {2}) with a minimum total cost of 1,785,854 baht and a maximum travel time of 91 min. On the opposite, to minimize the maximum travel time, all hubs are suggested to open (hub set = {1 2 3 4 5 6 7 8 9 10}) with a maximum travel time of 20 min and a minimum total cost of 10,114,198 baht. However, by implementing the biobjective programming model, we have more alternatives for the decision-makers. The Pareto solution points are shown graphically in Fig. 2. To get all Pareto solution points, we solve the problem by varying the ε value from its lower bound to the upper bound.

TABLE I. Pareto Points and Hub Locations for A Small Case Study with High Capacity

Pareto point	Max travel time (min)	Total cost (฿)	Hub set
1	91	1,785,854	{2}
2	90	1,786,530	{3}
3	80	1,864,684	{4}
4	70	2,003,427	{5}
5	60	2,187,355	{6}
6	45	2,474,260	{1 7}
7	40	2,633,248	{2 8}
8	35	2,657,462	{3 8}
9	30	3,361,492	{1 6 9}
10	25	6,343,403	{2 5 7 8 9 10}
11	20	10,114,198	{1 2 3 4 5 6 7 8 9 10}

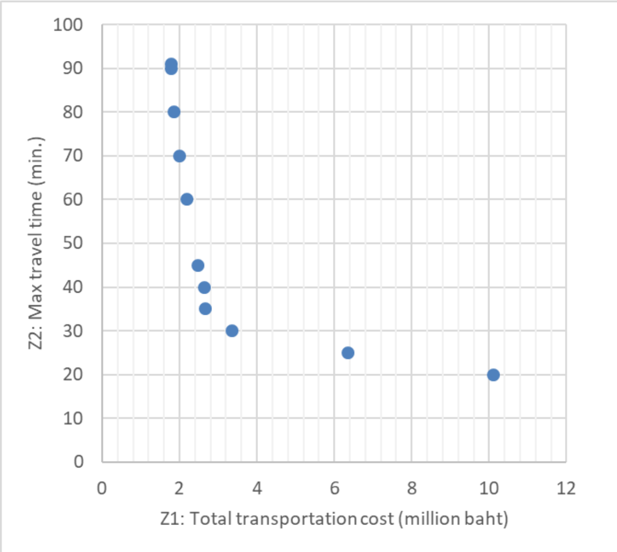

Fig. 2. Pareto points of a small case study with high capacity.

The results of the second experiment with low capacity are shown in Table II. The running times are from 1.69 s to 2.03 s. To minimize the total transportation cost, only one hub is suggested to open (hub set = {1}) with a minimum total cost of 1,853,095 baht and a maximum travel time of 101 min. On the opposite, to minimize the maximum travel time, all hubs are suggested to open (hub set = {1 2 3 4 5 6 7 8 9 10}) with a maximum travel time of 20 min and a minimum total cost of 10,114,198 baht. The Pareto solution points are shown graphically in Fig. 3.

TABLE II. Pareto Points and Hub Locations for A Small Case Study with Low Capacity

Pareto point	Max travel time (min)	Total cost (฿)	Hub set
1	101	1,853,095	{1}
2	80	1,864,684	{4}
3	60	2,187,355	{6}
4	45	2,474,260	{1 7}
5	40	2,638,141	{1 8}
6	35	2,782,898	{4 8}
7	30	3,361,492	{1 6 9}
8	25	6,343,403	{2 5 7 8 9 10}
9	20	10,114,198	{1 2 3 4 5 6 7 8 9 10}

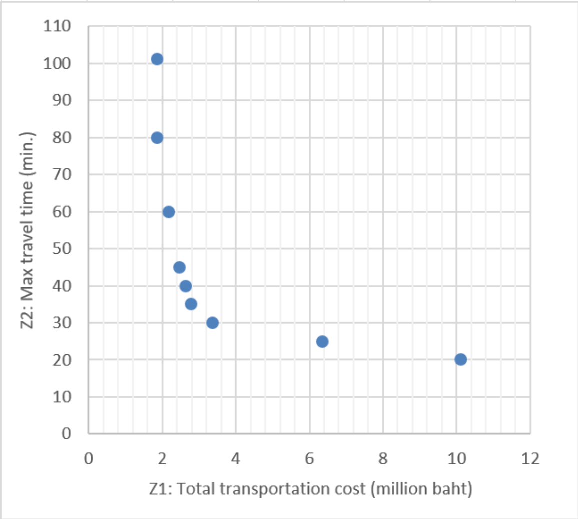

Fig. 3. Pareto points of a small case study with low capacity.

From the results of the two experiments, we can see that hub capacity has an effect on the hub location. Note that for the Pareto point 1, locating the hub at Station 2 (first experiment) is more savings than locating at Station 1 (second experiment). However, in the case that the capacity of Station 2 is limited, the model has to locate the hub at Station 1 with a higher total cost. With high capacity (Table I), we have more options of opening one hub, which are 2, 3, 4, 5, and 6, respectively. With low capacity (Table II), we have limited options, which are 1, 4, and 6, respectively.

B. Railway Case Study with A Medium Data Set

This case study is based on the north railway line, which routes from Bangkok to Chiang Mai, Thailand. The candidate stations are on the existing railway of the north route line with a total of 54 stations (n = 54). The transportation cost is associated with the travel distance. The discount factors (χ, δ, α, β) are fixed as (3, 2, 0.4, 0.5). The fixed cost refers to the cost of hub implementation, which is set to be the same for all hubs. Note that each hub has a different capacity based on the size of the stations. In this experiment, the hub capacity is fixed at a high level.

The results of this experiment with high capacity are shown in Table III. For each Pareto point, we report the maximum travel time (Z_2), the minimum total cost (Z_1), the open hub sets. The running times are from 20.76 s to 48.98 s. The model shows efficient performance by obtaining the Pareto points to a medium-sized problem in less than a minute. However, it takes a little more time when compared to a small-sized problem. To minimize the total transportation cost, only two hubs are suggested to open (hub set={1 40}) with a minimum total cost of 49,937,317 baht and a maximum travel time of 512 min. On the opposite, to minimize the maximum travel time, all hubs are suggested to open (hub set={1–54}) with a maximum travel time of 20 min and a minimum total cost of 546,441,658 baht. However, by implementing the biobjective programming model, we have more alternatives for the decision-makers. The Pareto solution points are shown graphically in Fig. 4.

TABLE III. PARETO POINTS AND HUB LOCATIONS FOR A MEDIUM CASE STUDY

Pareto point	Max travel time (min)	Total cost (฿)	Hub set
1	512	49,937,317	{1 40}
2	300	55,682,236	{1 40 54}
3	250	66,494,748	{1 22 40 47 54}
4	200	73,356,711	{1 12 27 40 47 54}
5	150	74,491,018	{1 22 30 40 47 54}
6	100	92,078,648	{1 12 27 33 40 47 51 54}
7	50	177,840,533	{1 6 12 15 22 26 27 30 33 37 40 44 47 49 51 52 54}
8	20	546,441,658	{1–54}

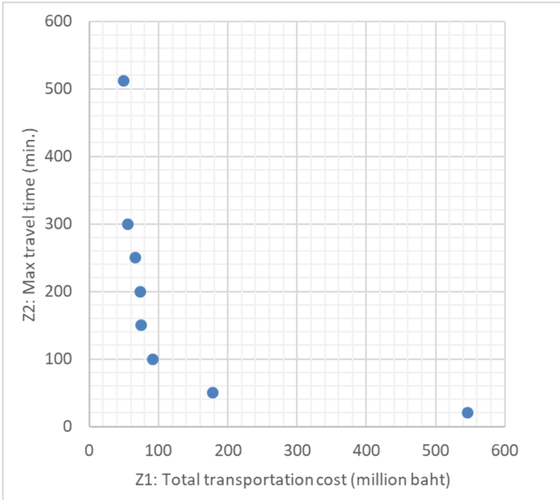

Fig. 4. Pareto points of a medium case study.

In the medium case study, we vary the value of ε from its upper bound to the lower bound (500 to 20 by 50), so the number of solutions that have been evaluated is 11 solutions. In Table III, we only show Pareto solution points. In this case, there are 8 Pareto solution points. Note that in the case of a dominated solution, we got a solution with one objective value that is not better than the other solution, or in other words, this solution is dominated by other solutions. For example, at Pareto point 2 of a medium data set, with the maximum travel time (Z_2) of 300 min, we should open 3 hubs at {1 40 54}, so the total transportation cost (Z_1) is 55,682,236 baht. The solutions at the maximum travel time of 500, 450, and 400 min. are not shown in Table III since they are dominated by the Pareto point 2. When fixed the maximum travel time at 500, 450, and 400, we got the same solutions of the hub set and the total transportation cost as the Pareto point 2. Since the problem is minimized, so solution of the Pareto point 2 is considered as a non-dominated solution.

Fig. 5 shows the behavior of the two objective functions, where Z_1 = the total transportation cost (million baht), and Z_2 = maximum travel time (min). As we can see from the graph, these two objectives are in conflict. At the system with the low total cost, passengers have to travel a long time. On the opposite, investing in the system with a higher cost, passengers tend to spend less time on their trips. To see a relationship between the number of open hubs and the objective function values, we present Figs. 6 and 7. As the number of hubs increases, the total transportation cost increases. Based on this experiment, opening more than 20 hubs raises significantly the cost. If we look at the maximum travel time, it decreases dramatically when we open more than 15 hubs. This information provides insightful guidelines for decision-makers in transportation planning.

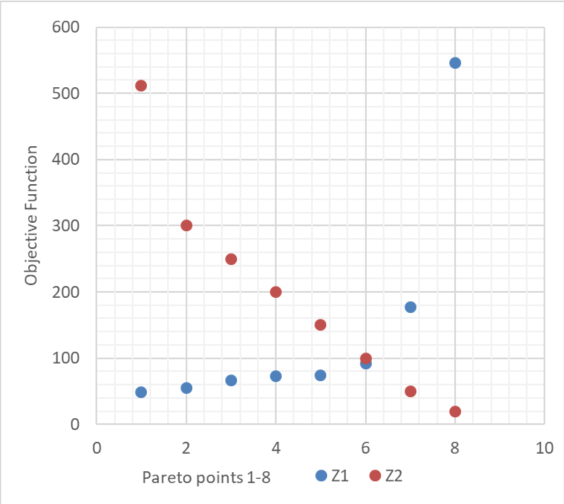

Fig. 5. The two objective functions: values at the Pareto points.

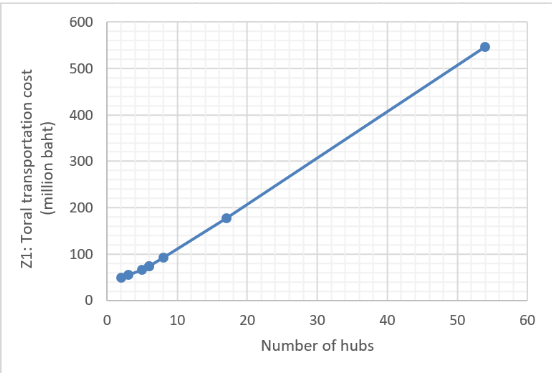

Fig. 6. The trend of total transportation cost when increasing the number of hubs.

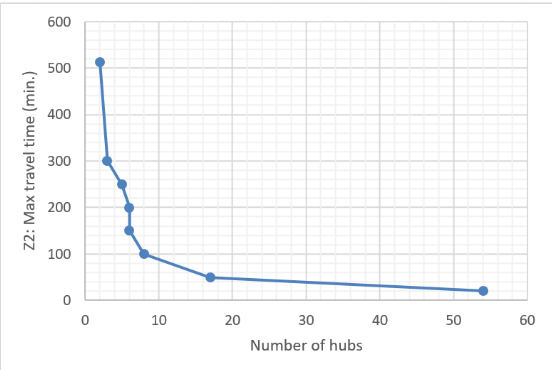

Fig. 7. The trend of maximum travel time when increasing the number of hubs.

Comparing the running times of these two data sets we see, the small-sized data set tends to find the Pareto points faster (within about 2 s), while the medium-sized data set requires more running time (up to about 50 s).

V. Conclusion

This paper proposed a biobjective programming model for the hub location problems of railway transportation systems. The first objective is to minimize total transportation costs, which are composed of fixed costs and operation costs. The second objective is to minimize the maximum travel time of a passenger in the system. The proposed model is able to optimize these two objectives simultaneously using ε-constraint method. The model is tested on the data of two case studies of railway transportation network systems, small-sized and medium-sized data sets. The model found optimal solutions in a few seconds and the Pareto points were obtained through the selected solution method. The results provided significant guidelines for decision-makers in transportation planning.

In this study, we assumed that demand is constant and does not change over time. But in real-world cases, demand may vary during the day. Therefore, for future research, we intend to study the case that demand or the number of passengers is not constant. Additionally, several factors have to be considered such as service level and coverage. In this research, all passengers are assumed to travel by train, but in real-world cases, it is up to the decision of the passengers. For example, if the location of the hub is too far a passenger will travel by other transportation modes. Since the real-world applications involve large-scale problems, we also intend to develop a metaheuristic algorithm for a solution method.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Sunarin Chanta conducted the research and wrote the manuscript; Ornurai Sangsawang wrote the manuscript; Margaret M. Wiecek and Norio Tomii supervised and edited the manuscript; all authors had approved the final version.

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