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Fair Dynamic Resource Allocation in Transit-based Evacuation Planning

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Abstract

Resource allocation in transit-based emergency evacuation is studied in this paper. The goal is to find a method for allocation of resources to communities in an evacuation process which is (1) fair, (2) reasonably efficient, and (3) able to dynamically adapt to the changes to the emergency situation. Four variations of the resource allocation problem, namely maximum rate, minimum clearance time, maximum social welfare, and proportional fair resource allocation, are modeled and compared. It is shown that the optimal answer to each problem can be found efficiently. Additionally, a distributed and dynamic algorithm based on the Lagrangian dual approach, called PFD^{2}A, is developed to find the proportional fair allocation of resources. Numerical results for a sample scenario are presented.

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Keywords: Emergency Evacuation; Resource Allocation; Fairness; Optimization; Distributed Algorithms;

1. Introduction

Resource allocation in emergency evacuation planning is critical and challenging. Even the simplest cases of resource allocation leads to the efficiency versus fairness debate (Zukerman et al., 2005; Joe-Wong et al., 2013). Consider the example shown in Figure 1 in which an explosion in Factory X results in a leakage of poisonous chemical substances. The leakage expands over time and puts both community A and community B in danger. The populations of both of these communities need to be evacuated to shelter S as quickly as possible. A fleet of buses is available to evacuate the people. However, suppose that the fleet size is not large enough to evacuate either of the communities in an hour. Because of the wind direction, the time that the chemical substance takes to reach community A is twice the time as it takes for community B; however, the density of the chemical substance at community A will be higher than that of community B (supposing that density degrades over distance). Moreover, the population of community B is three times the population of community A and the round trip time between community A and the shelter is twice the round trip time between community B

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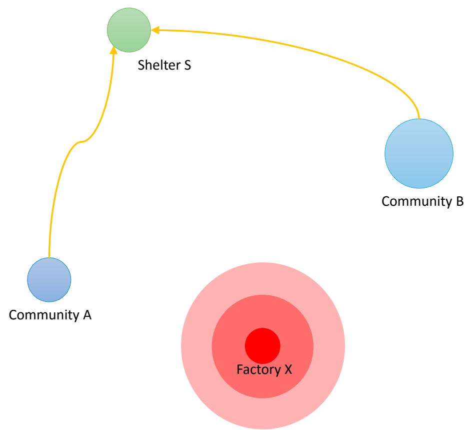

Fig. 1: An example of an evacuation scenario.

and the shelter. In other words, a bus assigned to community B can transport twice the number of evacuees compared to the same bus assigned to community A.

The central question is "What portion of the bus fleet should be assigned to each of the communities?". If the objective is to maximize the number of evacuees moved to the shelter in the next hour, the answer would be to assign the whole fleet to community B, since the round trip time is shorter for this community. However, if the objective is to evacuate people who are at higher risk as quickly as possible, the answer would be to assign the whole fleet to community A. While both of these answers appear to be correct for the corresponding objective, neither of them seems *fair*.

In this paper we consider the *resource allocation* problem during a transit-based emergency evacuation process. A network consisting of set of pickup locations and a set of shelters is considered. A fleet of constant size is available. Each pickup location has a known population of evacuees. Each shelter has a capacity constraint that has to be respected. We consider four different objectives and for each one we compute: (1) The percentage of the fleet that is assigned to each pickup location. (2) The number of evacuees who are transported from each pickup location to each shelter in order to satisfy the capacity constraints of the shelters.

We borrow tools from convex optimization, computer networks and economy theory to analyze the emergency evacuation problem. Four different variations of the evacuation resource allocation problem are considered:

MR-RA Maximum evacuation rate resource allocation in which the objective is to maximize the number of evacuees who reach safety by a given evacuation deadline.

MCT-RA Minimum network clearance time resource allocation in which the objective is to evacuate the whole endangered population to shelters in the shortest time possible.

MSW-RA Maximum social welfare resource allocation in which severity of the disaster in each pick-up location and evacuation deadlines are considered.

PF-RA Proportionally fair resource allocation in which the objective is to allocate the resources among different pick-up locations according to the criterion of proportional fairness.

Each variation is modeled using mathematical formulations. Each proposed model is shown to be either linear, or concave, or sum of sigmoidal functions, and thus efficiently solvable.

The contributions of the paper can be summarized as follows: