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MULTI-COMMODITY, MULTI-DEPOT, HETEROGENOUS VEHICLE PICKUP AND DELIVERY PROBLEM FOR AIR TRANSPORTATION IN THE TURKISH AIR FORCE*

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ABSTRACT

This study deals with the problem of air transportation in Turkish Air Force. The Turkish Air Force has different cargo aircraft to be used in air transportation operations, located in different airbases. The cargo aircraft are loaded cargo, equipment, personnel, repaired items etc. from one of airbases and transport them to the demanding airbases. In this military flight network, each airbase is a demand and support point for different kinds of items. Pickup and delivery demands are known deterministically. There are several operational constraints. The objective of the problem is to find a feasible set of routes for the cargo aircraft so that all requests are serviced, and such that the overall cost is minimized. Problem in hand is modeled and solved as multi-commodity, multi depot and heterogeneous vehicle pickup and delivery problem.

Keywords: *Air transportation, heterogeneous vehicle, multi depot, multi-commodity, pickup and delivery problem.*

HAVA KUVVETLERİNDE HAVA TAŞIMALARI İÇİN ÇOK ÜRÜNLÜ, ÇOK DEPOLU, KARIŞIK ARAÇLI AL VE DAĞIT PROBLEMİ

ÖZET

Bu çalışma Türk Hava Kuvvetleri'nde hava taşımaları problemi ile ilgilenir. Türk Hava Kuvvetleri'nde hava taşımalarında kullanılan, farklı üslerde konuşlandırılmış, farklı tiplerde kargo uçakları vardır. Kargo uçakları bir üsten yüklediği kargoyu, personeli ve tamir edilmiş parçaları talep sahibi diğer bir üsse taşır. Bu askeri uçuş ağında, her üs farklı tipte malzemeler için hem kaynak, hem de talep noktasıdır. Alma ve dağıtma talepleri önceden bilinmektedir. Problemde Hava Kuvvetleri'ne ait birçok operasyonel kısıt vardır. Problemin amacı, kargo uçaklarının olası rotalarının arasından, bütün taleplerin karşılandığı ve toplam maliyetin en küçük olduğu çözümü bulmaktır. Eldeki problem çok ürünlü, çok depolu, karışık araçlı, al ve dağıt problemi olarak modellenmiş ve çözülmüştür.

Anahtar Kelimeler: *Al ve dağıt problemi, çok depo, çok ürün, hava taşıması, karışık araç.*

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* The opinions expressed in this paper are entirely belongs to the authors and in no way binding upon the Turkish Armed Forces, Turkish Air Forces and other organizations.

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1. INTRODUCTION

Today, air warfare is used as one of the main tools to deter the enemy due to the features such as precision, sensitive timing and high blast affect. These unique features of the Air Force require fast and sustainable logistic capabilities. Because of this, the transportation is mainly maintained by the cargo aircraft. Also cargo aircraft are used for sustainment of Turkish Armed Forces.

Currently, different aircraft parts are transferred from the airbases to the factories located in different parts of Turkey and vice versa. In order to maintain the sustainability of the jet aircraft, there is a set of cargo aircraft transporting the goods in predetermined routes and schedules weekly. The routes are fixed regardless of the number of parts to be transferred. Cargo aircraft also carry personnel from one airbase to the other. The fixed routes make the transportation system cumbersome, slow and expensive. In this paper, a model is proposed to determine the cargo aircraft routes in order to satisfy the demand of each airbase while the cost is minimized. The military flight network has multi-commodity, multi-depot, different startup locations for heterogeneous cargo aircraft and several operational constraints. The problem is modeled as a special type of multi depot, heterogeneous vehicle pickup and delivery problem.

Turkish Air Force military flight network has three factories that the parts are transferred to. After the parts are received, they are repaired and send back to the original destinations. Therefore, these factories are supply point for repaired and/or new parts. In addition, the airbases transfer parts and personnel between each other, because each airbase has its own inventory and specialized personal. Therefore, airbases supply point to each other. There are different types of cargo aircraft. Therefore, the problem can be regarded as a multi-commodity, multi-depot, heterogeneous vehicle pickup delivery problem.

Pickup and delivery problem is an extension of the vehicle routing problem (VRP). The Pickup and Delivery Problem (PDP) generally consist of a fleet of vehicles and a set of customer requests. Each request has two stops, namely the pickup and delivery points. Each vehicle has to start its tour from the depot and the tour must end at the same depot. The pickup must be completed before the delivery. Total quantity of loads cannot exceed the vehicle capacity any time [1]. The PDP is known to be NP-hard in the strong sense [2]. Because it generalizes the Vehicle Routing Problem.

In literature, there are several classification schemes for PDP. Reference [3] classified PDP's according to the three-field scheme: structure, visits and vehicles. The first field "structure" specifies the number of origins and destinations of commodities. In many-to-many problems (*M-M*), any vertex can serve as source or as a destination for any commodity. In one-to-many-to-one problems (*1-M-1*), commodities are initially available at the depot and they are sent to customer vertices; commodities available at the customers are then sent back to the depot. In one-to-one problems (*1-1*), each commodity has a given origin and a given destination. The second field "visits" provides information about how the vehicles visit the customers. The pickup and delivery actions can simultaneously occur or one at a time. The last field "vehicles" fixes the number of vehicles used in the solution.

Reference [4]-[5] divides PDP's into two parts. The first part deals with the transportation of goods from the depot to the linehaul customers and from the backhaul customers to the depot. The second part considers that the commodities are transported between pickup and delivery customers. The second part is further divided into two subclasses. The first subclass refers to situation where pickup and delivery customers are unpaired (each picked up commodities can be used to fulfill the demand of any delivery customer). The second subclass refers to the situation where pickup and delivery locations are paired (each commodity has a pickup and delivery customer).

In Turkish Air Forces military flight network problem is a combination of (*M-M*) and (*1-1*) problem structures. In (*M-M*) problems, vehicle loads from one pickup point and delivers it to any one of the demanding points. In (*1-1*) problems, vehicle loads from one of the pickup points and delivers it to a specific delivery point. In the combined case, vehicle loads from any of the pickup points and delivers to each different delivery point just like the (*M-M*) case. But parts to be transported has specific destination points just like the (*1-1*) case. Therefore, the combination is named (*1-M/M-1*) case. Known by the authors, the problem considered in this paper is unique in its structure.

2. PROBLEM DEFINITION

This problem deals with the transportation of cargo and military personnel using available cargo aircraft and pilot regulations. The input to the problem consists of three major categories of data: cargo aircraft resources, pilot regulations and the military flight network. These categories and its constraints are:

Aircraft Resources

Landing cargo aircraft has to wait 15 minutes to load and unload. Each cargo aircraft has different capacity in weight (kg), flight duration (hour), air speed (knot) and cost. The payload cannot be more than the cargo aircraft capacity.

Pilot Regulations

Pilots cannot fly the cargo aircraft more than 12 hours. There has to be a half-hour break for lunch and each pilot has to take off and land less than 10 times in each tour in order to prevent over exhaustion.

Military Flight Network

There are more than one kind of cargo aircraft. Each cargo aircraft is stationed in its home airbase. The cargo aircraft have to return to their home bases after completing its tour. Pickup and delivery demands are known deterministically. Weather conditions are not considered in the problem. Distance matrix is known and satisfies the triangular inequality. All demands are static. Duration of a flight leg is determined using *D\H* formulation (*D*=distance between two airbases, *H*= air speed of a cargo aircraft).

3. PROPOSED MODEL

The proposed mixed integer linear programming model and the nomenclature are as follows:

Notation

$i,j \in V$	Airbases set,
$k \in K$	Aircraft types set,
$l \in L$	Commodity set,
x_{ijk}	If arc (*i,j*) traversed by cargo aircraft of type *k* equals to 1, otherwise 0,
D_{ij}	Distance matrix (Nautical Mile),
C_k	Unit distance cost of cargo aircraft type *k*,
A_k	Home base of cargo aircraft type *k*,
y_{ijkl}	Total amount of commodity *l* (kg) on cargo aircraft type *k* which is traversing arc (*i, j*),
u_{ijkl}	Amount of commodity *l* (kg) sent from *i* to *j* by cargo aircraft type *k*,
s_{ijl}	Demand of airbase *j* from *i* of commodity *l* (kg),
K_k	Capacity of *k* type cargo aircraft (kg),
B	Maximum number of flight leg,
H_k	Airspeed of cargo aircraft type *k* (Knot),
G	Maximum flight time for pilots (hour),
T_k	Maximum flight duration for cargo aircraft type *k* (hour)

Formulation

$$\min \sum_{i\in V}\sum_{j\in V}\sum_{k\in K}\frac{D_{ij}}{H_k}C_k x_{ijk} \tag{0}$$

s.t.

$$\sum_{i=A_k}\sum_{j\in V} x_{ijk} \le 1 \quad \forall k \in K \tag{1}$$

$$\sum_{i=A_k}\sum_{j\in V} x_{ijk} - \sum_{i\in A_k}\sum_{j\in V} x_{jik} = 0 \quad \forall k \in K \tag{2}$$

$$\sum_{j\in V} x_{ijk} - \sum_{j\in V} x_{jik} = 0 \;\; \forall\, i \in V,\;\; k \in K \tag{3}$$

$$M * \sum_{i=A_k}\sum_{j\in V} x_{ijk} \ge \sum_{i\in V}\sum_{j\in V} x_{ijk} \quad \forall\; k \in K \tag{4}$$

$$\sum_{h,i\in V}\left(y_{ijkl} - u_{ijkl} + u_{jhkl} - y_{jhkl}\right) = 0 \;\forall j \in V, k \in K, l \in L \tag{5}$$

$$y_{ijkl} \;\le\; K_k \;\;\forall\; i,j \in V,\;\; k \in K,\;\; l \in L \tag{6}$$

$$\sum_{k\in K} u_{ijkl} = \; s_{ijl} \;\;\forall\; i,j \in V, \quad l \in L \tag{7}$$

$$\sum_{i\in V}\sum_{j\in V} x_{ijk} \;\; \le B \;\; \forall\, k \in K \tag{8}$$

$$\sum_{i\in V}\sum_{j\in V}\left(\frac{D_{ij}\, x_{ijk}}{H_k} + x_{ijk}\frac{1}{4}\right) + \frac{1}{2} \le G \quad \forall\, k \in K \tag{9}$$

$$\frac{D_{ij}x_{ijk}}{H_k} \le T_k \;\;\forall\; i,j \in V,\;\; k \in K \tag{10}$$

$$\sum_{j\in V}\left(y_{ijkl} - u_{ijkl}\right) \ge 0 \quad \forall\; i \in V, k \in K, l \in L \tag{11}$$

$$M * x_{ijk} \;\ge\; \sum_{l\in L} y_{ijkl} \;\;\forall\; i,j \in V,\;\; k \in K \tag{12}$$

$$x_{ijkl} \in (0,1) \;\;\forall\; i,j \in V,\;\; k \in K \tag{13}$$

$$u_{ijkl} \;\ge 0 \quad \forall\; i,j \in V,\;\; k \in K,\;\; l \in L \tag{14}$$

$$y_{ijkl} \;\ge 0 \quad \forall\; i,j \in V,\;\; k \in K,\;\; l \in L \tag{15}$$

Equation (0) is the objective function, which minimize the total traveled distance. Equation (1) ensures that each cargo aircraft begins its tour from its home base. Equation (2) ensures that each cargo aircraft lands its home base after completing the tour. Equation (3) ensures that each cargo aircraft landing at an airbase takes off from the same airbase. Equation (4) ensures that if a cargo aircraft does not take off, then this cargo aircraft is not included in the solution. Equation

(5) is the commodity flow equation, which ensures that the arriving commodities to an airbase are equal to leaving commodities. Equation (6) is the cargo aircraft capacity constraint. Equation (7) ensures that the demands of all airbases are satisfied. Equation (8) limits the number of flight legs. Equation (9) limits the pilot's total flight time. Equation (10) ensures that the total flight time between two airbases cannot be more than the cargo aircraft's maximum flight time. Equation (11)-(12) are logical constraints and equations (13)-(14)-(15) are variable definitions.

4. CASE STUDY

A sample case containing 4 airbases, 3 types of cargo aircraft and 2 type of commodity is studied in order to depict the problem handling capability of the model. There are different numbers of cargo aircraft from each type. The airbases are *U1, U2, U3* and *U4*. Cargo aircraft types are *C1, C2* and *C3*. There are 4 cargo aircraft from type *C1*, 3 cargo aircraft from type *C2* and 2 cargo aircraft from type *C3*. *U1* airbase is the home airbase for type *C1* and *C2*. *U2* airbase is the home base for type *C3*. The commodities are *P1* and *P2*. Figure 1 illustrates the locations of the airbases and the cargo aircraft's home bases.

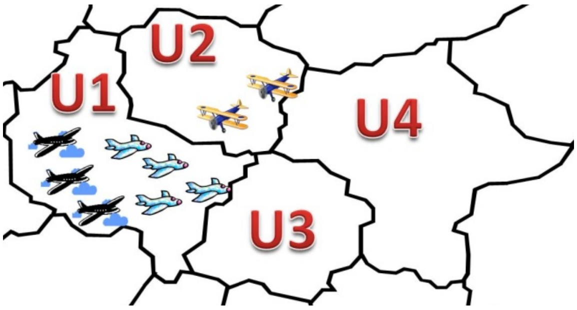

Figure 1. Illustration of Airbases and Cargo Aircraft on a Map.

Each cargo aircraft type has different airspeed, cost and capacity. The airspeed value of the each cargo aircraft type are 210, 240 and 280 knots respectively; cost of the each cargo aircraft type are $5000, $6000 and $5000 respectively and the capacity of each cargo aircraft type are 50000, 55000 and 60000 kg respectively. Maximum flight time for each cargo aircraft type is 10 hours. Distance between each airbase is given in Table 1. Airbase requests are given in Table 2.

Table 1. Distance Matrix (NM).

	U1	***U2***	***U3***	***U4***
U1	0	100	150	200
U2	100	0	175	150
U3	150	175	0	100
U4	200	150	100	0

Table 2. Demand Matrix.

kg	***U1***		***U2***		***U3***		***U4***	
	P1	***P2***	***P1***	***P2***	***P1***	***P2***	***P1***	***P2***
U1			10000	-	15000	-	5000	-
U2	-	20000			15000	-	-	15000
U3	-	-	-	10000			10000	-
U4	-	-	30000	5000	-	-		

Solving the problem with the (*1-M/M-1*) model, the total cost of transportation of goods is $8928.571. The one cost-effective type of cargo aircraft (*C3*) is included in the solution. Figure 2 illustrates the route of the *C3* cargo aircraft. The *C3* cargo aircraft loads 15.000 kg *P1* and 35.000 kg *P2* from *U2* to transport *U1*, *U3* and *U4*. It takes off from *U2* and lands *U1*. Unloads 20.000 kg *P2*, which are transported from *U2* and loads 30.000 kg *P1* to transport *U2*, *U3* and *U4*. It takes off from *U1* and lands *U3*. Unloads 30.000 kg *P1*, which are transported from *U1* and *U2* and loads 10.000 kg *P1*, 10.000 kg *P2* to transport from *U3* to *U2* and *U4*. It takes off from *U3* and lands *U4*. Unloads 15.000 kg *P1*, 15.000 kg *P2* which are transported from *U1*, *U2* and *U3* and loads 30.000 kg *P1*, 5.000 kg *P2* to transport from *U4* to *U2*. It takes off from *U4* and lands *U2*. Unloads 40.000 kg *P1*, 15.000 kg *P2* which are transported from *U1*, *U3* and *U4*.

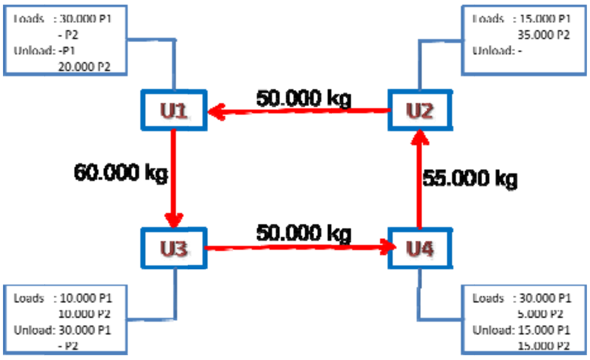

Figure 2. Illustration of The Solution.

The results show that the least cost option from the solution space is given from the set of feasible solutions. This small-scale sample could be generalized for larger problem instances. The model also can handle real case problems as effectively in terms of solution time and optimality.

5. CONCLUSION

This paper has introduced a special type of pickup and delivery problem, (*1-M/M-1*) model. Chancing the actual transportation system of Turkish Air Force with proposed model, disadvantages can be eliminated. Real case problems are solved using classified data and the results demonstrated that significant amounts of savings could be obtained from rerouting.

The model proposed in this paper is a special case of a pickup and delivery vehicle routing problem and could be used by civilian air transportation firms as well. Air transportation in general is similar to that of military deployment problems and could be modeled as a (*1-M-M-1*) model. The solution time is within acceptable limits with commercial off-the-shelve optimization software. Further study could be directed towards designing a method for solving the model with different user-specified constraints, pilot resources, equality in pilot's workload, weight effect on cost, risky environments etc. Demand is regarded static in the paper. Nevertheless, the nature of demand is dynamic in real cases and further research could include stochastic demands.

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VITAE

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He was born in 1981 in Eskişehir, Turkey. He graduated of Işıklar Military High School in 1999, Turkish Air Force Academy as Aerospace Engineer in 2003. He received M.S. degree as Industrial Engineer from Institute of Science at Selçuk University in 2006. He is pursuing PhD degree as Industrial Engineering from Graduate School of Engineering & Sciences at Osmangazi University. He is working in 4th Main Jet Base as a flight instructor. His research interest includes heuristics, linear programming.

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