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Unmanned Aerial Vehicle hub-location and routing for monitoring geographic borders

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ABSTRACT

Recently, hub location problems have become more common with successful applications in air transportation. In this paper, we consider a hub-location and routing problem for border (Borders in this work refer to land borders, unless otherwise stated.) security in Turkey. Security is currently one of the most important issues. Countries are spending large amounts to prevent threats that may come from neighboring countries. Land borders are required to be monitored because of illegal border crossing activities and terrorist attacks. Various geographical restrictions at the borders can cause difficulties in monitoring and gathering the required data. We focus on selecting hubs among the airports run by the General Directorate of State Airports Authority of Turkey, the assignment of demand points to hubs and determining optimal routes for each hub. The study consists of two stages. First, the single allocation p-hub median problem is solved to determine the locations of the hubs for unmanned aircraft. To select hubs, the decision model uses an appropriateness parameter that is obtained by using ELECTRE, a multi-criteria decision-making tool. Five criteria are considered: The type of airport, the remoteness from threats, the proximity to a land border, the aerodrome traffic density and the time that the possible hubs are open to the air traffic. In the second stage, optimal routes are determined for each hub by using two mathematical models. The first model is cost-oriented and there is one vehicle per hub. In the second mathematical model for routing, the monitoring frequency parameters which means the priority of monitoring of the demand nodes obtained by using ELECTRE are used to maximize the monitoring frequency of the demand nodes. The criteria for demand nodes are (1) the need for UAVs, (2) illegal border crossing, and (3) the number of the illegal border activities and attacks. There are three vehicles per hub in the second model. The results of two mathematical models for routing problem are evaluated.

1. Introduction

Border security has become one of the most important issues for countries at the present time. Many countries are investigating new technologies to protect their borders from potential threats. It is critical that countries should foresee and take measures to address threats from neighboring countries. Currently, developed countries use state-of-the-art technologies to protect their borders, such as Unmanned Aerial Vehicles (UAVs), satellite-based surveillance systems, and sensors. UAVs are

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remotely piloted or self-piloted aircrafts that can carry cameras, sensors, communications equipment or other payloads. According to Federation of American Scientists, they have been used in a reconnaissance and intelligence-gathering role since the 1950s, and more challenging roles are envisioned to include including combat missions such as situation development, battle management, and battle damage assessment. The UAV becomes especially important when the geological structure of the region has areas with very steep cliffs (read as [www.global security]").

Events, wars, and various political disputes in neighboring countries highlight how important it is to provide security at a country's borders. Various geographical restrictions at the borders can cause difficulties in tracking and taking action. The motivations behind the work is to address the monitoring of movements along the land borders of Turkey by unmanned aircraft. The cities on the borders have been taken as demand points. Existing airports in Turkey are chosen as possible hubs. This problem is related to "location-routing" and "transportation–location" problems in the literature, which have been active areas of research since 1970 [1–8]. These authors presented different problems and valuable models. Our study focused on the UAV location and routing problem for land border security. The first phase of the study is to address which airports will be chosen as a hub for UAVs. The model in this phase is the revised version of the model which is used for single allocation p-hub median problem to monitor land borders in our earlier work [9]. In this paper, the objective function of the decision model uses the appropriateness parameter to select hubs which will be used. In the second phase, it is determined which routes are optimal for each hub. In this study, three sub-problems have been addressed. First, the single allocation p-hub median problem is solved to determine the locations of the hubs. To reflect the regional features of possible hubs in the mathematical model, we determined an appropriateness parameter for these hubs. Within the scope of the problem, appropriateness parameter for possible hubs are determined with ELECTRE (ELimination Et Choix Traduisant la REalité – ELimination and Choice Expressing the REality) method, a multi-criteria decision making tool. In many areas, ELECTRE methods have been applied. The environmental management, agriculture and forest, energy, water management, finance, calls for tender, transportation and military are certain areas [10]. To obtain appropriateness parameter, five criteria are considered: The type of airport, the remoteness from threats, the proximity to a land border, the aerodrome traffic density and the time that the possible hubs are open to the air traffic. To decide the hub locations, a mathematical model is built and solved. The second sub-problem is the routing problem of the UAVs to minimize cost by considering flight restrictions. The third sub-problem is the routing problem of the UAVs to maximize the surveillance frequency of demand locations based on the monitoring frequency parameters obtained by the ELECTRE method. The multiple-trips case is considered as well. In this phase, for determining the optimal routes for each hub, two mathematical models are built and the results are evaluated.

The remainder of this paper is organized as follows. Section 2 introduces the basic concepts of hub location problem. Single allocation p-hub median problem for monitoring land borders is given in Section 3. Section 4 demonstrates the application of the model for monitoring land border. Our results are summarized in Section 5.

2. Hub location problem

Hubs facilities serve as switching or transshipment points in transportation and communication systems. Networks with hubs concentrate traffic flows on the hub-to-hub links and economies of scale for interhub movement provide a major incentive for hub systems [11].

Hub location problems are concerned with locating hub facilities and discounted transportation links, allocating origin and destinations nodes (e.g., cities) to hubs, and routing flows through the network. There are particular models such as hub center, hub median, hub covering in the literature [12]. Campbell's study gives formulations for four types of discrete hub location problems: the p-hub median problem, the uncapacitated hub location problem, p-hub center problems and hub covering problems [13]. The p-hub median problems focus on minimizing the total transportation cost (time, distance, etc.) needed to serve the given set of flows, given n demand nodes, flow between origin–destination pairs and the number of hubs [14]. The studies considering the p-hub median problem are analyzed in two different types (Fig. 1). The difference of hub networks is in how non-hub nodes are allocated to hubs. All the incoming and outgoing traffic of every demand center is routed through a single hub in single type while each demand center can receive and send flow through more than one hub in multiple allocation [14,15].

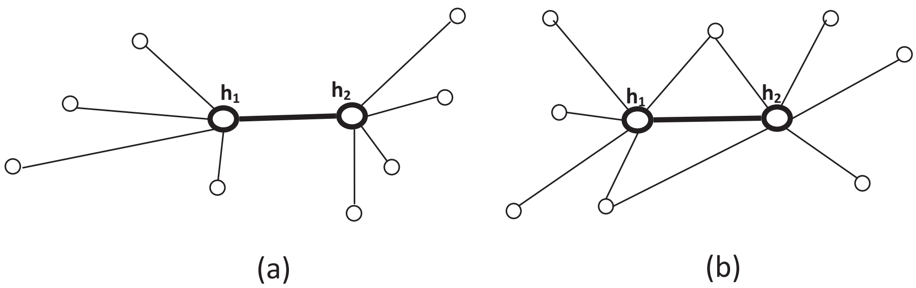

Fig. 1. (a) Single allocation type and (b) multiple allocation type.