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Debris removal during disaster response: A case for Turkey

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ABSTRACT

Debris occurs from the ruin and wreckage of structures during a disaster. Proper removal of debris is of great importance because it blocks roads and prohibits emergency aid teams from accessing disaster-affected regions. Poor disaster management, lack of efficiency and delays in debris removal cause disruptions in providing shelter, nutrition, healthcare and communication services to disaster victims, and more importantly, result in loss of lives. Due to the importance of systematic and efficient debris removal from the perspectives of improving disaster victims quality of life and allowing the transportation of emergency relief materials, the focus of this study is on providing emergency relief supplies to disaster-affected regions as soon as possible by unblocking roads through removing the accumulated debris. We develop a mathematical model for the problem that requires long CPU times for large instances. Since it is crucial to act quickly in an emergency case, we also propose a heuristic methodology that solves instances with an average gap of 1% and optimum ratio of 80.83%.

1. Introduction and problem definition

Though ultimate avoidance of natural disasters is likely impossible, disaster management operations play a vital role in minimizing the negative effects of disasters and loss of life. The disaster management literature is comprised of studies that focus jointly on preventive strategies for pre-disaster and damage reduction operations for post-disaster periods. The disaster management cycle consists of four phases: preparation, response, recovery and reconstruction. The preparation phase covers precautions that are taken before a disaster occurs to minimize negative outcomes. The response phase starts immediately after the disaster and involves providing emergency services to as many victims as possible as soon as possible. During the recovery phase, the main focus is to restore the disaster area in terms of communication, transportation and infrastructure; and finally, the main objective of the reconstruction phase is to fully rehabilitate the disaster area and normalize the daily lives of disaster victims.

As a result of the destructive effects of disasters, debris, occurs. Proper removal of debris is extremely important for unblocking roads and allowing emergency aid teams to access the disaster area. In this study, we focus on debris removal in the response phase of earthquakes. Complete debris removal may be postponed until the recovery phase, whereas removing debris on routes to critical disaster areas must be done in the response phase. Therefore, effective debris removal is necessary to access disaster victims.

During the response phase, since time is of the utmost significance, it is necessary to determine which areas to access first. It is critical to provide emergency aid as quickly as possible to districts that contain schools, hospitals, potential shelter areas, etc. In order to do so, however it may be necessary to travel on a path that includes blocked roads. In such a case, it is required to unblock these roads by debris removal operations. In this context, we define the *Debris Removal Problem in the Response Phase (DRP)* as visiting pre-specified critical disaster-affected districts as quickly as possible by removing debris on blocked roads if and when necessary. Proper distribution of resources will entail timely access to emergency supplies and will help defuse the post-disaster crisis. In accordance with this purpose, the disaster area is assumed to be aggregated into districts. Critical districts and the districts serving as the resource base are determined. The proposed methodology also determines the critical path for the emergency-response vehicle, called RESCUE (Relief Supply Carrier Under Emergency), which transfers relief materials to critical districts. Associated with the critical path, the arcs that require debris removal to resolve blockage and provide access are also identified. It is worth noting that all blocked edges on the critical path must be unblocked, and once an edge is freed from debris, it remains open for later use. Debris removal operations for blocked roads require extra effort,

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which is measured in terms of time in our approach. Traveling more than once on an edge from which the debris has been removed might be advantageous and in determining the critical path for traversing all critical districts, the algorithm will utilize this advantage.

The DRP is an NP-hard problem because the case when there are no blocked edges and all nodes are critical is equivalent to the travelling salesman problem (TSP) [1].

Since there are nodes that must be visited, and since an arc-routing aspect is inherently present, our problem can be defined as a variant of the general routing problem (GRP), which will be detailed in the following section. Different than the GRP, our problem implies that the only reason to traverse an arc is to reach a required node. To the best of the authors' knowledge, this variant of the general routing problem has not yet been defined in the literature.

Organization of the paper is as follows: In Section 2, related literature is visited. Development of mathematical model is in Section 3. In Section 4, heuristic solution methodologies are presented. Section 5 is devoted to computational experiments and their results. Finally, concluding remarks are in Section 6.

2. Related literature

The GRP aims to find a minimum-cost vehicle route that starts and ends at the same node and visits the required nodes at least once by passing through the required edges at least once. The required node set is a subset of all nodes and the required edge set is a subset of all edges [2]. The GRP includes both node- and arc-routing aspects, thus node-routing and arc-routing problems arise as special cases. For a comprehensive survey, we investigate both the arc-routing problems (ARP) and the node-routing problems, namely, the vehicle routing problem (VRP). Since one of the key aspects of our problem is debris removal on arcs in order to unblock them, we examine the arc-routing literature in detail.

2.1. Arc-routing problems

In ARPs, the aim is to find a minimum-cost vehicle tour that traverses through a specified arc subset, which begins and ends at the same node. The Chinese postman problem (CPP), the rural postman problem (RPP) and the capacitated arc-routing problem (CARP) are primary arc-routing problems. The difference between the GRP and the ARP is that the GRP also considers the node-routing aspect by visiting some nodes on the graph. When the required node set is empty and the purpose is to visit all edges, the GRP reduces to the CPP. On the other hand, if there is a subset of edges that needs to be visited with an empty required node set, then the GRP reduces to the RPP [2,3]. The CPP was first defined by Kwan-Mei Ko in 1962 [4,5] to find a minimum-cost tour that traverses all the arcs of a graph at least once. Waste collection, street sweeping and snow plowing operations, where it is required to pass through all arcs in the graph, are in the application area of the CPP. In 1974, Orloff [6,5] defined the RPP, where the objective is to find a minimum-cost tour that traverses only a subset of arcs, which are called required arcs, at least once. Lenstra and Rinnooy Kan [2] proved that both undirected and directed versions of the RPP are NP-hard. However, if the required edges are all edges of the graph, then the problem becomes a CPP [7]. Street sweeping, snow plowing, garbage collection, mail delivery, school bus routing and meter reading are the most common application areas of the RPP. When a capacity constraint of the vehicle is included, the problem is referred to as the capacitated arc-routing problem, which was first defined by Golden and Wong in 1981 [8]. There are many variations of CARP, and their application areas are also various, including winter gritting, refuse collection, mail delivery, street sweeping operations and police patrols. The aim of the problem is to find a minimum-cost traversal of all arcs such that each arc is serviced without exceeding the capacity of the vehicle.

2.2. Node-routing problems

Node-routing problems are special cases of the GRP, of which the VRP is one of the most famous. When there is a subset of nodes required to be visited with an empty required edge set, the GRP reduces to the VRP. Since the general VRP literature is too broad, we only focus on the VRP literature over blocked networks. One of the problems of the shortest-path classification is the Canadian traveller problem (CTP). In their article, Xu et al. refer to the CTP as an abstraction of the online shortest-paths/routing problems [9].

The CTP was first defined by Papadimitriou and Yannakakis and proven to be an NP-hard problem [10]. It is defined for a single source and a single destination and the aim is to find the minimum-cost route from source to destination. The traveller knows the graph structure and edge costs but some edges may be blocked, which the traveller does not know until he/she reaches the adjacent node of this blocked edge [9]. The classic version of the CTP is a stochastic problem and the blocked edges remain blocked forever [11,12]. Note that if all road blockages are known in advance, the optimal travel path can be obtained by applying a shortest-path algorithm from source to destination. However, since the problem has an online nature, the optimal travel strategy cannot be given by the shortest path [11]. In their study, Bar-Noy and Schieber introduced variations of the CTP [11], one of which is the recoverable-CTP, where blocked roads may become open again. There are both stochastic and deterministic versions of the recoverable-CTP. In the stochastic version, each edge has a blockage probability, and in the deterministic version, there is a fixed bound on the total number of potential blockages. In the recoverable-CTP, edges have recovery times. It is assumed that the recovery times of blocked edges incident to the same node are the same. When all recovery times are significantly large, the recoverable-CTP becomes the classic CTP.

The k-CTP is another variant of the CTP, where k is a parameter that represents the maximum number of potential road blockages. When k equals the number of edges, the k-CTP becomes the classic CTP [11]. In the CTP, the traveller selects a path and starts to travel without knowing future blockages, and when he/she encounters a blocked edge must determine whether to wait for the blocked edge to reopen or to look for another way. The main factor to consider is the recovery time versus the time to travel along another path. In this respect, if the problem structure becomes offline instead of online, Bar-Noy and Schieber state that, the optimal strategy is given by the shortest path from source to destination [11]. In the literature, no mathematical model has been developed for the CTP.

2.3. Emergency relief transportation literature

Ozdamar and Ertem provide a survey on the response and recovery phases of the disaster management [13]. In disaster management literature, activities of disaster operations management, such as emergency rescue and medical care are categorized in the phase of response, whereas the debris cleanup activities are categorized in the recovery phase [14]. There are a few articles which consider the debris removal as a prerequisite to transport emergency rescue in the response phase.

A study conducted by Berkoune et al. points out a transportation problem which focuses on the emergency aid supply in disaster