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Location and Capacity Planning of Freight Villages: The Case of Türkiye

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Abstract

Freight villages are logistics hubs where distribution and storage related activities meet. Determining their locations and capacities is a strategically important yet a difficult problem due to its complex structure. This paper provides a mixed integer linear programming model for identifying the locations, number, and capacities of freight villages. Objective is to set up a distribution network and minimize its total cost. The proposed model is computationally efficient as the optimal solution can be found within minutes. The model is applied using real life data in Turkey. The application includes major container ports as supply points and all cities as demand points, which are also alternative locations for freight villages. Optimal solution provides a plan and a budget to build the required capacity and number of logistics villages dispersed geographically. Sensitivity analysis is also conducted to investigate the system-wide costs and derive insights when there is a limit on the number of freight villages.

Keywords: Mixed integer linear programming, Capacity modelling, Location assignment, Logistics, Freight villages.

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1. INTRODUCTION

Logistics deals with moving goods from origins to destinations. In today's global business environment, bulk quantities travel across cities, regions, and countries. Logistics facilities help manage that movement rather efficiently. Traditionally, receiving, storage, and shipping are the typical operations at logistics facilities. The size and purpose of those facilities have evolved over years as the need for different logistics processes have emerged. Higgins and Ferguson (2011) categorize the changes in logistics processes historically into three as traditional warehousing, extended warehousing, and today's third-party services. As for logistics facilities, freight terminals progressed into freight hubs which evolved into logistics villages (Wu et al., 2009). UNESCAP (2009) defines a freight village as "*an area of land that is devoted to a number of transport and logistics facilities, activities and services which are not just located in the same area but also coordinated to encourage maximum synergy and efficiency*."

Accordingly, freight villages are distribution-storage centers that include logistics facilities, intermodal terminals, and shared customer-service facilities under a central management (Higgins & Ferguson, 2011). Thus, they are sophisticated centers where companies involved in logistics businesses meet. Such centers are termed differently in different countries. While they are called freight centers in Great Britain, they are named as logistics centers in the USA, Singapore and Japan, and transport centers in Denmark (Meidute, 2005). They are termed as logistics parks in China (Lyu & Chen, 2019) and logistics villages in Malaysia (Tambi et al., 2013). In this study, we will employ the terms freight village and freight centers interchangeably throughout the paper.

In addition to serving as logistics hubs, freight centers can be considered as an important part of urban logistics systems. Transportation activities in a city typically cause traffic congestion, air pollution and noise which affect the living conditions in urban areas. Establishing freight centers are thus recommended and encouraged to enable better protection of natural environment, and to minimize the negative effects caused by freight transportation in cities (Elevli, 2014).

The concept of freight center is around for more than 50 years with first examples seen in Europe (Kapros et al., 2005). With increased trade globally, freight villages have emerged in various parts of the world. In Turkey, related construction work took place first in early 2000's and planning of new ones are still going on (Baydar et al., 2019).

Freight villages are financed either by public, private or both, and the planning phase of locating freight villages includes a financial evaluation (Tsamboulas & Kapros, 2003). The evaluation phase consists of identifying a location and estimating the traffic volume there, defining the services offered, estimating the investment and operation costs, and evaluating the viability of the investment (Meidute, 2007). Location selection is basically choosing the best location among a set of alternatives, and it is an essential decision in freight-village planning (Lyu & Chen, 2019). As in traditional facility location models, that decision considers the demand (traffic volume), fix cost of construction (investment cost), variable cost of goods handling (a part of operation costs).

Meidute (2007) defines two steps for freight-center location selection. The first one is a macro-level decision with which a broad area close to a locality is chosen. This choice also identifies the possible distribution volume and network with other localities. Micro level decision is the second step and defines the boundaries of the freight center specific to the chosen locality. While optimization models may be used for the first step, multi-criteria decision making can be used for the second step. Our work concerns the macro-level planning of freight-center locations.

In choosing a location for a logistics village, the structure and density of the logistics network are the final determining factors (Özgen, 2011). When choosing the location of the logistics village, it should be considered that this area will provide many opportunities; Accordingly, proximity to the market, accessibility, reduction of operation times and costs, the pollution and congestion it will cause in the city, and how it will affect the city's quality of life should be taken into consideration (Erdil, 2010).

In this study, we consider a location-allocation problem with the goal of identifying the number, location and capacities freight centers. We construct a mixed integer linear programming model with the objective of minimizing total cost of building those centers and setting up distribution networks. The model is applied to the case of Turkey where supply points are container ports and demand points are cities. Sensitivity analysis are used to analyzed system-wide costs when there is a limit on the number of freight centers. Rest of the paper is organized as follows: In Section 2, we provide a literature review on freight-village location problem. The problem is defined in detail and the mathematical model is constructed in Section 3. Parameter values are explained and numerical analysis and conducted in Section 4, followed by sensitivity analysis in Section 5. Section 6 provides conclusions.

2. LITERATURE REVIEW

Facility location is a strategic decision and related problems have been well studied in the literature. The basic facility location problem can be defined as finding the number of facilities, their locations and capacities while meeting the demand. The main costs in such a problem are fix cost of facility and variable cost of transportation.

Called the P-median problem, Hakimi (1964) formulated the problem of locating P facilities to minimize the distance travelled between customers and facilities. Location problems have been addressed since then by various researchers using mathematical modeling. Detailed literature reviews on deterministic facility location problems are presented by Owen and Daskin (1998). Louveaux (1993) includes a survey on stochastic location problems. A comprehensive review of facility location in supply chains is provided by Melo et al. (2009). Terouhid (2012) extends the survey to cover sustainable facility location decisions.

Freight centers tend to be located in or around cities (Meidute, 2007). Taniguchi et al. (1999) work on locating public logistics terminals in the Kyoto-Osaka area in Japan. Considering the traffic conditions on a road network, they provide a mathematical model based on queuing theory and nonlinear programming. Genetic algorithms are used to solve the model. They conclude that optimal logistics-terminal locations are near large cities and improved road network reduces transportation costs.

Crainic et al. (2009) study a two-tiered city logistics network. City distribution centers, located in the uptown, form the first tier. Satellite platforms serve as the second tier from where shipments are destined to dense city zones. They provide mathematical models to schedule logistics operations in order to meet customer demand. Crainic et al. (2015) also provide mathematical models for scheduling a fleet of shuttles on a railway network between seaports and dry ports. The dry ports they consider are defined as inland freight terminals connected to seaports and handle container demand. They conduct numerical tests using real-world examples.

As in freight centers, a logistics hub can be used to consolidate shipments (Bookbinder & Fox, 1998). Ishfag (2011) develops a mathematical model of type p-hub median to design an intermodal logistics network. The costs associated include transportation, intermodal connectivity, and fixed costs for locations. Solution is found using a tabu-search algorithm. The paper indicates that the difference between railway and road rates has an impact on the logistics network structure. Gümüş and Bookbinder (2004) consider a logistics network where cross-dock facilities serve also as consolidation centers.

There are various papers where multi-criteria decision-making approaches are used for freight-center location problem. Among those, Kayikci (2010) employs a multi-criteria and multi-level decision making model in order to solve a freight-center location problem. The study integrates fuzzy-AHP and ANN where the former is used to identify criteria weights and most important factors, the latter is employed to select the best location. They conclude that using this hybrid approach can provide better results. Elevli (2014) employs a fuzzy PROMETHEE method for choosing potential logistics center locations. The study shows that the application provides reasonable results. Marković et al. (2013) consider the significance of selection and ranking of different locations, and they compare as objectively as possible the influences of various criteria and reduce them to a common function. Rostamzadeh et al. (2020) develop a framework that evaluates the third-party provider using multi-criteria decision making based on Fuzzy Additive Ratio Assessment. They identify 37 criteria and classify those into seven main criteria.

Gürbüz et al. (2016) aim to raise awareness on the logistics-village dimension in Karabük/Turkey by measuring the logistics-village perceptions of the managers of production enterprises operating in Karabük province, which does not currently have a logistics village. For this purpose, a survey is conducted to 103 production enterprise managers. As a result of the research, it is determined that there is a positive opinion that logistics villages would increase employment and exports in the province and reduce transportation costs, and a negative opinion that they would contribute to the media promotion of the products in the province. Within the scope of the opinions of those managers, a location proposal has been developed for the "logistics village" planned to be established in Karabük province.

Önden et al. (2018) focus on a multi-stage methodology that combines the fuzzy analytic hierarchy process, spatial statistics and analysis approaches to evaluate the suitability degrees of the logistics centers in Turkey. They use geographic information systems and fuzzy analytic hierarchy process techniques. Karaşan and Kahraman (2019) propose an integrated fuzzy decision model for the location selection of freight villages. They use DEMATEL for determining the most effective criteria, ANP for weighting the determined criteria, and TOPSIS for finding the best alternative location. Their proposed model is applied to a case study for the city of Istanbul in Turkey. Kumar and Anbanandam (2019) use intuitionistic fuzzy based multi-criteria decision making. They consider social, technical, economic, environmental, and political factors for choosing the locations of multimodal freight terminals. They conclude that technical and economic criteria are in order the most important factors affecting location decision. Their paper also includes a recent multi-criteria decision-making literature that shows contributions to selection criteria by identifying the papers on freight-center location problems.

In this study, we provide mathematical models for a freight-center location problem and their optimal solutions. Our aim is to provide stakeholders in freight-center financing an insight about costs associated with opening and operating freight centers. Our study includes major supply points as international seaports and all demand points as cities within a geographical region. Each of those cities is also a candidate for freight-center location. Numerical examples show the optimal number, location, and capacity of freight centers in Turkey based on real life data. Sensitivity analyses show the cost impact of opening a preset number of centers.

3. PROBLEM DEFINITION AND MODEL FORMULATION

We study a location-allocation problem in which a number of freight centers need to be located in order to serve all demand points. Ports that handle import products are supply locations. All shipments released from ports must arrive to freight centers first. Each port can be assigned to a single freight center. Freight centers serve the demand points which are the cities in a geographical region. Each demand point can be assigned to a single freight center. Freight centers receive shipments from ports, handle break-bulk operations, and release shipments to cities. Annual total supply and total demand quantities are equal to each other. Annual demand of each city is known and proportional to the population of the city. That demand must be met without backordering or lost sales. Similarly, annual supply is known and constant. The objective is to minimize the TC of constructing logistics centers, transportation, and handling products in order to meet the annual demands of cities. The notation in our models are as follows:

3.1. Indices

i: index for ports, $i = 1, 2, \dots, I$, where I is the number of ports

j: index for freight centers, $j = 1, 2, \dots, J$, where J is the maximum number freight centers

k: index for cities, $k = 1, 2, \dots, K$, where K is the number of cities. Note that $J = K$

3.2 Parameters

S_i: annual supply quantity of port i.

$s_i = S_i / \sum_{i=1}^{I} S_i$, proportion of port i's supply quantity to total supply quantity.

D_k: annual demand quantity of city j; $\sum_{k=1}^{K} D_k = \sum_{i=1}^{I} S_i$

$d_k = D_k / \sum_{k=1}^{K} D_k$, proportion of j's demand quantity to total demand quantity.

t_{ij}: transportation distance from i to j.

t_{jk}: transportation distance from j to k.

c_{ij}: cost of transporting a unit product per unit distance from i to j.

c_{jk}: cost of transporting a unit product per unit distance from j to k.

h_j: unit cost of product handling at j.

r_j: unit cost of product receiving at j.

l_j: unit cost of product releasing at j.

p_j: cost of a construction permit at j.

b_j: cost of building a unit capacity at j.

3.3 Decision Variables

X_j: capacity of freight center j

Y_j: equals 1 if a freight center is built at j, 0 otherwise.

W_{ij}: equals 1 if port i is assigned to freight center j, 0 otherwise.

Z_{jk}: equals 1 if city k is assigned to freight center j, 0 otherwise.

Next, we propose an optimization model as follows:

$$TC = \sum_{i=1}^{I} \sum_{j=1}^{J} (t_{ij} c_{ij} + r_i) S_i W_{ij} + \sum_{j=1}^{J} \sum_{k=1}^{K} (t_{jk} c_{jk} + h_j + l_j) D_k Z_{jk} + \sum_{i=1}^{I} S_i \sum_{j=1}^{J} b_j X_j + \sum_{j=1}^{J} p_j Y_j \quad (1)$$

s.t.

$\sum_{j=1}^{J} W_{ij} = 1, \forall\ i \in I$ (2)

$\sum_{j=1}^{J} Z_{jk} = 1, \forall\ k \in K$ (3)

$W_{ij} \leq Y_j, \forall\ i \in I,\ \forall\ j \in J$ (4)

$Z_{jk} \leq Y_j, \forall\ j \in J,\ \forall\ k \in K$ (5)

$\sum_{i=1}^{I} s_i W_{ij} = \sum_{k=1}^{K} d_k Z_{jk}, \forall\ j \in J$ (6)

$X_j \leq \sum_{k=1}^{K} d_k Y_j, \forall\ j \in J$ (7)

$X_j \geq \sum_{i=1}^{I} s_i W_{ij}, \forall\ j \in J$ (8)

$X_j \geq 0;\ Y_j, W_{ij}, Z_{jk}\ binary$

Total cost (1) is composed of the total transportation cost of products from ports to freight centers and the total cost of receiving those products at the freight centers (first term), the total cost of handling and releasing the products at freight centers and transporting them to cities. The last term of TC is the sum of total cost of construction permits and the total building cost of freight centers. Constraints 2 and 3 ensure that each port and each city respectively are served by a single FC. An FC can receive shipments (4), release shipments (5) and handle loads (8) only if it is open. Flow balance constraint (6) makes sure that what comes in an FC goes out. Finally, an FC's capacity should be large enough to handle the total load that comes in (thus goes out) (8).

The proposed model is a mix integer linear model where Y_j, W_{ij} , Z_{jk} are binary and $X_j \geq 0$. Note that the objective function includes the actual values of supply and demand quantities, S_i and D_k, but the constraints include the ratios s_i and d_k, which makes $X_j \in [0, 1]$. Using these ratios improve the computation times in solving the model without changing the optimal solution as total supply equals total demand. Next section includes a numerical example.

4. NUMERICAL EXAMPLE

The proposed model is used to locate the optimal number of freight centers is Turkey. For this purpose, the parameters in the model are gathered from the official reports of governmental agencies in Turkey including Ministry of Transport and Infrastructure, Turkish Statistical Institute, and Turkish Railway and Road Authority. Firstly, the number of ports to be included in the model is determined. Although there are 114 container ports of different sizes, 27 of those handles 96.5% of the total import/export load in Turkey. Hence, those 27 ports are selected as supply points in our model. Locations of the 27 ports are depicted in Figures 1 and 2 as triangles. Their capacities in TUE are listed in Table 1.

Table 1. Container handling capacity of the 27 container ports

Port Code	TUE /Year	Port Code	TUE /Year	Port Code	TUE /Year
A	2600000	J	1000000	S	350000
B	2500000	K	1000000	T	350000
C	2500000	L	1000000	U	300000
D	2300000	M	850000	V	250000
E	2100000	N	680000	W	250000
F	1500000	O	500000	X	200000
G	1300000	P	480000	Y	250000
H	1300000	Q	450000	Z	150000
I	1200000	R	400000	AA	25000

Various types of products arrive to the ports. However, since our model deals with a macro-level decision making with aggregate capacity planning, we assume a single type of product named as load in tons. Load of tons for import products at 27 ports in 2019, which are the supply quantities in the model, are given in Table 2.

Table 2. Supply quantities of the 27 container ports

Port Code	Supply Quantities (Tons)	Rate	Port Code	Supply Quantities (Tons)	Rate
A	26144201	0.1008	O	5027731	0.0194
B	25138655	0.0970	P	4826622	0.0186
C	25138655	0.0970	Q	4524958	0.0175
D	23127562	0.0892	R	4022185	0.0155
E	21116470	0.0814	S	3519412	0.0136
F	15083193	0.0582	T	3519412	0.0136
G	13072101	0.0504	U	3016639	0.0116
H	13072101	0.0504	V	2513865	0.0097
I	12066554	0.0465	W	2513865	0.0097
J	10055462	0.0388	X	2011092	0.0078
K	10055462	0.0388	Y	2513865	0.0097
L	10055462	0.0388	Z	1508319	0.0058
M	8547143	0.0330	AA	251387	0.0010
N	6837714	0.0264			

The demand points are the cities in Turkey. Imported products are assumed to be distributed to 81 cities of Turkey in proportion to the population of a city over the population of the country. Total supply quantity from all ports is assumed to be equal to the total demand in all cities. That total demand is then divided among the cities using the population ratios. Demand quantities of cities based on 2019 data are provided in Table 3.

Table 3. Demand quantities of 81 cities

City Code	Demand Quantities (Tons)	City Code	Demand Quantities (Tons)	City Code	Demand Quantities (Tons)	City Code	Demand Quantities (Tons)
1	6977972	22	1290564	42	6960617	62	263973
2	1953339	23	1843064	43	1806143	63	6465598
3	2274553	24	731949	44	2494941	64	1155260
4	1671887	25	2376135	45	4491874	65	3544447
5	1053272	26	2767177	46	3598529	66	1313316
6	17582829	27	6452347	47	2615338	67	1858513
7	7831565	28	1398126	48	3065470	68	1298246
8	532794	29	512982	49	1274680	69	264543
9	3464048	30	876139	50	944795	70	789732
10	3830879	31	5078946	51	1131413	71	882457
11	684181	32	1387257	52	2351615	72	1897819
12	872463	33	5738507	53	1070147	73	1651357
13	1085434	34	48389598	54	3210483	74	618147
14	985692	35	13617236	55	4204799	75	303444
15	844351	36	889918	56	1029824	76	621867
16	9529085	37	1182998	57	680489	77	844912
17	1690464	38	4388349	58	1992286	8	774700
18	610477	39	1128217	59	3290810	9	444289
19	1655252	40	757489	60	1910566	80	1679869
20	3234050	41	6089629	61	2522408	81	1222787
21	5476368						

Transportation is assumed to be carried out by road with two types of vehicles. Transporters with up to 264 tons of allowed load-weight can be used between ports and freight villages at a cost of $ 0.23 per ton per km. Since bulk will be decomposed into smaller loads at freight centers, smaller trucks with up to 16 tons of allowed load-weight can be used between freight centers and cities at a cost of $ 0.37 per ton per km.

Costs of receiving, handling, and releasing a ton of load at a freight center are $ 0.53, $ 1.00, and $ 1.33 per ton, respectively. These costs are assumed to be identical among all freight centers. Similarly, unit cost of a construction permit is identical all over the country since this cost is regulated by the government.

That cost is set to $ 0.13 per square meter for logistics centers in 2019. Total building area in square meters for a freight center is found by averaging the closed areas in ongoing government-supported project in two cities, namely the Kars and İzmir logistics villages. The construction cost, p_j, is then set to ($ 0.13/ m2) x (average construction area) = $ 37868 per freight center.

Table 4. Summary of the optimal solution

Optimum Solution (21 FC) (*TC* = $ 34.349 billion)					
Y_j (FC)		W_{ij} (from Port_i to FC_j)		Z_{jk} (from FC_j to City_k)	
Y_j node	Y_j capacity	Port_i	FC_j	FC_j	City_k
4	0.008	X	4	4	4, 76
5	0.016	R	5	5	5, 24, 29, 60
6	0.097	C	6	6	6, 18, 38, 66, 71
7	0.036	O and Q	7	7	7, 15, 70
10	0.026	N	10	10	10, 17, 64
16	0.047	I	16	16	11, 14, 16, 77
19	0.006	Z	19	19	19
23	0.039	K	23	23	12, 21, 23, 62, 72
25	0.012	U	25	25	25, 36
30	0.014	T	30	30	30, 56, 73, 75
31	0.02	W and Y	31	31	31
33	0.102	A and AA	33	33	1, 2, 27, 33, 46, 80
34	0.22	D, E and G	34	34	22, 34, 37, 39, 57, 59
35	0.097	F and L	35	35	9, 35, 45, 48, 79
41	0.05	H	41	41	41, 54, 67, 78, 81
43	0.097	B	43	43	3, 20, 26, 32, 40, 42, 43, 50, 51, 58, 68, 74
44	0.01	V	44	44	44
49	0.019	P	49	49	49, 65
55	0.033	M	55	55	8, 28, 52, 55, 69
61	0.014	S	61	61	53, 61
63	0.039	J	63	63	13, 47, 63

Unit building capacity that can handle a ton of load is approximated using again the information from ongoing projects in two cities. That unit capacity is found to be 0.425 m2/tons. Building cost per square meter is identified as $ 85/m2 (source). That cost is also assumed to be identical over cities as raw material and labor costs do not vary much from one city to another. The cost of building a unit capacity is then found to be (0.425 m2/tons) x $ 85/ m2= $ 36 / ton.

Each city is a possible location for freight center. A matrix of 27x81 and another matrix of 81x81 that include the road distances from ports to logistics centers, and from logistics centers to cities respectively are formed. Geographical data were used to measure the road distances.

The model is them solved by GAMS Cplex 12.9 on a computer with 64 RAM and 2.2 Ghz processor with 16 cores. The solution is found in 276 seconds. Table 4 shows the optimal results of the problem.

Results show that a total of 21 freight centers are opened and the minimum total cost is $ 34.349 billion. The breakdown of the total cost is total transportation cost (70.59 %), total cost of building the required capacity (27.22%), total cost of construction permits (0.02 %) and the total cost of receiving, handling and releasing (2.17%). Hence, 27.24 % of the total cost is the fix cost of constructing the logistics network that includes the optimal number of freight centers. The remaining 72.76%, $ 24.992 billion, is the annual cost of logistics, which corresponds to around 4.5% of the country's GDP.

Figure 1 shows the locations of the freight centers to be built and the delivery routes from ports to them. Although ports are densely located in certain regions, it is seen that the freight centers are geographically dispersed in order to meet the demand in 81 cities. Long delivery routes are observed since the major portion of the total supply capacity is in northwest (namely, the Marmara region).

Figure 1. Optimal FC locations and delivery routes from *i*th port to *j*th FC

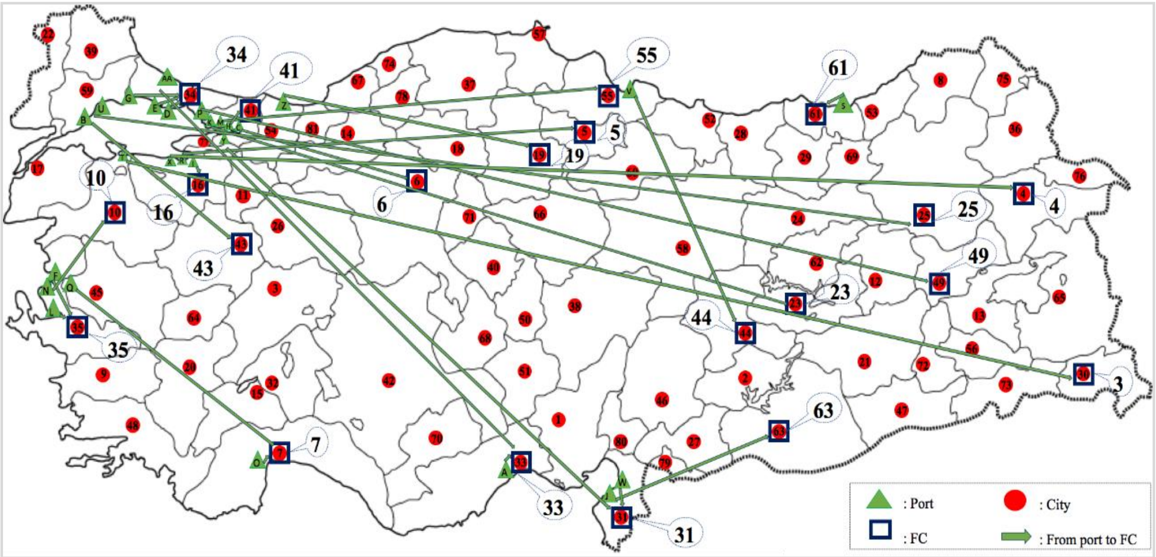
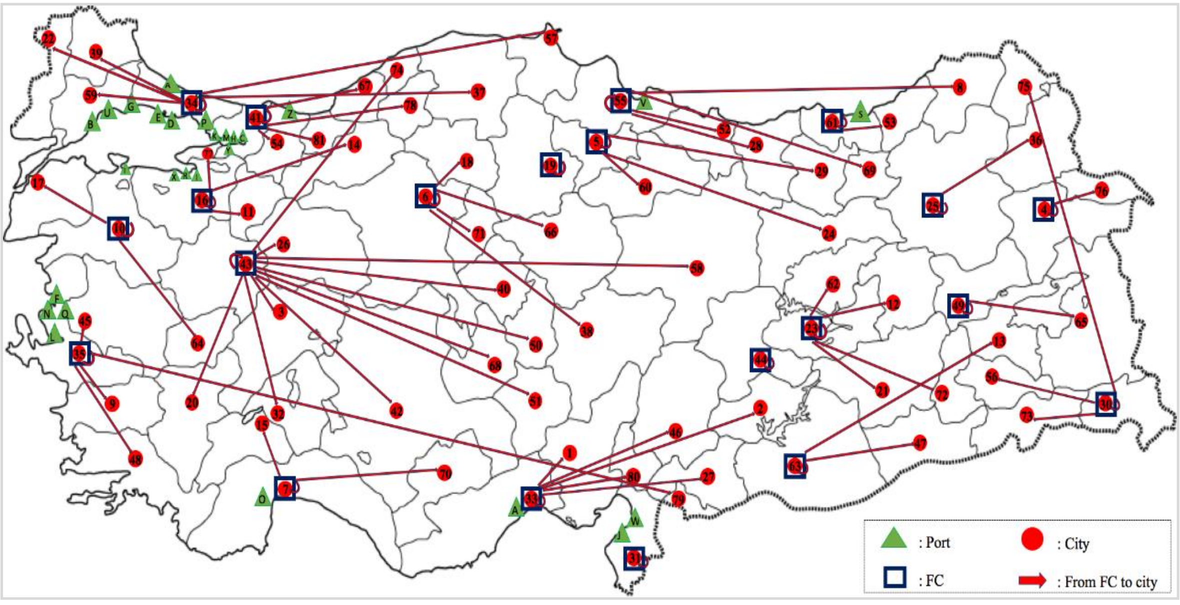


Figure 2 shows the distribution routes from freight centers to cities. It is seen that other than the freight villages numbered 19, 31 and 44, all villages serve multiple destinations. Naturally, the delivery routes are shorter here compared to that of Figure 1 as freight centers serve mostly the nearby cities.

Figure 2. Delivery routes from *j*th FC to *k*th City.



5. SENSITIVTY ANALYSIS

Our model identifies the number of freight centers and their capacities in order to distribute import products to the cities of Türkiye. Optimal solution shows that a total of 21 freight enters are required in order to minimize the total distribution, handling and construction costs. We see in the model and that total handling cost is independent of location-allocation decisions as all of total supply needs to go through freight enters. Similarly, cost of building the total capacity required for handling does not change as total capacity depends only on the total supply. That is to say, $\sum_{i=1}^{I} S_i \sum_{j=1}^{J} b_j X_j$ is the same in all feasible solutions as $\sum_{j=1}^{J} X_j$ always equals one. Hence, optimal solution depends only on the number of the freight enters to be built and the cost of construction permit.

Optimal solution shows that the total cost of construction permits is 0.02 % of the total network. Note that this percentage is rather small even when there are 21 freight centers are opened. Furthermore, this cost portion is based on government regulations and hence do not change. Our sensitivity analysis thus will look at the variations in solutions as we vary the total number of the freight enters that can be built.

In our sensitivity analysis, we introduce a new index *z* to indicate scenario number where it also indicates the number of freight centers that can be built. Hence, *z* is between 1 and 21 as the optimal number of FC's is found to be 21. In addition to equations 1-8, we then add to the following constraint and solve the model for each *z*, *z* = 1,… ,21.

$$\sum_{j=1}^{J} Y_j = z \qquad (9)$$

We then compare the original optimal solution (*z* = 21) and each other case of *z*. Let TC^z be the optimal total cost, and Y_j^z be the optimal set of freight-centers locations in scenario *z*. Also let $TTC_1^z = \sum_{i=1}^{I} \sum_{j=1}^{J} c_{ij} S_i W_{ij}^z$ and $TTC_2^z = \sum_{j=1}^{J} \sum_{k=1}^{K} c_{jk} D_k Z_{jk}^z$ be the the total transportation cost to and from freight centers, respectively, and TTC^z be the sum of them. For each scenario *z*, we define GAP_TTC^z= TTC^z- TTC^{21}, %GAP_TTC^z= 100 (TTC^z- TTC^{21}) / TTC^{21}, and %TTC^z = 100 TTC^z/ TC^z as the sensitivity measures. Findings are summarized in Tables 5 and 6 and in Figure 3.

Table 5. Comparison of scenarios in terms of costs and computation times

z = # of Freight Centers	Computation Time (Sec)	TC^z (billion $)	TTC^z (billion $)	GAP_TTC^z (billion $)	$\%GAP\_TTC^z$	$\%\ TTC^z$
21	276	34.35	24.25	0.000	0.00	70.59
20	340	34.36	24.26	0.015	0.06	70.60
19	355	34.42	24.32	0.071	0.29	70.65
18	288	34.49	24.39	0.141	0.58	70.71
17	241	34.59	24.49	0.243	1.00	70.80
16	279	34.73	24.63	0.386	1.59	70.92
15	288	34.90	24.80	0.555	2.29	71.06
14	322	35.10	25.00	0.757	3.12	71.23
13	89	35.32	25.22	0.969	4.00	71.40
12	96	35.69	25.59	1.340	5.53	71.70
11	86	36.09	25.99	1.744	7.19	72.02
10	41	36.51	26.41	2.163	8.92	72.34
9	26	37.00	26.90	2.653	10.94	72.71
8	39	38.00	27.90	3.654	15.07	73.43
7	33	39.17	29.07	4.826	19.90	74.22
6	23	40.64	30.54	6.291	25.95	75.15
5	26	43.30	33.21	8.961	36.96	76.68
4	21	45.86	35.77	11.522	47.52	77.99
3	20	50.26	40.17	15.918	65.65	79.91
2	22	57.73	47.64	23.393	96.48	82.51
1	22	82.11	72.02	47.772	197.02	87.71

Table 5 includes the computation times and costs in all the scenarios considered. It is observed that the proposed models for each *z* can be solved within reasonable durations and in at most six minutes. We also see in Table 5 that as the number of freights that can be built decreases, total cost increases. This increase stems from the increased transportation costs, as clearly seen in $\%\ TTC^z$. The share of transportation cost in the total cost is 70.59 % when *z* = 21 and goes up to 87.71% when *z* = 1. Moreover, $\%GAP\_TTC^z$ icreases expeonentially as we decrease the number of freight centers, and it takes a value of 1 % or less when the number of freight centers is between 17 and 20. Although this looks like a small percentage, monetary value of the increased cost is $ 243 million when that gap 1%. In addition, this value is per annum indicating that for a longer period of time opening just a few less than 21 freight centers costs much.

Figure 3 shows the breakdown of total cost in each scenario. We see that the total transportation cost to freight centers, TTC_1^z, tends to increase gradually as the number of centers increase. This shows that when there are fewer freight centers to be opened, their locations get closer to supply point and shipment consolidation can be achieved. On the other hand, deconsolidated shipments from those centers need to travel longer distances as demand locations are dispersed. This in turn results in an exponential increase in TTC_2^z, which also increases the total transportation cost exponentially.

Figure 3. Breakdown of total transportation cost

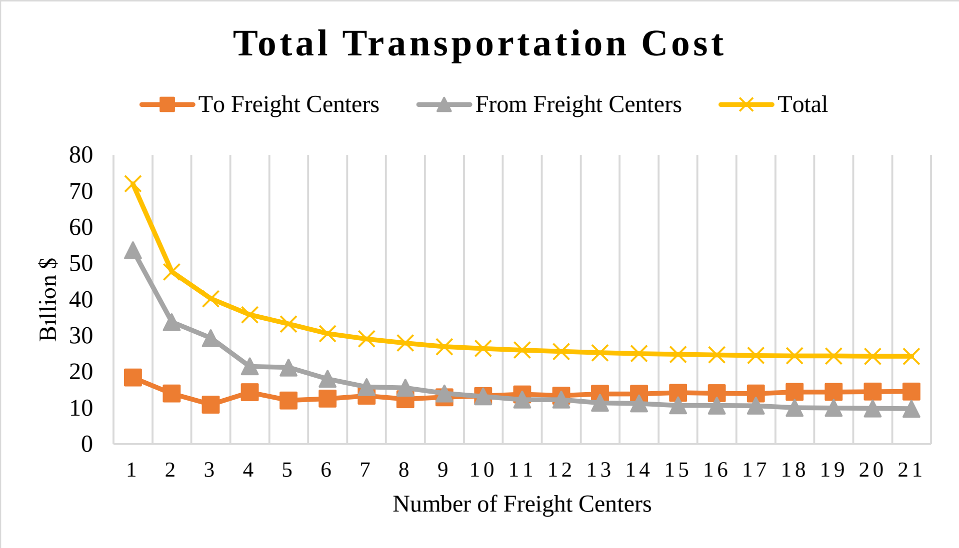
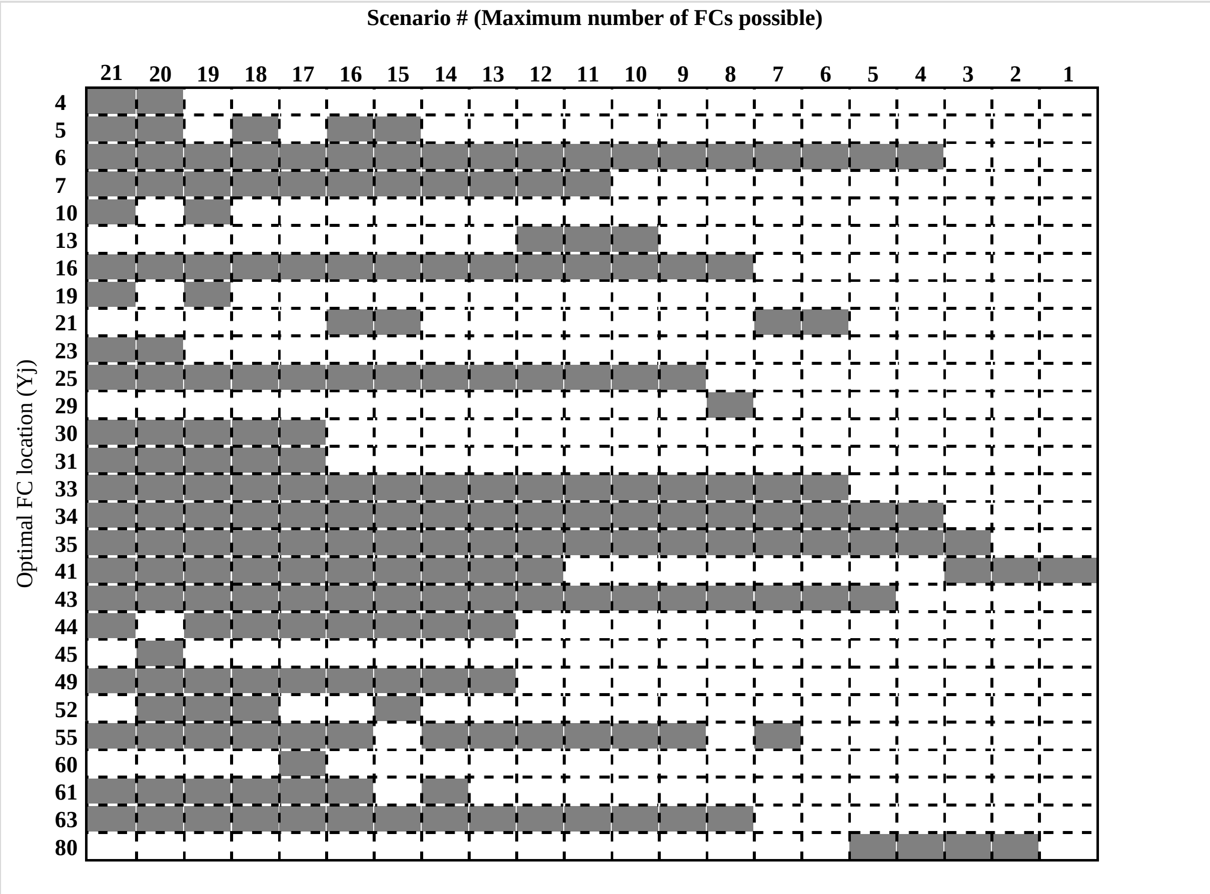


Figure 4 shows comparison of optimal locations in 21 scenarios. Note that a scenario number is also equal to the maximum number of FCs that can be opened in the model. Hence, scenario # 21 refers to the optimal solution where 21 LCs were opened. For each scenario, a shaded cell indicates that the city in the corresponding row is chosen for building a freight center. It is seen that the most stable locations are cities numbered 6, 34 and 35 which always hosts a FC if *z* is greater than 3. Moreover, the same 13 cities are chosen when *z* is greater than or equal to 13. The figure is also useful to set the sequence of construction when the policy makers determine the total number of FC's to build. If that number is, say, 13, it is better to start with city 41 as it is the optimal when *z* is 1.

Figure 4. Optimal freight center locations in 21 scenarios



6. CONCLUSION

This paper provided a mix-integer linear model to determine the location and capacities of freight centers. The model was used to identify the locations of freight villages in Türkiye. Sensitivity analysis were performed to see the impact of limiting the number of villages. All numerical analysis was performed using realistic figures for costs, supply, and demand quantities. Supply points were taken as the major container ports and demand locations included all the cities that needed to be served.

Numerical analysis shows that the investment costs for building the required number of freight centers in Türkiye is 27.24% of the total cost and amounts to around $ 9.357 billion. Transportation and handling related costs, on the other hand, is 72.76 % of the total cost with a value of $ 24.992 billion per year, corresponding to 4.5% of the GDP.

As all the demand of cities need to be served through freight centers, the required total capacity is independent of the number of freight centers. With a single freight center to serve all cities, all that capacity would go to a single facility. As cost of building a unit capacity can be assumed to be the same for all cities, increasing the number of freight centers does not change the total investment cost especially for government-financed projects. Similarly, total handling-related costs is constant. Increasing the number of freight villages to the optimum identified by the model, however, promises large savings in transportation costs.

Freight centers encompass activities related to product distribution and typically are connected to major transportation modes. An efficient freight-center network in a country is a key factor in increasing the efficiency of national as well as global freight transport. These centers are also an important profit and investment initiatives as they significantly contribute to the competitive advantage of the region where they are located. Results of this study also provides insights for policy maker as to where freight centers can be located for future planning. Comparison of optimal freight center locations in 21 scenarios can be regarded as a roadmap for building new facilities in the short, medium and long terms and for allocating necessary construction budgets accordingly.

Future studies may consider incorporating location priorities in the model or developing new models for micro level location decisions. Development plans for certain regions set by national authorities may be included in the model by weighting alternative locations to set precedence. Economic development index, quality of infrastructure and availability of land, among others, may be used to allocate weights. Another stream of future research may consider identifying the specific boundaries of a freight center in a particular city.

The study does not necessitate Ethics Committee permission.

The study has been crafted in adherence to the principles of research and publication ethics.

The authors declare that there exists no financial conflict of interest involving any institution, organization, or individual(s) associated with the article. Furthermore, there are no conflicts of interest among the authors themselves.

The authors contributed equally to the entire process of the research.

REFERENCES

Baydar, A.M., Süral, H. & Çelik, M. (2019). Potential effects of logistics clusters: The case of Turkish Freight Villages. *Journal of Cleaner Production*, (233), 399-411. https://doi.org/10.1016/j.jclepro.2019.05.294

Bookbinder, J.H., & Fox, N.S. (1998). Intermodal routing of Canada–Mexico shipments under NAFTA. *Transportation Research Part E: Logistics and Transportation Review*, *34*(4), 289–303. https://doi.org/10.1016/S1366-5545(98)00017-9

Crainic, T.G., Ricciardi, N., & Storchi, G. (2009). Models for evaluating and planning city logistics systems. *Transportation Science*, *43*(4), 432-454. https://doi.org/10.1287/trsc.1090.0279

Crainic, T.G., Dell'Olmo, P., Ricciardi, N., & Sgalambro, A. (2015). Modelling dry-port-based freight distribution planning. *Transport. Research Part C: Emerg. Technol*., (55), 518-534. https://doi.org/10.1016/j.trc.2015.03.026

Elevli, B. (2014). Logistics freight center locations decision by using Fuzzy PROMETHEE, *Transport*, *29*(4), 412-418. https://doi.org/10.3846/16484142.2014.983966

Erdil, M. (2010). *Ekonomik kalkınma stratejisi olarak lojistik köyler* [Unpublished master's thesis]. Marmara University.

Gümüş, M., & Bookbinder, J.H. (2004). Cross-docking and its implications in location–distribution systems *Journal of Business Logistics*, *25*(2), 199-228. https://doi.org/10.1002/j.2158-1592.2004.tb00187.x

Gürbüz, A., Ayaz, N. & Kebeci, S. (2016). Üretim işletmeleri yöneticilerinin lojistik köy algıları: Karabük ili örneği. *Karabük Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, (2), 1-19.

Hakimi, S.L. (1964). Optimum locations of switching centers and the absolute centers and medians of a graph. *Operations Research*, *12*(3), 450-459. https://doi.org/10.1287/opre.12.3.450

Higgins, C.D., Ferguson, M.R. (2011). *An exploration of the freight village concept and its applicability to Ontario*. McMaster Institute for Transportation and Logistics. https://macsphere.mcmaster.ca/bitstream/11375/18911/1/MITL_Freight_Villages_January.pdf

Ishfag, R., & Sox, C.R. (2011). Hub location-allocation in intermodal logistic networks. *European Journal of Operational Research*, *210*(2), 213-230. https://doi.org/10.1016/j.ejor.2010.09.017

Kapros, S., Panou, K., & Tsamboulas, D. A. (2005). Multicriteria approach to the evaluation of intermodal freight villages. *Transportation Research Record*, *1906*(1), 56-63. https://doi.org/10.1177/0361198105190600107

Karaşan, A., & Kahraman, C. (2019). A novel intuitionistic Fuzzy DEMATEL – ANP – TOPSIS integrated methodology for freight village location selection. *Journal of Intelligent & Fuzzy Systems*, *36*(2), 1335-1352. https://doi.org/10.3233/JIFS-17169

Kayikci, Y. (2010). A conceptual model for intermodal freight logistics centre location decisions. *Procedia Social and Behavioral Sciences*, *2*(3), 6297-6311. https://doi.org/10.1016/j.sbspro.2010.04.039

Kumar, A. & Anbanandam, R. (2019). Location selection of multimodal freight terminal under STEEP sustainability. *Research in Transportation Business and Management*, *33*, 100434. https://doi.org/10.1016/j.rtbm.2020.100434

Louveaux, F.V. (1993). Stochastic location analysis. *Location Science*, 1(2), 127-154.

Lyu G., & Chen, L. (2019). Logistics resources, capabilities, and operational performance: A contingency and configuration approach. *Systems*, *119*(2), 230-250. https://doi.org/10.1108/IMDS-01-2018-0024

Marković, G., Gašić, M., Kolarević, M., Savković, M., & Marinković, Z. (2013). Application of the MODIPROM method to the final solution of logistics centre location. *Transport*, *28*(4), 341-351. https://doi.org/10.3846/16484142.2013.864328

Meidutė, I. (2005). Comparative analysis of the definitions of logistics centres. *Transport*, *20*(3), 106- 110. https://doi.org/10.3846/16484142.2005.9638005

Meidutė, I. (2007). Economical evaluation of logistics centres establishment. *Transport*, *22*(2), 111-117. https://doi.org/10.3846/16484142.2007.9638108

Melo, M.T., Nickel, S., & Saldanha-da-Gama, F. (2009). Facility location and supply chain management – A review. *European Journal of Operational Research*, *196*(2), 401-412. https://doi.org/10.1016/j.ejor.2008.05.007

Owen, S.H., & Daskin, M.S. (1998). Strategic facility location: A review, *European Journal of Operational Research*, *111*(3), 423–447. https://doi.org/10.1016/S0377-2217(98)00186-6

Önden, I., Acar, A. Z., & Eldemir, F. (2018). Evaluation of the logistics center locations using a multi-criteria spatial approach. *Transport*, *33*(2), 322–334. https://doi.org/10.3846/16484142.2016.1186113

Özgen, H. (2011). *Samsun modern lojistik köyünün 21. yy ekonomisine entegrasyonu: Gelişen ve değişen şartlara uyumu stratejik yaklaşımlar* [Conference presentation abstract]. Samsun Sempozyumu 2011, Samsun, Turkey. https://www.samsunsempozyumu.org

Rostamzadeh, R., Esmaeili, A., Sivilevičius, H., & Nobard, H. B. K. (2020). A fuzzy decision-making approach for evaluation and selection of third party reverse logistics provider using fuzzy ARAS. *Transport*, *35*(6), 635-657. https://doi.org/10.3846/transport.2020.14226

Tambi, A. M. A., Mohid, M. N., Shukor, I. A., & Arip, M. S. M. (2013). Planning for a logistics village. *World Applied Sciences Journal*, *25*(3), 421–427. https://doi.org/10.5829/idosi.wasj.2013.25.03.60

Taniguchi, E., Noritake, M., Yamada, T. & Izumitani, T. (1999). Optimal size and location planning of public logistics terminals. *Transportation Research Part E*, *35*(3), 207–222. https://doi.org/10.1016/S1366-5545(99)00009-5

Terouhid, S., Rie, R., & Fard, M. (2012). Towards sustainable facility location - A literature review. *Journal of Sustainable Development*, *5*(7), 18-34. https://doi.org/10.5539/jsd.v5n7p18

Tsamboulas, D. A., & Kapros, S. (2003). Freight village evaluation under uncertainty with public and private financing. *Transport Policy*, *10*(2), 141-156. https://doi.org/10.1016/S0967-070X(03)00002-7

UNESCAP-United Nations Economic and Social Commission for Asia and the Pacific. (2009). *Review of developments in transport in Asia and the Pacific*. New York. https://www.unescap.org/publications/review-developments-transport-asia-and-pacific-2009

Wu, Y., Sengpiehl, C., Toh, K., & Nagel, P. (2009, July 5-8). *The progression to logistics city and its implication of economies of agglomeration* [Conference presentation full text, 595-601]. 14th International Symposium on Logistics (14th ISL), Istanbul, Turkey. https://www.islconf.org/14th-isl-istanbul-2009/