A spatial analysis approach to evacuation management: shelter assignment and routing

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1. Introduction


- 2011 Queensland flooding affected over 200,000 people across the state and leaded to an estimated reduction in Australia’s gross domestic product (GDP) at about $30 billion. Evacuees were approximately 3,600 households in metropolitan Brisbane, which is expected to be more than 8,000 people according to the average household size (namely 2.3 persons per household) in 2011 census data for Brisbane inner city.
1. Introduction

- Town councils and shires have started mapping the 100-year flood areas. However, they still leave the evacuation-related options to residents. People are assumed to know their vulnerability and take the responsibility for their own information acquisition and evacuation preparation (Astill et al., 2014; Bohensky et al., 2014).

- Therefore, in case residents do not seek evacuation information actively, greater operations from local governments to assist communities exposed to flood threats are required.
1. Introduction

From the emergency manager’s perspective, it is beneficial to preserve an evacuation map showing the arrangement of accommodating potential evacuees. Also, including the official evacuation buildings into the analysis can help evaluate the spatial coverage and effectiveness of existing shelters.
2. Aims

(1) What is the nearest achievable shelter for a given community in the inundation zone during a flood evacuation? And what are the corresponding detailed instructions for evacuating by car?

(2) What is the possible congestion condition for the given residential locations?

(3) How do the existing shelters serve the evacuees? And what is the potential location for new shelters to achieve a better supply coverage?
3. Datasets and study area

Table 1: Datasets participating in the analysis and their sources

<table>
<thead>
<tr>
<th>Datasets</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011 QLD floodlines</td>
<td>Queensland (QLD) Government</td>
</tr>
<tr>
<td>Road network for Brisbane city</td>
<td>Open Street Map (OSM)</td>
</tr>
<tr>
<td>Official shelters</td>
<td>News report during the event</td>
</tr>
<tr>
<td>2011 QLD mesh blocks extent</td>
<td>Australian Bureau of Statistics (ABS)</td>
</tr>
<tr>
<td>2011 Australian mesh blocks census counts</td>
<td>Australian Bureau of Statistics (ABS)</td>
</tr>
</tbody>
</table>

Figure 2: 2011 Brisbane flood lines and affected mesh blocks
3. Study area

Flood lines which descript the flood extent in year 1974 and 2011 are available from Queensland government.

A comparison of these two flood boundaries shows that they are very similar in most areas of Brisbane city.

Therefore although the Annual Return Interval of flooding is uncertain, the boundary of inundation is largely predictable.
4. Assumptions

- Firstly, it was assumed that evacuees are distributed across all the inundation areas.
- Secondly, the whole routing strategy was car-based, with an evacuation speed of 30 km/h (Mas et al., 2013).
- Thirdly, each evacuee moves to its closest shelter, using the shortest possible route on the road network.
- Lastly, we chose 30 minutes as the maximum time that evacuees would be willing to travel to shelters by car.
5. Methods and results

Network Analyst

- Route and nearest facility solvers (Dijkstra’s algorithm)

Two criteria: real network distances, bridges across Brisbane river unusable

Figure 3: Evacuation route (a) and instructions (b)
5. Methods and results

Urban Network Analysis

- “Betweenness” solver

The “Betweenness” of a building is defined as the fraction of shortest paths between pairs of other buildings in the network that pass by building i (Freeman, 1979).

\[
\text{Betweenness}[i] = \sum_{j,k \in G-\{i\}, d[j,k] \leq r} \frac{n_{jk}[i]}{n_{jk}} \times w[j]
\]

Where

- \( r \) is the search radius, \( G \) is the graph, \( d[j,k] \) is the distance from node \( j \) to node \( k \)
- \( n_{jk} \) is the number of the shortest path from node \( j \) to node \( k \)
- \( n_{jk}[i] \) is the number of the shortest path from node \( j \) to node \( k \) and pass by node \( i \)
- \( w[j] \) is the weight of each origin \( j \)

The “Betweenness” method estimates how many times each mesh block is passed by evacuees on their way from their locations to shelters along the shortest paths.
5. Methods and results

Urban Network Analysis

- “Betweenness” solver

If the \( w[j] \) is assigned with demographics for example population, the “Betweenness” can estimate the frequency of passersby at different buildings on the network.
5. Methods and results

Network Analyst

- Service area solver

It calculates the shortest network distance (Dijkstra’s algorithm) and stores it as the height of locations in a triangulated irregular network (TIN).

The service area polygons are formed by carving out regions covering areas in between the specified break values.
5. Methods and results

Network Analyst

- Origin-destination (OD) cost matrix solver

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of mesh blocks covered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Site 1  Kedron Wavell Services Club</td>
<td>5</td>
</tr>
<tr>
<td>Site 2  RNA showgrounds at Bowen Hills</td>
<td>314</td>
</tr>
<tr>
<td>Site 3  Salvation Army</td>
<td>328</td>
</tr>
<tr>
<td>Site 4  Nathan</td>
<td>249</td>
</tr>
<tr>
<td>Site 5  Good News Lutheran Church</td>
<td>130</td>
</tr>
<tr>
<td>Site 6  St Catherine Anglican Church</td>
<td>106</td>
</tr>
</tbody>
</table>
5. Methods and results

Table 2 shows that site 2 and 3 provide shelter services to the largest number of mesh blocks. Most of the mesh blocks assigned to these two shelters locate within 10 km.

Site 1 will accommodate the second largest number of mesh blocks; the majority of the evacuees escaping to this shelter will travel more than 10 km.

Site 5 and 6 have similar total number of mesh blocks to serve; the reason could be that they are close to each other.

The service area of site 4 only covers 5 mesh blocks, which indicates that it is far for evacuating by car and it may be set up for accommodating residents rescued by helicopters.
6. Limitations

- The results from the Network Analyst toolbox are sensitive to the relative location of residents and nearby road segments.
- A service area is illustrated as a polygon which connects adjacent points at the cut-off location along a road segment.
- Tools in Urban Network Analysis do not support barriers. Constraints on bridges need to be set up manually in the analysis.
7. Conclusions

The results show that spatial analysis can provide evacuees with detailed information on shelter selection and possible routes. Congestion conditions at the mesh blocks’ locations can also be predicted on the basis of individual choice of shortest paths for evacuation. Evaluation on existing shelters and locations is performed in order to establish new shelters. This study has shown the capability and effectiveness of spatial analysis to address evacuation management problems which need to be accurately resolved by emergency managers.
THANK YOU!