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Heuristic Solution Approaches for Due Diligence in Disaster Management

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ABSTRACT

The number of studies in the field of disasters is rising as a result of the rising number of disasters worldwide. Planning, supervising, and coordinating disaster management operations are crucial. Special infrastructures are needed for emergencies such as search and rescue, humanitarian aid, evacuation operations, etc.; establishing due diligence as soon as a crisis strikes is one of the most crucial aspects of disaster management. In order to minimize the number of victims, debris must be found quickly, especially during earthquakes. Due diligence becomes challenging when severe disasters like earthquakes disrupt facilities like the phone, internet, and electricity lines. Finding the locations of the wreckage is crucial to assisting with search and rescue operations. This study looks at an arc routing problem to assess the state of buildings in an earthquake-affected area. The goal is to locate the locations as soon as possible by inspecting every path and road within the disaster area at least once. Getting a quick fix for an arc routing problem is more important for disaster management than getting the best outcomes. Two distinct heuristic approaches have been put forth in this regard, and the outcomes have been contrasted.

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Disaster management;
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1. Introduction

Disasters may not have a set date, so it is crucial to be constantly prepared and respond quickly. Especially in large-scale disasters such as earthquakes, damage to communication and transportation infrastructure can make rescue operations difficult. Therefore, disaster management plans need to be prepared and constantly updated to include such scenarios. Planning swift and effective search and rescue operations is crucial to disaster management. Prompt planning is essential to minimizing fatalities (Tran et al., 2020).

This study is centered on the earthquake. Infrastructures for transportation and communication suffer significant damage during large-scale events like earthquakes. Transportation to the area, communication with the disaster area, and due diligence operations within the region are all impacted by this situation. Finding the wreckage quickly is essential for conducting search and rescue operations. Reducing casualties is significantly aided by this situation (Yuna & Erkayman, 2024).

Infrastructure deficiencies negatively affect disaster response. Problems in the electrical infrastructure, especially in terms of limited communication tools and technological equipment use, In this case, it becomes even more difficult to assess the situation in the disaster area and coordinate rescue operations. Power outages also impact healthcare, emergency, and other essential services, complicating post-disaster response (Tran et al., 2020).

Deficiencies in transportation infrastructure prevent rescue teams from reaching the disaster area and moving quickly. Problems in the communication infrastructure may disrupt information flow and coordination. In this case, it will be more difficult to communicate and cooperate with security forces, rescue teams, and other aid organizations in the disaster area. As a result, infrastructure deficiencies can slow disaster response, reduce its effectiveness, and compromise the safety of disaster victims. Therefore, disaster management plans need to be updated to take into account infrastructure deficiencies.

Early intervention is very important in disaster management in order to be least affected by the bad consequences of disasters and to ensure human safety. The destruction that occurs after a disaster causes major problems in technology and electrical infrastructure. This may negatively impact modern disaster management processes. Technology provides one of the most important contributions to disaster management. Thanks to technology, rapid information exchange and communication are provided first. However, in the absence of technology, it becomes difficult to obtain information about the disaster's size, location and impact. Therefore, emergency response teams may not be able to intervene. In the absence of technology, search and rescue processes become difficult. Decision makers find it difficult to obtain information from the disaster area and crisis management cannot be done effectively.

Electrical infrastructure problems affect many important processes after a disaster, such as communication, emergency, logistics, transportation, and medical services. After a disaster, electrical and technological deficiencies make the work of rescue teams difficult in search and rescue and situation assessment efforts. One of the important elements of disaster management is determining the area in which to intervene. This situation becomes even more difficult in devastating disasters. It is necessary to scan the disaster area to coordinate rescue operations. These scanning processes become very difficult due to deficiencies in technology, qualified personnel, and electrical infrastructure. In this study, based on these problems, two heuristic methods based on the Arc Routing Problem have been proposed, aiming to scan the disaster area in the shortest time and at the least cost when there are deficiencies such as technology, computer, solver and electricity.

Infrastructures like the internet and electricity are severely damaged during major disasters. Teams reacting to the disaster are, therefore, impacted by this circumstance. It can be challenging to locate severely damaged or destroyed buildings after an earthquake and point search and rescue teams toward the debris. It is more challenging to pinpoint the exact location of the destruction in the early stages of the disaster due to the damage to the infrastructure. This study proposes two distinct nearest neighbor search heuristics to perform situation determination studies in an earthquake-ravaged region.

The goal of the arc routing problem is to control every street in the impacted area by passing by them at least once. Solvers can be used to find the best answers to related problems. However, this study focuses on quick damage assessment during severe shortages in computers, internet, electricity, solvers, and other resources.

2. Literature review

An iterated greedy heuristic was presented by Vincent and Lin (2015) for the time-dependent prize-collecting arc routing problem. An arc routing problem with capacity restrictions and time-dependent service costs was studied by Tagmouti et al. (2007). Keskin and Yılmaz (2019) have suggested a formulation for the postman problem that takes this into consideration since the costs related to the edges may differ in real-life applications. Sun et al. (2015) proposed the arc-cycle formulation, an expanded version of the formulation in Wang and Wen's (2002) groundbreaking work that directly models time-varying CPP.

Tagmouti et al. (2010) presented a variable neighborhood descent heuristic approach in a different study to address the issue in the context of capacity restrictions and time-dependent service costs. CARP (capacitated arc routing problem) modeling has been used in real-world problems by Bodin and Kursh (1978), Stern and Dror (1979), Bodin et al. (1989) and Haslam and Wright (1991). The dynamic capacity arc routing problem for winter gritting applications was covered by Tagmouti et al. (2011). A new problem known as TD-PARP (Time-Dependent Prize-Collecting Arc Routing Problem) has been described by Black et al. (2013). The Variable Neighborhood Search and Tabu Search meta-heuristics were used to solve this problem.

Studies on the evaluation of damage after a disaster have emerged as a key field of research. For instance, Nex et al. (2019) presented a novel method for real-time UAV mapping of building damage. Sugita et al. (2020) demonstrated a quick response to disasters using UAVs and aircraft. The deep learning-based damage map estimation method put forth by Tran et al. (2020) is another study. Many of these studies are not appropriate for use right away following significant calamities. Skilled workers are required to complete related tasks in addition to using computers, electricity, and the internet in order to complete these tasks.

Yuna and Erkayman (2024) suggested a heuristic with a single team for the due diligence study. This study proposes two different working situations for the two teams. The study's main objective is to develop a due diligence plan that can be applied in situations without infrastructure, including a phone, internet, computer, or electricity. Two nearest neighbor search heuristics based on the arc routing problem is suggested for this reason. To the best of the author's knowledge, neither arc routing problem nor disaster situation assessment studies have been discussed in the literature from this perspective.

3. Methodology

Keskin and Yılmaz (2019) stated that one of the well-researched issues in the literature is the arc routing problem (ARP). Finding the shortest closed path that visits every edge of an undirected network is the aim of the Chinese Postman problem (CPP). An ARP variant is CPP. It can be categorized as directed or undirected depending on how the edges are doing. Cost is an additional consideration. In this study, the cost is defined as the distance from the source. For this reason, this study's edges are undirected. Since the distances are unaffected by the direction of the transition, the issue is also symmetric.

Two heuristic approaches are suggested in this study. The heuristics presented in the study aim to visit every arc at least once without going back to the starting arc. It is enough to make at least one trip in any direction to the arcs. The determination of the situation at each street or avenue is guaranteed by going through them at least once.

The teams consist of people who will assess the situation in the disaster area. However, two teams are used in Heuristic 1 and Heuristic 2. In Heuristic 1, two teams start the solution from the same starting point, while in Heuristic 2, two teams start the solution separately from the two different points farthest from each other. Heuristics aims to scan and determine the situation of the relevant network as soon as possible and with the least transition cost. The solution stages of Heuristic 1 are given below.

1. Start with 2 teams from the same starting node. Save 0 ($n_i = 0$) as the initial number of passes from the edges. The number of passes of edge i is indicated by n_i.
2. Randomly determine which team will visit the first edge. Select the least costly edge of the starting node for one team, and then select the next least costly edge for the other team. Add one ($n_i=n_i+1$) to the total number of passes for the chosen edges. Update the initial nodes with the new nodes once the new nodes are reached.
3. Update starting nodes for each team individually. Decide which nodes to start with. Sort the connected edges' costs and passes by number, going from smallest to largest.
4. Perform this step separately for each team. Based on cost, select the edge with the fewest passes. If every edge has the same number of passes, choose the least expensive edge. If the costs and the number of passes made by the edges are equal, choose at random. The number of passes for the chosen edge is increased by 1 ($n_i=n_i+1$).
5. Once the new nodes are reached, go back to Step 3 and update the starting nodes with the new nodes.
6. Continue until all edges have been passed at least once.

The Heuristic 1 method aims to scan the disaster area faster with 2 teams. The stages of heuristic 2 are as follows:

1. Start with one team from each of the two different nodes that are farthest from each other. Save 0 ($n_i = 0$) as the initial number of passes from the edges. The number of passes of edge i is indicated by n_i.
2. Determine the starting nodes of the teams. For each team, choose the least costly edge of the starting node. Add one (n_i=n_i+1) to the total number of passes for the chosen edges. Update the initial nodes with the new nodes once the new nodes are reached.
3. Update starting nodes for each team individually. Decide which nodes to start with. Sort the connected edges' costs and passes by number, going from smallest to largest.
4. Perform this step separately for each team. Based on cost, select the edge with the fewest passes. If every edge has the same number of passes, choose the least expensive edge. If the costs and the number of passes made by the edges are equal, choose at random. The number of passes for the chosen edge is increased by 1 (n_i=n_i+1).
5. Once the new nodes are reached, go back to Step 3 and update the starting nodes with the new nodes.
6. Continue until all edges have been passed at least once.

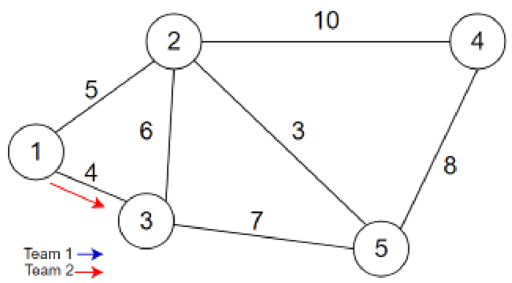
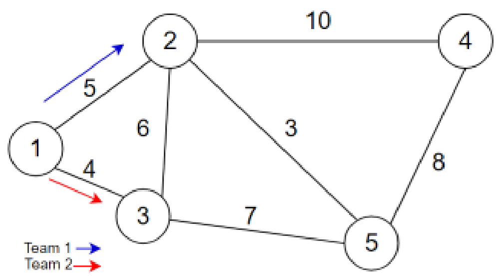
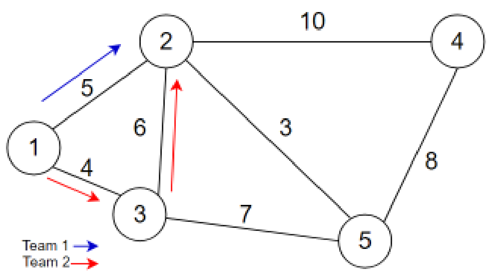
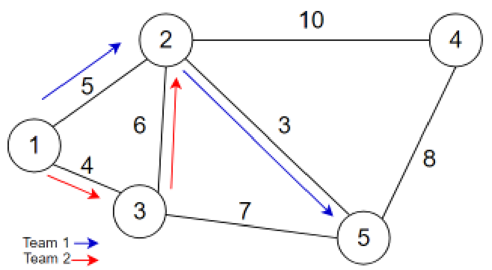
The Heuristic 2 method aims to scan the disaster area faster with 2 teams while also trying to prevent extra visits to the edges. While it provides a faster solution compared to the Heuristic 1 method, it is also expected to be less costly. Total transition costs and total network scanning times are compared in section 4.

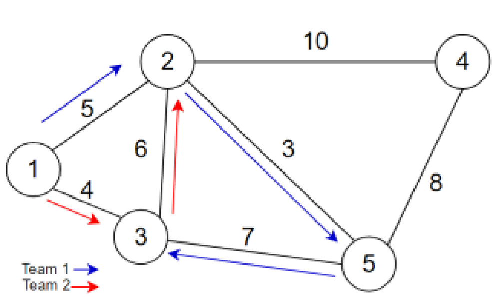
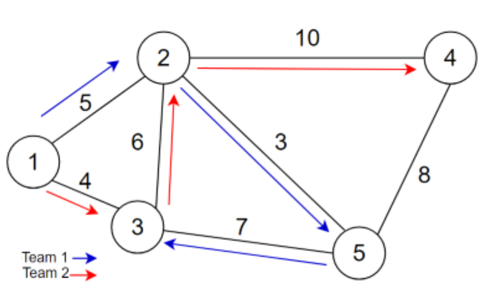
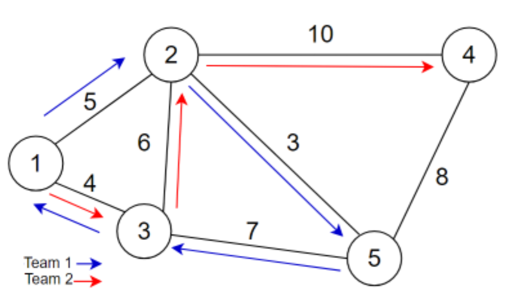
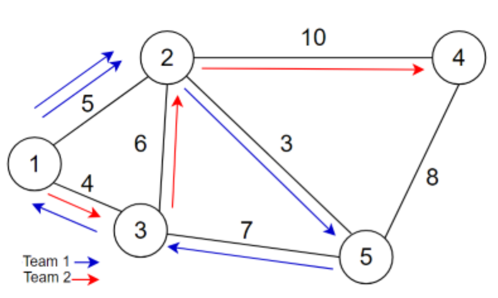
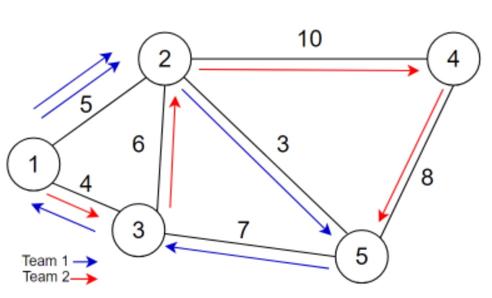
Search and rescue teams can quickly complete debris detection with this information using the proposed heuristics, which only require a network and edge costs. This information is particularly useful in environments where infrastructures like the internet, phone, and computer are damaged because it is easily calculable by people without the need for any technological infrastructure.

4. Case study

The suggested heuristic methods are applied to a network with five nodes and seven edges. Tables 1 and 2 provide specifics on each stage of the solution of the heuristic method. The term "cost" describes the total cost of each edge that can be reached from the starting node. The number of times each edge that can be traveled from the starting node has been used independently is known as the number of passes. The edges that, in accordance with the suggested heuristics, can be utilized in the following step are referred to as feasible edges.

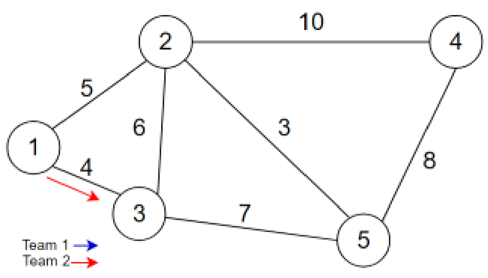
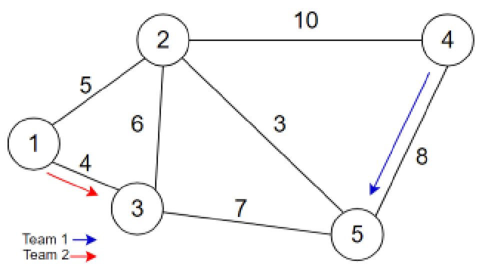
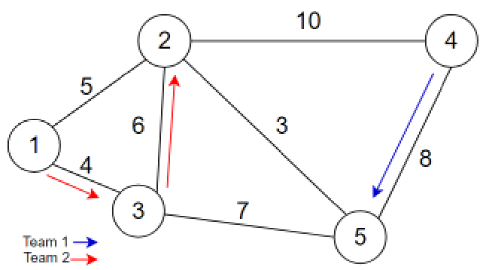
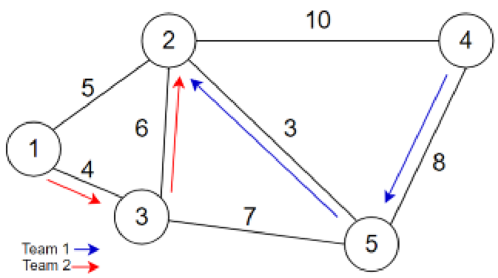
Table 1. An Example of Proposed Heuristics 1.

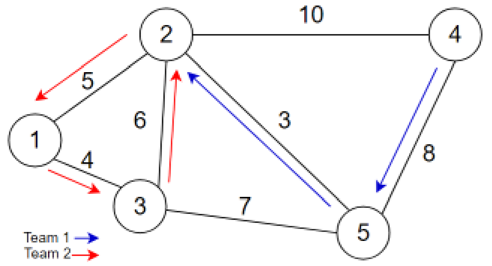
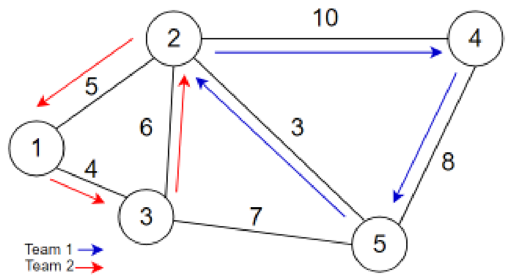
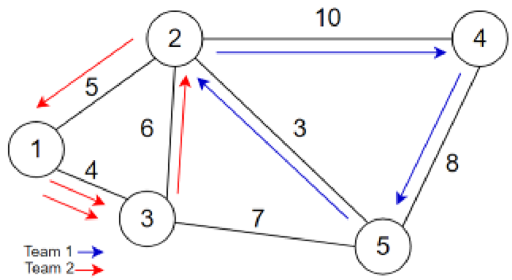
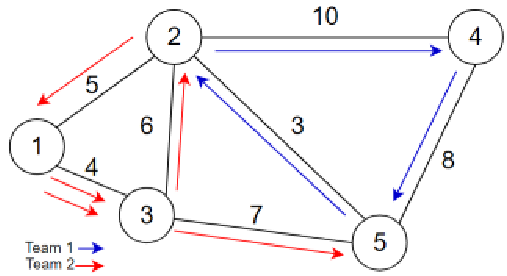
<table>
<tr><th colspan="2">The Heuristic 1 Solution</th></tr>
<tr><td>
</td><td>Both teams start at node 1. Team 1 is chosen randomly. Among the edges connected to node 1, 1-3 edge with the lowest cost is selected.</td></tr>
<tr><td>
</td><td>Team 2 selects the lowest-cost edge 1-2, excluding edge 1-3 connected to node 1.</td></tr>
<tr><td>
</td><td>Team 2 reaches node 3. Among the edges connected to node 3, the lowest cost and least visited 3-2 edge is selected.</td></tr>
<tr><td>
</td><td>Team 1 reaches node 2. Among the edges connected to node 2, the lowest cost and least visited 2-5 edge is selected.</td></tr>
</table>

<table>
<tr><th colspan="2">The Heuristic 1 Solution</th></tr>
<tr><td>
</td><td>Team 1 reaches node 5. Among the edges connected to node 5, the lowest cost and least visited 5-3 edge is selected.</td></tr>
<tr><td>
</td><td>Team 2 reaches node 2. Among the edges connected to node 2, the lowest cost and least visited 2-4 edge is selected.</td></tr>
<tr><td>
</td><td>Team 1 reaches node 3. Among the edges connected to node 3, the lowest cost and least visited 3-1 edge is selected.</td></tr>
<tr><td>
</td><td>Team 1 reaches node 1. Among the edges connected to node 1, the lowest cost and least visited 1-2 edge is selected.</td></tr>
<tr><td>
</td><td>Team 2 reaches node 4. Among the edges connected to node 4, the lowest cost and least visited 4-5 edge is selected.</td></tr>
</table>

According to the proposed heuristic 1 result in Table 1, Team 1's route is 1-2-5-3-1-2 and Team 2's route is 1-3-2-4-5. Team 1 costs 24 and Team 2 costs 28. The total cost for Heuristic 1 is 52 units. As can be seen, all edges have been visited at least once. The twice visited edges are 1-3 and 1-2 edges. It is assumed that both teams are identical. If 1 unit of distance is assumed to be 1 unit of time, scanning the entire network is calculated as 28 units of time.

Table 2. An Example of Proposed Heuristics 2.

<table>
<tr><th colspan="2">The Heuristic 2 Solution</th></tr>
<tr><td>
</td><td>Nodes 1 and 4, which are furthest from each other, are selected. Team 2 starts from Node 1. The assignment of nodes to teams is random. Among the edges connected to node 1, 1-3 edge with the lowest cost is selected by Team 2.</td></tr>
<tr><td>
</td><td>Team 1 starts from Node 4. The assignment of nodes to teams is random. Among the edges connected to node 4, 4-5 edge with the lowest cost is selected by Team 1.</td></tr>
<tr><td>
</td><td>Team 2 reaches node 3. Among the edges connected to node 3, the lowest cost and least visited 3-2 edge is selected.</td></tr>
<tr><td>
</td><td>Team 1 reaches node 5. Among the edges connected to node 5, the lowest cost and least visited 5-2 edge is selected.</td></tr>
</table>

<table>
<tr><th colspan="2">The Heuristic 2 Solution</th></tr>
<tr><td>
</td><td>Team 2 reaches node 2. Among the edges connected to node 2, the lowest cost and least visited 2-1 edge is selected.</td></tr>
<tr><td>
</td><td>Team 1 reaches node 2. Among the edges connected to node 2, the lowest cost and least visited 2-4 edge is selected.</td></tr>
<tr><td>
</td><td>Team 2 reaches node 1. Among the edges connected to node 1, the lowest cost and least visited 1-3 edge is selected.</td></tr>
<tr><td>
</td><td>Team 2 reaches node 3. Among the edges connected to node 3, the lowest cost and least visited 3-5 edge is selected.</td></tr>
</table>

According to the proposed heuristic 2, results in Table 2, Team 1's route is 4-5-2-4 and Team 2's route is 1-3-2-1-3-5. Team 1 costs 21 and Team 2 costs 26. The total cost for Heuristic 2 is 47 units. As can be seen, all edges have been visited at least once. The twice visited edge is only 1-3 arcs. It is assumed that both teams are identical. If 1 unit of distance is assumed to be 1 unit of time, scanning the entire network is calculated as 26 units of time.

Table 3. Costs and Network Scanning Times of Heuristics.

Heuristics	Total Transition Costs	Total Network Scanning Times
Heuristic 1	52 units	28 units of time
Heuristic 2	47 units	26 units of time

In this study, two heuristics were proposed and their results are given in Table 3. Table 3 shows that the heuristic with the least transition cost is heuristic 2. In addition, looking at the network scanning time, heuristic 2 stand out. Time is very important in disaster management. Rapid response to disasters is of critical importance in mitigating the consequences of disasters and reducing loss of life. Therefore, the time factor must be taken into account in disaster management studies. Considering the time factor, it has been observed that heuristic 2 gives the best result. At the same time, heuristic 2 has one of the lowest costs in terms of transition costs.

5. Conclusion

A rapid and effective damage assessment after a disaster is critical in helping disaster victims and accelerating search and rescue efforts. Recently, advanced technologies such as unmanned aerial vehicles have become an important tool to accelerate this process and obtain more accurate data. These vehicles can quickly scan debris fields, assess damage and provide necessary information to rescue teams. However, some disasters can be so large that reaching the scene becomes extremely difficult. In this case, infrastructure problems also play an important role. Basic equipment such as computers, phones, electrical power and communications tools are vital to disaster management and first response. However, if these facilities are not operational or damaged after the disaster, it may negatively affect the response and detection process.

Therefore, it is important to know the debris's location, especially immediately after the disaster. For this purpose, the proposed nearest neighbor search heuristics perform debris detection without the need for any infrastructure, technology or trained personnel. These heuristics play an important role in the first hours after a disaster and speed up the response process by providing necessary information to rescue teams. In this way, the damages caused by the disaster can be minimized and disaster victims can be helped more quickly and effectively.

The basis of the proposed heuristic approaches is to have a detailed map of the relevant disaster area and streets. This map helps guide the damage assessment team when starting work from any point and locating the debris. Thanks to the information on the map and the proposed heuristic, the team quickly and effectively scans debris fields and assesses damage. This greatly affects the disaster management and response phases.

Search and rescue operations are often complex and dynamic. However, applying these heuristic approaches, the team works with more awareness and is more likely to respond to the disaster. While this approach makes the post-disaster response process more effective, it also provides faster and more effective assistance to disaster victims. Therefore, the use of these proposed heuristics is an important point in the field of disaster management and response.

The results of 2 different proposed heuristics are compared. When the results of the proposed heuristics are examined, it is seen that the most appropriate solution is taken in the Heuristic 2 method. According to these results, it was observed that as the number of teams increased, the scanning time of the disaster area decreased. However, the further away the teams start working from each other, the lower the scanning cost. When there are major deficiencies in the technological infrastructure, coordination problems are inevitable. Therefore, assigning teams to disaster areas in a number that can communicate with each other will make things easier in terms of coordination. Therefore, the status of the disaster area will be determined at the smallest cost and in the shortest time. The greatest benefit of early intervention in a disaster area is saving lives. Even seconds are very important in the struggle for life. Therefore, the first goal is to prevent loss of life. Providing timely medical assistance will reduce the loss of life. In addition to the aim of saving lives, the proposed heuristic methods also provide the opportunity for early intervention in situations such as evacuation of people from the disaster area, shelter needs, and psychological support.

The heuristics proposed in future studies can be tested for much larger networks. Moreover, any shortcomings of this heuristic can be revealed using test problems. A separate proposed solution can be developed for roads that may be closed due to debris.

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