GeoScience Engineering

APPLICATION OF GIS FOR THE CONTROL OF MAJOR ACCIDENT HAZARDS

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ABSTRACT

The presented study discusses the importance of GIS in assessing the fire and explosion modelling involved in major accident hazards. The simulation of toxic dispersions in the atmosphere is especially dangerous for densely inhabited areas, or close to the sensitive environment, which are called the target systems. Therefore, mathematical-physical predictions from hazard modelling programs such as Areal Locations of Hazardous Atmospheres (ALOHA) have to be combined with a Geographic Information System (GIS) such as ArcGIS. This multidisciplinary approach allows experts to couple the consequences and the target systems in one representation of major accident hazards. This unique combination of the two programs allows us to calculate the consequences to human life for a real accident scenario case study. Description of methodical approach and four accident scenarios are investigated based on ALOHAs models for carbon monoxide release combined with ArcGIS for Liberty Ostrava a.s. as a case study.

Keywords: ALOHA; ArcGIS; Carbon monoxide; Major accident hazards; Modelling of release and dispersion.

1 INTRODUCTION

There are different methods of modelling dangerous gases in cases of major accidents from road and rail transportation in urban zones. [1] The experimental data for toxic dispersion in the atmospheric boundary layer are collected by direct measurements of chemical concentration levels of concern (LOC). Such measurements, however, are very expensive, time-consuming and only with limited resolution. The results of mathematical-physical modelling with the given geographical information system represent a cheap, and well-resolved source of information. At the same time, to visualize major accident hazards from toxic substances released into the atmosphere, mathematical modelling combined with geographic information systems are the foremost tool.

1.1 Major accident hazards

To evaluate the major accident hazards of the chemical facilities, individual and societal risks that consider the population within the impact area of the major accident are used [2]. To calculate the effects of major accident to its surrounding, a large number of calculation models have been developed which are based on the physical and chemical properties of substances and physical behaviour in general, and on validation experiments for specific, often extreme process conditions. Basically, they consist of models that convert these accident-specific results into damage to people, environment, and structures [3].

1.2 Geographic information system

GIS-based tools for modelling major accident hazards have progressively increased in the last decade to help emergency planning. GIS-based tools allow us to identify, visualize, model, and represent the real world through maps and graphical outputs. GIS represents an extension for the visualization of major accident hazard modelling [3]. While a software package for modelling as ALOHA serves for the computation and processing of the model, GIS is the way to visualize the outputs of the model in maps. Also, GIS allows calculating the number of affected structures, peoples, etc. Despite the fact that GIS represents powerful tools, its role in the field of major accident hazards is still underestimated. Nevertheless, we can find some examples of such types of research. Researchers in [4] used ALOHA in conjunction with ArcGIS for the delineation of flammable zones for ammonia, and in [5] they used GIS as the emergency response system for major dangerous chemical accidents on the highway.

2 METHODICAL APPROACHES AND ACCIDENT SCENARIOS

2.1 Methodical approaches

Software package ALOHA is a standard pre-accident modelling program commonly used in the assessment of major accident releases and dispersions [1]. Software package ArcGIS represents a well-known and widely used GIS software. For hazardous zones modelling, we used software packages ALOHA 5.4.7 [6]. For visualization, we used software packages ArcGIS [7].

2.2 Accident scenarios

The dispersion of carbon monoxide (a toxic gas) was calculated by the Gaussian model for neutrally buoyant gas after the release. The fatal zones for toxic substances were modelled by a probits function [1]. The urban roughness was considered during all simulations to approximately match the multiple obstacles in cities. Two main releases of the selected substances were modelled: instantaneous release of toxic gas as the worst-case scenario and continuous release as an alternative scenario representing a more probable accidental situation [1]. The following scenarios for pipelines above-ground were considered: 1. rupture in the pipeline (instantaneous) and 2. leak with an effective diameter of 10% of the nominal diameter, up to a maximum of 50 mm (continuous). The location of the rupture is important for the outflow rate. Each of these scenarios is always simulated for two cases: 1. temperature 25 °C, air stability class D, wind speed 5 m/s, and 2. temperature 10 °C, air stability class F, wind speed 1.7 m/s.

2.3 Characteristics of carbon monoxide

Carbon monoxide is a flammable and toxic, odour-free, colourless gas that is the main product of the incomplete combustion of carbon-containing materials. Its molecular weight is comparable to air (relative density app. 0.9657). By inhalation, carbon monoxide enters the bloodstream where haemoglobin binds to the blood dye more tightly than oxygen, which is to be transported via the body to the organs and tissues via haemoglobin. Small concentrations of carbon monoxide, which may occur in the air, for example, in cities, may cause serious health problems, especially to people suffering from cardiovascular diseases. Longer exposure to elevated concentrations of carbon monoxide in the atmosphere can cause a variety of problems for healthy people, such as reduced work performance, reduced manual skills, impaired ability to study, and difficulty in performing more complex tasks. In pregnancy, exposure to small doses of carbon monoxide can cause a lower birth weight of the new-born. However, at higher concentrations, which are not normally present in the atmosphere, carbon monoxide is directly toxic. Poisoning is manifested by the brown-red coloration of the skin followed by coma, convulsions, and death [8–9]. The summary of chemical data for ALOHA modelling is depicted in Table 1.

Vol. 68 (2022), No. 2
pp. 151–157, ISSN 1802-5420
DOI 10.35180/gse-2022-0077

Table 1. *The summary of chemical data for ALOHA modeling*

Chemical data	
Risk source:	Pipeline
Chemical name:	Carbon monoxide
The physical state of releasing:	Gas
Total amount:	2502 m^3
Molecular weight:	28.01 g/mol
Ambient boiling point:	-191.5 °C
Consequence:	Toxic release

3 CASE STUDY

In the present study, we predict artificial release threat zone distances in Liberty Ostrava a.s. We consider a small leak in the pipe containing carbon monoxide under atmospheric pressure. There is a pipeline for transportation of toxic gas - carbon monoxide at the Liberty Ostrava a.s. in Ostrava-Kunčice (Liberty Ostrava a.s., Vratimovská 689, 707 02 Ostrava-Kunčice, Czech Republic). The pipeline length was estimated at 1000 m. The pipe diameter was 1.785 m. The total volume of the pipeline was calculated to be 2502 m^3 under given atmospheric conditions. The ground-level atmospheric temperature was 10 °C and 25 °C; the wind blew from the north at 5.0 and 1.7 m/s (measured by the meteorological station at 3 m above ground level). The sky was covered by clouds of 5/10 and the ambient air humidity was set at 50%. No atmospheric inversion was observed. The range of ground concentrations of substances is determined for 3 concentration levels of 7000 ppm (corresponding to LC50 at 30 min. exposure), 2000 ppm (corresponding to LC10 at 30 min. exposure), and 1000 ppm (corresponding to LC1 at 30 min. exposure). There are first-class roads connecting Ostrava and Havířov, the train station Ostrava - Bartovice, and several businesses and family houses near the industrial company. Table 2 summarise all-important input data necessary for modelling the releases and dispersion of the selected dangerous substance.

Table 2. *The summary of input data for mathematical modeling*

Scenario	Release	Stability	Wind speed (m/s)	Temperature (°C)	LOC (ppm)
1	Instantaneous	D	5	25	7000, 2000, 1000
2	Instantaneous	F	1.7	10	7000, 2000, 1000
3	Continuous	D	5	25	7000, 2000, 1000
4	Continuous	F	1.7	10	7000, 2000, 1000

ppm = parts per million

3.1 Data and data processing

The results given by the software package ALOHA were exported to the KML (Keyhole Markup Language) file, which is the native format for Google Earth Pro (GEP). It was necessary to import data to ArcGIS software with the usage of the extension Data Interoperability. KML files were transformed into the geodatabase. Consecutively, we transformed each threatening zone into a buffer with a radius calculated by ALOHA software (see Fig. 2 and 3). The original threatening zones calculated with ALOHA were represented by directional rosette and wind direction confidence lines 1000 ppm (Fig. 2). The resulting buffers were shown on the Base map of the Czech Republic in conjunction with of Digital Surface Model of the Czech Republic of the 1st generation (DMP 1G). With the tool Select By Location, we have chosen all structures from the vector datasets Fundamental Base of Geographic Data (ZABAGED®), which were reached by the boundary of each threat zone (Fig. 3).

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4 RESULTS AND DISCUSSION

In the first step, we visualized ALOHA outputs using Google Earth Pro software. Data import to GEP is simple as well as user interference. In addition, the results can be shown on the 3D terrain model as shown in Fig. 1 (north at the top).

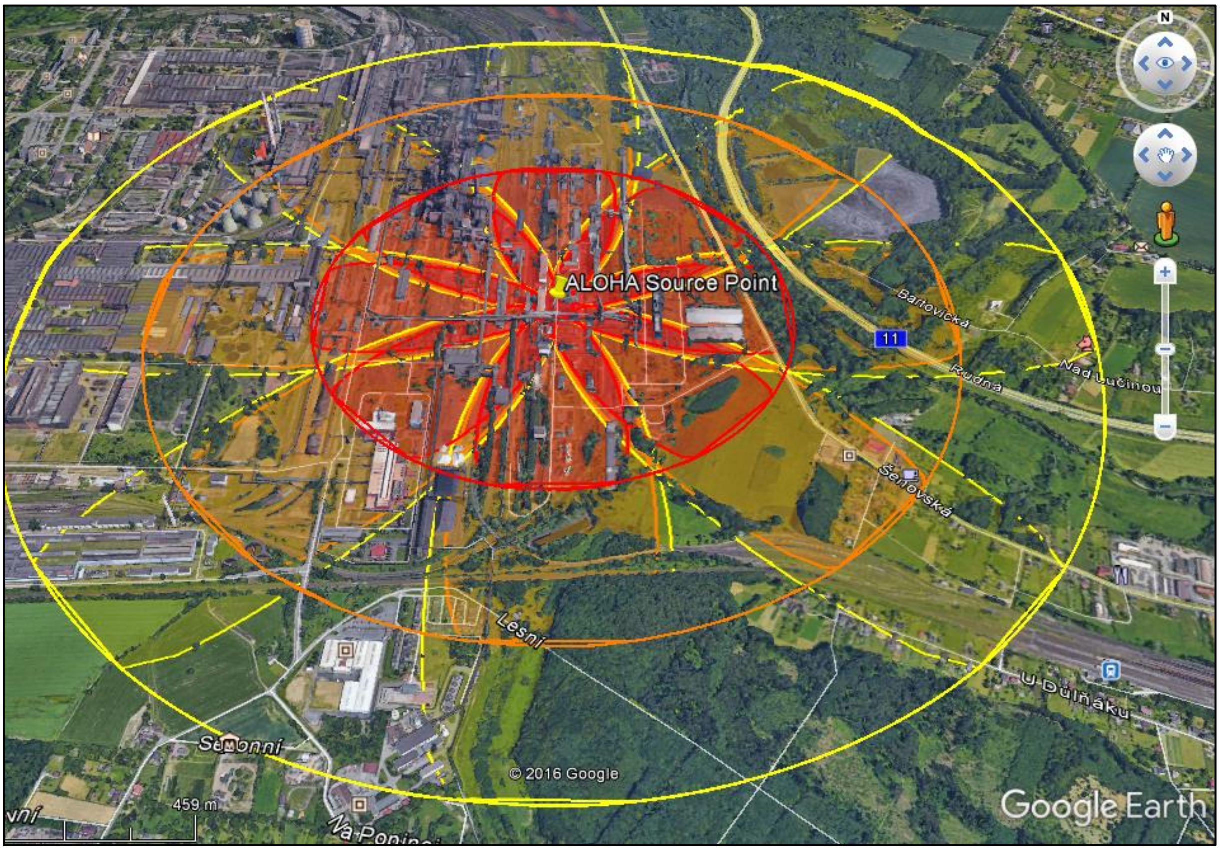

Figure 1. *Modelling of the results for scenario 4 of carbon monoxide by ALOHA visualized in Google Earth Pro software with original data given by ALOHA*

However, the principal disadvantage of this solution is the inability to create a legend, further data processing, data analysis, etc. Therefore, we have decided to use commercial software ArcGIS, which contains all the tools previously mentioned.

The results of hazardous zones obtained by ALOHA are summarized in Fig. 1–3 and Tab. 3. Fig. 2 below (scale 1:30 000, north at the top) is a visualization by ArcGIS for Scenario 1: 25 °C, air stability class D, wind speed 5.0 m/s, most probable atmospheric conditions, and different wind directions. The source release point is indicated as a red circle in the centre of Figure 2.

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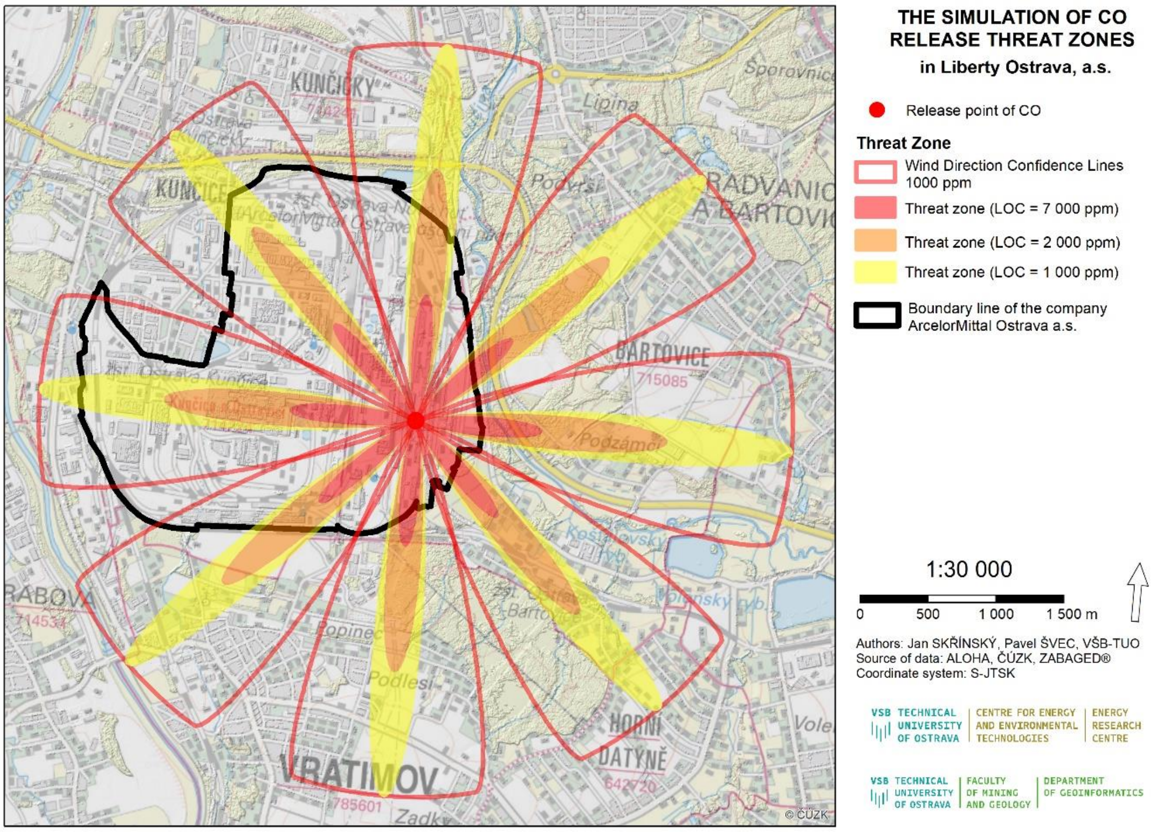

Figure 2. *Modelling of the results for scenario 1 of carbon monoxide by ALOHA visualized in ArcGIS software with original data given by ALOHA*

The curves in Fig. 2 show the iso-lines with the same concentration of carbon monoxide in the atmosphere around the source point of the carbon monoxide pipeline for the given conditions. The red curve represents a concentration of 7000 ppm; the maximum estimated carbon monoxide concentration corresponds to 50% of the mortality at a 30-minute exposure time. The orange threshold curve represents the concentration of 2000 ppm; the maximum estimated carbon monoxide concentration corresponding to 10% of deaths at a 30-minute exposure time. The yellow curve represents the concentration of 1000 ppm; the maximum estimated carbon monoxide concentration corresponding to 1% of mortality at a 30-minute exposure time. The ALOHA program calculated the range of outdoor concentrations in Liberty Ostrava as follows: 7000 ppm (red curve) could be measured at a distance of 552 m, a concentration of 2000 ppm (orange curve) at a distance of 1.1 km, and a concentration of 1000 ppm (yellow curve) even at distances of 1.6 km. The conditions with corresponding given temperatures for all wind directions in specific classes were modelled at specific air stability classes. The following Table 3 provides an estimate of the consequences for scenarios 1–4.

Table 3. *The summary of modeling*

Scenario	**1**	**2**	**3**	**4**
Rate of discharge:	95.6 kg/s	101 kg/s	21.1 kg/min.	21.1 kg/min.
Amount released:	5735 kg	6041 kg	1264 kg	1264 kg
Length of the cloud:	1.6 km	1.1 km	55 m	207 m
Fatal distance:	552 m	403 m	21 m	75 m

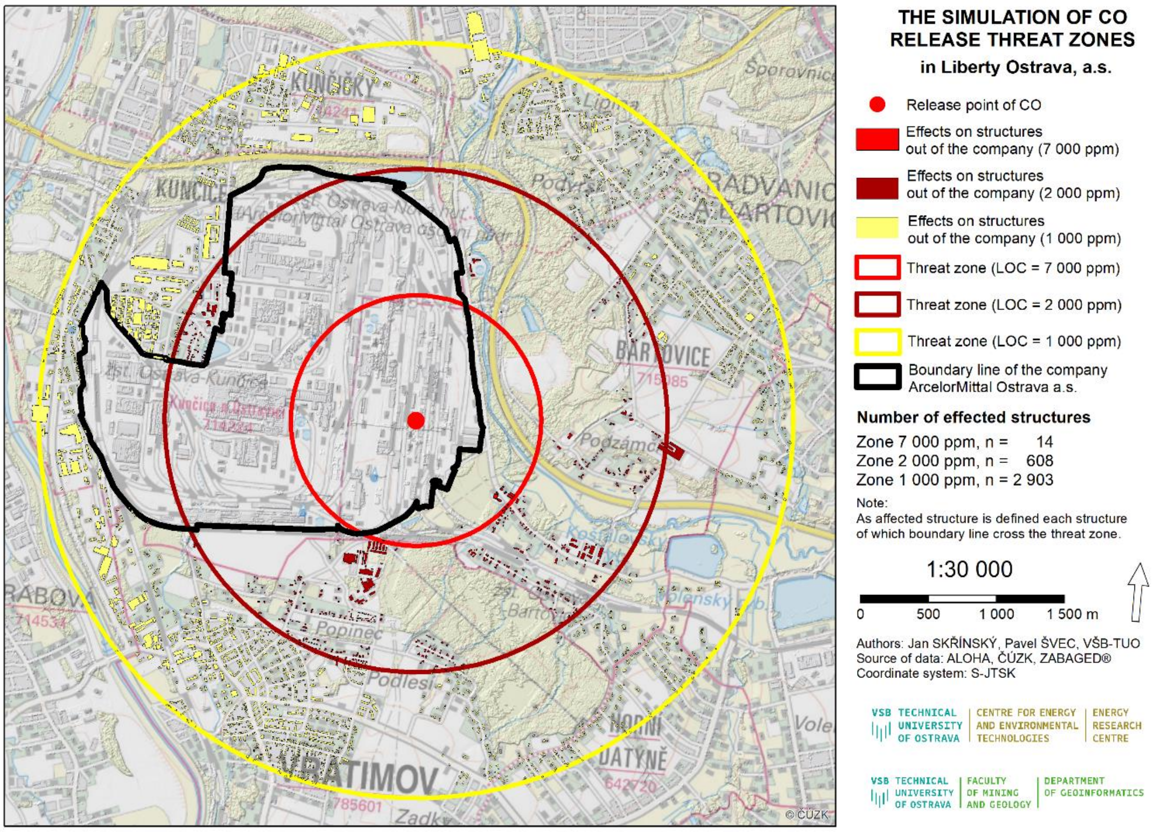

Figure 3. *Modelling of the results for scenario 1 of carbon monooxide by ALOHA visualized in ArcGIS software with the usage of the buffer*

The curves in Fig. 3 represent the estimation of affected structures. Using the spatial query, we chose all the structures, and which boundary line touched each threat zone (Fig. 3). To fulfil the maximum safety level, we used a conservative approach. Then, reached structures in the selected zones were considered affected. Only structures outside Liberty Ostrava a.s. the factory were considered. 14 structures have been chosen for the threat zone level of concern of 7 000 ppm; 608 structures for the threat zone level of concern of 2 000 ppm, and 2 903 structures for the threat zone level of concern of 1 000 ppm. In case we had the data on the number of inhabitants at the level of individual buildings from the register of inhabitants, it would be possible to calculate the exact number of affected people. Unfortunately, these data are not available to the general public in the Czech Republic.

5 CONCLUSION

Model releases and dispersion of toxic gas carbon monoxide in the case study have been investigated and their possible consequences are discussed in our paper. Our results can be employed when preparing more sophisticated simulations based on computational fluid dynamics modelling [9–10] and wind tunnel experiments [11]. Furthermore, we aimed to investigate the limitations of standard models and their improvement. ArcGIS software proved as a suitable tool for the visualization of ALOHA outputs.

Vol. 68 (2022), No. 2
pp. 151–157, ISSN 1802-5420
DOI 10.35180/gse-2022-0077

ACKNOWLEDGMENTS

This work would not have been possible without the financial support of the Technology Agency of the Czech Republic, project No. SS02030008, Programme: Prostředí pro život.

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