Geographical Information System for Analysis of Critical Infrastructures and their Hazards due to Terrorism, Man-Originated Catastrophes and Natural Disasters for the City of Gdansk

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Abstract. The paper presents a web-based Geographic Information System (GIS) for assessment and visualization of Critical Infrastructure (CI) and its hazards which was developed by the Department of Geoinformatics at Gdansk University of Technology for the City of Gdansk. The system allows spatial processing and mapping of various CI analysis results, with the CI analysis module based on the CARVER2™ technology adapted to particular requirements of the Gdansk City Hall Crisis Management Department (CMD). The system works as an integrated solution for both visualization of hazard scenarios and a team-enabled environment for information analysis and sharing among geographically distributed decision makers. The paper focuses on the sample applications with reference to the analysis, visualization, and mapping in a geographical context of several threat scenarios, such as blast attack, chemical attack, and toxic leakage as well as the spatial distribution of critical infrastructure components in Gdansk, Poland.

Keywords: GIS; CARVER2; Critical infrastructures; Hazards
1 Introduction

Many regions and places in the world, previously considered relatively safe, have recently become targets of various kinds of terrorist attacks, as the incidents of terrorism have been increasing continuously in recent years. This situation concerns many regions of Europe, including the country of Poland. It requires determined and effective actions for the protection of people and critical infrastructures (CI) against such attacks and their consequences. Within this context, for prediction of hazards and to support the activities for minimizing their results, some type of new information and communication technology achievements and solutions may be a useful aid. Specifically, Geographic Information Systems (GIS), when applied to CI protection, are used for real-time monitoring and information sharing purposes, visualizing threats as they are discovered [1]. Taking the case of CI components and their threats within the area of Gdansk in Northern Poland as a real-world implementation example, this paper presents the recently developed GIS application. The system allows for comparison of different types of CI as well as spatial analysis of all its aspects, including various threat scenario simulation. This approach should result in an overall increase in CI protection effectiveness, due to the system’s assistance in the creation of better response scenarios leading to quicker and more decisive actions and potentially reducing the impact of different threats. The system’s architecture is shown along with its sample applications with respect to several hazards, including terrorist attacks, man-originated catastrophes, natural disasters, etc.

2 The System Structure

The block diagram of the developed system architecture is presented in Fig. 1.

In general, the system consists of the CI analysis module based on the CARVER2™ technology, the web-based GIS system and authorized remote end users [2,3]. CARVER2™ delivers synthetic data regarding CI to the Geodatabase which stores them along with threat scenarios as well as digital charts of the city of Gdansk. The stored data is processed by spatial analysis module. The spatial data along with its processing results are disseminated for the authorised users in a form of thematic layers by the internet map server and via the WWW access portal.
CARVER stands for the acronym from Criticality, Accessibility, Recoverability, Vulnerability, Espyability and Redundancy [4].

quick and easy identification and comparison of potential terrorist targets at the local, state, and national levels in order to assist government officials in the allocation of protective resources.

The CARVER2™ analysis tool is a software for comparing dissimilar types of critical infrastructure using the same standards. It is designed for quick and easy identification and comparison of potential terrorist targets at the local, state, and national levels in order to assist government officials in the allocation of protective resources.

Regarding the presented system, the CARVER2™ technology has been adopted to the particular requirements of the Crisis Management Department of Gdansk City Hall (CMD). Specifically, these requirements have been defined with respect to:

2.1 The CARVER2™ Module

Fig. 1 The system architecture
The specific homeland security strategic objectives on the Polish national and regional level
The accessibility of data on several CI sectors and types for the city of Gdańsk
The experience of CMD.

It was decided that, in the implemented prototype application of the system, the following types of CIs would be analyzed:

- Energy
- Water and sewage
- Specific, potential concentrations of people (hospitals, schools etc.)
- High buildings
- Local authority and crisis management centers.

The following types of hazards have been selected by analysis by the system:

- Blast attack
- Chemical attack
- Liquid toxin leakage
- Gas toxin leakage
- Radioactive material leakage.

The CARVER2™ criticality assessment algorithm takes into account the complex interdependencies between sectors of critical infrastructures, as well as the susceptibility of evaluated infrastructures to various types of attack, as is presented on the diagram in Fig. 2.

Fig. 2 CARVER™ interdependencies of critical infrastructures
The synthetic score calculated by CARVER2™ module reflects the total value of all data inputs and gives the numerical basis for making the infrastructure comparisons.

### 2.2 The Geodatabase and Spatial Analysis Module

These modules are responsible for creating and storing the thematic layers of spatial data in response to various user queries, like results of threat scenario simulation or visualizations of different distance relations between processed CIs.

The Geodatabase is involved in optimized and integrated storage, maintenance, and updating of the various kinds of data. The spatial analysis module performs several spatial processing and analysis functions operating on critical infrastructure data, background data, hazard scenarios data, and other types of data possessing the spatial component. The sample possible analysis tasks include:

- Basic geoprocessing tools
- Advanced spatial analysis tools
- Creation of time-varying thematic layers.

Basic geoprocessing tools can prove to be a useful aid in analysis of urban areas in relation to spatial distribution of CI. The example here may be the creation of a thematic layer of polygons basing on the rule that the distance from any of them to the nearest CI (with respect to a specified range of scores in a chosen category of criticality or not) is not greater than a chosen value. Another example might be the selection of an area where objects belonging to two or more CI overlap and occupy the same or very close spatial locations, like viaducts in the case of roads and railway systems [5].

Advanced spatial analysis tools operate on both vector and raster data as their input or output. An example may be the creation of a thematic (raster) layer with the value of each point (pixel) defined as the local density of CI objects, calculated as the total number of critical objects of a specified type (weighted by its score or not). The result can be presented in the form of a layer overlaid on the source data, as is presented in the next section. Another example could be the interpolation of vector point data, obtained previously as a result of a given spatial processing or analysis, using the specified interpolation method, e.g., inverse distance, spline, or kriging [5].

The spatial analysis module allows for the creation of time-varying thematic layers based on threat simulation algorithms results. These use the spatial models describing several scenarios for the cases of occurrence of various types of hazard, like terrorist attacks (chemical, biological, bomb,
etc.), natural disasters (e.g., flood), or disasters of other origin (e.g., toxic leakage).

The internet map server is responsible for providing the authorised users with layers of CI spatial data, background data, analysis results, and other contents of the Geodatabase through a comfortable, intuitive, web-based interface. The user is granted a set of GIS functions for accessing the spatial data served by the system, including:

- Basic map viewing tools like scrolling, zooming, panning, etc.
- Tools for easy map object information retrieval, including nonspatial attributes like number of inhabitants
- Creation of queries for selection of object subsets using both spatial and nonspatial criteria
- Execution of the geoprocessing and spatial analysis procedures and definition of their parameters
- Customization of map appearance.

3 Sample Applications of the System and Processing Results Obtained

Sample data obtained from the CARVER2™ analysis tool for various CI in the Gdansk area is presented in the Table 1. For the purpose of visualization of this data, two different methods were used.

Table 1. CARVER2™ scores of chosen critical infrastructures in Gdansk, Poland

<table>
<thead>
<tr>
<th>Critical Infrastructure</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gdansk Refinery</td>
<td>165</td>
</tr>
<tr>
<td>2 Port of Gdansk</td>
<td>138</td>
</tr>
<tr>
<td>3 Hospital</td>
<td>144</td>
</tr>
<tr>
<td>4 Straszyn – Water Source</td>
<td>172</td>
</tr>
<tr>
<td>5 Power Station</td>
<td>90</td>
</tr>
<tr>
<td>6 Gdansk Airport</td>
<td>142</td>
</tr>
<tr>
<td>7 Railway Station</td>
<td>112</td>
</tr>
</tbody>
</table>

The visualization of CI synthetic scores in a spatial context utilizes GIS and electronic chart techniques. These include presentation of the scores in several layers overlaid, where the score values are interpolated between the individual CIs using the inverse distance weighted (IDW) method, as shown in Fig. 3. The IDW implicitly assumes the decrease of influence.
with distance from its sampled location [3]. In such a manner, the obtained raster layer may be treated as a graphical representation of the local CI element concentration.

For a more thorough overview of CI distribution over an area, the system provides three-dimensional visualization. In this context, the height of each peak of the plot is directly related to the value of CARVER2 score of the respective CI (see Fig. 4).
Fig. 5 Spatial visualization of simulated blast attack on the railway station, showing affected buildings. *Dark circle* – complete damage zone, *light circle* – severe injuries zone.

The system provides a more complete overview of CI vulnerabilities by means of complex visualizations of various hazard scenarios. For example, spatial visualization of the outcome of a blast attack on the railway station (see Fig. 5) reveals greater costs (CI as well as citizen-related) than pure CARVER2™ or GIS-derived data. The radii of the structural damage zone (the air pressure over 27kPa) and severe injuries zone (the air pressure below 27kPa and above normal) are calculated on the basis of the mathematical model used for blast effect assessment [6]:

\[ R = \left( \frac{185m^{0.4}}{p} \right)^{0.8333}, \]

where \( R \) is the radius of zone in m, \( m \) is the mass of the used explosive material in kg, \( p \) is the threshold pressure in kPa.

Visualization of the spatial distribution of different CI allows more comprehensive analysis of the examined region’s vulnerability to various threats, therefore becoming an invaluable asset for strategic planning.

Another example concerns the simulation of chemical hazard using the simple hazard zone assessment algorithm based on the NATO ATP-45 norm [7]. Figures 6 and 7 present the spatial visualization of simulated chemical leakage from containers situated in the facility of Port of Gdańsk. Figure 6 presents the case with relatively low wind speed (5km/h⁻¹), whereas Fig. 7 depicts a substantially different wind speed of 15km/h⁻¹.
Fig. 6 Spatial visualization of the simulated chemical leakage from containers situated in the facility of Port of Gdansk for the assumed wind speed of $5\text{km/h}^{-1}$.

Fig. 7 Spatial visualization of the simulated chemical leakage from containers situated in the facility of Port of Gdansk for the assumed westerly wind speed of $15\text{km/h}^{-1}$.
The system incorporates necessary tools for effective simulation and visualization of outcomes of various other threat scenarios, including natural disasters. Figures 8 and 9 show visualizations of two different results of the flood scenario simulation over the same area. In Fig. 8, most of the area is covered by the overflowing water. Figure 9 represents the result of the simulation after the addition of protective dykes.

![Fig. 8 Visualization of flood scenario simulation outcome](image1)

![Fig. 9 Visualization of flood simulation outcome after addition of dykes](image2)
4 Conclusions

The web-based Geographic Information System for assessment and visualization of CI and its hazards was presented. The developed system allows for CI risk assessment and visualization of potential hazard scenarios simulations (blast attack, chemical attack, toxic leakage, flood) and provides different tools for data analysis and sharing between geographically distributed decision makers. The system’s verification and validation was performed by the Crisis Management Department of Gdansk City Hall. Preliminarily, the system has proven to be very useful for medium as well as large agglomeration municipalities in the European Union. The presented approach should result in an overall increase in CI protection effectiveness, due to the system’s assistance in the creation of better response scenarios leading to quicker and more decisive actions and potentially reducing impacts of different threats.

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References
