Towards an Emergency Evacuation Planning Service

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***Abstract*—Due to the increasing impact of both natural and artificial disasters on modern infrastructure the need for Evacuation Route Planning (ERP) has grown ever more imperative. By considering capacity constrained network, this work proposes a scalable algorithm to safely migrate maximum evacuees, in a multi-party scenario, to a set of safe locations while minimizing the total egress time using a modified Dijkstra's algorithm with weight criteria as the node priorities and edge travel times.**

I. Introduction

Evacuation route planning (ERP) is an essential component of emergency management that seeks to minimize the loss of life or harm to the public during natural disasters or terrorist attacks. Events such as the 2009 earthquake in L'Aquila, Italy, testify to the importance of emergency preparedness in densely populated regions. While civic authorities had indeed planned for such events, in each case, chaos and confusion marked much of the evacuation process. Yet very few would disagree that much remains to be done to improve emergency planning. During the occurrence of a disaster, rescue teams need to know not only which routes minimize the time to evacuate the vulnerable population but also how to respond to secondary events not anticipated in the initial planning, such as bridge failures and traffic accidents.

In this extended abstract, we describe an algorithmic approach developed for ERP that we envision to be the basis of an online service that guides evacuees to safe places via the better route calculated considering the actual situation. This service needs smart city infrastructure that collects updated information about the city possibly asking also real-time data to users. Such an infrastructure will be our future work and it will be designed on the basis of the algorithm we propose that is in deed the contribution of this abstract.

Given a transportation network $G = (N, E)$, the number of evacuees and rescue teams, their initial locations, and the safe locations, our goal is to determine an evacuation plan consisting of a set of source–sink routes and a scheduling of evacuees on each route. The aim of the proposed approach is to minimize evacuation egress time. In a typical evacuation planning scenario, the spatial structure is represented and analyzed as a network model with non-negative integer capacity constraints on the nodes and edges. With additional information pertaining to initial locations of all evacuees, rescuers and their final destinations, the ERP problem produces a set of origin and destination routes for evacuees. Consider a simple ERP problem in Fig 1, where each node, N of G typically has two parameters: *current population*, y_i and *maximum capacity*, n_i [1]. The current population can vary over time but maximum capacity is constant and remains a limiting factor of any given node. Each edge has two parameters: *travel time*, t_{ij} and *edge capacity*, c_{ij}. Travel time describes the duration of time steps to traverse the entire edge connected between two nodes. Edge capacity however, unlike a nodes maximum capacity, does not describe the maximum population limit of a given edge, but rather the maximum rate at which people may enter the edge [2]. This distinction is quite subtle, but is however more akin to limitations of flow rates and evacuation times within reality.

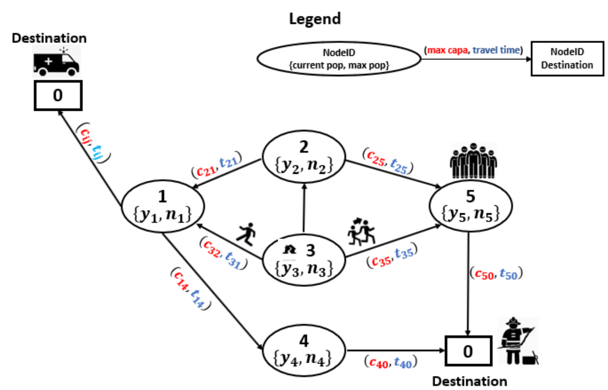

Fig. 1: Network Model for a multi-party evacuation route planning.

II. Proposed Approach

The goal of the proposed approach is to estimate the total evacuation time for multiple parties involved in an emergency evacuation process, where each of these parties have separate objectives such that, evacuees may start from a source in danger and migrate to a safe location while inversely rescuers may start anywhere with the goal to migrate to a destination in danger. For any type of emergency evacuation planning, areas defining both hazards and safety are defined, giving an evacuee route planner a set of endangered sources and safe locations. Hence, we would like to generate evacuation plans for all the evacuees while minimizing total evacuation time.

`pMPCCRP` in Algorithm 1 is an extension of CCRP [2], [3] and it calculates the quickest possible route at the soonest possible time given a list of sources and destinations. It generates a single pair additional super-source, S_S and super-sink node S_D, that connects to the list of sources and destinations respectively using edges of zero travel time and infinite edge capacity. In order to cater for the multi-party nature of the algorithm, we generated a party-specific sub-sources (E_S, R_S) and sub-sinks (E_D, R_D) that were connected to their respective locations, while also sharing a common super-source or super-destination parent see Fig 2. These sub-sources serve as an intermediary between the capacity constrained network and the fictitious super nodes. The modified algorithm verifies that the current shortest path found includes a source and sink for a common party.

Nodes are the categorized based on priorities such that areas/nodes that are assumed to be high risk need to be evacuated first before low risk nodes. This allows for a modified Dijkstra's algorithm to solve for the shortest path between the two super nodes using edge travel time and node priorities as the weight criteria. Once this path P is found, the maximum flow along that path is calculated by determining the minimum of the three parameters i.e. current source population, minimum available edge and node capacity along the path. The bookkeeping for available capacities within the graph is done using a time-series dictionary that allows the algorithm to check and update reservations along the path. If the quickest path at the current start time has no more available capacity, it repetitively looks into the future by a time step and checks for available capacity along same path again. This calculation of the flow ensures that the capacity of any given path is not exceeded while simultaneously maximizing evacuation times.

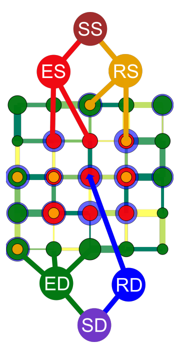

Fig. 2: Network Model for a multi-party evacuation route planning.

III. Conclusion

We proposed an approach which provides a better total egress time for multiple parties emergency evacuation taking into consideration node priorities in the underlying network. Moreover, because almost all arrangements of evacuee and rescuer source and destination overlaps are possible, such as rescuers and evacuees sharing the same source location, or evacuees having the same destination as a rescuers' source and vice versa, additional precautions are necessary to ensure that fictitious paths that backtrack down one party sub-source and up another that provide a teleportation-like behavior across the real transportation network are not utilized.

Algorithm 1: Priority Multi-Party Capacity Constraint Route Planning (pMPCCRP)

Input: spatial network $G = (N, E)$, with the set of source and sink nodes, $S \subset N$ and $D \subset N$ respectively and book-keeping of available capacities of G using time-series dictionary

Output: evacuation plans for all evacuees while minimizing the total evacuation time

Generate party specific pseudo sub-sources (E_S and R_S) and pseudo sub-sinks (E_D and R_D) connected to the respective source and sink nodes with 0 travel times and ∞ capacities.

Add super-source (S_S) and super-sink (D_S) connected by edges of 0 travel times and ∞ capacities to the respective sub-sources and sub-sinks.

Categorize each source node based on priority

while *(any source has evacuees)* **do**

- Find the shortest path P between the two super nodes (S_S and D_S) using the generalized Dijkstra's algorithm with edge travel times and node priorities as the weight criteria
- Calculate the maximum flow along this path
- Update the book keeping dictionary

Output evacuation plan

Such an approach will be the core engine of a novel smart city service that is able to guide evacuees and rescuers after a disaster to bring safely as much people as possible out the risky places. The service must be fed by real-time information (which roads are safe enough, which are damaged by the disaster, how many people are in a specific area, and so on). Starting from our proposed algorithm, we are able to specify, design and implement a smart city infrastructure and connected mobile app able to collect all the needed data. These together with the proposed algorithm will realize the rescue and evacuation service for smart cities of the future.

Acknowledgment

This work was partly supported by Territori Aperti (a project funded by Fondo Territori, Lavoro e Conoscenza CGIL, CISL and UIL) and by SoBigData-PlusPlus H2020-INFRAIA-2019-1 EU project, contract number 871042.

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