Research Statement

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My research primarily focuses on developing solution approaches for logistics, transportation, and scheduling applications. My primary academic interests are in disaster management and humanitarian logistics problems motivated by real-world applications and real-world data to solve these problems.

For my thesis, I have focused on developing improved preparedness and response methods for two kinds of humanitarian applications. First, I have developed approaches for storing and distributing fuel to reduce the impact of disasters on islands. Second, I have identified the best roads and bridges to upgrade to enable quick travel through cities after a flood event and mitigate its consequences. All of this work requires applying operations research (OR) methodologies and developing OR-based techniques to build, improve, and solve integer programs (using tools such as Gurobi/CPLEX). I use complexity theory, network theory, and develop analytical results. The work on flood mitigation also requires the use of geographic information systems (GIS) tools. Accordingly, I use ArcGIS software to capture spatial data, analyze mapped data, visually display geographical data, and demonstrate solutions.

The literature in disaster management has a gap in combining applications of GIS and geographical spatial data with optimization. The use of maps, including layers such as elevation, transportation, populated places, administrative boundaries, hydrography, and inundated areas, can be valuable in providing realistic solutions. My long-term research approach is to address such a gap and further understand the various ways in which GIS can be utilized in humanitarian private and academic sectors, reveal how the OR academic community can utilize such technology in their research, and help guide future research in this field.

1 Thesis Research

1.1 Fuel Distribution Planning for Disasters on Islands

After a disaster on an island, there is often an increased demand for fuel because islands often do not have refineries, and it could take several weeks for ships to arrive with more fuel. Through this research, I conducted several interviews with FEMA employees who worked in Puerto Rico during Hurricane Maria to understand how to better prepare for future disasters on islands. This study proposes a two-tier optimization approach to, first, determine how to allocate and preposition fuel to the different regions (**Tier 1**). Second, it considers how to strategically use ships to supplement the fuel after a disaster (**Tier 2**). Tier 1 focuses on the first few days after a disaster when there is no fuel available to the island other than what existed prior to the disaster, and no replenishment from outside sources has occurred yet. However, Tier 2 evaluates the strategic use of ships to reduce the arrival time of the shipments from outside sources. While most disaster-related studies focus on the mainland, this research fills this gap by providing distribution models appropriate for islands.

Tier 1: The work in this research models the uncertainty of the problem using a set of disaster scenarios created by historical data. The scenarios capture which fuel storage locations are unavailable and which regions face higher demands due to the impact of the disaster. I formulate a set of stochastic mixed-integer models that focus on planning for equitable and efficient fuel distribution. I have examined how different allocation, prepositioning, and distribution strategies could benefit Puerto Rico, and the results highlight the importance of prepositioning fuel in new locations. *This paper is accepted at Transportation Research Part E* [1].

Tier 2: Immediately after Hurricane Maria, FEMA ordered a ship filled with fuel to be sent from Louisiana to the port of San Juan in Puerto Rico. Based on the success of this effort, FEMA discussed their future plans to use ships to deliver fuel from the mainland to the island's fuel dispensing sites to help with quick distribution after disasters. Even if FEMA determines the location of the sites, there remain questions about how many ships to use, which ports should be visited by the ships, and what points of origin to use for these ships to improve the citizens' quality of service. All of these decisions impact the arrival time of the fuel at the different dispensing sites.

By reducing this problem to the dominating set problem, I have proved its NP-Hardness. I have developed analytical results that significantly reduce the number of variables and, on average, improve the solution time by 58%. To further reduce the size of the search space and the branch-and-bound tree, I have developed several valid inequalities and lower bounds. In some instances, the improvements reduce the runtime by 98%. *This paper accepted at the European Journal of Operations Research (EJOR)* [2].

1.2 Road Network Flood Mitigation

When a flood occurs, providing access to healthcare facilities (HFCs) is a top priority. However, floods can deteriorate and block transport systems, leading to loss of access to HFCs. To mitigate the consequences, it is crucial to determine how changes to transportation infrastructure, such as road improvements, can improve access to emergency service facilities. In an ideal scenario, all roads with the risk of potential flooding would be upgraded. However, due to budget restrictions, not all of them can be upgraded at once. Like the Department of Transportation (DOT), agencies struggle to select the best set of roads to upgrade. This research addresses a pre-disaster planning problem to strengthen a road network to maximize the residents' accessibility to HCFs and minimize their travel times subject to budget and capacity restrictions.

In this research, unlike the literature, I have proposed a model that does not limit each origin to be served by a pre-specified destination. Due to this difference, the methodology of this work requires developing novel pruning techniques to enable solving of realistic problem sizes. I have proved that the problem is NP-hard by reducing it to the generalized assignment problem (GAP). Subsequently, I have explored the structure of the optimal solution to develop preprocessing techniques that reduce a large number of variables present in the problem. On average, the proposed techniques can reduce the size of the network and the runtime by 30% and 39%, respectively.

I conducted a case study in the City of Coralville, in the State of Iowa. To create realistic test instances, I have utilized data-driven techniques and a GIS road network demographic database to calculate the road distances and obtain the location of population centers. The vulnerability of network segments is assessed in reference to the 100-year flood scenario using the floodplain spatial data layer in ArcGIS. This work, develops resourceful data, tools, and models for carrying out mitigation plans and helps the federal and state authorities respond to disasters efficiently. We believe this work is a good fit for the journal of Transportation Research Part B [3].

1.3 Robotic Cell Scheduling

In some manufacturing industries, robots occupy around 38% of the total energy consumption. In order to get the maximum benefit from this high-cost investment, where robots are used to produce identical/different parts, some complex operational problems must be solved. This study is the first in the literature of robotic cell scheduling problems that simultaneously consider the energy consumption and throughput rate. I use Lagrangian multipliers and Karush-Kuhn-Tucker optimality conditions to determine the optimal robot move speeds analytically. Employing the proposed approach, we can get not only an economic return but also an environmental benefit through reducing carbon emissions by decreasing the need for electric power across the manufacturing sector. For the case in which energy consumption is not a concern, this research proposes mixed-integer programming formulations. I developed hybrid metaheuristic algorithms that combine genetic algorithms with tabu search to solve these strongly NP-Hard problems. *I served in writing the proposal of this project that was accepted and funded by the Scientific and Technological Research Council of Turkey (82,000 $) in April 2016. Two published papers and one paper in preparation are what I derived from this research* [4, 5, 6].

2 Next Steps: The Use of Drones in Road Network Flood Mitigation Problem

After a disaster, it is hard to make route plans for delivering aid and supplies due to the unknown conditions of the roads in the network. It is beneficial if the first emergency responders can assess the road conditions to draw strategies for reducing the delivery time to those in need. In such situations, drones can assist in the decision-making process with the birds-eye view of the affected area, providing beneficial knowledge of the state of transportation and logistics in a short amount of time.

In the literature, the benefits of drones have been mostly investigated in either providing essential information for decision-makers or delivering small loads of first-aid medical supplies to those in need. In the first case, drones are accommodating in (i) mapping large areas where infrastructure has been destroyed, (ii) mapping water level and gauging the damage caused by floods, (iii) providing information about the amount of debris on roads, and (iv) getting high-spatial-resolution imagery, especially when GIS centers providing satellite imagery are flooded. In the second case, the literature primarily focuses on the benefits of drones as relief distribution vehicles by investigating the optimal number of drones, or the optimal number and locations of their distribution/recharge centers, whereas the research on their benefits in minimizing the travel times is limited.

As an extension of my research mentioned in Section 1.2, drones can be used to look ahead and see if those proposed roads are achievable as the users keep driving down the paths. Similarly, they can be used to direct trucks filled with relief supplies to damaged areas. I aim to explore how utilizing drones can decrease the trucks' travel times from origins to destinations for an extension. In a vast network, a drone cannot search the whole region due to its battery charging limits. There is the strategic decision of where to deploy the drones, how far to send them out on the path considering path limitations.

3 Future work

GIS is an efficient tool for visualizing geographical data and displaying the information on geographical maps. While data visualization techniques are used to show, optimization is used to plan. In my future research, I would like to utilize the integration of GIS with optimization techniques to develop more concrete solutions in a range of applications, such as logistics and location-allocation problems. For instance, deciding where to locate hospitals and allocate healthcare resources combined with proposing a mitigation plan is a potential application that could benefit from GIS. Healthcare facilities (supply) and patients (demand) in a healthcare market interact with each other across geographical and spatial borders, and measures of healthcare accessibility need to capture that. Defining a geographic unit for the healthcare market is critical for researchers and policymakers to evaluate healthcare delivery, and GIS can help define the unit (e.g., hospital service areas) efficiently and optimally. *While these research topics are of interest to me for pursuing in the future, I am open to other areas as I build new collaborations in my next institution.*

References

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