SEISMIC RISK MANAGEMENT OF LIFELINE SYSTEM IN URBAN INFRASTRUCTURE

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Abstract. *Evaluating the risk of natural disasters is an intensely debated issue, both on national and international level. In the present paper, after a brief review of the international research in this field and an introduction in risk management, we insisted on risk analysis of an urban area, called urban system. More precisely, we investigated the evaluation of risk and the behavior of the pipelines infrastructure characteristic to an urban area during an earthquake.*

By taking into account a certain region in Iasi city area, we present a methodology of evaluating seismic risk of the utilities network of the region. The methodology consists in establishing the necessary steps to be taken in such an evaluation. These steps are also graphically displayed for the gas pipelines of the area, and emphasizing the critical points existent in that sector (e.g. gas stations).

Using the cellular automata technique, inspired from the artificial intelligence and complex system fields, based on the GIS map of the analyzed region, we obtained a map with the risk areas in case of an earthquake, taking into account the gas pipelines network and the existing critical points.

Key words: risk management; lifeline system; urban system; Geographical Information System; cellular automata.

1. The International Context and National Strategies

International Strategy for disasters prevention

The general objective of the strategy is to enable all societies to overcome natural, industrial, and environmental disasters in a way that enables the reduction of environmental, human, economic, and social losses. Based on this, the following four objectives were identified (Tusler, 2005):

- Increasing the awareness of the public to promote an understanding of risks, vulnerability, and prevention of disasters at international level;
- The involvement of public authorities in the implementation of policies and actions in the area of disaster prevention;
- The promotion of multi-disciplinary partnerships, including the extension of prevention networks;
- The improvement of scientific knowledge in the area of disaster prevention. Thus, the scientific and academic sectors are directly involved.

To attain these objectives, a number of areas of general interest were defined: some of these concern the evaluation of vulnerability, some concern

the management of ecosystems, land, urbanism sauvage etc. and, finally, others concern legal instruments relating to disaster prevention.

Another important stage in the battle against disasters was marked by World Conference on Disaster Reduction which was held in Kobe, Japan, in January 2005. At the end of this four-day conference, a final document, the Hyogo Framework for Action 2005-2015, was adopted, which provides a reference framework for the measures to be taken over the next decade. A Final Declaration was also adopted at the conference. The measures defined in the Framework for Action involve governments, international organizations, and civil society. They also incorporate all decision levels, i.e. local, regional, national, and international. The conference highlighted the urgent need to establish prevention and preparation programmes which are better coordinated at global level.

At European level, at Commission and national level of each member state, the majority of cooperation and development strategies, either those of the OECD's Development Cooperation Directive (DAC) include now the evaluation of risk and disaster management. At European Commission level, a humanitarian aid department (ECHO) was created in 1992 with the goal of providing aid to the victims of humanitarian crises outside the European Union. In view of the scope and repercussions that natural disasters can have in the most vulnerable countries, ECHO launched its disaster preparedness programme DIPECHO (Disaster Preparedness ECHO) in 1996. The basic objective of this programme is to reduce the vulnerability of populations to natural disasters, offering support to different projects targeting the integration of disaster preparedness measures in aid operations and in development programmes.

2. Basic of Disaster Risk Management

Disaster risk management seeks to comprehensively reduce the disaster risk to which people are exposed in disaster-prone regions. The top priority is to reduce the population's vulnerability to earthquake, floods or storms, and prevent the emergence of new risks(Kohler and Schaef, 2004).

Risk management is a systematic management of the process exposures to achieve its objectives in a manner consistent with public interest, human safety, environmental factors, and the law. It consists of planning, organizing, leading, coordinating, and controlling activities undertaken with the intent of providing an efficient pre-loss plan the minimizes the adverse impact on risk on the organization's resources, earnings, and cash flows (Tusler, 2005).

2.1. The Elements of Risk Management

Risk Management comprises two key elements: **Risk Assessment** and **Risk Control**.

Risk Assessment can take place at any time during the implementation of a project, though the sooner the better. However, Risk Control cannot be effective without a previous Risk Assessement. Similary, most people tend to thing that having performed a risk Assessement, they have done all that is needed. Far too

many projects spend a great deal of effort on Risk Assessement and then ignore Risk control completely.

The Assessment of Risk focuses on three elements:

- **Identify Uncertainties** explore the entire process plans and look for areas of uncertainty.
- **Analyze Risks** that which specify how those areas of uncertainty can impact the performance of the project, either in duration, cost or users requirements.
- **Prioritize Risks** when it is established which of those Risks should be eliminated completely, because of potential extreme impact, which should have regular management attention, and which are sufficiently minor to avoid detailed management attention.

The Control of the Risk comprises three elements:

- **Mitigate Risks**: take whatever actions are possible in advance to reduce the effect of Risk. It is better to spend money on mitigation than to include contingency in the plan.
- **Plan for Emergencies**, for all those risks which are deemed to be significant, have an emergency plan in place before it happens.
- **Measure and Control**: track the effects of the risks identified and damage them to a successful conclusion.

3. Urban Lifeline System exposed to natural disasters' effect

A city or an urban agglomeration can be easily considered as a system. To understand how this system works, we analyze the city using two main approaches. In the first approach, one defines the urban components and the system's functioning, its representative indicators, their characteristics as urban resources, and their vulnerability. In the second approach, one analyzes the elements of risk and their distribution in the urban components (Ancas, Doniga and Atanasiu, 2006).

The urban system can be studied from several points of view. It can be seen as a place of heterogeneous groups of humans congregating, a place of living, a place of economic, cultural, and administrative activities, and a place of power and decision-making. It is a place that also provides a certain number of services and occupies a specific place within a given geographical and decision-making environment. It is place where different systems converge, assuming specific shapes, and marking the urban identity and image, by radiating its influence.

3.1. The Operation aspect of Urban Lifeline System

Urban development and functioning are dependent of a numerous internal relations between its urban components. The damage caused by an earthquake to the same elements of risk in two different cities, will not create the same disruptions and consequences for the whole system. The corresponding impact of the disaster will depend on internal and external relationships, and possible

functional substitutions of damage elements. This means that the risk analysis must not only consider the vulnerability of elements at risk, but should also assess the failure and resistance chains due to interdependency of the main functions, activities, decision-making, and human behaviour in an urban system.

Thus, a city can de defined as an **open working system**, as it is the place of numerous social, economic, political, and physical exchanges. The urban system is not only dependent on inner flows, but also on its external environment and relationship at regional, national and international levels.

3.2. Risk Analysis for the Urban System

In analyzing the risk for an Urban System, the following seven components are defined:

- Populations: inhabitants, workers, tourists, transients, demographic distribution, demographic growth, etc. The inhabitants are the city's heart and a part of the city's vulnerability
- Urban space: natural environment, built-up environment (buildings, infrastructure, lifelines etc.), and policy environment (spatial organization, land-use, urban fabric and natural features, natural resurces)
- Urban functional activities and services bear on the main urban services: housing, supply, sanitation, transportation and communication, social and emergency functions, presenting different levels of adaptation to seismic threat.
- Urban activities respectively economic, administrative and cultural activities those are variably vulnerable to earthquakes
- Urban government and actors: institutional, socio-economic, and political organizations, urban actors, urban policy, decision-marking process with special emphasis on emergency management
- Identity and culture: social cohesion, local culture and history (with special emphasis on the culture and memory of risk), symbolic images and representations, etc.
- External radiance: symbolic features, external image and representations, regional position, etc.

Considering an analytical approach, the **Urban System** can be characterized by three categories of values: material, human, and immaterial, potentially exposed to natural risks. These categories are:

a) Material assets represented by classes of:

- **Buildings:** housing, economic activity units, administrative activity units, cultural and sports activity units, urban-function units;
- **Main infrastructures and roads:** transportation terminals, civil engineering infrastructures, highways, roads, streets, bridges, etc.;
- **Lifelines and reservoirs:** energy systems (electricity, gas, oil, etc.), drinking-water system, sewagw system, waste-disposal system, telecommunications system, radio system, etc.;
- **Patrimony:** natural resurces as woods, waters, etc., historical buildings, other physical symbols;

- **Areas or geographic units** identified as being homogeneous according to the urban frame.

b) Human assets:

- **City users,** composed of: citizens, visitors, workers, etc.;

- **Urban actors at different levels**: institutional and socio-economic managers, political and economic actors, decision-makers, public-service representatives, health and crisis-management specialists, etc;

-Outstanding personalities: key political figures, captains of industry, well-know artists, etc. Such persons can play determinant roles in city life, either directly such as the mayor, or indirectly such of captains of industry.

c) Immaterial elements

This category includes certain symbols or representations of the city related to inhabitants, its image, its culture, or to social fabric or history. One place will be considered as particularly young and dynamic, whereas another will be known for its calm and good life. Such immaterial and subjective-though quite real-elements share in a city's development and its position in reletion to the outside word. Just like the other elements, they are vulnerable to a major disaster such as an earthquake. In this chapter one can include:

- identity: culture, history, social cohesion, preparedness, and

- **radiance of the system:** projected image, external relationship.

To evaluate the consequence of a disaster such as an earthquake, the method aims at identifying the essential elements for the functioning and development of an urban system. This refers to the elements of "significant value", in terms of socilal or utility value for city operations. This ranking is necessary for fine-tuning the vulnerability analyses, by subjecting the main issues to in-depth analysis and limiting the secondary use to a rapid evaluation (Schmid, 2006).

The aim of the Urban System Exposure approach is to evaluate the role of these elements at risk in the urban system's functioning. In order to do it, it's necessary to use some adapted tools.

4. Seismic Risk Assessment of Lifelines Systems

4.1 Risk definition

The first step in Project Risk Management is Risk Assessment and the next one is Risk Control. Risk Assessment implies the inventory of all risk elements encountered in the area in question, their analysis as well as establishing an indicator for each of them, according to its importance in case of a natural disaster of on earthquake. Naturally, according to this indicator, a hierarchy of all these risk elements shall be settled. As seen, an urban system is characterized by three elements exposed to risk: material elements, human elements, immaterial elements.

A high risk within an urban system appears in the lifelines systems (material elements), whose efficiency is reflected in the development and evolution levels of the society in question. These systems represent a complex

set of components and subsystems essential in sustaining and developing the life of the community.

The modern society is totally dependent on an installation infrastructure which a subsystem of the lifelines system made of numerous different networks. The common factor is: to provide utilities without which the society could not exist: water supply, sewage, gas distribution, power supply, telecommunications network, etc.

The risk assessment of lifelines, infrastructures and essential facilities follows the general equation, used also by (Pitilakis, Alexoudi et al, 2006):

{Seismic risk } = [seismic hazard] x [vulnerability] x [elements at risk] (1)

The complexity of elements at risk in the case of lifeline systems, their variability from one place and one country to another, and tiil recently, the lack of well validated damage and loss data from strong earthquakes, make the vulnerability assessment of each particular component and of the network as a whole, a very difficult problem. Adding to that the spatial extend of lifelines, the synergies between different systems and the uncertainties in seismic hazard estimates, it is obvious that the risk assessment of lifelines is indeed an extremely complex and challenging issue. This is probably the reason why seismic risk assessment of lifelines has been of limited use for the management of emergencies and natural disasters.

The research performed lately around the world lead to significant advance in discovering new data, useful in preparing the community for the direct and indirect loss derived from the damage provoked by an eventual earthquake (Pitilakis, Alexoudi et al, 2006). The implementation of a new methodology for risk assessment leads to the minimization of the damage. The risk, once established may help determining the priorities in risk management in order to evaluate and compare the risk level to the specific standard one.

4.2. Seismic Risk Assessment of Lifeline Urban Infrastructure post - Earthquake

4.2.1. Socio-Economical Impact

The functioning of the installation infrastructure **during and especially after** a destructive earthquake is of vital importance for the society and contributes to the rescue and emergency operations, as well as to weighing the anchor. The malfunctioning or the nonfunctioning of certain systems within the infrastructure leads, in the best case scenario to the breaking of a branch of the network in question, this fact leading to losses on a certain area more or less important in the urban system. That is why, within a settlement, when assessing the risks it is necessary the division of the area in question in certain sectors of importance, assigning an indicator for all the sectors with the same degree of

relevance: maximum, medium and low. Establishing this indicator is based on an evaluation of the losses induced by a natural disaster: direct and indirect economic loss, human, material and immaterial losses as well as on a precise evaluation of all prejudice (Masure and Lutoff, 2006).

The development of IIS and respectively GIS ensures an excellent platform for the efficient implementation of the risk analysis methodology in an urban area.

In the future, each city exposed to a certain seismic risk has to benefit from a real warning system. The emergency services predict the intensity of the damage and the spatial distribution for the future events, estimate the losses for each material and immaterial risk elements and the strategies to reduce them, founding the implementation of certain intervention strategies in case of a seismic event.

4.2.2. Basic Characteristics of Building Services Infrastructure

The installation infrastructure is composed of several systems and pipe networks essential and singular, each system having its own distinct characteristics: the transported agent, the served area and implicitly the corresponding number of consumer, the indicator of the served area etc.

These networks are made of lines and joints with different typologies. Being familiar with these typologies is an important step in risk assessment. The malfunction of some of these networks represents a higher risk according to, for example, the importance of the served buildings: hospitals, kindergartens, firemen stations, governmental buildings, etc.

In conclusion, the basic characteristics of the installation infrastructure are:

•Spatial distribution in the serviced urban areas;

•Different typologies for each system.

Any system is given by own intrinsic features as the name of the network and its functionality and respectively the interactions and the synergies between various systems.

4.2. 3. A Methodology for Seismic Risk Assessment in Urban Area

The following essential steps for assessing seismic risk in urban area cause identified:

a) the establishment inventory data: comprises the identification and the classification of all subsystems according to their typology, with geometric functional and structural characteristics. The attributes of each location, the geometry, the material properties, the wear and tear degree, the level of seismic projection are considered starting point data in establishing the seismic risk.

This information is gathered distinctly for a certain utilities net: for example for a water supply, the inventory comprises:

• General information

The geographic location-coordinates, the coordinates of the location of the pressure valves, the exact locations of connections, the locations of the shafts, the flap doors, etc, the location of the isolation valves. In case of their absence - the isolated pipe segments – spreading area, served consumers.

• Geometrical and constructive details

Length – m, type, fragile, ductile, diameter-mm, width – mm, apparent or buried, material, tensions, type of connection, tolerance to rotation, height, type of cover, type of material protection, operational-characteristics – free, under pressure, working pressure, transported agent, year of construction, corrosion (yes, no, possibly, I don't know), the executed repairs, method of repair.

• Urban and economic characteristics

Type of served consumers – important, regular, connection to critical facilities-hospital, police department, direction options, pipe segment evacuation time, economic costs of construction, cost of reconstruction after an earthquake.

b) the establishment of the "global value": the global value of each risk element does not depend directly on the human or physical value, but also on the material-immaterial value represented by the utility and the purpose of the urban system in a certain moment. The indirect value can be different according to the situation and time circumstances. That is why the assessment is performed during three stages: **normal, crisis** and **restoration**. The global value for each element depends on each operational attribute, soil, influence on the population, human losses, socio-economic impact during the three stages. Thus, the qualitative and quantitative indicators are defined based on a certain period. For example the indicators and the measurement sizes may be proposed for each system. These steps are:

- Defining the adequate criteria for estimating the global value for each risk element- collecting all data requested for evaluating the global value.
- Collection of all necessary data required for the evaluation of the global value
- Establishing a relative value from 0 to 1 for each risk element and for each stage.
- Identifying the main result, important and secondary for each stage.

A typical example of the selected indicators for gas pipes lines is givin in Table 1. The method has been applied for the gas and other utility and transportation systems in urban system. Risk management priorities in terms of post seismic restoration strategies, pre-seismic retrofitting decisions and co-seismic rescue are influenced by this description of global value.

Indicator	Measuring Unit	Relative Value	Period		
			N	C	R
Function (supply diameter)	D≥200 mm. D∈ (200, 150] mm. D∈ (150, 100] mm. D < 100 mm.	1.00 0.75 0.50 0.25	+	+	+
Emergency	Yes	1.00	-	+	-

	No	0.00			
Radiance	Subsystem of pipes Transmission pipes Distribution pipes	1.00 0.50 0.25	+	-	+

Table 1. Indicators and value scale for gas pipelines

A relation for estimating the global value is the one presented below, after (Pitilakis, Alexoudi et al, 2006).:

Global value = Σ (Relative values selected for each period) (2)

At the end of the evaluation, each element considered in the analysis is characterized by one or several relative values and three global values: one for the development period, one for the critical period and the last for the recovery period. Thus, this evaluation method allows a comparison between two elements in terms of importance for the city, even if they are not evaluated according to the same indicators.

c) the establishment of the interactions which represents the high interdependency between different systems is a very important aspect in the study of the seismic risk. Thus, the interactions may be very important, leading to direct consequences.

Subsequent to the establishment of the inventory data, the interactions between the systems may be identified, as belonging to three different categories:

- the physical interaction represents the physical propagation of the damage, as the damage of some pipe networks caused by the coming down of a bridge, etc.
- the functional interaction represents the functional propagation of the damage, that is the fall out of certain components of a network, leading to the seizure of the entire system
- the imposed interaction represents the closure of a system for a limited period of time in order to execute certain repairs.

Subsequent to establishing this data, one can assess the risk in case of a seism to which an installation infrastructure from a certain urban background is exposed. Thus, we can move forward to the steps to be followed within the project: **Risk Control** with its three elements: **risk mitigation, plan for emergencies, measure and control.**

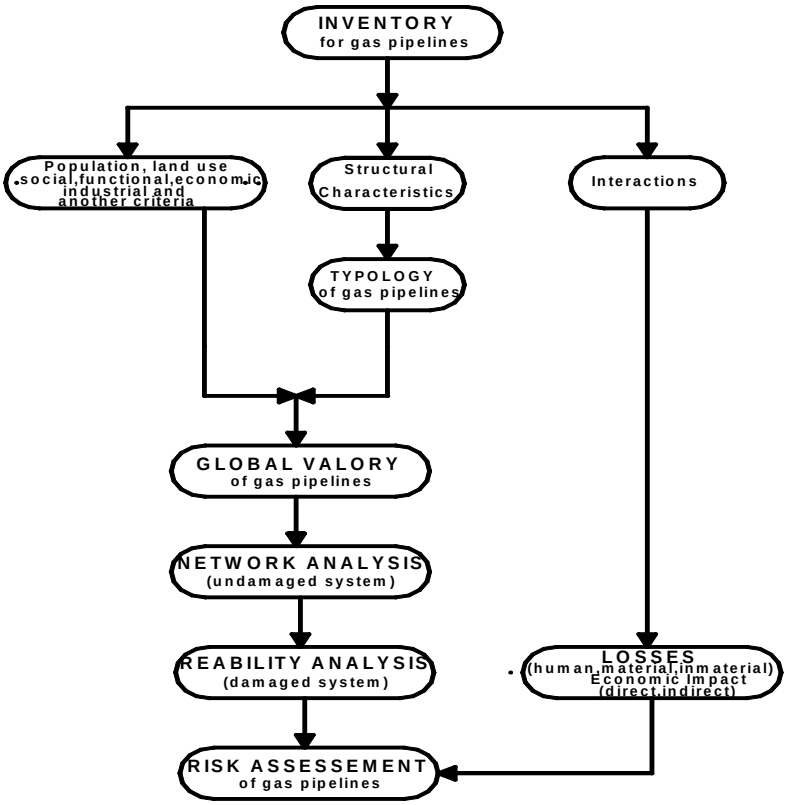


Figure 1. Flowchart of risk assessment methodology of gas pipelines
Adapted after (Pitilakis, Alexoudi et al, 2006).

Figure 1 describes the main steps of proposed methodology for risk assessment in case of gas pipelines supply.

Inventory, classification and typology definition are the necessary steps to describe the elements exposed to seismic risk and to quantify their importance in normal, crisis (i.e. earthquake) and recovery period. Vulnerability is the expected response of an element (building, bridge, pipeline, roadway, oil tank, etc.), or a network of specific elements (i.e. gas system) to a specific earthquake event, defined in the seismic hazard analysis. The estimation of site specific seismic ground motion for different earthquake scenarios is the basis of the seismic hazard analysis.

The development of the Geographical Information System (GIS), (http//: www.datainvest.ro) technology offered an excellent platform for the implementation of efficient and innovative techniques (Atanasiu and Galea, 2005). Several procedures were proposed for lifeline risk assessment in urban environment, aiming to minimize losses, enhance the reliability of the systems or to improve mitigation policies.

5. Case Study on Iasi urban sample

Following our objective of preventing the disasters effects on people safety from a dense populated urban area we choose from the digit map of an area of Iasi city presented in **Figure 2** an urban generic sample which includes the gas station and gas pipelines afferent the zone.

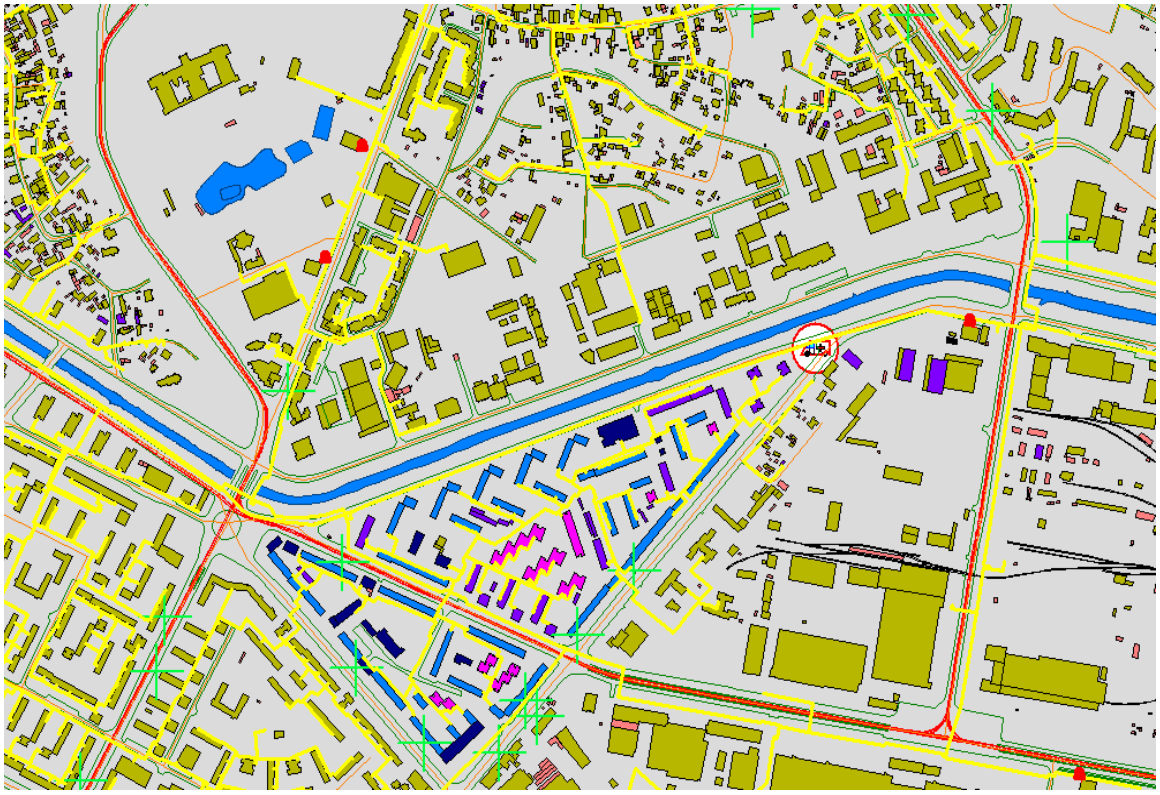


Figure 2. GIS map of an urban sample of Iasi City, Romania

For the case study we have considered an urban sample of Iasi, where the gas stations and gas pipelines have been identified and located using GIS technology. The goal of the study was to analyze the seismic risk of the analyzed urban sample of Iasi, by using specific tools of artificial intelligence IA cellular automata, originating from the field of complex systems/artificial life.

Cellular automata (Schatten, 2006) are discrete dynamical systems and are often described as a counterpart to partial differential equations, which have the capability to describe continuous dynamical systems. The meaning of discrete is that space, time and properties of the automaton can have only a finite, countable number of states. The basic idea is not to try to describe a complex system from "above", to describe it using difficult equations, but simulating this system by interaction of cells following easy rules. In other words the idea is not to describe a complex system with complex equations, but let the complexity emerge by interaction of simple individuals following simple rules.

The essential properties of a cellular automaton are:

- a regular n-dimensional lattice (n is in most cases of one or two dimensions), where each cell of this lattice has a discrete state,
- a dynamical behavior, described by so called rules. These rules describe the state of a cell for the next time step, depending on the states of the cells in the neighborhood of the cell.

The basic element of a cellular automaton is the cell. A cell is a kind of a memory element and stores the states. In the simplest case, each cell can have the binary states 1 or 0. In more complex simulation the cells can have more different states. It is even possible that each cell has more than one property or attribute and each of these properties or attributes can have two or more states.

These cells are arranged in a spatial web, a lattice. The simplest one is the one dimensional "lattice", meaning that all cells are arranged in a line. The most common cellular automata are built in one or two dimensions. The one dimensional cellular automata have the big advantage that they are very easy to visualize. The states of one time step are plotted in one dimension, and the dynamic development can be shown in the second dimension. A flat plot of a one dimensional cellular automata hence shows the states from time step 0 to time step n. Consider a two dimensional cellular automata: a two dimensional plot can evidently show only the state of one time step. So visualizing the dynamic of a 2D cellular automaton is by that reason more difficult.

One can arrange the rules of a cell state change in two classes:

- every group of states of the neighborhood cells determines the state of the core cell;
- the state of the next state core cell is only dependent upon the sum of the states of the neighborhood cells

Based on the IA judgment the GIS map of the Iasi urban sample has been divided into a grid of small (pixel-sized) cells. To each cell could be assign one of 3 values, representing different level of seismic risk: for no seismic risk (green);1 for the case of moderate seismic risk (yellow) and respectively 3 for major seismic risk (red).

To each cell a value is assigned, according to one of the following rules:

• if a cell is at a distance less than 5 cells from a gas pipelines, than mark it as a major risk cell;

• if a cell is at a distance less than 15 cells from a gas station, than mark it as a major risk cell;

• if a cell is at a distance less than 15 cells from a major risk cell, than mark it as a moderate risk cell;

• otherwise, if none of the above rules apply, then mark the cell as a no risk cell.

Using the above described technique the seismic risk map of the sample of urban area of Iasi, represented in Fig. 3 has been developed.

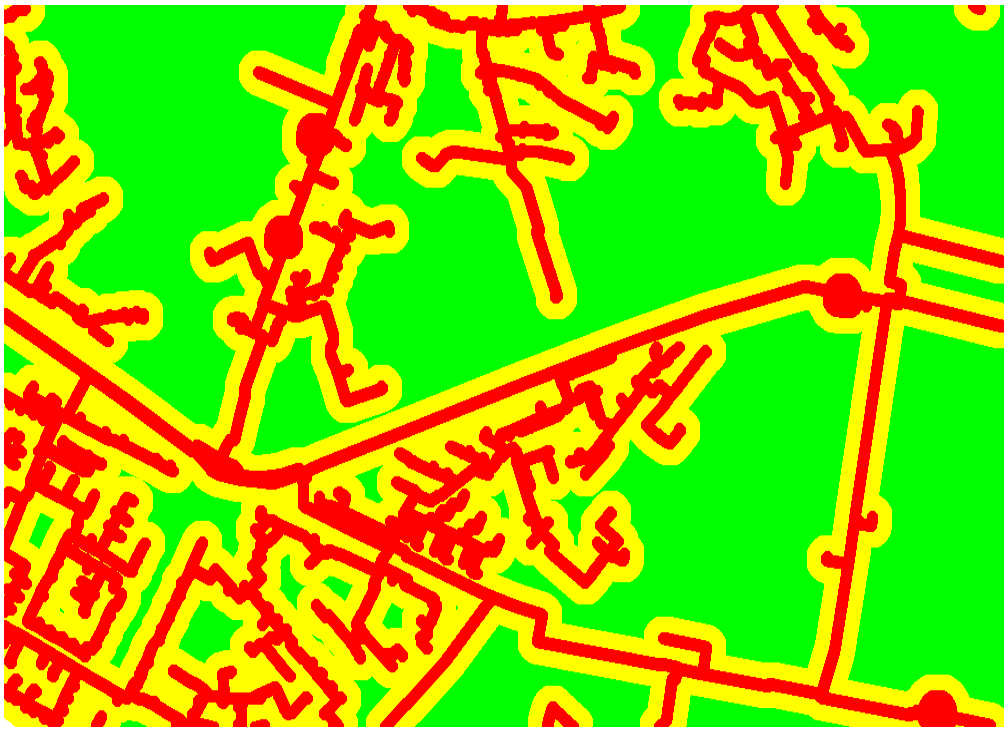


Figure 3. Risk map for the gas pipelines and gas stations of Iasi urban sample

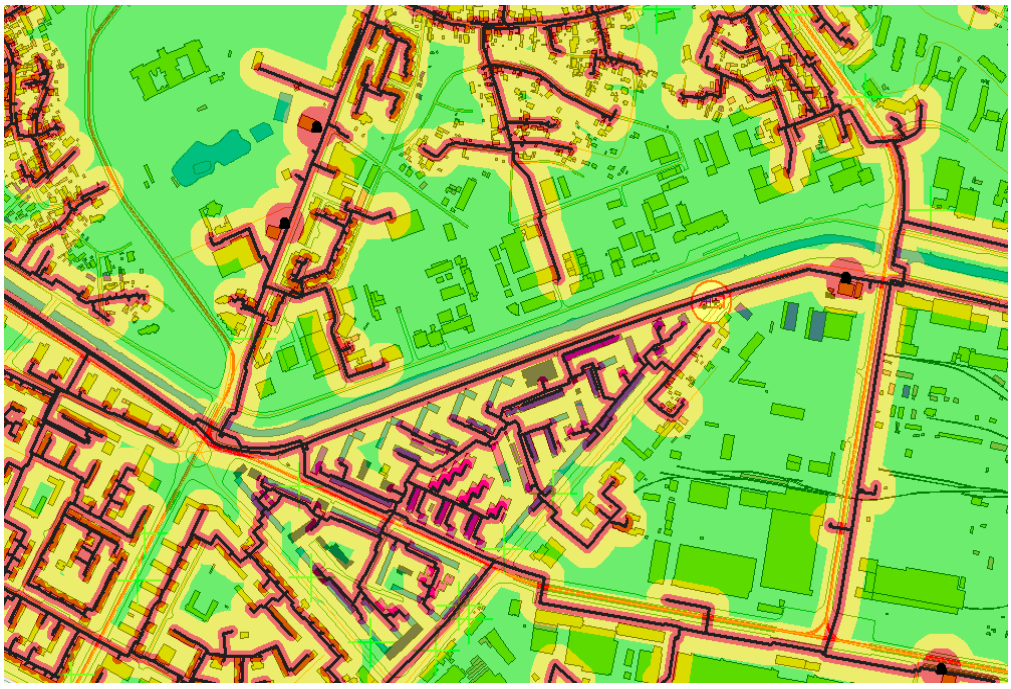


Figure 4. GIS based identification of seismic risk on lifeline infrastructure of Iasi

The seismic risk map focused on Lifeline Infrastructure was later on superposed on GIS map of Iasi urban sample, as shown in **Fig.4**. The gas pipelines and gas stations are marked as dark gray, and the seismic risk due to lifeline exposure to a possible seismic event can be now identified on urban sample of Iasi, analyzed in the case study, marked using a transparency effect.

6. Conclusions

An important stage in risk management of urban areas is risk assessment. Within an urban settlement the risk elements are numerous and of high importance, depending on the study of the phenomena implying the risk in question: earthquake, fire, etc. In case of the risk assessment of the city focused on building equipment and installations, respectively lifeline infrastructure all inventory elements must be known, in terms of systems interaction. Only an "in depth" knowledge of all the elements leads to a correct risk assessment of the analyzed and studied phenomena. Most certainly, the problematic is very generous, project risk management being a broad theme, which can only be solved by structuring the project into subchapters, with a clearly defined project theme each (ex. risk management in case of a flooded urban settlement).

The present paper focused only on one risk element, respectively on the potential seismic risk on the installation infrastructure of an urban situ, with application to Iasi, in case of a seismic event.

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