Interoperable Routing Services in the Context of Evacuation Schemes due to Urban Flooding

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Abstract

Climate change scenarios predict an increasing frequency of extreme flood events in coastal areas. Many big cities in North-Western Europe are located within the reach of these floods. Flood protection schemes have been built and enhanced everywhere. But a residual risk exists that these flood protection schemes will fail and the areas behind these structures will be flooded severely. Within the last decades many of these cities expanded significantly into former floodplain areas as well. Building complexes within harbor areas which served as store- or warehouses in former times are now being transferred to high end business and living facilities. These structures have always been subject to the thread of flooding due to the proximity to open waters.

Against this background, means for disaster management in the context of extreme flood events are being paid high attention on all administrative levels. The main objectives of these activities among others are to save people's and other creature's lives as well as to avoid environmental hazards, e.g. due to spilling of hazardous chemicals, and to avoid assets to be destroyed.

In order to design evacuation schemes for different flooding scenarios evacuation paths need to be determined for every building in the potentially flooded areas. The times for flood mitigation as well as travel and "get ready to go" times among other details need to be taken into account in this context.

Routing Services provide means for determining travel routes and travel times on the basis of a predefined street network. Dynamically expanding inundated areas need to be excluded from this street network for route searches. The Open Geospatial Consortium (OGC) has specified Routing Services as part of Open Location Services which have been implemented by the Cartography Research Group at the University of Bonn. This paper introduces into disaster management due to urban flooding as well as to OGC's OpenGIS Location Services with special emphasis on Routing Services. An example for utilizing Routing Services in order to identify critical evacuation paths (Bottleneck Analysis) is presented. The paper documents the results of a close collaboration in the research projects "RIMAX" and "OK-GIS" which are both funded by the German Federal Ministry of Education and Research (BMBF).

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1. Introduction

The population density close to estuary and coastal areas, respectively, has risen significantly since the middle of the 19th century in North-Western Europe. Industry and commerce activities in these areas coincided with this tendency as well. A continuous raise of asset values in these areas corresponds to this trend. In order to protect the population as well as the assets in these areas against flooding extensive dike complexes were built according to commonly agreed design principles. This holds in particular true for estuary areas of rivers mouthing into the North Sea on the German shore.

A rise of extreme flood events for the German North Sea region is predicted by climate researchers (Norddeutsches Klimabüro 2008). This calls for new methods of dealing with this thread. Along with traditional techniques - e.g. physically strengthen dike complexes – innovative new ways of logistically dealing with these challenges are required. In this context a combination of flood wave propagation calculations behind dike systems (e.g. due to dike failures or dike overtopping) and determining bottlenecks for disaster management for evacuating people from these areas as well as moving assets or environmentally dangerous substances to flood save areas. Most of the data being utilized in these processes are spatially attributed. Therefore, GIS functionality is assigned an important role in this process.

Today, there exist stable open source libraries for handling, processing and visualizing spatial data. But since disasters are not restricted to administrative boundaries there is a need for tools and systems within disaster management for components that interact easily across institutional boundaries. This interoperability is achieved by utilizing standardized interfaces between the components. Since spatial aspects are predominantly of interest in disaster management (e.g. spatial distribution of resources and people, spatial-temporal spreading of the disaster) the standards defined by the Open Geospatial Consortium (OGC 2008) are considered to be very important in this context. These standards define a broad set of specifications for developing services with standard interfaces based on the service-oriented paradigm.

The system presented in this paper is very much focused on available open source codes and applying the service-oriented paradigm for accessing services via standard interfaces (Service-Oriented Architectures, SOA). It has been implemented in Java as an Eclipse Rich Client Application (Eclipse 2008) based upon the Kalypso framework (Kalypso 2008). This framework encompasses among others the deegree GIS (deegree 2008) for managing and displaying geographical data and the Java Topology Suite (JTS 2008) for carrying out geometric operations such as intersection and buffering of geographical data. Kalypso contains a bundle of OGC standards, e.g. Web Map Service Client (WMS, OGC 2006), Web Feature Service Client (WFS, OGC 2005 a), Web Processing Server and Client (WPS, OGC 2007) as well as interfaces to GML formatted geographic data (Geography Markup Language, OGC 2004).

This paper focuses on the specification of OpenGIS Location Services (OpenLS, OGC 2005 b) by the OGC which define – among others – interfaces for interoperable route planning services. Route planning comprises a major function in the field of disaster management, e.g. Emergency Routing (Neis et al. 2006) and Accessibility Analysis (Neis & Zipf 2007).

The paper is set up as follows: In chapter 2 mechanisms of disaster management in the context of urban flooding are discussed. Chapter 3 introduces into routing services in the context of disaster management. An application example for using routing services in the context of bottleneck analyses (BNA) is presented in chapter 4. Finally, chapter 5 summarizes the paper and introduces to ongoing developments in this area.

2. Disaster Management in the Context of Urban Flooding

Urban flooding events e.g. due to dike failures or dike overtopping of dikes develop within short time intervals leaving virtually no time for decision makers to respond. Only a close monitoring of the flood processes (e.g. gauging stations for runoff and rainfall) as well as relevant flood protection schemes (e.g. dikes, outlets) in combination with flood simulations will provide a basis for decision makers to decide on their actions. These decisions are of course closely related to on-site available resources (e.g. manpower, equipment) and logistic constrains.

Flittner et al. (2006) describe a flood information and warning system (FLIWAS 2008) which is based on these premises. Schimak et al. (2006) report about a project (ORCHESTRA 2008) which specifies an open service-oriented architecture for supporting collaboration processes of various stakeholders in the context of risk management.

The Free and Hanseatic City of Hamburg, for instance, has a complex set of rules and regulations for dealing with flood events. The authorities provide extensive information on calamity management to the public including a web site with special emphasis on flood events. Special leaflets inform the public about the strategies of the city's authorities in case of flood events (City of Hamburg 2008). The proposed evacuation schemes very heavily rely on the accessible street network.

3. Routing Service for Disaster Management

Response times are crucial within disaster management, as disasters may spread very fast and destroy or block the passage to or from the disaster area. Both, the time it takes the rescue staff to get to the affected area is important and the time people need for leaving dangerous zones. Therefore, routing services are needed to find the most time-efficient solutions for these tasks. In particular, all possible hindrances, such as traffic jams or blocked roads / areas need to be included in this calculation in order to by-pass them. Therefore, an Emergency Route Service (ERS) was derived on the basis of the basic Route Service (RS) to cope with these requirements (Neis et al. 2006).

Following, a brief overview of the OpenLS framework will be provided which currently includes five core services:

- Directory Service,
- Gateway Service,
- Location Utility Service (Geocoder / Reverse Geocoder),
- Presentation Service and
- Route Service.

Only recently the "Tracking Service" has been standardized as another service in this context. But it is not considered a "core" OpenLS service. The "Navigation Service" will be included as another service in the upcoming version 1.3 of the OpenLS framework specification. Most of these services were implemented at the Cartography Research Group at the University of Bonn. This paper focuses on the Route Service.

The RS response parameters for a determined route may include:

- RouteSummary – meta data about the route, e.g. total distance, total estimated travel time
- RouteGeometry – list of waypoints of the route (LineString, GML Specification, OGC 2004)
- RouteInstruction – step-by-step (driving) route instructions which may be requested in different languages, e.g. German, English, Italian, Swedish
- RouteMaps – both, overview maps as well as detailed maps of the route can be generated

The Emergency Route Service is a special RS. It automatically adds up-to-date information about current danger zones and closed roads to the route request and therefore allows to by-pass avoid areas. The interface of the ERS is identical to the OpenLS RS, thus assuring interoperability. The ERS adds information about blocked areas or closed roads from an OGC Web Feature Service (WFS, OGC 2005 a) or a spatial database to the request of the original RS. This information within the WFS needs to be maintained by the disaster management authorities. The RS interface allows the definition of parts of the street network (AvoidList) which shall not be taken into account when calculating the route. Internally, the determination which street parts need to be excluded from the route calculation is implemented as a geometric intersection of the danger zones and the street network.

The Route Service has already been successfully used within several projects of the Cartography Research Group at the University of Bonn; within these projects several extended versions have been derived from the standard RS. For example, the Route Service 3D (RS3D) maps the determined route geometry onto a digital elevation model (DEM) which may then be analyzed with a 3D-Viewer (Neis et al. 2007). The Accessibility Analysis Service (AAS) represents another extension of the RS which is not standardized yet. This service determines a polygon which represents the area being accessible within a certain time period based on a given street network and a selected start point (Neis & Zipf 2007). This service can provide important information in the context of evacuation simulations. In particular, it is possible to determine the affected population by using a WPS which utilizes the AAS as has been demonstrated by (Stollberg & Zipf 2008).

4. Application Example

Flood disasters are highly dynamic by nature. This especially holds true in the case of dike failures. Evacuation schemes therefore need to take the temporal-spatial spreading of inundated areas into account. The vital question in this context to answer is: How much time is left after such a catastrophic event has occurred to evacuate people or move hazardous materials along critical paths to save places?

Of course, a reasonable catastrophe management will not operate on a last second basis. But by simulating such processes a more in depth knowledge of special patterns for rescuing lives and assets may be obtained which can be trained with the emergency management staff. BNA in this sense can help to optimize the assignment of scarce resources – e.g. personnel and material – in the process of stage management.

How do we define BNA in this context? A BNA determines whether a building or bus stop is either accessible by foot, car or bus from a save place within the risk area (refuge shelters) or from a save place outside of the risk area and vice versa. In the first case emergency personal (e.g. ambulance teams, rescue teams, teams for moving environmentally hazardous materials to save spots) can be sent into the flood threatened area. The second case focuses mainly on evacuating people to save areas.

In order to take the temporal-spatial spreading of inundated areas in the case of flooding for determining optimal routes into account, Avoid Areas are defined. These Avoid Areas are determined on the basis of predicted flooded areas from hydro-dynamical models (Kalypso 2008) or observed data utilizing remote sensing technologies, e.g. satellite data or airborne survey data. Figure 1 depicts two screenshots which contrast the optimal evacuation routes from an arbitrary single building to an arbitrary refuge shelter within a study area

- without any spatial restrictions on the street network (black, left side) and
- blocked inundated parts of the street network (black, right side).

The screenshots depict the street network and footprints of buildings as well as predefined bus stops for emergency evacuations. In addition, the right screenshot also shows the inundated areas due to a flood event.

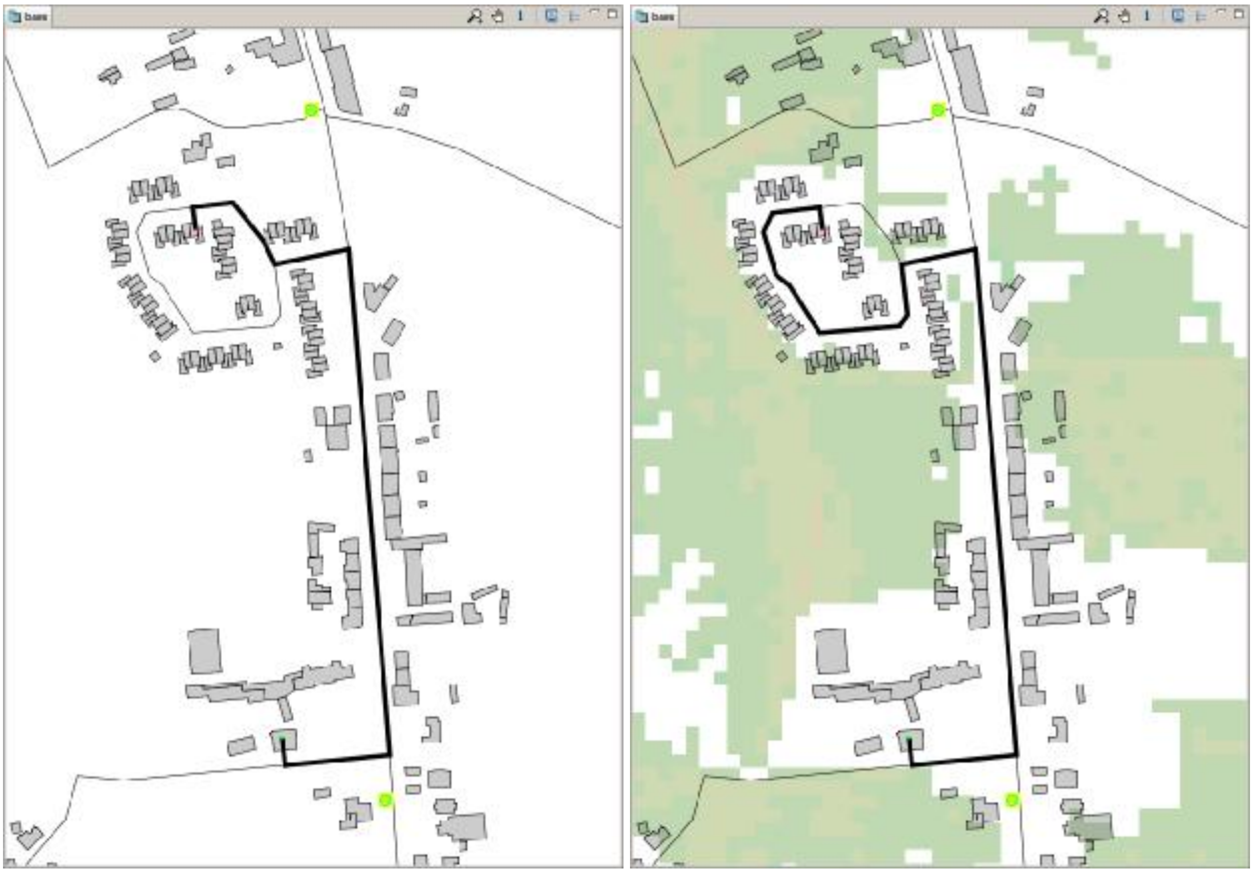

Fig. 1: Calculated routes with and without taking flooded areas into account (Kalypso User Interface)

The application includes among others functions for distributing available inhabitant statistics from city districts to buildings in these districts according to available information on buildings (e.g. building category, number of stories), identification of catchment areas of predefined emergency bus stations, redistribution of catchment areas from flood-blocked bus stations, determination and display of isochrones for these catchment areas as well as identification of buildings which cannot be evacuated on time in case of an unexpected flood.

5. Summary and further Developments

Routing services in combination with dynamic evolving inundation areas – e.g. as a result of hydrodynamic simulation of dike failures – constitute an important basis for carrying out bottleneck analyses in the context of setting up and evaluate existing evacuation measures in case of severe flood events. This paper presents an application which allows for carrying out such analyses. The application has been designed according to the Service-Oriented Architecture (SOA) paradigm. Following this paradigm allows for designing and implementing "standardized services" as well as reusing these services as building blocks in order to develop complex services and applications, for instance, by chaining different OGC services (Weiser & Zipf 2007, Stollberg & Zipf 2007).

In particular, the OGC Web Processing Service (WPS) can be utilized to add processing and analyses functionalities to spatial data infrastructures. Within the OK-GIS project various geospatial operations have been implemented as WPS which are now ready to be accessed by other applications in particular in the field of disaster management.

Within the joint research project Spatial Data Infrastructure Grid (GDI-Grid 2008) interoperable processing of spatial data according to OGC-standards is for instance applied to GRID-computing in the context of flood simulation and emergency response. Objectives of this research project are among others to speed up the processing of digital terrain models needed for flood simulations (Lanig & Zipf 2008) as well as to accelerate the overall hydraulic computation.

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