Optimal navigation of first responders using DBMS

Sisi Zlatanova
Delft University of Technology,
Jaffalaan 9, 2628 BX Delft, The Netherlands
s.zlatanova@tudelft.nl

Safiza Suhana Kamal Baharin
Delft University of Technology,
Jaffalaan 9, 2628 BX Delft, The Netherlands
S.S.BintiKamalBaharin@tudelft.nl

ABSTRACT

Decision-making in crisis situations requires a good positional awareness about all the emergency response units (fire brigade, paramedics, police and municipality). Since locations of first responders may change frequently, they are referred as to moving objects. Generally, locations of moving objects can be continuously recorded and dynamically visualized (a service available also in command and control software), but still a limited attention is given to real time analysis and simulation. Dedicated software (usually available for one emergency sector and even for a specific region) allows for more elaborated route calculations taking into account traffic jams and street blockings, but computations are usually completed for one vehicle and on a predefined road network. In large emergencies, much more complex questions need to be answered such as 'which ambulance is closer to the place of incident', 'how to send in the quickest way three fire trucks to the place of incident', 'what is the closest meeting point', etc. This paper reports initial results on performing complex analysis in a Database Management System (DBMS).

Keywords

Navigation, moving objects, analysis, data modeling, DBMS, disaster management

1. INTRODUCTION

The major goal in case of emergency is to safe lives, reduce the number of injuries and casualties, and limit damages on the property (Kevany 2008, Jafari et al, 2003, Neuvel and Zlatanova 2006). To succeed in this, the decision-making process requires excellent information preparation. The information must be appropriate, complete, actual and correct. Research is currently going on regarding various aspects of managing and analyzing of emergency response data. Special attention is given to the spatio-temporal component of data (Brecht, 2008, Diehl et al 2006, Kevany 2008, Zlatanova et al 2007, Lee and Zlatanova, 2008). One of the success factors in decision-making is situational awareness, which is related to the activities of rescue units.

Location information about mobile rescue units (cars, trucks or people) can be obtained through various technologies outdoor and indoor like GPS, UMTS, and WiFi, but disaster management institutions hardly analyze this data. The moving point information is used only for visual monitoring and tracking. Dynamic analysis can greatly facilitate the decision-making process by providing information about hospitals and possible shelters in vicinity, selecting the best routes, estimating time of arrival, etc. which can be derived from typical spatial operations like proximity, navigation, tracking, fencing, etc. Employing such dynamic analysis will also allow for making predictions and simulations.

Besides location awareness, information about the context in which information is requested, is often critical. Environmental conditions (smoke, rain, darkness), task assignment, used hardware (handheld or laptops), communication networks (UMTS, WLAN), vehicle type, condition of patients, etc can influence the way data is provided to the user. These context factors are important as they might change dynamically and therefore may influence the location or moving direction of mobile objects. We believe that a better decision can be made by integrating information about moving objects with context data, as it will be adapted to dynamic changes within the incident area.

Many researches have been working on managing moving objects but mostly for transportation tasks. Wolfson et al. (1997) presented a model to manage location of moving objects in a DBMS. This model is capable of tracking moving objects and predicting near future positions, but the context of objects is not considered. The researches do not discuss other spatial analysis than the simulation. Zhang et. al (2002) reported a similar approach for management and prediction. They use the *bound of deviation* of given number (i.e. 1 mile) to determine location of vehicles, which accuracy is practically insufficient for emergency situations. Baars (2005) presented a spatial schema for management and analysis of driver's behavior on high ways in peak hours. Approaches for modeling and analysis of moving objects are discussed also by Meratnia (2005) and Laurini, et al, (2005).

Much research has been reported in analyzing moving objects with respect to existing road networks, represented as linear referencing network. Sutton and Wyman (2002) reported an approach to synchronize locations of moving objects with a network road model. Nornha and Goodchil (2000) discussed the accuracies of maps represented by topological and network models with respect to vehicles locations. Ahlers et al (2008) discussed matching of GPS tracks with existing road network.

Although related to analysis of moving objects in emergency situations, these works are not intended to represent the high diversity and dynamics during emergencies. Therefore we have initiated a research on management and analysis of moving objects for emergency response. This paper gives first insights on the model and a set of analysis related to optimal navigation of mobile rescue units. The paper begins with formalization of the navigation cases for emergency response. Section 3 discusses the management of moving objects with their context in database management system. Existing spatial data types for points and lines represent moving objects and road networks. The model and the functions are implemented in PostGIS. Section 4 presents first tests with the model. The results are visualized in the freeware software uDig.

2. TAXONOMY OF NAVIGATION

Togt et al. 2005 suggested four main groups of analysis, which might be of interest for moving objects namely *position*, *fencing*, *navigation* and *tracking*. In this paper we concentrate on *navigation* assuming moving objects are continuously tracked. Generally, *navigation* requires start and end points, a network, a cost function (defining criteria for arrival) and an algorithm to compute the shortest path. Many commercial navigation systems have been developed in the last years (Tom-Tom, Mio, Garmin), which can provide personalized routing on static (pre-defined) network making use of cost function based on shortest distance, shortest time, preferred roads. Some of the systems are even able to incorporate information about blocked by traffic jams areas and suggest alternative routes. But these systems are mostly for personal use and cannot provide sufficient flexibility for emergency response.

Successful navigation of mobile units in emergency situations depends on many factors, which can be subdivided into three general groups: *spatial*, *user* and *event* information. Although present in all other navigation systems, these factors are slightly complicated compared to other 'daily' applications as transportation or tourism.

Spatial information refers to the possibilities to move through using roads (different categories), pedestrian areas, bicycle paths, etc. In contrast to road networks for transportation purposes, emergency cars and trucks have quite high driving freedom. They can use networks originally not intended for vehicles. Some of the units (e.g. fire brigade) possess road maps for particular types of vehicles, which are generally not in the national road network. Additionally, some vehicles can and are allowed to drive though green areas. This means that the road network (and therefore computed routes) can be dynamically changed and adapted to different driving alternatives.

The information about *users* (defined in the user context) can include personal data such as (age, gender, health conditions, disabilities, etc.), location (obtained from GNSS, UMTS, WLAN), personal handheld devices (type, used communication channel, preferences for alerting, etc.) and performed task. Personal information generally influences the way of presenting the navigation, e.g. by giving possibility to replace graphics with text (or voice) instructions. In emergency situation, the user information can influence the optimal route for navigation. For example, depending on the health condition of a patient, the ambulance may be re-routed to a new hospital.

The last aspect, *event* (threat) information comprises all the information that may disturb the travel. In a normal situation this might be information about traffic congestion. In emergency, this information ranges from data about disaster/incident itself like pollution areas, flooded areas, spread of fire, smoke, rain, wind, etc. to information about the damaged infrastructure. This information is critical for accessibility and/or availability of parts of the network and therefore has direct impact on the routing. For example, depending on the water level, parts of the road network can be still available for fire brigade trucks, while not recommendable for regular cars (Mioc et al 2008).

In emergency situation, response units need to cooperate and perform tasks together. They need to obtain individual routes (optimized with respect to all above-mentioned criteria) but also taking into consideration other units in the area. To be able to reflect the cooperation aspect we classify the navigation problem with respect to multiplicity of moving objects and destinations (end points). We suggest that destination points can either be static or dynamic (moving) objects. We distinguish between seven different navigation cases as follows:

1. One moving object has to be navigated to one static point (e.g. one ambulance should be guided to a given hospital) under a certain condition. This is the most trivial case, similar to possibilities in commercially available systems. However in emergency situation the user information and the event conditions have to be continuously monitored and in case of change a new route have to be computed. For example, an ambulance is given the route to the best hospital (in terms of facility provided) for certain patients based on location of ambulance. But if the condition of the patient is getting worse (i.e. user profile changes), a new route to the nearest hospital should be provided.

2. One moving object has to be navigated to the best (out of many) static points according to a set of criteria (Figure 1). A decision has to be taken which of the available destinations meet the set of criteria. For example, it should be possible to provide the list of hospitals within 5 km from current location of an ambulance. The ambulance may select the appropriate hospital based on the condition of the patient at current moment (for example the shortest route). Only after that the navigation to the dedicated hospital will be delivered. Similarly to the first case, as conditions change, the system should be able to re-direct to a second or third choice with respect to an initially provided list.

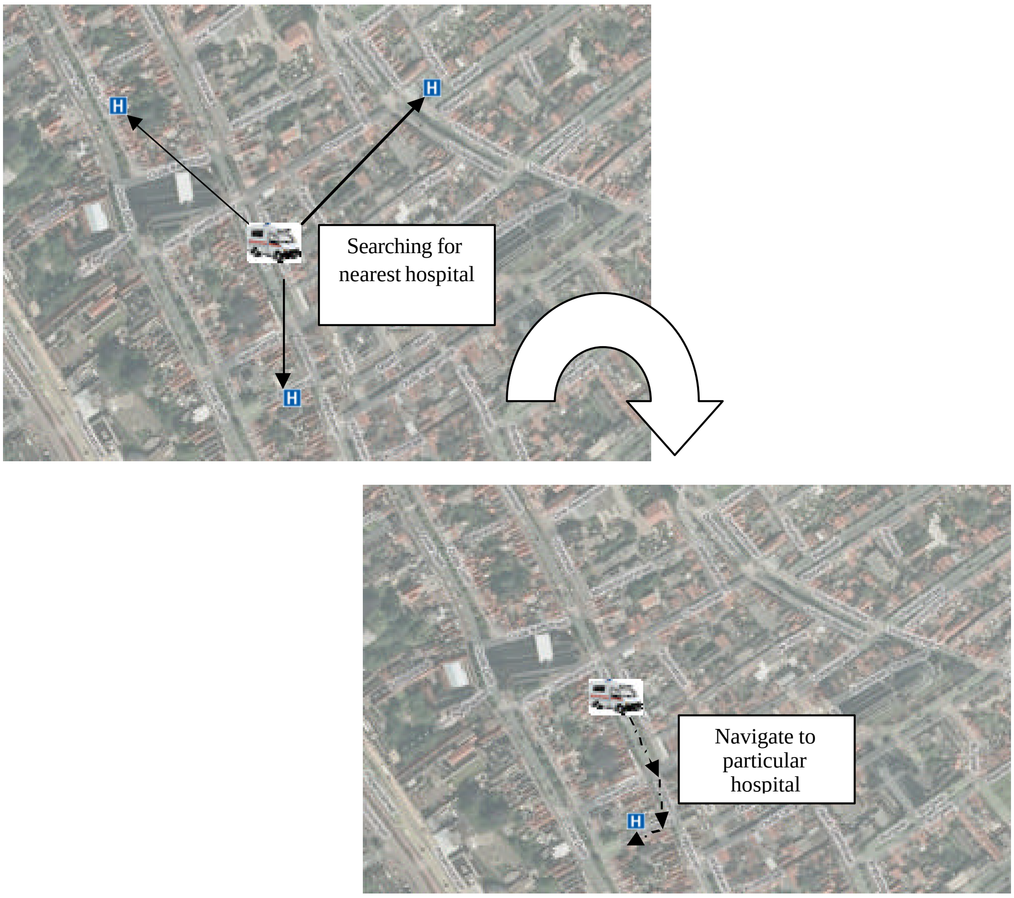

Figure 1: Case 2: One moving object has to be navigated to one of many points.

3. One moving point has to visit several static points in the best possible way. This situation may occur, when a decision-maker or officer needs to visit several affected areas, e.g. locations of emergency teams, field hospitals, shelters, etc. If the moving object is a truck carrying first aid medicaments, food, cloths, etc., this case becomes identical to one of the variants of transportation problems in which goods have to be delivered to several destinations.

4. Many moving objects have to be navigated to one static point (figure 2). A very typical example is guiding five fire trucks to the place of fire. The system should be able to compute the routes to the fire destination simultaneously, taking into account that the trucks should not drive after each other. Monitoring the location, and the event, the system should find the nearest fire brigade that could arrive

at destination at certain time, or, alternatively, compute the paths in such a way to allow all trucks reach at destination simultaneously.

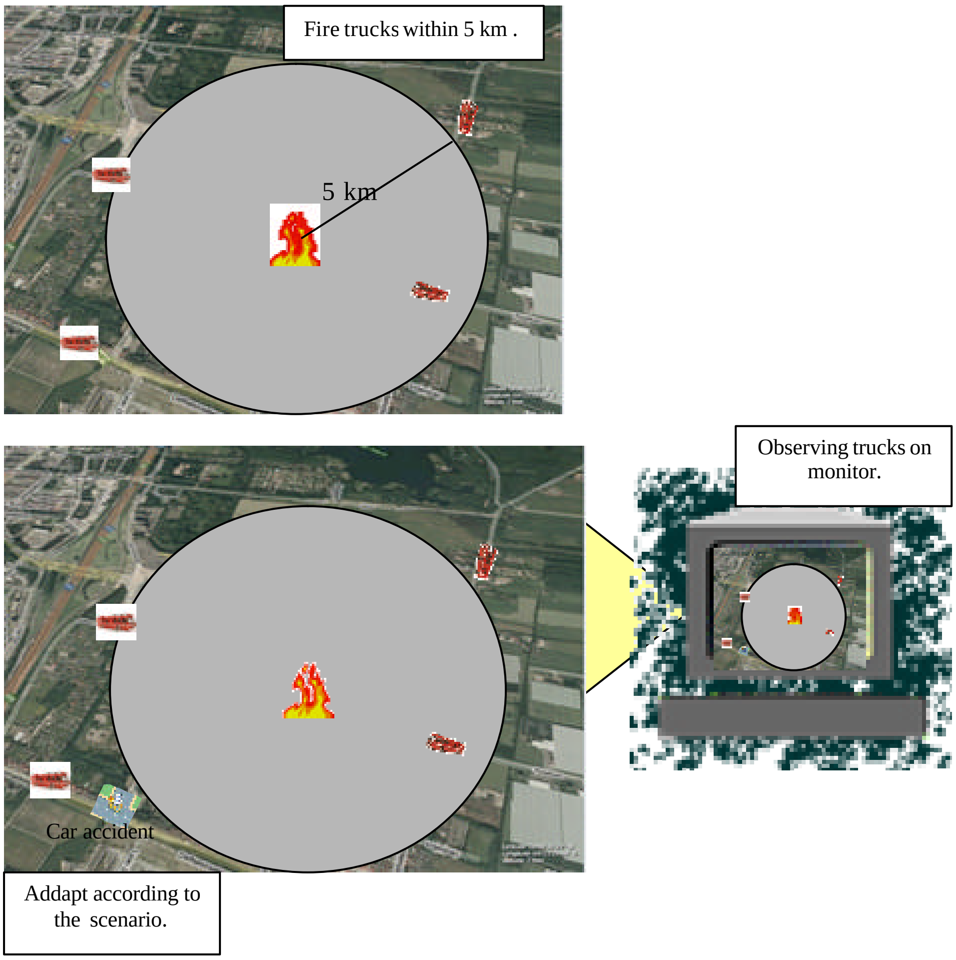

Figure 2: Case 4: Many moving objects have to be navigated to one static point

5. Many moving objects have to be routed to many static points. The moving points may have started either from the same source point or from different. For example, ambulances have to bring patients to different hospitals, of several supply trucks have to vis its shelters. If the starting and arriving criteria (e.g. time) of the different moving objects are not mutually related, most probably this case can be restructured to one the previously mentioned cases. If such relation exist (e.g. time should be the same, type of goods to be delivered are depended), the case will need simultaneous solution for all moving objects. Similarly to case 3, if product (food, clods, medicaments) have to be delivered, the problem becomes very similar to the well-know transportation problem (http://www.ii.metu.edu.tr/~ion562/demo/Section1/page2c.html). The major difference will be in computing the transportation cost, which will depend on the spatial and even parameters and may need to be computed dynamically.

6. Many moving objects have to be navigated to one dynamic point. This situation could happen when the best meeting point has to be found as the mobile objects move through an area. The meeting point has not been fixed and can change with respect to the conditions. For example, two teams have to exchange equipment and they have to meet somewhere. Distance of team 1 to a meeting point might be far more compared to the second team, but they can arrive simultaneously because one of the teams can drive through free of traffic area. Another very interesting example is following and trying to block criminals (for example with a stolen car).

7. Many dynamic objects have to be routed to many dynamic points is the last most complex case. Such situation may occur when first responders have to be evacuated from a fast developing flooding but to meeting points, which may change with the time.

The optimal path for arriving at a given destination is based on a multi-criteria analysis (e.g. shortest path, fastest path, condition of patient, emergency conditions, use of different network, etc.).

3. MANAGEMENT OF MOVING OBJECTS IN DBMS

In our research, we assume locations of moving objects are continuously recorded in a DBMS and organized according to a predefined spatial-temporal schema. The manner of recording, as well as dealing with failures in tracking is outside the scope of this research. DBMS was selected for the management of the moving objects because of many attractive characteristics for crisis situations, e.g. management of large amounts of data; good protection of data in case of power breakdown, wrong operating by the user, or hardware errors; support of spatial data types and spatial functions. Many DBMS have provided navigation models (e.g. Network model in Oracle Spatial 10g, PGrouting in PostGIS) which permits managing networks (topology and geometry) and performing network operations (Pu and Zlatanova 2005). Several algorithms for shortest path computations are readily available in DBMS. Depending on the complexity of the analysis and/or the size of the resulting data set, this approach may even contribute to reducing the response time.

The rest of the paper concentrates on the freeware DBMS PostGIS (http://www.postgis.org/). PostGIS extends the PostgreSQL (http://www.postgresql.org/) with support of geographic features, which are implemented according to the Simple Feature Implementation Specification for SQL (SFS) of the Open Geospatial Consortium (http://www.opengeospatial.org/standards/sfs). PostGIS is also open source software released under the GNU General Public License (http://www.opensource.org/licenses/gpl-2.0.php).

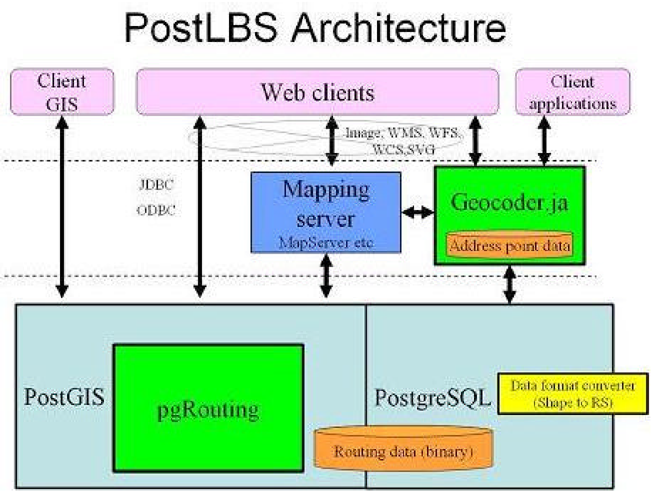

Figure 3:Architecture of PostLBS (courtesy http://www.postlbs.org/)

The network model to be used here comes from another extension of PostGIS, PostLBS (http://www.postlbs.org/). PostLBS aims at providing routing and geo-coding (Figure 3). Presently, geo-coding is only available for Japan. The data stored in PostGIS can be visualized either in a freeware software (uDIG, QGIS, GRASS), or commercial software (e.g. ESRI products). In this paper uDIG (http://udig.refractions.net/) is used.

The software has been selected to be freeware and open source by purpose; one of the goals of our project is to investigate the applicability of such software for disaster management. Freeware software is easy to employ and configure, which makes it an attractive option in cases of partial or complete destruction of existing computer networks. Indeed freeware software could be more prone to bugs and malfunctioning compared to commercial software.

3.1. Emergency response network model

The data model is designed to represent the user, event and spatial information. These groups are termed ‘packages’ and are named Network, Event, Route and User (Figure 4). Each package contains a set of feature classes and the relationships between those classes. The Network represents the Spatial component, the Route is result to be provided to the mobile users (moving objects), the Event contains the environmental conditions and the User contains the context information related to the user. The models used for the tests presented in this paper are relatively simple. For example, we consider only one Network to be available, the Event components are limited to only unavailability of nodes/edges of the Network and the User context contains only location.

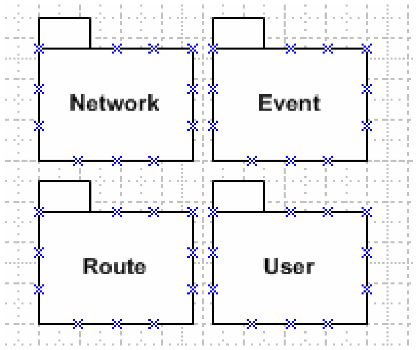

Figure 4: The Four packages in PostGIS

The **Network package** has two classes which are Network and Geometry (Figure 5). The Network package contains the classes that are used to define the spatial aspects of road netowrk. Roads (streets), cross roads and objects of interest along streets are the most important spatial features defining the Network In the real world, road or street features are usually described by their name, physical location and by their ability to connect both physically and logically to other features. Thus a 'road feature' in the network model has the same attributes: name, geometry representing its physical location, topology (connectivity) to represent how it is physically connected to other features and relationships to represent logical connections with other features (Chunithipaisan, et. al., 2002). In many cases the length is also stored as an attribute.

There are two options to represent road (street) network: either using geometry or graph. The geometry representation provides means for quantitative description to define the shapes and location of features. The geometry representation can be taken from existing maps, representing road (street) networks. Road (street) networks can be described with points, lines and polygons. The graph representation deals with the relationships between geometric features (in our case roads, crossroads). The graph model contains only nodes and edges, and represents the connectivity between nodes and edges.

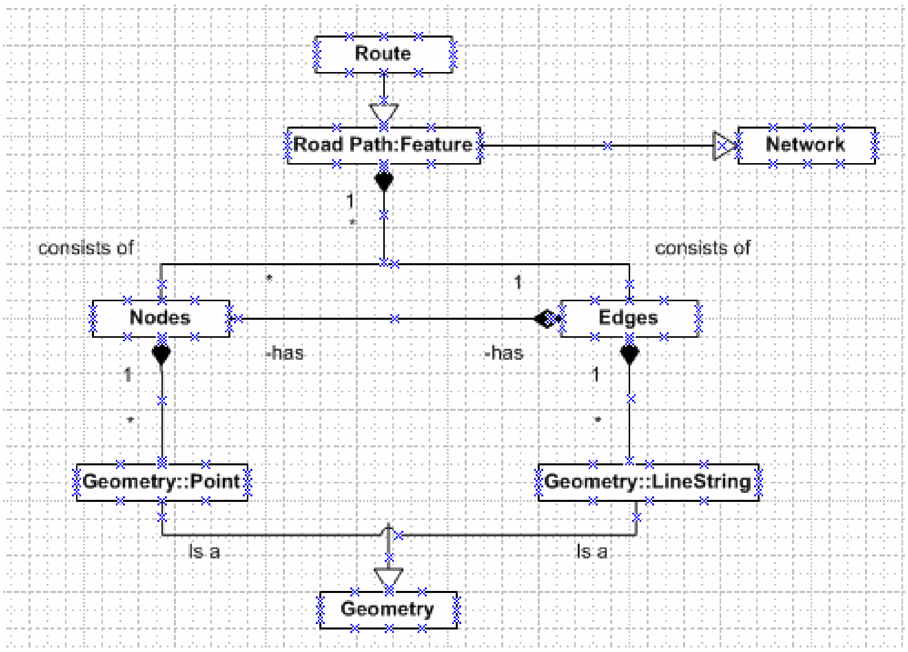

Figure 5: Network class

There are three basic elements in the network package: *nodes*, *edges* and *paths*. The nodes correspond to the object of interest and crossings, the edges represent relationships between nodes, and the paths are parts of the network with a particular meaning. Edge, node and path can have a weight, which represent the impedance cost of traversing them. In our case only the edge has a weight, which is the length of a street segment.

Event package contains conditions, which are result of the incident and which may influence the normal network. These can be result of flooding, smoke, meteorological conditions (wind, heat), traffic accidents or other types of blockings and closings. There could be also planned actions like closing roads for renovation, reconstruction of houses along streets, etc. We believe many events and objects can influence the transportation network in case of disasters and therefore a special package is devoted to them. These event objects are dynamic (temporal) and are not part of the network. Conceptually, this package has to record the event objects as they are defined by the users, i.e. either by points, lines or areas and with a description about the type of event. Spatial analysis between these objects and the network will derive which nodes and edges are not available for what kind of mobile objects. For example, a road flooding of 50 cm, which might be problematic for personal cars, will not be a problem for the trucks of the fire brigade. The Event package contains currently only EventFeature class (Figure 6), which represents nodes, edges and paths, which are not accessible during disaster.

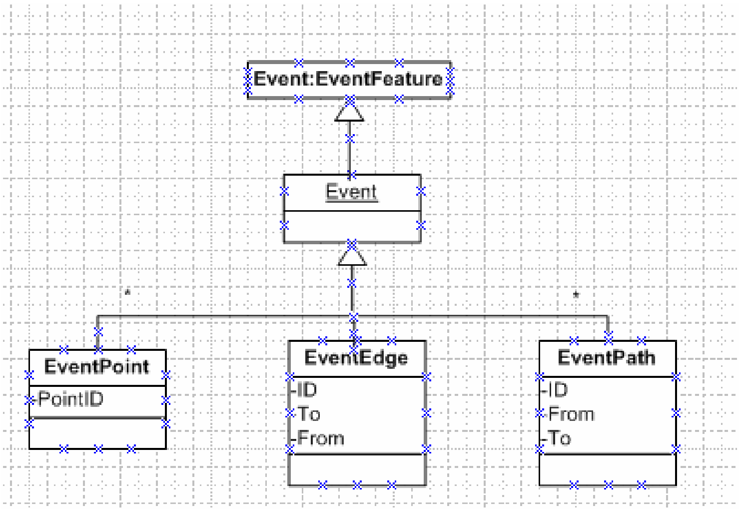

Figure 6: EventFeaure class

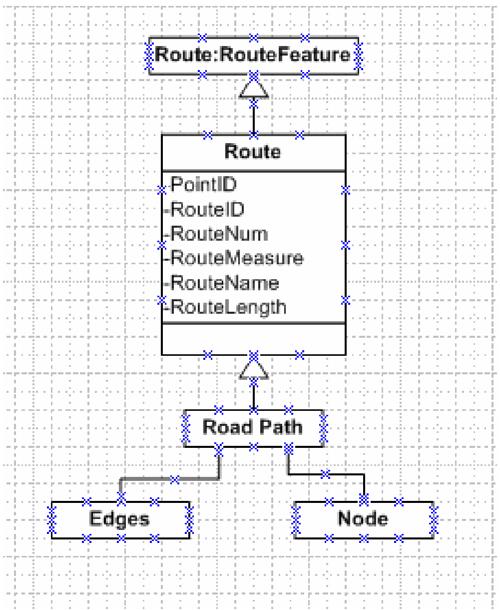

Figure 7: RouteFeature class

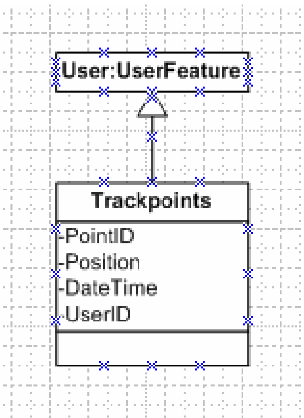

Figure 8: UserFeature class

The package **Route** contains the optimal routes delivered to the moving objects with respect to the cost function. The cost function for emergency response should reflect the type of the network and its availability, event conditions and context of the users. All the routes are persistency stored in the database not only for real-time analysis and prediction (e.g. to compare alternatives) but also for post-disaster analyses. The package as presented here is relatively simple and contains only the computed routes with indication to the mobile object they are computed for (Figure 7). The cost function includes only the length of the edges (i.e. shortest distance is computed).

The last package is **User** and it is intended for the context of the user like location, used personal device, personal data etc. (Figure 8). The user model presented here has location (given within the Dutch coordinate system) and time for a given moving object. Other context parameters are not of interest for the scope of this paper.

3.2 Building the Network model in PostGIS

The Network model can be represented in PostGIS in relational tables, which can be queried either using SQL or pgSQL functions. The street/road geometry is stored in the PostGIS geometry model and the network model is derived from the geometry using pgSQL functions. The network model consist of four tables one for the geometry of the edges and the geometry of the nodes and two giving connectivity between nodes and edges. The model is created with three functions freely available from PostLBS. The text bellow describes the step needed to create the four tables in PostGIS.

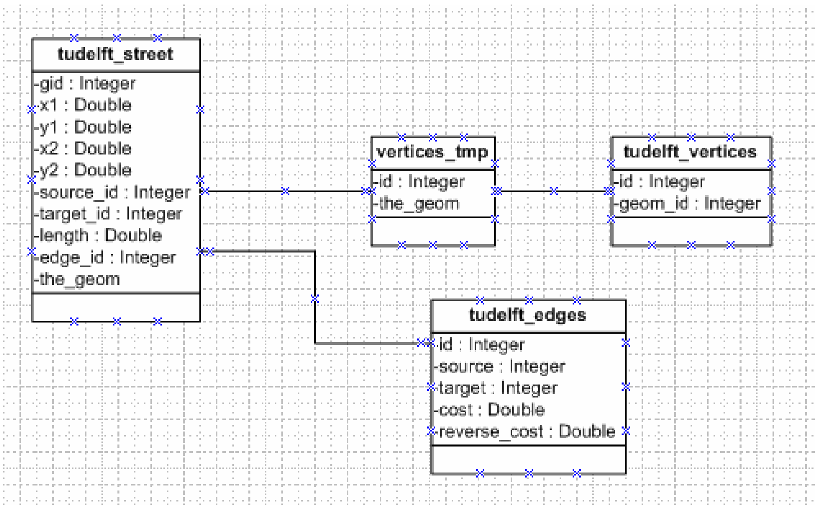

Figure 9: PostGIS network model

The geometry of the streets can be imported in several way in PostGIS, using different loaders. In our cases, we have used ESRI shape file format. Shape files can be imported in PostGIS using the function *shp2pgsql*. *Shp2pgsql* is a data loader that converts ESRI shape file into SQL scripts, which can be executed into the PostGIS enviroment. For example, the shape file named *TUDelft_Rd.shp* is used to create the script file *TUDelft_Rd.sql*, which is executed in PostGIS database (named *Network*):

```
# shp2pgsql -i -D -s 28992 TUDelft_Rd.shp TUDelft_Rd > TUDelft_Rd.sql
```

```
# psql -U postgres -f TUDelft_Rd.sql -d Network
```

The loader creates the tables according to the geometry stored in the shape file. In our case all the streets were represented as loose lines and they were stored in one table (*tudelft*) using multilinestring data type. This table contained around 36 columns. For this research, only ID of objects and their geometry was copied in a table *tudelft_street*, which was created to contain columns that are needed for the PostGIS Network, as follows:

```
create table tudelft_street (

        gid int UNIQUE,
        x1 double,
        y1 double,
        x2 double,
        y2 double,
        source_id bigint,
        target_id bigint,
        length numeric,
        edge_id numeric,
       );

select AddGeometryColumn('tudelft_street','the_geom',28992,'MULTILINESTRING',2);

Insert into tudelft_street(gid,the_geom)(Select gid,the_geom from tudelft);
```

The new table *tudelft_street* contains columns for network id, coordinates of first and second point, IDs of source and target nodes, length, and edge ID, but only geometry and ID are filled out with data after this step. The fields with the x1, y1, x2 and y2 is filled out using a PHP script. These coordinates are needed to define the edges of the network. A fragment of the script for X1, Y1 is shown below:

```
$start = "SELECT astext(StartPoint(the_geom))as startpoint from tudelft where
gid='$x'";
 $res_start= pg_query($con,$start);
   $start_point = pg_result($res_start,"startpoint");
     $array_01=array("POINT(",")");
  $array_02=array("","");
     for($r=0;$r<sizeof($array_01);$r++)
   {
    $start_point=str_replace($array_01[$r],$array_02[$r],$start_point);
    }
$explode=explode(" ",$start_point);
$x1=$explode[0];
$y1=$explode[1];
```

The fields *source_id* and *target_id* are then populated with data by the function *assign_vertex_id* (http://pgrouting.postlbs.org/wiki/Workshop-PrepareDikstra).

```
Select Assign_vertex_id('tudelft_street',1);
```

This function creates nodes between all intersecting edges or edges in a given tolerance (1 meter) and stores the information in a new table *vertices_tmp*. The geometry column of this table contains interpolated coordinates for each node. The *edge_id* column is filled in by the *create_graph_tables* function. This function creates two new tables which are *tudelft_edges* and *tudelft_vertices*. After this step *cost* column in *tudelft_edges* table and *length* column in *tudelft_street* table are still not filled in. This is done with the function *update_cost_from_distance*. It fills in the *cost* column in *tudelft_edges* table with the length of the line (in the column *the_geom*) and also updates the distance value of *length* column in *tudelft_street* table.

4. CASE STUDY

The model described above was used to implement two cases of navigation: one moving object (ambulance) to a static point (accident location) and many moving object to one static point (i.e. list of nearest fire brigades to a given location). The considered scenario is as follows: A road accident has occurred at a given location J. One ambulance and several fire brigades (Figure 2) have to be sent to this location as fast as possible. Thus the location of the accident on the network is considered as static point.

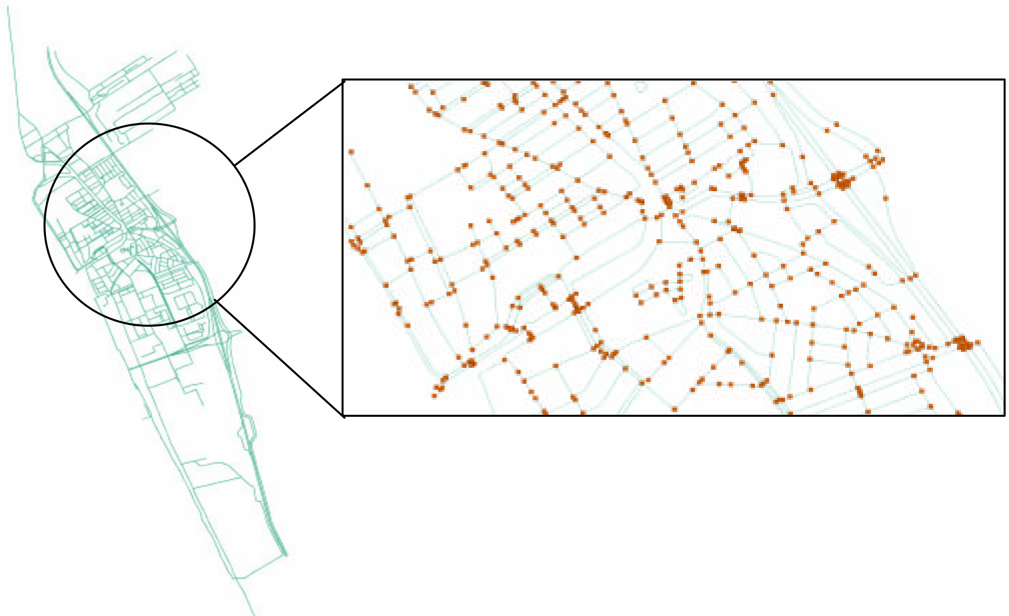

Figure 10: Geometry and Graph model of the campus of Delft University of Technology (used for the tests).

We have used two data sets: street data and GPS logs for the area of TU Delft. The streets of the large topographic map of Netherlands (GBKN 1:1000) were used to create the network (Figure 10). The street network is derived from manually modeled center lines of the streets. A set of GPS track-logs for the same area was imported in PostGIS and used for simulating moving objects. The GPS track-logs were loaded similarly to the streets in PostGIS. After loading, a selection of the available information was made to fit the user model as presented in Figure 8.

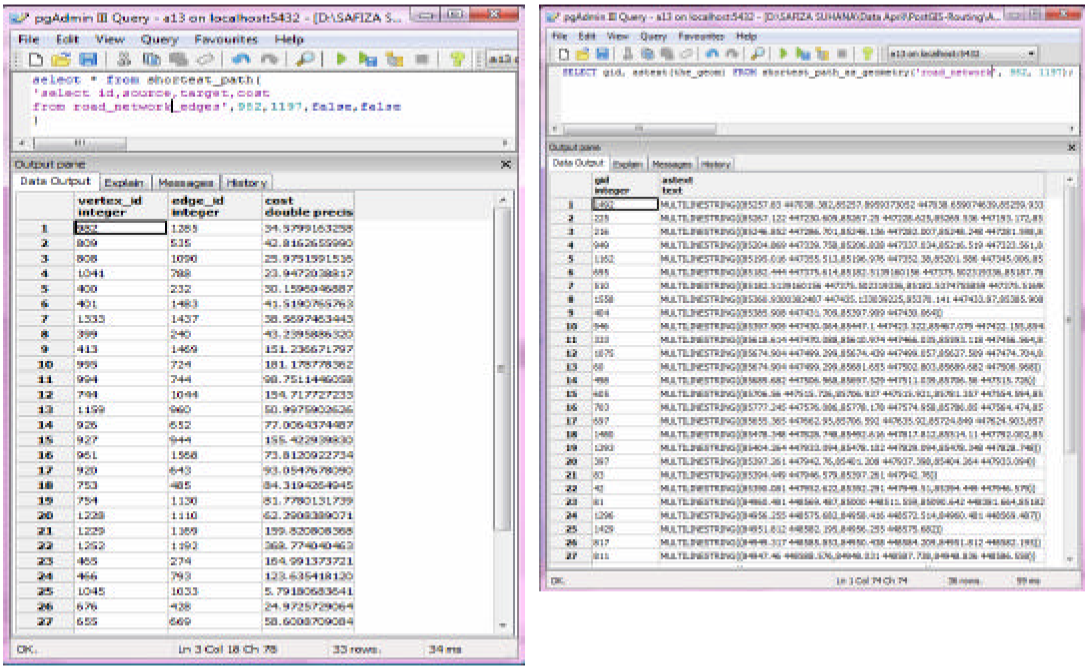

Figure 11: Shortest path between nodes 981 and 1197.

4.1. Case 1: Navigation of one moving object to a static point

By using the geometry and network models created in PostGIS, the navigation of one moving object to a predefined static point can easily be implemented. The information needed is 1) the node of the network, where the ambulance is at the moment of the query and 2) the destination node. The coordinates of the moving object can be obtained from the continuous tracking and matched with the nearest link or node. The shortest path algorithm can be performed then using one of the three algorithms Dijkstra, A*, and shooting star (http://pgrouting.postlbs.org/), available in PostGIS. For example, if the ambulance is in a node with id = 981 and has to be navigated to a point with id = 1197, the following SQL statement has to be used:

```
select gid,the_geom from shortest_path_as_geometry('tudelft_street',981,1197);
```

This function requires five parameters, which helps to traverse of the model as given on figure 9. The result of this function is a set of rows. There is one row for each crossed edge, and an additional one containing the destination node (Figure11). The columns of each row are:

- vertex_id: the identifier of source node of each edge. There is one more row after the last edge, which contains the node identifier of the target path.
- edge_id: the identifier of the edge crossed
- cost: The cost associated to the current edge. It is 0 for the row after the last edge. Thus, the path total cost can be computed using a sum of all rows in the cost column.

In order to visualize the route computed by the *shortest_path* function, we use the *pgsql2shp* function to convert the PostGIS table into a shape file (figure 12). This application uses functionality from *shapelib 1.2.9* to write to ESRI Shape files (http://www.postgis.fr/tarball/postgis-cvs/loader/README.pgsql2shp). The general syntax of the function is as follows:

```
pgsql2shp -f filename -h hostname -u username -P password -g the_geom databasename_tablename
```

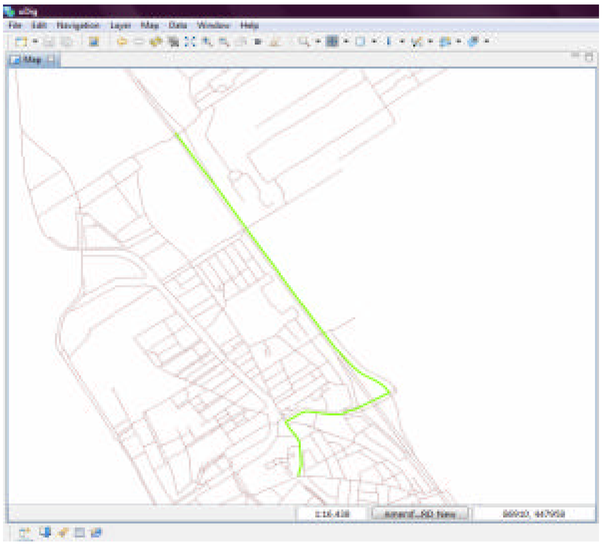

Figure 12: Visualization of computed path using uDig software.

4.2. Case 4: Navigation of many moving objects to one static point.

The navigation of many moving objects to one static point is also relatively easy to implement in three steps: 1) finding all the fire brigade trucks in the given area, 2) matching the real position to a node/edge on the graph, and 3) running shortest path algorithm according to a given cost function. In order to perform this analysis, the user information stored in the table *trackpoints* has to be used.

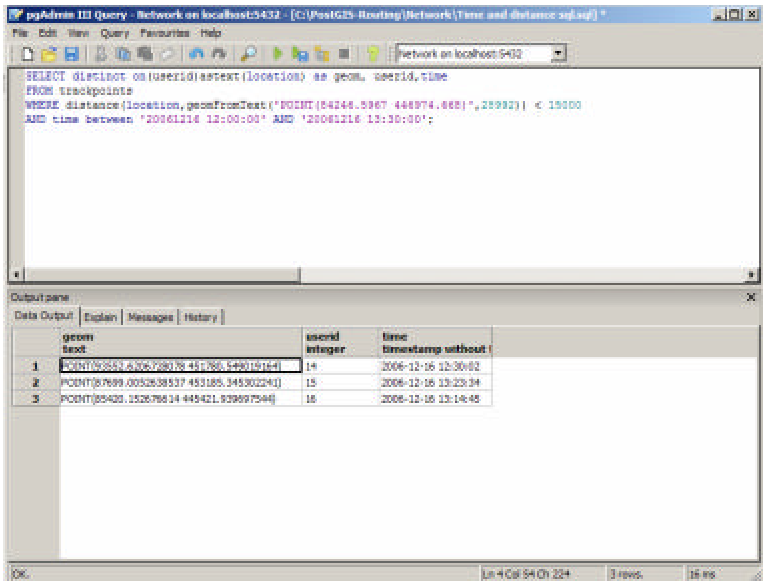

Figure 13: SQL statement resulting list of objects located within 15km from a given point (i.e accident location).

By using the spatial functions of PostGIS, we can search for all the fire trucks that located within 15 km of accident location at given point and given time. The functions that could be of interest are *within_distance* and *distance*. The SQL statement bellow shows the use of *distance*.

```
select distinct on(userid)astext(location) as geom, userid,time
       from trackpoints
       where distance (location,geomFromText('POINT(84246.5967 446974.668)',28992)) < 15000
       and time between '20061216 12:00:00' AND '20061216 13:30:00';
```

It should be noted that executed in this way the function will give the distance computed on the straight line connecting the point of interest and the fire trucks. If more precise distance has to be computed, the available street network has to be used. Figure 13 illustrates the results for the query above, i.e. 3 trucks are found in the given range. The second step is to estimate which is the closest node/edge from the network for each of the three trucks. This operation can be performed using the same functions: *distance* and *within_distance*. The navigation to the accident location will be then computed using the *shortest_path* function as Case 1 above. The tree steps can be integrated in an pgSQl script and defined as a separate function.

5. CONCLUSSIONS

This paper has reported first results of research on analyses of mobile objects for the purpose of emergency response. The goal of this research is to supply a model and tools able to support decision-making for rescue units. This paper concentrated on the navigating rescue units in and outside a disaster area. Navigation cases of interest for first responders are organized in 7 groups with respect to type and multiplicity of source and destination points. The models are intended to consider spatial, user and event information in preparing the optimal paths.

Initial tests with simplified versions of the models were performed in PostGIS. The first results are very encouraging. The database is freeware and easy to employ. The possibility to maintain geometry and network (and shortest path algorithms on it) in one database opens new possibilities for analysis and visualization. The models can be queried with respect to different spatial, spatio-temporal and non-spatial criteria. Other spatial data sets like topographic maps, orthophoto images, etc. can be used to enhance the analysis by providing surrounding information such as houses, gardens, etc. which might not be initially included in the street network model.

The visualization of the analysis is also straightforward. We have experimented with uDig but several other alternatives of freeware software (offering more functionality at the client side) can also be exploited. Currently, the visualization is done by accessing the PostGIS tables, but some experiments with GeoServer have shown that WFS or WMS might be a better option.

Next short coming steps will be extension of the models according to the concepts discussed in the paper.

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