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OPTIMIZATION OF BATTERY ALLOCATION FOR POST-EARTHQUAKE DAMAGE ASSESSMENT USING DRONES

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ABSTRACT

Earthquakes are one of the most common natural disasters and assessing the hazard levels of the affected regions and planning post-disaster operations, including search and rescue operations, are very critical. As the roads can be blocked due to an earthquake and debris removal may take time preventing critical rescue operations from starting, drone utilization has been increasing. Since the drones fly, it will be easier to assess the damage levels. However, drones have a major drawback, their batteries. In this study, we propose a scenario-based mathematical model to allocate a limited of batteries before the earthquake while computing the drones' paths for each scenario maximizing the total expected priority scores. Our preliminary analysis shows that small instances can be solved very efficiently.

1 INTRODUCTION

Earthquakes are among the most prevalent natural disasters worldwide. In recent years, drones have emerged as a cutting-edge technology for both humanitarian aid distribution and hazard assessment in post-earthquake scenarios (Castillo et al. 2021). Drones have a high ability to capture images that can be utilized to assess hazard levels in the affected regions (Hassan et al. 2022). However, drones have a major drawback since their batteries limit their lives. In many post-disaster environments, the electricity infrastructure may be severely compromised, making it difficult to recharge drones in a timely manner (Chowdhury et al. 2021). Another option to utilize a drone constantly is switching its battery with a new one at a charging station. Even if this option seems like an efficient one as we can ignore the time required for charging, it brings new operational problems, such as where to charge and how many batteries to stock.

These operational problems become more complex considering uncertainties where a common uncertainty is about the hazard levels of the affected regions. Thus, scenarios help capture varying damage levels of the affected regions. Critically damaged regions are assigned a higher priority than less damaged regions as they require immediate help, such as search and rescue operations (Hassan et al. 2022). In each scenario, drones' paths will also vary as visiting critically damaged regions is prioritized more than visiting less damaged regions. However, some of the paths include visiting charging station(s) to switch the drone battery and if there is not enough battery at the charging station(s), these paths may not be realistic. Even if all possible paths of drones are generated, they may be unrealistic due to inadequate battery stocks. To avoid this, we aim to compute the number of batteries to stock at charging stations while maximizing the total expected priority scores collected by drones and their chosen paths. This study proposes a scenario based mathematical model to allocate a limited number of batteries before a disaster occurs and compute which possible paths are chosen considering the uncertainties about the hazard levels.

2 OUR PROBLEM

Our research addresses a critical challenge in the use of drones for post-disaster assessment: optimal battery allocation at charging stations (CSs). The primary goal is to compute the number of batteries to stock at each RS, ensuring drones remain functional across a myriad of potential paths and scenarios. These scenarios mirror various possible outcomes in a post-disaster environment, where grids might depict varying levels of damage: heavily damaged, medium, or low. The model is designed to optimize expected total priority scores. For instance, assessing a heavily damaged grid yields a greater score compared to assessing a medium or a low-damaged one. Paths are further complicated as a drone's journey might commence from a grid or an RS and terminate similarly and it necessitates a visit to an RS to swap its depleted battery for a charged one. This reinforces the importance of having adequate stocks of batteries at each RS, guaranteeing uninterrupted hazard assessments in these critical situations.

We first define the sets for grids representing the affected regions, possible paths, RSs, and scenarios. $p^s{}_i$ represents the priority score of grid i at scenario s. One of our decision variables is $x^s{}_p$ representing whether path p is chosen at scenario s, whereas our second decision variable is an integer decision variable representing the number of batteries to stock at each RS, z_r. Our first set of constraints prevents choosing more paths than the total number of drones at each scenario. Our second constraint set controls the adequacy of battery stocks at each RS for each chosen drone path and we limit the total number of batteries as our aim is to allocate a limited number of batteries. The mathematical model is developed using the IBM ILOG CPLEX Optimization Studio Version 22.11.

3 NUMERICAL RESULTS AND CONCLUSION

We developed a representative dataset consisting of 2 RSs, 4 drones, and 30 scenarios, encompassing 25 grids, of which 16 were utilized. The optimal solution, the number of batteries allocated at each RS and scenario-based path decisions, is computed within 4.65 seconds. Our subsequent findings will further detail these insights. The technical specifications of drones to resemble real-life conditions, more scenarios, and a detailed sensitivity analysis will be possible future works.

One can also simulate this battery allocation system considering various uncertainties while our mathematical model's result can be used as a warm-start. In our work, the set of possible paths remains unchanged during the assessment horizon, however, drones' possible paths may change as some grids may be scanned via other resources, such as satellite images or ground teams. Additionally, uncertainties may arise from grids' priority scores and the number of available drones.

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