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Domestic flight network hub location problem under traffic disruption with sustainability provision

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ABSTRACT

There are many models in the current literature used extensively for the last 20 years on hub location problems and collect-distributive network structures. A centrally hub located facility serves as the main distribution base and flows from other facilities are collected in this hub then distributed. This centralization approach and expansion of the operational network brings the advantage of economies of scale in these days. According to the airline companies, the flight network in form of a distributor increases the profit of airline companies and provides significant savings in costs. In this study, a new hub location problem as homogeneous multi allocation p-hub median problem is proposed and solved considering the effects of airplane types and characteristics on hub locations were investigated. The results showed that the constraints and parameters used in the developed model have a significant effect on hub site selection and assignment to the different flight routes of low-cost airline companies.

1. Introduction

The liberalization experienced in the USA after the 80′s had a global impact and since the mid-80′s the world airline industry has witnessed significant structural, institutional and legal changes. Many countries have gone to liberalize their domestic routes, and bilateral agreements have been signed between them. Open skies projects have been implemented in Europe and North America. Increasing competition and economic stagnation in this process caused great losses in the international airline industry.

Liberalization has bring a lot of challenging task to decide in this industry. Decision-making process of an airline consists of many planning stages like flight network and fleet planning, airplane and crew scheduling. In this process, the most important problems for a company to make strategic decisions are flight network and fleet planning. Flight network planning includes the selection of the starting and arriving points where the transportation service will be carried out and planning the route of the airplane between these points (Lederer and Nambimadom, 1998). Carriers had to go through restructuring in order to increase productivity and reduce costs (Oum and Yu, 1998).

Significant change in this process took place in the airline flight network structure with developing the hub and spoke network structure and arranging the flight routes according to this principal. This has also affected other airline services and operations. Similarly, the fast-moving cargo companies also adapted on hub and spoke network. Development of the distribution network structure in aviation has been one of the most important innovations after liberalization. Although the hub and spoke network structure has been brought to the news with successful applications in airline passenger and cargo transportation, it has been successfully applied in road transport, communication networks and logistics systems (Aykin, 1995).

Increasing in demand for road and air transport in the world means that an increase in national and international air traffic. Traffic increase volume will accelerate further with population density, industrial activities, and the reduction of prices. As a result, it is inevitable to create new routes for airline companies and to restructure their networks at this stage. Establishing the right network structure of airlines is a vital process that affects the company's stay and growth in the sector. Fig. 1 shows that most of the passenger demand is met by 5 airports in Turkey. All of these airports are international airports. Geopolitical position of Turkey makes the airports more attractive especially as transit airports. Opposite of this situation, there is no low cost domestic carrier in

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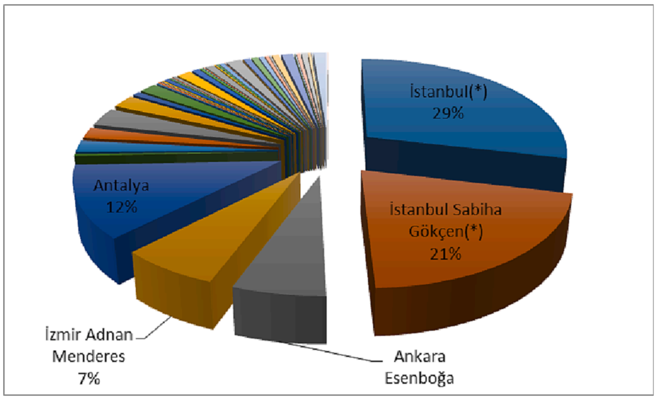

Fig. 1. Total Passenger Demand on Turkish Airports in 2020 (TURKSTAT, 2020).

Turkey. It's obvious that most of the air passengers are concentrated on 5 airports. According to that, it is essential to determine the main distribution bases of the airlines serving with hub and spoke network structure.

Aviation industry is also the sector that is most affected by sanctions and international relations, as it is located in an area that integrates with many other sectors. In this sense, the COVID-19 pandemic is an important issue that disrupts the aviation industry in the world. Just using the appropriate hub and spoke network structure will make be possible to provide time and cost benefits for the customer and airline business. In this study, we make a search for solutions to hub allocation problems for a new low-cost domestic airline to minimize total operational cost in Turkey taking into account the specific characteristics of airports and traffic continuity.

1.1. The contributions of the study

The main contribution of this paper is to fill a gap with a new hub location problem. It's called homogeneous multi allocation p-hub median problem, is proposed and solved considering the effects of airplane type characteristics on hub locations for Turkey. The main requirements of the study are listed as follows;

- COVID-19 Outbreak show that traffic continuity on airline industry is vital for sustainability of industry.
- There is need for an airline company which serves just domestic routes in Turkey.
- Different from the current situation, scenarios should be evaluated in order to reduce flight times.
- Expanding flight network and frequencies can affect utilization of air transportation.
- Increasing the accessibility of air transportation can lead economic developments.

Therefore, the main distribution base allocation problems are aimed to be more realistic and to be usable by all airlines taking into account the specific characteristics of airline passenger transport. It is aimed to contribute to healthy and planned development of airline passenger transport in Turkey. In the study, a sensitivity analysis was also applied by using different values of the parameters and newly developed constraints to the models and the results were discussed in order to observe how the results change with the change of the structure of the parameters and models in hub placement problems. The evaluations of proposed models were made according to airplane types, and airport runway costs were also taken into consideration in Turkey in those models. The results show that the constraints and parameters used in the proposed models have a significant impact on low-cost airlines' selection and assignment of distribution location to different flight routes. Because it is aimed to design a flight network in accordance with the low-cost approach where profitability is high and costs are reduced, in particular, the period of the COVID-19 outbreak causing to stop operations of many airline companies all over the world makes this study important.

2. Literature review

An important application area of hub and spoke network structures is passenger/cargo and fast package transportation by airlines. The studies that have been carried out in the field of airline passenger transport as well as fast package transport and cargo transport are examined and given below. Demand or flow terms used in hub allocation problems refer to transport sector applications between a city pair airplane, trains, trucks, and so on. Nodes refer to facilities such as airports and terminals.

In the airline transportation system, every model encompasses the objectives of minimizing airline costs and achieving maximum access by loosening the acceptance of flows through hubs nearly (O'kelly, 1987). Flynn and Ratick conducted a study of the Essential Air Services program (Flynn and Ratick, 1988). In this program, air transport service is offered to small groups in the network of the hub and spoke. Stop points are small cities where one or more stops are made before arriving at hubs.

Kuby and Gray developed the research of Flynn and Ratick, taking into account hub and spoke points (Kuby and Gray, 1993). In the basic hub and spoke network, the nodes are assigned directly to the hubs and the loads originating from the starting point are sent to a hub. In their research, unlike other studies, small cities are used as stopping points and the demands between these cities are carried with feeders. Feeders, pick-up loads from small cities then transfer them to large cities. Loads are transported to hubs by large aircrafts. They discussed the relationship between load factors, economies of scale, time constraints, and distance (Jaillet et al., 1996). They introduced a mixed-integer model that minimizes the total network cost for Federal Express, a package transport company in West America. The model uses a specific hub and compared to the original hub and spoke network when the network uses standstill and feeders. This shows that network costs decreased, load coefficient increased, less distance traveled and fewer airplanes required (Hall, 1989). Fast express companies such as Federal Express use small or regional hubs as well as large hubs. Hall modeled this type of hub and spoke network structure and examined the effect of time constraints on network design in fast packet transport (Hall, 1989). He proposed the use of a large hub to send streams between regional and small hubs.

Important point in network designs with large and small hubs is that there is a connection between hubs and the time constraint limits such connections. Daskin and Panayotopoulos proposed a route model in an existing hub and spoke network structure to maximize profit (Daskin and Panayotopoulos, 1989). Study was developed with a heuristic approach based on Lagrange relaxation which determines the upper limit of the objective function. In model, the starting point of the route is a hub, and the routes are modeled to return to the hub point after the planes cross one or more cities. Dobson and Lederer (Dobson and Lederer, 1993) expanded the work of Daskin and Panayotopoulos by adding the customer's preference. Their study models the flight plan and route prices to maximize profit for an existing hub and a network of airline. Customer demand is a function of service quality and prices. Service quality is related to flight quality and flight length.

In all studies discussed above, hub locations within the hub and spoke network structure are evident and new characteristics are added to these structures. However, it is known that assignments are affected by hub location choices and vice versa. Considering this, researchers have developed models in which the number and location of hubs are determined together with the solution. In addition, new models have been developed by the use of direct connections between non-hub nodes, fixed costs for establishing hubs, capacity constraints to reduce

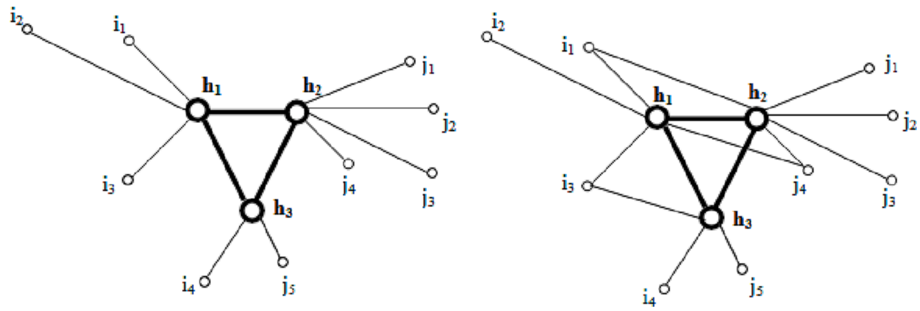

Fig. 2. Single (left) and multiple (right) assignment hub location.

congestion at hub points, constraints that prevent connection lines from opening under a certain use.

Aykin developed the first model with limited capacity for air transport (Aykin, 1994). In this work, the capacity constraint was not linear and branch and bound algorithm was used to develop a heuristic based on clustering method. Another alternative to the capacity constraint is to limit the amount of flow sent between hub locations. Such a capacity limitation limits the transport of large quantities and supports the opening of a second hub on the same route. In multi-assignment models, limiting the amount of flow in the connecting lines leads to very little flow in some lines. Marianov and Serra dealt with the problem in a similar way and developed a hub and spoke network structure model considering the congestion problem in airports used as hubs (Marianov and Serra, 2003). The number of airplane waiting for landing is limited by a constraint and a model has been developed according to the tail theory. The aim of the study was to determine the number of runways required for each hub.

O'Kelly discussed the use of large and small hubs in the hub and spoke network, where hub locations are not clear for fast packet transport (O'Kelly, 1998). The cost of transport is a function of the amount of flow sent through the lines. The basic hub location model uses the cost reduction coefficient for transports between hubs and is determined by user regardless of the flow rate. Also, O'Kelly and Bryan developed a model in which transport costs depend on the amount of flow (O'Kelly and Bryan, 1998). Authors found that in the case of basic hub location and assignment problems, if inter-hub transport costs are handled independently of the flow rate, not only the total cost calculation, but also the best hub location and assignment would be wrong. Therefore, he developed a model by using segmented linear function to reflect the economies of scale between hubs. However, it is stated that this model is more suitable for cargo transportation by air because it maximizes the load factor regardless of route, therefore, their model proposals should be modified for studies on passenger transport and that the balance between minimizing the effort of the passenger total cost should be established (O'Kelly and Bryan, 1998).

In another study, Aykin examined three different hub and spoke network structures using direct connections between airline and nodes for passenger transport, using one-hub and two-hub (Aykin, 1995). He used the cost reduction coefficient. The study also revealed an intuitive approach to the solution of models. Results showed that the total network cost of structures that allow direct routes between non-hub nodes is always less than or equal to the cost of a single hub structure (Aykin, 1995). Jaillet, et al. developed the work of Aykin (Aykin, 1995) and introduced a hub and spoke network model (Jaillet et al., 1997). In that study, it is assumed that hub and spoke network structure is not a priority. If the cost is lower than this assumption, the resulting network structure suggests the existence of hubs. Sasaki et al. demonstrated the problem of choosing one-stop p-median hub locations for passenger transport by airline (Sasaki et al., 1999). They assumed that all demand points were connected to hub points but only one hub could be used in each route. The aim was to minimize the total distance covered. A definitive solution method and two heuristics been developed for the solution. Besides, Sasaki et al. studied the one-stop multitasking p-hub median problem similar to previous studies (Sasaki et al., 1999). They proposed two heuristics based on the branch and bound and the greedy algorithm were revealed. Drezner and Drezner presented a one-stop p-hub location problem that aims not to minimize the total distance traveled by the passenger in air transport. A new model was developed according to the law of gravitation (Drezner and Drezner, 2001).

Another important aspect of airline passenger transport is the effect of prices and the competitive environment. A limited number of studies have been conducted on the relationship between pricing and the network structure. Marianov et al. presented a model for the problem of p-hub location selection and assignment, which could be applied to airline and cargo transportation and focused on winning customers in a competitive environment (Marianov et al., 1999). In this model, flows between origin and destination points are sent over one or two hubs and nodes can be assigned to more than one hub.

3. Problem definition, material, and method

3.1. Hub location problem

Hub location problem has become a vital research area of location theory for the last 20 years. Use of hub and spoke network structures in modern transport and telecommunications systems plays a major role in this. A centrally located plant in the hub and spoke network serves as a collection and distribution point. This center, which is used as a collection and distribution point, is called as "hub". In a hub and spoke network system, flows between all start-arrival points are collected in hubs to benefit from economies of scale, not through direct connection lines, and sent to the destination via hubs. Thus, with fewer connection lines, it is possible to access more points at lower costs. Hub allocation problems are mainly used in air transportation, postal and cargo distribution services, the emergency services sector, and telecommunication fields (Campbell et al., 2004). Hub location problem involves two sub-problems; first problem is choosing a location for the hub, and the second problem is assignment of the spoke points to the designated hubs (Mayer and Wagner, 2002). Some researchers have addressed only the assignment aspect of the problem. Since the best assignments will be influenced by hub location selections and the best hub location selections will be affected by assignment decisions, location and assignment problems should be handled together in hub network structure design (Bryan and O'Kelly, 1999).

3.2. Classification of hub location problem

In hub location problem, there are two different assignment structures, which are single and multiple hub assignments. In single-assignment structures, incoming and outgoing traffic of each node are sent over a single hub. This means that a node is assigned to a hub. In multi-assignment structures, each node sends or receives incoming and outgoing streams across multiple hubs. Fig. 2 shows a single and multi-assignment hub allocation schematically.

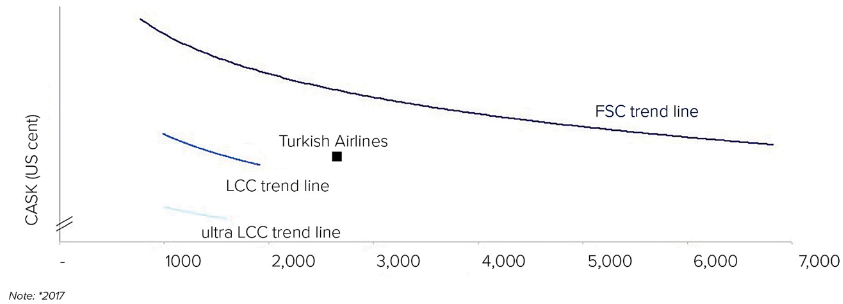

Fig. 3. Trend line of Turkish Airlines (CAPA, 2018).

Campbell grouped the hub location problems in four different ways, similar to the facility problems; "p-hub median", "p-center hub", "Hub coverage" and "uncapacitated hub location" problem (Campbell, 1994). Hub location problems are defined for discrete and continuous spaces. In discrete space, the location of demand points, and start-arrival points are clear. In continuous space, the demand points are defined at any point in the coordinate plane.

Hub location problems are defined for networks with n origin and destination points and potential hubs. Basic parameters of the problem; the flow data for each start-arrival pair, the unit transport cost (time, distance, monetary cost) and the cost reduction coefficient used to benefit from economies of scale in transports between two hubs Campbell, 1994). The hub layout problem was firstly modeled by O'Kelly (O'Kelly and Miller, 1994) for planar allocation problems. Then, the first model for a single-assignment p-hub median problem was proposed by O'Kelly (O'Kelly, 1986). The model has binary variables with a square objective function which is minimizing the total cost of transport. The squared integer model is accepted as the basis of Hub location problems. In O'Kelly's model (Eq. (1)–(5)) (O'Kelly, 1986), *N* is the set of nodes, *i* is the starting point of the flow, *j* is the arrival point of the flow, *k* is the potential hub point, *p* is the number of hubs to be opened, w_{ij} is the amount of flow from *i* to *j*, and c_{ij} is the unit transport cost and α∈ (0 or 1) cost reduction coefficient. The x_{ik} node is a binary variable that is set to 1 if the node k is assigned to the hub, and otherwise *0* (zero). $x_{kk} = 1$ means that node k is a hub, and $x_{kk} = 0$ means that node *k* is not a hub.

$$Min\sum_{i,j} w_{ij}\left[\sum_{k} c_{ik}x_{ik} + \sum_{k}\sum_{m} a.c_{km}x_{ik}x_{jm} + \sum_{m} c_{jm}x_{jm}\right] \tag{1}$$

subjectto;

$$\sum_{k} x_{ik} = 1\forall \in iN \tag{2}$$

$$\sum_{k} X_{kk} = p) \tag{3}$$

$$X_{ik} \leq X_{kk}\forall i.k \in N \tag{4}$$

$$X_{ik} \in \{0,1\}\,\forall i.k \in N \tag{5}$$

Equations (2) and (5) explain the assignment to only one hub of each node. The equation (4) allows assignments to be made only to the main distribution bases. The number of hubs is limited to (Eq. (3). Objective function (Eq. (1) minimizes the total transportation cost.

In addition, heuristic algorithm was developed according to the closest facility (hub) assignment approach. It is seen that Civil Aeronautics Board (CAB) and Australia Post (AP) data are mostly used to evaluate the effectiveness of the studies. CAB data were firstly used in O'Kelly's study (O'Kelly, 1986). On the other hand, Rostami et al. improved two-stage formulation for the hub location problem under single allocation condition which contains the reallocation of sources to a backup hub in case the hub breaks down (Rostami et al., 2018). Habibi et al focused on hub location problem in context of two distribution networks belong to different supply chains (Habibi et al, 2018). Uncertainty corresponding to the supplementary cost included in the setup cost of establishing a shared hub facility is taken into account. Similarly, Zetina et al. presented robust counterparts for uncapacitated hub location problems in which the level of conservatism can be controlled by means of a budget of uncertainty. Both studies consider to take control of uncertanities and reallocation of resources (Zetina et al., 2017).

Musavi and Amiri modeled a different problem as a multi-objective MILP optimizing the total transportation costs, freshness and quality of foods on time of delivery and the total GHG emissions of the vehicles to fulfill the sustainability desire of the environment (Musavi and Bozorgi-Amiri, 2017) Another green approach is developed by Dukkanci et al. Their model proposes the best locations for hubs, assignments of demand nodes to these hubs and speed of trucks/flights so as to route the demand between any origin–destination pair (Dukkanci et al., 2019). The model considers also the reduction of GHG emissions which vary dependent on speed, payload etc. of fleet. Tiwari et al. made effort for hub location problem of an entrant airline that tries to maximize its share in a market with already existing competing players as in our study (Tiwari et al., 2020). They propose four alternate approaches to solve the problem. In another study, Shang et al. introduced a stochastic multimodal hub location problem with direct link strategy and multiple capacity levels for cargo delivery systems under demand uncertainty (Shang et al., 2020). Their study focuses on cargo delivery networks and its hub selection with cone programming with the data of Turkish networks.

In this study, it is aimed to give different views to hub allocation problems for air transportation. Thereby, hub allocation problems are aimed to be more realistic and usable by all airlines considering the specific characteristics of airline passenger transport. Hence, it is aimed to contribute to the healthier and planned development of airline passenger transport. However, Turkish airlines, which we can see as the mirror of Turkish aviation, are still trying to maintain the low-cost trend (see Fig. 3) and keep this market alive.

P-hub median problem developed by Ernst and Krishnamoorthy and fixed cost hub allocation problem models (Ernst and Krishnamoorthy, 1998) of Ebery et al. have been rearranged considering the sectoral characteristics of air transport and the extent to which the restrictions mentioned below and which are specific to direct air transport affect the choice of the hub (Ebery et al., 2000). In addition, taking into account the airline operating and airport infrastructure costs, the impact of different airplane types on hub placement problems has been demonstrated. The models developed based on Ebery et al. were programmed using licensed GAMS software and p-hub median and fixed cost hub location problem models were solved with CPLEX solver. In the solution, bird flight distances, flow quantities, and cost reduction coefficients were used as the main determinant parameters.

Specific parameters related to our study are explained in the following. Infrastructure costs related to the airport, which may affect the hub allocation problem in air transportation are also explained. The ability of an airplane to take-off and landing from any runway depends on the performance characteristics of the airplane, weight, meteorological conditions, and runway characteristics. For example, an airplane may take off from a runway with no load and at low air temperature, while the same airplane may not take off from the same runway with a full load and at high air temperature. This necessitates the assessment of the suitability of the runways of the airports, which will become the main distribution base according to the airplane to be used. In this study, the suitability and adequacy of the runways were examined for two different types of airplane (A320 NEO – B737MAX8) if airports were designated as hubs. The necessary investment costs are calculated for suitable and inadequate airports.

3.3. The proposed model: Uncapacitated multi allocation p-hub median problem under traffic control (MApHuTC)

In this study, constraints and objective function have been developed for p-hub median and fixed cost hub allocation problems. Firstly, the developed constraints and objective function are explained and then the models are given. Ability of an aircraft to take off and landing from any runway; depends on the performance characteristics of the aircraft, weight, meteorological conditions, and runway characteristics. Unlike the areas where hub allocation problems are applied, such as telecommunications and postal distribution, the use of airplanes as connection lines in air transport and the establishment or improvement of the airports for take-off and landing require very high costs. In addition, since airports to be designated, as hubs will be used extensively, the facilities should be sufficient to meet this heavy traffic. Additional investment will be required in airports with inadequate facilities. Therefore, in order to make the hub location selections and assignments realistically and accurately, it has been seen that both the costs related to the connection lines, for instance, unit transportation costs, and the costs that may arise for the airports should be taken into consideration. The objective function is modeled taking into account the transport and airport infrastructure costs as follows (Eq. (6). The following parameters were used differently from O'Kelly's model (O'Kelly, 1986).

Decision variables and parameters

N: Airports, T: number of passengers,

n: Number of airports, p: Number of Hubs will be opened.

i: Departure point, j: Arrival Point, k and l: Potential Hub points

$$H_k = \begin{cases} 1 if k is assigned as Hub \\ 0 Otherwise \end{cases}$$

B^i_{kl} = The amount of flow passing through Hubs k and l from the starting point i.

A^i_{lj} = The amount of flow from the starting point i and passing through the Hub l to the point j.

E_{ik} = The amount of flow from the starting point i to Hub k.

I_k = Airport infrastructure cost.

F_k = Airport Facility restoration cost.

C_{ij} = Unit cost between i and j.

d_{ij} = distance between points i and j.

R = Maximum range, $PT_{(month,k)}$: passenger traffic on month k.

L_i = Total flow rate out from node i.

L_{ij} = Amount of flow from i to j.

αβγ = cost reduction coefficients (hub-hub, hub-node, node-hub)

$$Min\sum_{i\in N}\sum\gamma c_{ik}d_{ik}E_{ik}+\sum_{k\in N}\sum_{l\in N}\alpha c_{kl}d_{kl}B^i_{kl}+\sum_{l\in N}\sum_{j\in N}\beta c_{ij}d_{ij}A^i_{lj}+\sum_k(I_k+F_k)H_k \tag{6}$$

Subject to;

$$\sum_{k\in N}H_k = p \tag{7}$$

$$\sum_{k\in N}E_{ik} = L_i\forall i\in N \tag{8}$$

$$\sum_{k\in N}A^i_{lj} = L_{ij}i,j\in N \tag{9}$$

$$\sum_{l\in N}B^i_{kl}+\sum_{j\in N}A^i_{kj}-\sum_{l\in N}B^i_{lk}-E_{ik} = 0\forall i,k\in N \tag{10}$$

$$E_{ik}\le L_iH_k\forall i,k\in N \tag{11}$$

$$A^i_{lj}\le L_{ij}H_l\forall i,j,l\in N \tag{12}$$

$$A^i_{lj},B^i_{kl},E_{ik}\ge 0\forall i,j,k,l\in N \tag{13}$$

$$d_{ik}H_k\le R\forall i,k\in N \tag{14}$$

$$TH_k\le PT_{(month,k)}\forall k\in N \tag{15}$$

$$H_k\in\{0,1\}$$

Objective function (Eq. (6) includes transportation costs, and total infrastructure costs that may arise if the airport is designated as a hub. Objective function minimizes the total cost. Constraint (Eq.7) provides that the number of hubs is limited to p. Constraints (Eq. 8–10) are the constraints that show the flows of each starting point. Equation (11) restricts flow to a non-hub point. Equation (12) restricts the distribution of flow from a non-hub to other points. Equation (13) is an integer constraint and provided to take positive value of flow amount decision variables.

Since airplanes are used as connecting lines in aviation, the effect of the range of the airplane to be used must also be taken into account. The airplane's range must be greater than the distance between the hub-hub and node-hub in the network structure. Therefore, the range of the airplane to be used in the problem has to be taken into consideration and a range constraint has been developed for this purpose. Constraint to indicate the range of the airplane R is as written in Equation (14). It is ensured that the distance between the two nodes is at lower distances than the range of the airplane in determining hub location and assignments with the constraint Equation (14), taking into account the range of the airplane. The range of the airplane is determined for two cases when the airplane is idle and fully loaded. Since one of the objectives of hub allocation problems is to transport high loads, especially between hubs, the airplane may need to fly when fully loaded between two nodes. Therefore, in the range limitation of the airplane, range determined by the maximum take-off weight" must be taken into consideration.

It is seen that some airports are used intensively in some months and less used in some months if the monthly passenger traffic data of airports are examined. The current traffic here may be shifted to other modes of transport due to irregular and small traffic. Instead of investing in these airports, it would be a good approach to use existing airports more effectively. In addition, some airports are used under their capacity due to unhealthy infrastructure despite the high traffic demand. Investing in airports not having regular traffic during the year and not being used extensively but which are candidates for hubs may increase the cost. However, it would be a more appropriate approach to invest in airports that have regular traffic and over a certain amount but have an insufficient infrastructure. For this purpose, a constraint that controls the continuity of cargo traffic has been developed. The hub location decision variable previously defined was used in the same way. T is the limit for the amount of passenger traffic and PT_k is the total monthly passenger flow of the airport.

Equation (15) restricts the allocation of airports with monthly road traffic (PT) above a certain amount as hubs. The restriction is designed to take into account flows in all months of the year and is also possible to cover certain months of the year. The constraints developed can be appropriately arranged for all types of hub layout problems. In this study, constraints were applied to the multi-assignment p-hub median problem and the results were analyzed.

4. Implication of the proposed model

In this section, firstly selected airplane types are mentioned and brief information is given about the A320 NEO, A220, and B737 MAX-8 airplanes referenced in the study. Airports evaluated in the study are also mentioned. Study of the suitability of airport runways according to runway requirements and calculation of runway investment costs are explained. Then, information about unit transportation costs is given.

4.1. Airports evaluated in the study and their characteristics

Statistics of DHMI (State Airports Administration of Turkey) in the year 2018 for 17 airports to determine the air cargo network in Turkey were examined and airline transportation in density was determined accordingly. International code abbreviations of airports were used in the study. Airport infrastructure costs are runway costs and passenger transit terminal costs. First of all, it was examined whether the runways were sufficient for the use of the designated airplane, and then the improvement costs of the runways were mentioned according to the results of this investigation. Ability of an airplane to take-off and landing from a runway depends on performance characteristics, weight, meteorological conditions, and runway characteristics. Apart from the varying airplane weight and meteorological conditions it also depends on the following physical characteristics of the runway.

The reference runway length and width to which an airplane can take-off and land are determined by standard atmospheric conditions and sea-level conditions during airplane design. This information is contained in the airplane's flight manual. Various weight and configurations of the airplane, required runway length, strength according to various altitude values, different weather conditions (temperature and wind conditions), and the runway's physical characteristics are presented in tables or diagrams in the manuals mentioned. However, the flight manuals may not be sufficient to determine the appropriate runway length and must be calculated taking these data into account.

The first step in calculating the required runway length is to determine the reference runway length in accordance with the operational requirements of the airplane. Reference runway length is the runway length required for take-off and landing at zero altitude, zero wind, and zero runway slope conditions under standard atmospheric conditions. Reference runway length should be increased by 7% for every 300 m altitude relative to the altitude of the runway. Runway length must be also increased again by 1% for every 1 °C exceeding the challenge reference temperature. When the total increase rate according to the altitude and temperature exceeds 35%, the necessary correction is obtained with a special study. Operational characteristics of some airplane do not correspond to the correction coefficients for altitude and temperature. A computational study is required to determine the necessary runway length of such an airplane according to operational requirements and the current conditions of the region (ICAO, 2006). Procedures for determining the necessary runway length described above are given in the equations (16)–(19) below,

RL_1 = Runway length required for take-off at standard atmospheric conditions at sea level (m)

A_E = Altitude of the airport (m)

T_{RA} = Airport reference temperature ($^\circ C$)

T_{SA} = Temperature of airport altitude under standard atmospheric conditions ($^\circ C$)

S_{RL} = Slope of Runway (%)

RL_2 = Required runway length adjusted for altitude (m)

RL_3 = Runway length adjusted for altitude and temperature (m)

RL_4 = Runway length adjusted for altitude, temperature and runway slope (m)

Table 1
Required runway length.

Airplane	Required runway length
A220	2090 m
A320 NEO	1460 m
737 MAX8	2500 m

Table 2
Airport runway requirements.

Airports	Length required to extend (m) A320neo	Length required to extend (m) 737MAX8
DLM	0	17,67
ADA	0	292,96
TZX	0	175,35
BJV	0	17,67
EZS	655	1120,64

$$T_{SA} = -1\left[\left(\frac{6,5}{1000}A_E\right) - 15\right] \tag{16}$$

$$RL_2 = \left[RL_1 * 0,07\frac{A_E}{300}\right] + RL_1 \tag{17}$$

$$RL_3 = [RL_2(T_{RA} - T_{SA})0,01] + RL_2 \tag{18}$$

$$RL_4 = [RL_3 * S_{RL} * 0,01] + RL_3 \tag{19}$$

Runway altitude and reference temperature values of airports discussed in this study and necessary runway lengths were calculated by considering the maximum take-off weight of the aircraft. Runway slopes were neglected in the study. Runway lengths required taking off with maximum weight in order to determine the runway lengths of the airplane subject to the study are obtained from the properties book presented in Table 1.

Based on these lengths, length calculations for the maximum take-off weight were evaluated for all aircraft. Reference temperatures and lengths of airports were obtained from publications published by AIP (Aeronautical Information Publication). Runway lengths calculated by reference temperature, elevation, and runway length are shown in Table 2. It is also calculated how long the runways of the airports which are considered unsuitable for take-off and landing as shown in Table 2.

As a result of the calculation, all airports have appropriate for the A220 airplane take-off and landing processes. However, EZS airport was not deemed suitable for landing of A320 airplane. Likewise, the runway of DLM, ADA, TZX, BJV, and EZS airports were not suitable for the use of 737 MAX8. Unsuitable runways of airports should be extended. Since the runway length was chosen as the main cost criterion in this study and the runway widths were not taken into consideration. In addition, revised cost of the facility and the revised cost of the runway were processed together.

4.2. Determination of the unit transportation costs

Unit transportation costs are calculated by dividing the total operating cost per flight to the desired ton or mile. Unit transportation cost differs according to airline, type of airplane used, and routes. In this study, unit transportation costs were determined separately for A220, A320NEO, and 737MAX-8 airplane according to each route. In calculation of these costs, the data presented by MIT's airline data project were used. Data obtained are given directly as CASM (Cost available seat mile) and used proportionally for each airplane. Basically, costs are examined under four main headings. However, many airlines consider costs under three headings: ACMI (Airplane, Crew, Maintenance, Insurance), fuel, and other expenses. Fuel cost is the monetary value of the

Table 3
Hub locations determined by actual data.

	Cost ('000 TL)	Hub locations	Cost decrease (%)
P = 1	698 000	SAW	39,97
P = 2	419 000	ADA-IST	30,55
P = 3	299 000	AYT-IST-TZX	1,03
P = 4	294 000	AYT-IST-TZX-ESB	0,68
P = 5	292 000	ADA-ADB-AYT-SAW-TZX	0,34
P = 6	291 000	ADA-ADB-AYT-ESB-IST-TZX	0,34
P = 7	290 000	ADA-ADB-AYT-ESB-IST-SAW-TZX	0

Table 4
Effect of infrastructure cost.

AIRPLANE TYPE: A320		AIRPLANE TYPE: B737-8MAX	
Cost (Million TL)	Hub locations	Cost (Million TL)	Hub locations
915	SAW	915	SAW
483	IST-MLX	483	IST-MLX
325	DLM-MLX-SAW	326	DLM-MLX-SAW
276	ASR-ERZ-DLM-SAW	277	ASR-ERZ-DLM-SAW
239	ADB-AYT-ESB-EZS-IST	239	ADB-AYT-ESB-EZS-IST
213	ADA-ADB-AYT-ESB-EZS-IST	213	ADA-ADB-AYT-ESB-EZS-IST
204	ADA-ADB-AYT-ESB-EZS-IST-EZS	205	ADA-ADB-AYT-ESB-EZS-IST-EZS

amount of fuel consumed on that flight. Fuel consumption depends on a number of parameters, such as the configuration, speed, weight, position of the throttle, altitude, meteorological conditions, and flight time in each flight phase of the airplane (Park and O'Kelly, 2014). However, in this study, when calculating ACMI which includes all expenses, cost per kilometer and the distance between two points are multiplied.

Sensitivity analysis can be applied in linear decision models. Since hub location models used in this study are mixed integer linear and nonlinear decision models, sensitivity analysis methods cannot be applied. Therefore, different values of the parameters and newly developed constraints were applied to the models and the results were analyzed in order to observe how the results change with the change of the structure of the parameters and models in hub placement problems. Proposed model parameter settings are as follows; inter-hub cost reduction coefficient (α) is 0.8, node-Hub ((β)- Hub-node (γ)cost reduction coefficients are taken as 0.2. Models are solved with the CPLEX solver in hub allocation problem programmed using the licensed GAMS software.

4.3. Effect of traffic flow

If traffic flow values between all start-arrival points are constant ($W_{ij} = cst$ and W_{ii} is 0); p is two for SAW and ADA. Proposed model behaves to select airports depending on hierarchy of the airports.

If real flow data is entered as a parameter, it is seen that hub locations change. For p is two for ADA and IST; p is three for AYT, IST, TZX; p is four, AYT, ESB, TZX, and IST. These airports are designated as hubs. It shows that passenger flow traffic and distances between nodes are the main determinants in locating hubs (see Table 3).

4.4. Effect of infrastructure cost

In order to observe effect of infrastructure costs on developing hub-locations, objective function of model was changed and impact of infrastructure costs that may arise in case an airport is a hub was reflected. Airport infrastructure costs are determined separately for all aircraft and are included in the model as such. According to results of the newly proposed model, same airports were identified as hubs for all airplane types.

Common point in determining the mentioned airports as hubs is that designated airports either do not require infrastructure costs or require very little infrastructure costs. If p is five, higher cost is obtained for A320 NEO and 737MAX8 airplanes. The reason for this is that ADA, one of airports designated as a hub, has infrastructure costs. Therefore, it is clear that infrastructure costs affect total cost. This shows that infrastructure costs should be taken into consideration in hub location problems (see Table 4).

4.5. Effect of range constraint

Since the range of all aircraft is sufficient, the range constraint has not been observed to create significant differences. However, it can be said that instead of the types of airplane used, smaller and shorter range airplane will change the hub points to be selected. In this circumstance, the range constraint affects locations of hub points to be selected. For instance, if range is decreased from 2000 km to 700 km, hub locations are getting closer to each other.

4.6. Effect of traffic continuity constraint

In this study, monthly passenger traffic limit was determined as 200,000 passengers. The proposed model was studied for two, three and four hubs. According to model results, it is observed that if monthly passenger traffic constraint is used or not, same airports are assigned as hubs. This is due to fact that the airports assigned as hubs have a regular and exceeding amount of passenger traffic for 12 months. In other

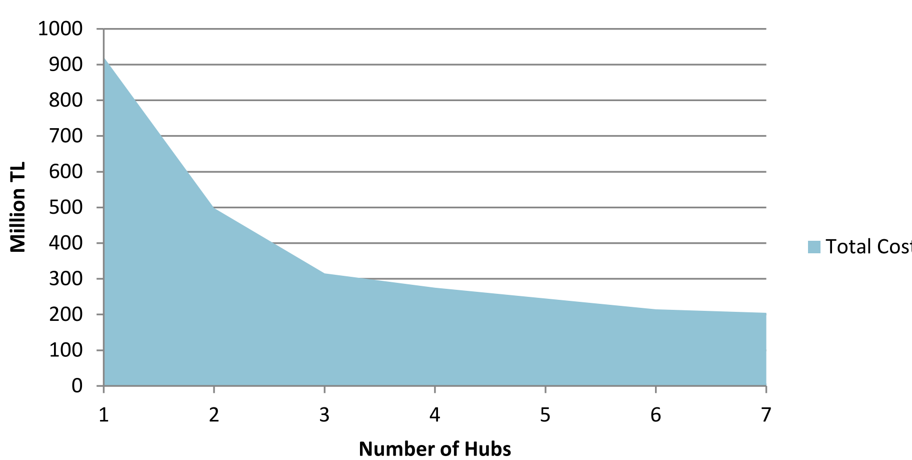

Fig. 4. Relationship between number of hubs and total cost for A220.

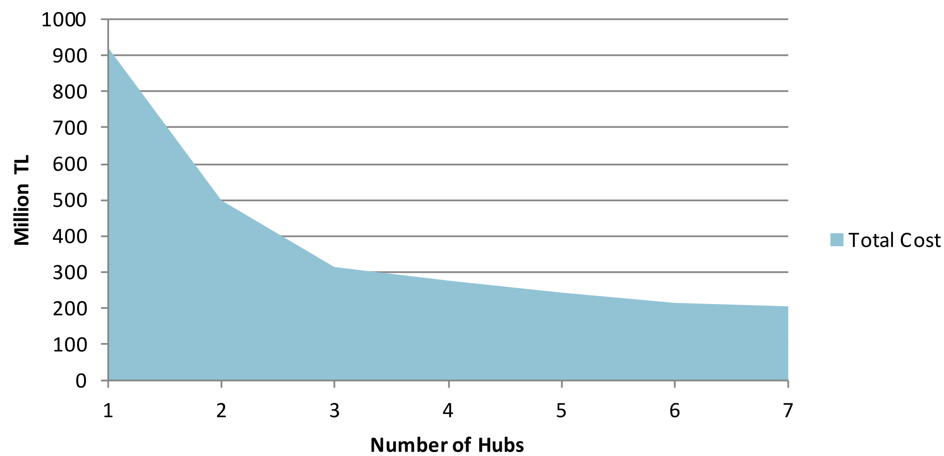

Fig. 5. Relationship between number of hubs and total cost for A320 and 737MAX8.

Table 5
Behavior of model due to constraints for p = 2.

Hub #	Specification	Hub Location	Definition
$p = 2$	$FL_{ij} = d_{ij} = cst, I(k) = 0$	ASR, IST	The model selects and assigns hub locations based on geographic locations.
	$FL_{ij}, d_{ij}, I(k) = 0$	IST, MLX	By entering flow data, hub location selection and assignments have changed.
	$FL_{ij}, d_{ij}, I(k)$	IST, MLX	The infrastructure costs of airports designated as hubs are *I (k) 0 (zero)*.
	$FL_{ij}, d_{ij}, I(k), Cij$	IST, MLX	Since the unit transport costs of the A220 airplane bring extra transport costs, the total cost has increased, although the same hubs have been identified.
	$FL_{ij}, d_{ij}, I(k), Cij, R$	IST, MLX	According to previous analysis is sufficient according to the range A220 airplane has been no change in the geography of Turkey selection in the hub. However, in the experiments carried out by decreasing the range, it was seen that the cost increased.
	$FL_{ij}, d_{ij}, I(k), Cij, PT (month,i)$	IST, MLX	Passenger traffic of the airports designated by the model as hubs is continuous.
	$FL_{ij}, d_{ij}, I(k), Cij, R, PT(month,i)$	ADA, ESB	All parameters and constraints were used in this analysis. According to all parameters, different airports were identified as hubs and different costs were obtained.

words, current annual and monthly passenger traffic flow data conforms to this limit. Different results will be obtained with different data. In last analysis, all constraints, parameters and new objective function were used.

4.7. Effects of number of hubs

In order to observe the effect of hub number (p), the model was programmed and run for different p values ranging from one to seven. Results of the analysis are given in Fig. 4 and Fig. 5.

However, this value does not show a significant decrease for p is three to six. The costs become nearly stable if there are more than three hubs. Similarly, for all airplane types, p is given from two to seven and it is seen that the total cost for p is seven reaches the minimum value. If p is higher than seven, choosing a hub is not make sense because this network becomes direct flight network.

All analyzes performed at this stage have been made considering A220 because A320 and 737MAX8 show similar characteristics in terms of costs and have higher total costs than A220. It can be said that the optimal number of hubs p is seven with the lowest value. However, the total hub number was chosen as three because after that point costs are becomes stable and shows tendency to increase. Experiment shown in Table 5 is designed to understand how all constraints interact with each other. This experiment was developed to observe how constraints were incorporated, influenced into the model and contributed to the results. Therefore, number of hub p to be selected as two.

5. Conclusion and discussion

In this study, a domestic passenger carrier airline route network design was carried out considering traffic flow and infrastructure cost for a LCC in Turkey. We preferred hub and spoke network structure instead of direct flight network because most of the air passenger demand is concentrated on 5 airports in Turkey. Main reasons are explained as the aim of this study.

- Study is trying to search to establish a flight network which is serving just for domestic routes with the cheapest cost possible.
- Hence, according to the aim adopted, preferred aircraft size and operation range are constraint our operation area. This situation pushes the possible solutions from direct flight network to hub and spoke approach.
- Preference on direct flight network is also considerable with bigger aircraft fleet. In this circumstance, operation cost and profitability would be relatively low. That is why we've used hub and spoke approach.
- Air passenger concentration on 5 airports can be create a chance to adoption of new transportation trend and lead to improved utilization of air transportation.

Due to the high-cost aviation operations that arose with COVID-19 outbreak, a low-cost flight network scheduling requirement has emerged. The IATA estimate that revenue passenger kilometers (RPK) will be −38% lower in 2020 than in 2019, with a resulting revenue loss of US$252 billion (IATA Economics, 2020) and airports, just like airlines, are also facing a financial crisis, with estimated losses of US$76.6 billion in 2020 (Airports Council International, 2020). The COVID-19 crisis should be seen as an opportunity to critically reconsider for implying greater benefits (Gössling et al., 2020). For instance, as a result of the significant deficit in demand, airlines have begun to phase out old and inefficient airplane and reschedule the flight routes (Simple Flying, 2020). Optimum results were obtained in proposed models. With these models, hub location was selected among the selected 18 airports in Turkey and a flight network was designed to meet the daily calculated

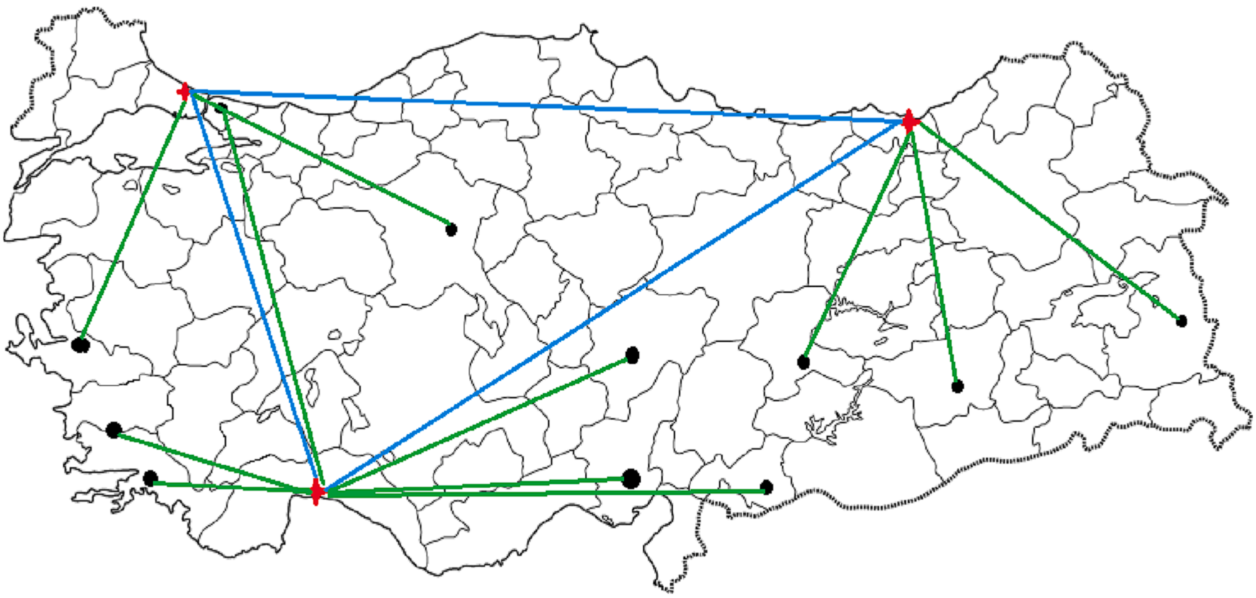

Fig. 6. The optimal daily direct flight routes scheme.

demands and schematized in Fig. 6. The designed flight network consists of routing single-assignment homogeneous fleet airplane. With the hub approach, an effort has been made to move the requested passengers from one airport to another as soon as possible with minimum cost. Blue lines represent the intra-hub connections while green lines are show hub-node connections under the red dots are the main hubs and black dots are nodes.

In the study, which has been encountered from the past in the history of aviation and the solutions of the companies; It has been determined that the first response of airlines to the crisis is to take measures to reduce costs in terms of better route network planning. Among the costs, the issues that can be interrupted while the flight activity continues are personnel reduction, change in service quality, change in flight destinations and flight frequency. In addition, following the decrease in demand, companies make changes in their business models, investor balances change, and invest in sub-sectors in order to continue their business in an environment of uncertainty. It has been observed that companies that have followed the old business models for years, being closed to changes, cannot hold on to the market, including new competitors, and that the competitive conditions are quite tough, and companies that come out of the crisis with little or no damage have been profitable in the medium and long term, considering the size of the companies in the market. This proves how important and vital issue crisis management is for aviation companies. In addition to all these management skills, fleet organization and efficiency should also be considered (Atay et al., 2022).

The economic measures given by the airlines to the crises did not differ in the last epidemic period, and the sector's memory continued to function with similar reflexes. However, due to the grounding of the aircraft encountered for the first time in aviation history and the excess demand, there is no comprehensive study on the subject in the literature and it is an obligation to design profitable routes in case of crisis. This makes the study unique in that it covers more than one airline and country. In the current recent global crisis, it has been observed that the effects of the implementations of decision-making bodies on the sector, outside the jurisdiction of aviation companies, are very important in terms of functioning. The process, which cannot be carried out in a coordinated way and which is managed by each state with its own rules, shows the lack of coordination and unity in the aviation sector. Between the extremely strict travel bans, the aviation industry, which is on the verge of bankruptcy, and the virus epidemic, which has accelerated within the scope of comfortable travel, decision makers need to make decisions in terms of both economic and public health. While some countries have maintained this balance by implementing measures such as rapid testing practices and quarantine processes, some have closed flights completely or mandated long quarantine processes. In the countries in the second group, both the tourism and air transport sectors have been severely damaged. It has been determined that the airports where their main centers are the first choice of the airlines, which have to land their planes due to excess demand, in terms of parking and maintenance requirements.

A real problem was examined in proposed models and the data were obtained from reliable sources and solutions were made according to these data. However, some assumptions were used on developing phases of the proposed models. One of these assumptions is that daily changes that affect to demand are not taken into account. There will be situations in which demand fluctuation is uncertain in real life applications because the changeable demands have consequences that can directly affect the flight network. The changes in fleet design can be examined by selecting more than 2 airplanes and calculating the relevant parameters and using the hub site selection and assignment model. Exchange of Turkey's population forecast for the next 20-year period and cargo data made possible settlement hubs identified. Reports may be submitted to the administrations on this matter.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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