A Methodology for Designing an Information System for Road Infrastructure Monitoring and Traffic Management in Disasters

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Abstract. The impact of natural disasters and other adverse events on road infrastructure leads to a partial reduction or complete renunciation of its working capacity. Currently, there is no online-based information system to disclose and manage traffic in the event of a problem or disruption of a transport segment from the road infrastructure. The main purpose of the paper is to present a common methodology for designing a cloud-based online information system for road infrastructure monitoring and traffic management in disasters. The methodology of the information system is based on traditional geographic information system (GIS) solutions, Web-based technologies and GPS navigation systems.

1. Introduction

Successful implementation of passenger and freight transport is a complex task that is directly dependent on the working capacity and quality of road infrastructure [1], [2]. In a number of cases, when a disaster occurs, road infrastructure is compromised and it has a reduced or totally discontinued ability to perform its functions [3]. In such cases, it is important for the disaster services to properly register and map them and to take the necessary steps to overcome the disaster situation, and to inform the public of the dangers and actions they have taken [4], [5]. Specifically, for transport infrastructure, this means that the affected transport sections must be marked on the relevant map and more specific information concerning the time of occurrence, estimated time to solve the situation and other important information that has to be entered into the database in which these events are recorded [6], [7].

In the event of a disaster in the area where it has occurred and developed, it is necessary from the operational point of view to carry out a number of measures for reallocation of the traffic on alternative arcs of the transport network with a view to minimizing the complexity of the operation of the transport. Recently, the so-called "intelligent transport systems" have been developed to achieve dynamic driving and navigation [8], [9]. By their nature, they are still in the area of traffic safety and they have information-advising role on the navigation of individual means of transport. In these information-advising systems, the so-called transport and flow-through tasks that provide alternative pathways in the event of a problem with a given point on the network, based mostly on the criterion of "shortest" or "fastest" traffic workaround.

Regarding the magnitude of traffic in the road network, there are a number of developments in the field of real-world information systems and applications, while in terms of the impact of disasters on traffic, things have not yet developed enough and there is a front for systematization and development.

The fact is that there is still no developed unified and commonly accepted disaster mapping system, and there are separate developments mainly in the developed countries of Europe and the world.
The purpose of the paper is to present a common methodology for designing a cloud-based online information system for road infrastructure monitoring and traffic management in disasters. The main idea is to analyse and classify the adverse events resulting from disasters, taking into account their impact on the road infrastructure's working ability in transport. Common methodological guidelines are also formulated to create a cloud-based online information system that will improve traffic management in transport. The chosen model for operating the system is based on GPS information and navigation systems, GIS systems for mapping events at individual transport points and sections of the road network.

2. Classification, registration and mapping of disasters

The essence and main elements of classification, registration and mapping of disasters can be summarized as follows:

- Disaster is an event where there is a significant disturbance in the normal functioning of society that is caused by natural phenomena and / or human activity and it results in negative consequences for people's life or health, infrastructure, property, the economy and the environment. This creates a crisis situation that needs to be dealt with and managed, as well as it should be mapped and registered.
- Classification of disasters is done on certain features that characterize the origin of the event (natural and anthropogenic), the territorial scope (local, regional, global), the mode of occurrence (fast and slow) and duration (sudden, rapid and prolonged). The natural events are geophysical, meteorological, hydrological, climatic and biological, while the anthropogenic (as a result of human activities) are radiation accidents, industrial accidents, transport accidents and catastrophes, terrorist acts, humanitarian and social crises, fires, smuggling, etc.
- Mapping for disaster protection and crisis management is performed: before a disaster, during a disaster, after a disaster. It is also necessary to take into account the timing of the event and the time of eventual elimination of the consequences of the event. In addition, the individual stages of recovery and actions and information messages, instructions of a methodical and other nature can be registered.
- The mapping signage system, the meaning of which is a set of graphic signs and their meanings, including the rules for making the signs and applying them to the particular map, must be designed in such a way as to ensure readability, visibility, distinctiveness and consistency between the signs and their corresponding objects of reality [10]. Although there is no such a unified and universal standardized sign system, a simplified model of such a color rendering system can be used in this case on the elements of the transport infrastructure. Offered on a given point or section of the road, it is has been marked with the following colors: green, orange, red, and blue with "X" indicating the ability of the point or section to have maximum, disturbed, minimal working capacity or completely out of action.

The acquired accurate information serves the relevant specialized authorities to effectively manage and make quick and adequate solutions to the situation. This information serves as a means of risk assessment, planning of preventive measures, planning of protection and rescue activities, assessment of the affected areas, such as planning recovery activities.
The transport infrastructure is central to the overall state infrastructure and it is also under management, control and restoration of its working capacity. It is particularly important that the events of registering the problems in its working capacity or the faults caused by the disasters are known to the respective services and persons involved in the monitoring and restoration, as well as to the general public in order to prevent subsequent accidents and problems with the people, who are in or passing through a given region or transport segment.

3. A model for the operation of the proposed information system

The general model for the operation of the proposed information system is presented on Figure 1. This model represents possible options for both predicting potential hazards and disaster-related and post-disaster-related actions.

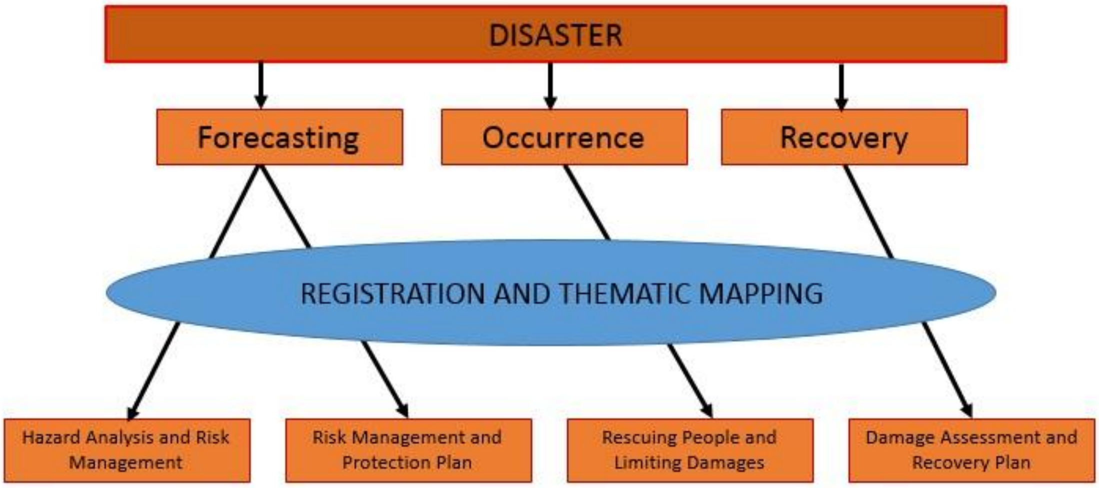

Figure 1. Model for registration and thematic mapping of disasters and actions for their forecasting, time actions and disaster recovery.

The following expression presents the main components of the recorded disaster as part of the set of all recorded disasters:

$$Disaster \in DISASTERS \left\{ \begin{matrix} disasterID(uniqueID), location(area), \\ time(begin, end), damages(people, equipment), \\ cash(direct, indirect), moreInfo(freeText) \end{matrix} \right\} \quad (1)$$

Generally, for each disaster registration, the area is mapped where damages are expected or occurred, the start and the end of the disaster period, breakdowns and casualties, direct and indirect cost of prevention, and an explanatory text describing another additional information related to the disaster itself.

A classification that should cover the proposed information system from the point of view of the mapping of the events for prevention and disaster recovery is presented on Figure 2.

An exemplary graphic model for representing the road network with the marked traffic zones, which are directly and indirectly affected by a disaster is given on Figure 3. The following areas of the road infrastructure are formed:

$$DisasterZone_i \begin{cases} All\ DangerZone_j, & where\ j = 0,1,2, \dots, J \\ All\ DifficultZone_k, & where\ k = 0,1,2, \dots, K \end{cases} \quad (2)$$

When using a ready-made GIS base, it is necessary for each element of the graphic road infrastructure to add information about the type of events caused by the disasters, the characteristics of thece disasters, the affected road sections, the corresponding time intervals and other useful information.

Figure 3 shows a model for the so-called "Quick" and reference maps that reflect the immediate impact of disaster events.

This graphical model is based on the Google Maps APIs toolkit [11]. An alternative GIS toolkit may also be used to develop the software, but this should be the result of a more thorough study of alternative technologies and the capabilities of their application development environments.

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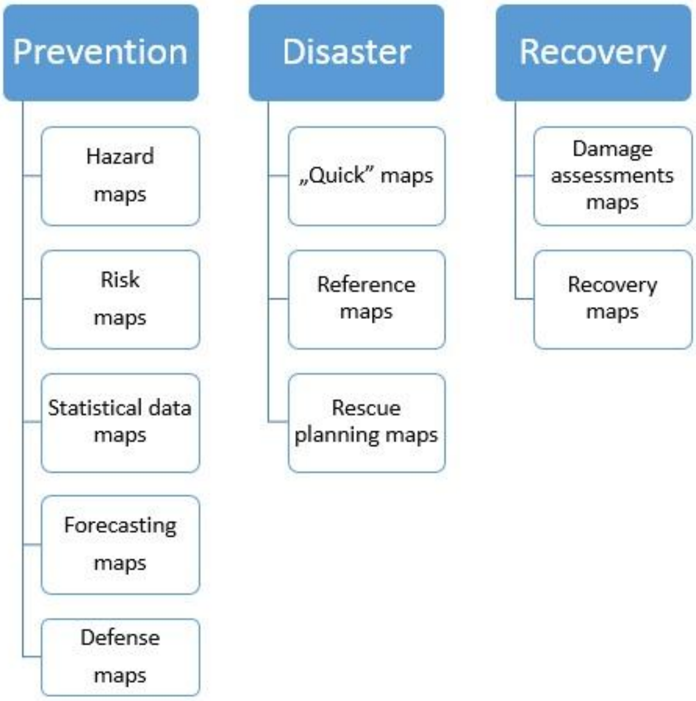

Figure 2. Classification of event mapping and disaster recovery events.

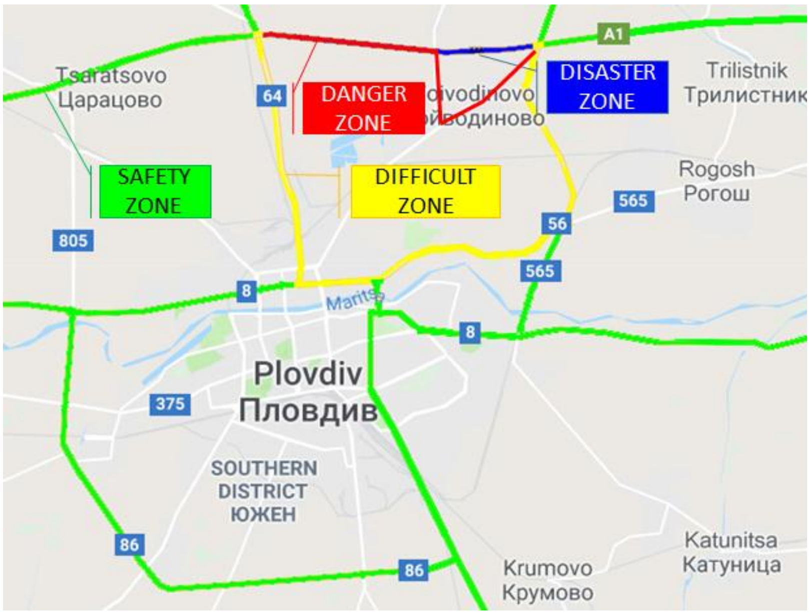

Figure 3. Graphical presentation of the road infrastructure by marking the areas affected by disasters.

4. Main methodological guidelines for designing of the information system

The presented issue for information service for crisis situations is quite complex for technical implementation and in any case it will be related to the building of a number of regional information systems, which in synchrony exchange and transmit data to each other, i.e. to work similarly to the model of the weather forecasting system.

This means they should be connected to sensors that record the disaster events and to have the appropriate governmental and other services to enter information into the database, including after receiving civilian signals and information. The information service of such systems is a responsibility of the respective specialized institutions for Civil Protection [12], [13] and Road Infrastructure system [14], [15].

Main methodological guidelines with regard to software technology:

- The environment should be built on modern cloud technologies including server, database and geo-data virtualization;
- The client part is a Web based interface, fully compatible with WWW Consortium (W3C) standards, supported by all popular Web browsers.
- A reference interface APIs should be setup that implement connection to GPS-based navigation systems.

5. Conclusion

The paper discusses the methodological issues for the registration of adverse events caused by natural disasters and crises and which affect the road infrastructure's efficiency. The issue of disaster thematic mapping, which is at the heart of the planning of prevention, action and disaster recovery, is considered.

The main focus of the paper is on the functioning of road infrastructure, which is related to the natural disaster events. They lead to a partial reduction or complete destruction of the infrastructure capacity, resulting in short and long interruptions of transport performance as well as to the heavier decommissioning of large-scale road infrastructure.

It is pointed out that all stakeholders should take into account the impact on road infrastructure efficiency of adverse events caused by disasters. Common methodological guidelines and requirements for their information provision and a cloud-based online information system have been formulated, which will improve traffic management in transport. The model of this information system is based on traditional GIS solutions, and a visualization is planned to be achieved through Web-based technology tools. This includes the use of information resources from modern GPS navigation systems.

6. References

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