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Accessibility modeling in earthquake case considering road closure probabilities: A case study of health and shelter service accessibility in Thessaloniki, Greece

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ABSTRACT

One of the main focuses of disaster management is to decrease the impact of disasters by developing efficient emergency management plans and strategies. In this context, accessibility modeling of emergency related services such as health, fire, security services, or shelter sites in earthquake case can be a valuable tool for disaster managers, especially in assessing the vulnerability of urban districts as well as the sufficiency and appropriateness of the emergency service sites. Although there are several studies on the accessibility modeling of emergency related services in the aftermath of a disastrous event, the literature that integrates road closure probabilities into the accessibility estimation is quite limited. Hence, this paper aims to develop a methodology for modeling of accessibility based on a probabilistic estimation of road closures in earthquake case. The mentioned probabilities are predicted for given road network and hazard acting upon it and then incorporated into the accessibility analysis. The developed methodology is demonstrated through an application on health services and shelter sites in the city of Thessaloniki in Greece with and without considering the road closures, corresponding to road network under earthquake and normal conditions respectively. In this particular study, the road closures are associated to ground failure and damage to bridges, as well as damage of overpasses and collapses of buildings adjacent to road edges. The developed methodology could provide advanced and more realistic support to the emergency managers and decision-makers who deal with accessibility, location/allocation, and service/catchment area of critical facilities.

1. Introduction

Past experiences show that transportation networks are vulnerable to earthquakes and failure of their components can cause economic losses, disruption of activities and can affect the rescue and evacuation procedures in the area. Therefore, one of the main goals of disaster management is to reduce the impact of disasters by developing efficient emergency plans and risk mitigation strategies. In this respect, accessibility modeling of emergency related services such as health, fire and security services or shelter sites could provide a vital decision support for disaster managers to assess the vulnerability of urban districts and to test the sufficiency and appropriateness of the emergency service sites for an earthquake disaster.

Several researchers studied the vulnerability of transportation networks in case of earthquake following different approaches. They are distinguished according to the time scale (emergency or recovery phase), the geographical scale (e.g. urban, regional), the objectives (e.g. emergency or mitigation planning) and the type of analysis (e.g. connectivity, traffic flow, estimation of direct and indirect losses). Several studies focus on the emergency operations immediately after the earthquake [24,36,57]. In some cases the impact of collapsed buildings in the emergency services is also considered [29]. The purpose is to identify which portions of the network have the higher risk for loss of connectivity. In other studies the losses due to physical damage and travel delays are evaluated [35], while the exposure of the network to ground shaking, liquefaction and landslides is considered separately in the analysis [52]. Fragility curves are essential tools in evaluating the vulnerability of each component of the network. They describe the probability that a structure will reach or exceed a certain damage state for a given ground motion motion. An overview of existing fragility models for bridges, is made by Tsionis and Fardis [56],

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while Argyroudis and Kaynia [4] summarize existing fragility curves for other road elements. Some researchers studied different aspects in the vulnerability assessment of bridges which are the most critical elements. These for example include the performance of integral and jointed bridges [46], or the effect of aging and environmental deterioration [2,28,60] and the impact of these processes to the seismic resilience of bridges and highway networks [3,7].

Although there are increasing literature on vulnerability assessment of transportation networks in case of earthquake, the research that integrate the vulnerability of transportation components into accessibility modeling process is quite limited, which can be considered as a significant lack in terms of providing accessibility related support for the emergency related decision makers. Hence, this paper aims to propose a methodology for accessibility modeling based on a probabilistic estimation of road closures in case of earthquake. In particular, the closure probabilities are predicted for a given road network and then incorporated into the accessibility analysis. The proposed methodology is demonstrated through an application on health services and shelter sites in the city of Thessaloniki in Greece. In this application, road closures due to ground failure, damage to bridges and overpasses and collapses of buildings adjacent to road edges are considered. The accessibility modeling is performed both under earthquake and normal conditions. In the proposed methodology, three major steps are followed: (a) Data collection and analysis phase. (b) Traveling cost calculation phase. (c) Accessibility modeling and visualization phase. The proposed approach has been developed in the framework of the EU FP7 SYNER-G project [49], as part of a general methodology for the systemic vulnerability and risk analysis of networks and infrastructures.

2. Overview of the accessibility modeling techniques in GIS

Physical accessibility measures describe the spatial characteristics of the study area and need large amount of computation and organization between huge and complex spatial data sets. Hence, accessibility modeling is commonly based on GIS technologies in terms of data collection, manipulation, programming, analysis and presentation of results. As GIS have unique capabilities to handle and analyze geospatial data, it provides a powerful interface to the decision makers who deal with accessibility, location/allocation and service/catchment area related issues. The GIS based accessibility modeling techniques can generally be divided into three categories, which are briefly presented hereinafter and described in detail in Makrí and Folkesson [41] [34,14,18,20].

2.1. Zone-based technique

Accessibility is computed for predefined zones, which are determined based on the available data, the objectives and required detail of the study. While a national or regional scale accessibility study generally requires a coarse zone representation such as state, county or district, a local/city scale study usually involves smaller zones such as neighborhood, quarter or parcel. It must be noted that is more difficult to obtain the required data for the smaller zones than the coarse zones [31]. In this method, traveling cost calculation between supply and demand points are usually based on the centroid of the zones. An example in GIS environment is given in Fig. 1 (see several examples for detail in [14,31,37,12,11,59]). The basic advantage of this technique is that it enables easier comparison of accessibility scores between the zones such as administrative boundaries.

In zone-based technique the cumulative time/distance cost is calculated from each administrative district centroid to all services. For the calculation of accessibility score for each of the origins (A_i), Eq. (1) is used:

$$A_i = \sum_{(j)} \frac{1}{time\ OR\ distance(i,j)} \tag{1}$$

According to Eq. (2), (i) is the origin, (j) is the destination, (A_i) is the accessibility score for each of the origins. A_i is inversely proportional with the time or distance cost from one origin (centroid of the zone) to all destinations (health service or shelter site), which means that the less time or distance cost between districts and services the better is the accessibility.

When a gravity measure (G) such as size, capacity or scale of services is accounted in the accessibility measure, then Eq. (2) is used:

$$A_i = \sum_{(j)} \frac{G(j)}{time\ \mathrm{OR}\ distance(i,j)} \tag{2}$$

According to Eq. (2), (i) is the origin, (j) is the destination, (G) is the gravity measure of the service, (A_i) is the accessibility score for each of the origins. In this case A_i is directly proportional with the

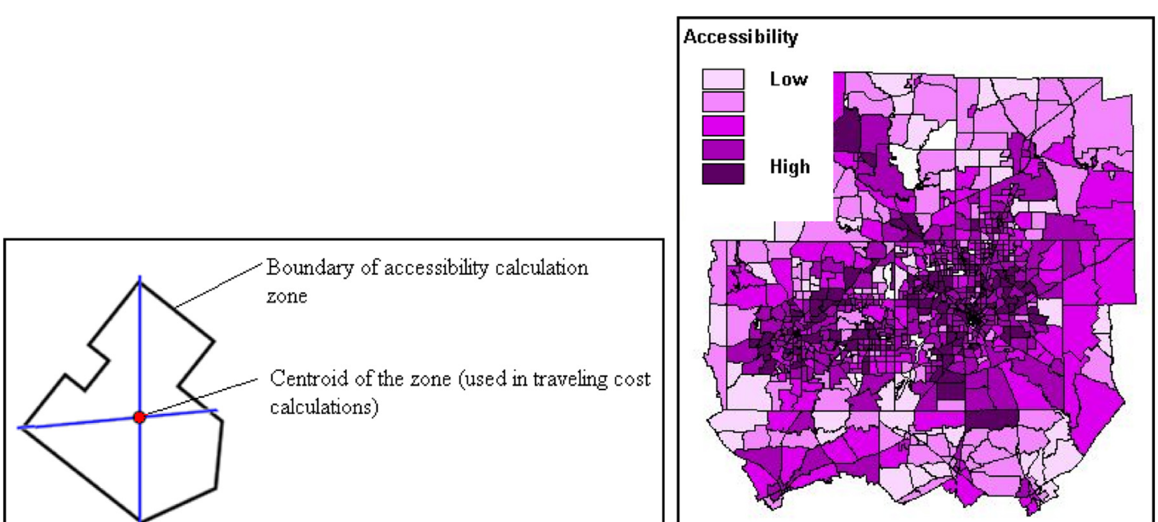

Fig. 1. Centroid of a zone, zone-based representation of accessibility (Source: [14,18]).