Simulating Relief Resource Distribution Strategies in Urban Settings

M. J. Widener[1], L. Liu[2]

[1] University of Cincinnati, PO Box 210131, Cincinnati, OH 45221-0131
Telephone: 1.513.556.2849
Email: michael.widener@uc.edu

[2] School of Geography and Planning, Sun Yat-sen University,
University of Cincinnati, PO Box 210131, Cincinnati, OH 45221-0131
Telephone: 1.513.556.3429
Email: lin.liu@uc.edu

1. Introduction

Given the increasing frequency of extreme weather events due to climate change, and corresponding growth of cities worldwide, it is important to derive strategies that mitigate the negative effects of weather on urban infrastructure (Fuchs et al., 2011). One component of climate change that is particularly problematic in China's growing urban centres is flooding (Wong and Zhao, 2001). Flood events disrupt transportation networks, damage infrastructure, pose threats to residents' lives, and are responsible for economic losses (Zhan'e et al, 2011). A critical part of flood damage mitigation strategies involves distributing appropriate resources to locations throughout an afflicted region so that demand for different services is met in a timely and efficient manner.

Geocomputational methods have enabled researchers to develop models that provide intelligent solutions to the problem of distributing limited resources across space to locations affected by an extreme weather event (Widener and Horner, 2011). Particularly relevant to the research presented in this extended abstract is the vehicle routing problem (VRP), which seek to optimally service a number of points of demand with a fleet of vehicles originating from a central depot (Dantzig and Ramser, 1959). Unfortunately, the VRP requires researchers to make a priori assumptions about how long a servicing vehicle must spend at a location with demand, something that may not be known in an emergency context. Given this, it is important to employ alternative techniques that can account for the dynamics of the on-the-ground situation and provide decision makers with robust relief strategies.

Dynamic simulations, like agent-based modelling (ABM), provide a complementary geocomputational technique for developing efficient strategies for distributing relief workers to flood events throughout an urban environment. An advantage of using ABMs is that relief workers are explicitly represented as agents and can exhibit more complex behaviour than the simple routing determined in a VRP. Additionally, ABMs can easily account for non-linear changes in the environment, which affect agent decisions in "real time." These changes can result in on-the-fly adjustments to the baseline relief strategy. By testing these adjustments in a simulation, their effectiveness can be gauged and more successful responses can be developed.

2. Data and Model Structure

This research focuses on the distribution of police officers in the Chinese city of Guangzhou to flooded roads in need of support to alleviate traffic congestion. We present an exploration of a proof-of-concept 2-stage model that integrates the vehicle routing problem and agent-based modelling. The entirety of the model is executed in AnyLogic dynamic simulation software; a Java-based modelling platform that includes agent-based and GIS libraries.

In the first step, the VRP is solved heuristically in Java using an algorithm developed by Clark and Wright (1964) for *p* police computational agents (located at a single police headquarters) to service some *n* number of flooded road "agents" with traffic congestion. A heuristic is employed because exact solutions can be time intensive (Eksioglu et al., 2009). The travel cost information required to solve the VRP (the distances between police headquarters and potential flood sites) is calculated before hand using road network data in a GIS. The locations and level of traffic congestion at the *n* flooded road agents are chosen based on past flooding events. The changes in the level of traffic congestion are modelled using a system dynamics framework, which captures the traffic backup's dynamic nature (Figure 1). When a police agent arrives at a flooded road agent,

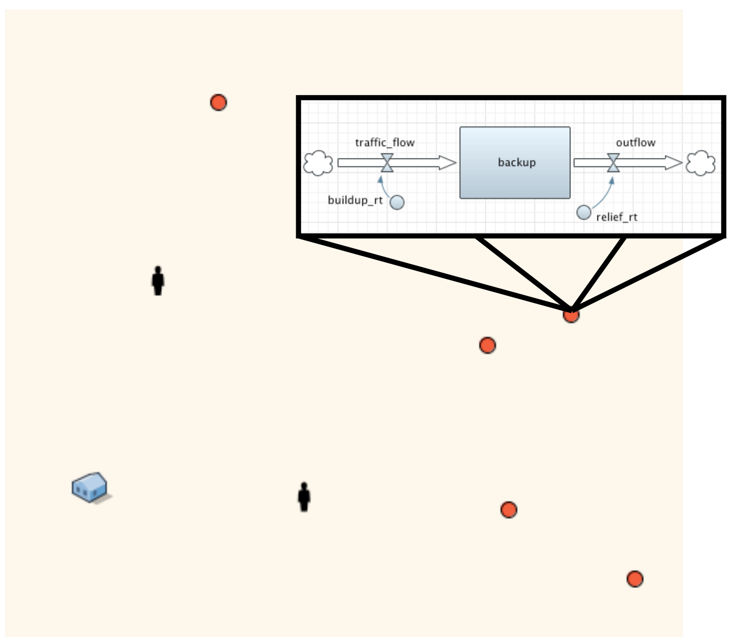

Figure 1. A prototype of the model shows police agents (black) traveling to flooded road agents (red dots). The traffic congestion at each of these flood points is abstracted using a system dynamics model, embedded in every flooded road agents. The rate of traffic build up is based on observed data from CCTV of the Guangzhou road network and the rate of congestion relief is increased when police agents arrive at the flood point.

it relieves the traffic congestion until there is no vehicle backup at that location. At that point, the flooded road agent is assumed to be cut-off from the road network, and no more vehicles will attempt to pass through this problem area.

With police agents assigned a subset of the flooded road agents, all police agents are dispatched. In the baseline scenario, all police agents visit their flooded roads, alleviate the traffic congestion in a set amount of time, and then return to headquarters. The simulated time it takes to achieve this baseline is then compared to more realistic scenarios, where the time it takes to clear a flooded road of traffic is based on observed data. From this point, more complex experiments are implemented, where police agents adjust their strategies based on changing on-the-ground conditions.

3. Experiments

Three experiments are conducted in the simulation model that aim to develop general strategies for police workers dispatched to relieve traffic congestion at flood points throughout the study region.

The first experiment will implement the rule that a police agent *a* will provide assistance to a nearby police agent *b*, if agent *a*'s current flooded road assignment is relieved of congestion and *a* and *b* are within a certain distance threshold. By doubling the police presence at this location, they double their effectiveness and clear the flooded road agent of traffic more quickly. For example, if a flooded road takes 30 minutes to clear with one police agent present, two police agents can clear the road in 15 minutes. Once agents *a* and *b* are finished collaborating, they return to their scheduled routes.

The second experiment dispatches all police agents on their routes until completion, but if a number of police agents finish before others, these agents are assigned a still active police agent to shadow, thereby increasing their effectiveness at clearing traffic congestion at their remaining flooded road locations.

The third, and final experiment covered in this research, is a variation of the second experiment. Instead of dispatching the finished police agents to shadow still active police agents, a new VRP is solved with the available police agents and remaining congested flooded road agents.

4. Discussion

The two-stage model described here provides a novel way to address clearing backed up traffic at flood points in a road network. By combining the VRP with dynamic simulation, more complex behaviors can be explored, thereby increasing the realism and usefulness of the computational models. Having the ability to incorporate this added flexibility in a decision-making model is important given the uncertainty present during extreme weather events in complex spatial areas, like flooding in dense urban regions.

5. References

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