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CASPER: Intelligent capacity-aware evacuation routing

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ABSTRACT

We propose a new method to perform urban routing efficiently under capacity constraints. This new method helps with evacuation routing as well as other urban transportation challenges. Traditionally, simulation software or shortest path routing combined with zonal scheduling have been used to solve routing problems. Our method utilizes a state-of-the-art algorithm to connect each source node to its nearest destination. It also intelligently takes into account transportation network capacity and traffic flow to minimize congestion and system-wide transportation times. We have compared our method with previous routing algorithms and a common simulation method. We show that our algorithm generates reliable and realistic routes and decreases global transportation time by at least an order of magnitude, without any loss of performance.

1. Introduction

1.1. Overview

Multi-source, constrained routing is important to urban transportation decision systems, because the transportation challenges and possible solutions may vary from one day to the next. The best we can do is to route one person at a time providing individuals with historical traffic data so that they can calculate the fastest path to their destination. However, there are certain scenarios where we know the source and destination and more efficient routing is demanded. Take, for example, a sporting event. We know that a certain number of people will be driving toward the stadium at a given time from multiple directions. The same applies in cases of freeway construction since those driving on the freeway would need a detour around the construction. Similarly, for some urban evacuations, we know everyone is going to drive from their residences to the nearest shelter. In each of these scenarios, the outcome will be chaotic if we do not consider network bottlenecks in route calculations.

Despite the importance of the aforementioned urban transportation challenges, the solutions proposed thus far are either inefficient or inappropriate. In this work, we present a new, intelligent algorithm for capacity-aware routing. The new approach generates routes for every traveler whilst minimizing traffic congestion. The produced routes have total travel times that are at least an order of magnitude better than any previous work. The traffic model is no longer hard-coded into the algorithm but an input to the system and as a result, the predicted final travel times are more realistic. The algorithm also scales to large areas with limited memory, so that a user can perform routing on a larger network with potentially larger throughput.

The remainder of Section 1 describes the motivation and challenges. Section 2 reviews related work on evacuation routing. Section 3 formally defines the problem and investigates the solution. Section 4 presents the experimental results. Section 5 offers conclusions and some thoughts on future work.

1.2. Motivation

On 11th March, 2011, the Tohoku earthquake and tsunami occurred off the coast of Japan. Shortly afterwards, the Pacific Tsunami Warning Center in Hawaii issued a tsunami warning for the entire Pacific Ocean. The Alaska and West Coast centers also issued tsunami warnings for coastal areas of Alaska, California, and Oregon. Approximately 11,000 people were evacuated from coastal areas in the Kuril Islands (Russia). The tsunami reached the California shoreline in less than a day and given different circumstances, the tsunami may have required evacuation of residential areas.

However, urban transportation networks are not designed to handle sudden increases in traffic flows. Given an imminent tsunami threat, many people may want to travel from their residences to one or more designated safe areas. For example, there are 1.2

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million people living less than 20 m above mean sea level in Los Angeles and Ventura counties (Fig. 1). Without an evacuation plan, many evacuees will pick the same paths and will most probably bring traffic to a standstill. The CASPER (Capacity-Aware Shortest Path Evacuation Routing) system can help to avoid such an outcome. The algorithm at the core of this system combines the road capacity with its length to predict speeds under different traffic conditions. One can think of the road capacity as the number of lanes. CASPER takes a traffic model with two parameters – the road segment capacity and traffic flow – as input. The function is going to return a new speed estimate for the road segment, which then affects the path finding process. The algorithm keeps these new speed estimates up-to-date and iteratively generates routes specific to each evacuee to minimize global evacuation time.

CASPER also differentiates between population size and flow. Traditionally the number of people at one location would be treated as the source flow. While this is a good approximation, it does not need to be embedded in the routing algorithm. For example, take Hurricane Sandy and the evacuation of New York City. Since this is a densely populated area, the transportation network does not have the capacity for everyone to evacuate simultaneously and as a consequence, each zone was scheduled to evacuate during an allocated time (Saul, 2012). In other words, by reducing the source population, the flow was reduced to relieve the network bottleneck. Another method is to have all zones evacuate at the same time but enforce a time delay between each vehicle in each zone. Due to this metered but continuous traffic flow, the overall source flow to the network is reduced without reducing the source population. This same idea is implemented every day on freeway ramps (Papageorgiou & Kotsialos, 2002).

We argue that through careful implementation of these traffic modeling and metered source flow concepts, CASPER can route everyone to safety whilst minimizing global evacuation time and eliminating the need to schedule evacuation times. Fig. 2 visualizes how these two concepts can improve evacuation routing. The graphs present two sources which need to travel to a single destination (left to right). The left-hand graph has two non-metered and overlapping paths whereas the right-hand graph has metered and non-overlapping paths.

1.3. Contribution

In this article we examine solutions to the urban evacuation routing problem. Below we summarize the contributions of this article.

- We generalize the evacuation routing solution to work with any traffic model so long as it satisfies certain conditions.
- We utilize a simulation to measure how realistic the predicted travel times are.
- We develop a heuristic to improve performance of the graph path finding algorithm without pre-computing the network. Therefore, our solution generates realistic routes for large areas in reasonable time using limited memory.

This article is an extended version of an earlier article (Shahabi, 2012). The previous work demonstrated CASPER's ability to calculate routes in a city-sized network. In this work, we extend the experiments to larger geographic areas. The previous work does not report the mathematical details of our method.

2. Related work

To the best of our knowledge, research of urban evacuation problems is about three decades old. Some of the earliest studies sought to estimate the network clearance times for people living close to nuclear power plants (Sheffi, Mahmassani, & Powell, 1982). The MASSVAC software was later proposed and used for simulating urban disaster evacuations (Hobeika & Jamei, 1985). The problem was simply to predict traffic conditions during evacuations given a certain population density and network topology in these early works. Today, we are interested in a broader range of research topics, including evacuation routing optimality, applicability, and scalability.

The existing evacuation routing methods can be divided into descriptive and prescriptive methods (Fig. 3). Of course not all research works would fit into this schema. For example, Cova (1999) showed how GIS can be utilized to help gather data from different sources, visualize emergency situations, and execute response plans without taking any specific descriptive or prescriptive approach.

Descriptive methods are solutions that visually simulate a given emergency situation. The goal is to mimic reality as closely as possible. Flow-based simulation, agent-based modeling, cellular automata modeling, and activity-based modeling are some of the methods which would fall into this category (Santos & Aguirre, 2004). In contrast, prescriptive methods determine the optimal evacuation routing strategies to achieve some evacuation goal without necessarily performing a fine-scale simulation (Chiu, Zheng, Villalobos, & Gautam, 2007). CASPER is an example of a prescriptive solution.

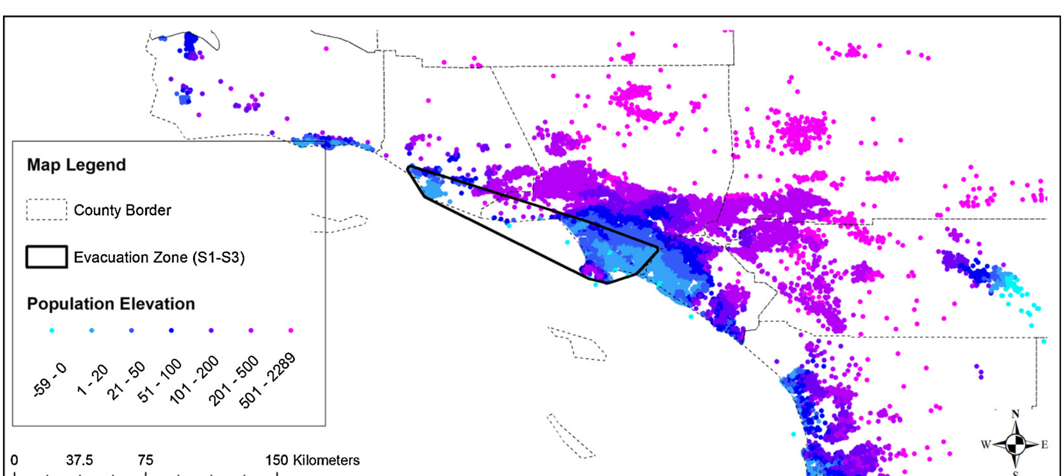

Fig. 1. Southern California population map. The various colored points indicate residential areas with different elevations (0–2290 m). The indicated evacuation zone represents approximately 1.2 million people living less than 20 m above mean sea level.