A new approach to risk assessment from the Civil Protection perspective

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Abstract: Risk assessment is strongly necessary to carry out the Civil Protection functions, because it constrains and supports prevention activities and emergency planning and managing. In order to make risk assessment actually working into Civil Protection procedures, the need of a quite different perspective in risk assessment has been detected. At the same time many uncertainty factors have to be managed. For these reasons a new "universalistic", "systemic", "incremental" and "decision-oriented" approach to risk assessment as well as its technical implementation are proposed.

Key words: Civil Protection; risk assessment; risk zonation; territorial system; GIS; uncertainty, systemic risk

1. Introduction

Risk assessment is of primary importance to carry out the Civil Protection tasks, because it constrains and supports prevention and emergency activities, with regards to the localization and quantification of resources, best way to act, expected results, etc..

Usually, in order to assess the risk, several scenarios are defined and each one refers to a specific potentially dangerous event. Each scenario stems from a forecast analysis of the event and from the assessment of the potential vulnerability of the exposed elements. Normally, each scenario results in a specific emergency plan (Presidenza del Consiglio dei Ministri - Dipartimento della Protezione Civile, 2007). By using this approach, neither the possibility of simultaneous occurrences is taken into account, nor the capacity of an event to trigger off other events. Furthermore, this approach does not consider the potential interaction among territorial elements as a cause of the amplification of risk. These limits are very important for the effectiveness of the Civil Protection process, mainly if we refer to the emergency management. Then, a quite different perspective has to be assumed in risk estimation, in order to better fulfil the Civil Protection process requirements. Moreover, we have to face with uncertainty related to the risk estimation process although in a very general way.

For these reasons, a new conceptual formulation of the risk evaluation process is needed and technical instruments have to be implemented, in order to make risk assessment actually working into Civil Protection procedures. Toward these objectives, within an agreement between Tor Vergata University in Rome and the Province of Rome for the implementation of municipal and provincial Civil Protection plans, a new approach to risk assessment from the Civil Protection perspective and its technical implementation were developed.

2. Risk assessment from the Civil Protection perspective

Risk assessment from the Civil Protection perspective aims to support prevention activities, emergency planning and emergency managing. For this purpose it is necessary to take into account the possibility that more than one dangerous event can take place in the same time and in the same space and that some of them can trigger off others, and the possibility of damage to the whole territorial system, constituted by numerous and different elements (population, buildings, cultural heritage and environmental assets, infrastructures, etc.) and complex relationships among them.

Firstly this has to be done because prevention policies, aimed to eliminate or to reduce risk, can be more effective and efficient if we consider that:

- reducing risk for an element carrying out functions for other elements in the territorial system could, at the same time, reduce risk for all these elements;
- acting on a single feature of an element could reduce its vulnerability to more than one dangerous event;
- it is possible to realize greater benefits from reducing exposure in places where many dangerous events could happen.

At the same time effectiveness and efficiency of emergency planning and managing can be increased if typology, dimension and localization of resources are defined considering that:

- restoring or replacing the functionality of a territorial element could prevent more serious damage to other elements;
- the same resource could be useful for the same typology of elements in case of different dangerous events or for different elements exposed to the same dangerous event;
- the same resource could be useful in case different events happen at the same time, for one or more elements.

Besides these aspects, it is also important to consider that information produced by risk assessment have to be really useful in a complex process where many subjects (public institutional bodies, private bodies, emergency crews, etc.) coexist with different objectives and different approaches, but acting on the same physical or not physical elements (water, soil, breach of planning control, etc.) generating or amplifying one or more hazards and on the same vulnerability features.

3. Uncertainty in risk assessment

Because of the need to take into account at the same time the potential simultaneous occurrence of multiple events and the presence and the potential interaction of different territorial elements, the quantification of the risk, based on the commonly used Varnes' formula (Varnes, 1984) or United Nations' definition (United Nations, Department of Humanitarian Affairs, 1991), can be very difficult both from a methodological and a practical point of view. In particular it needs a totally quantitative assessment of:

- the probability that a dangerous event could be triggered off by another one;
- the vulnerability of each territorial element compared to all the others, both regarding to a single event and to all the considered events;
- the possibility of damage of a territorial element caused by the damage of another element carrying out functions for the first one;
- the value of each territorial element compared to all the others.

Consequently a quantitative assessment of the risk is not completely possible, because of the lack of historical data and of models concerning the relationships among dangerous events, as well as the well-known difficulty to establish the probability of occurrences (Delmonaco 2000) (Department of Regional Development and Environment Executive Secretariat for Economic and Social Affairs Organization of American States, 1991). Furthermore, the data-gathering needed to carry out a totally quantitative assessment requires a big amount of resources and time.

While quite good quantitative methodologies are nowadays available to quantify hazard, empirical methods are often used to assess the vulnerability and the value when many different territorial elements have to be taken simultaneously into account. However it seems important to underline that those methods are always conditioned by policy driven and specific cognitive objectives, so they can not be assumed as general methods and used to reach objectives different from the adopted one. It also stands to reason that from the Civil Protection perspective cognitive objectives are very numerous.

The described difficulties related to the quantitative analysis constitute a first uncertainty element in risk assessment. In addition there are other aspects increasing uncertainty that it is necessary to consider. Firstly, to perform analysis in the field of Civil Protection a great deal of data is needed, often gathered and managed by different bodies, which have different approaches and objectives, so the data are often deeply heterogeneous. Moreover, time is a critical element because territorial system is strongly dynamic, so data gathered are soon obsolete, and it is also important to consider that prevention and emergency planning activities have to be performed in short-lasting cycles. Another interesting point concerns the unpredictable dangerous events, whose causal factors can not be completely analyzed. In the Civil Protection perspective a kind of modelling is anyway needed to manage this sort of events. This could also help to manage predictable dangerous event, seeing that they never take place in the exact way they were predicted, due to the described above uncertainty elements and to the uncertainty always embedded in each modelling process.

Although these considerations, the uncertainty related to risk assessment in the Civil Protection perspective has to be managed, then suitable information and instruments to support the cognitive process are needed.

4. The components of the new approach

4.1. *Uncertainty management: the "universalistic" approach*

In this work, we propose an innovative "universalistic" approach to analyze the territorial system, based on the following concepts:

- all hazards may be individually assessed to finally provide a summary of the level of global risk acting on a territory, considering the possibility of simultaneous occurrence of multiple hazardous phenomena;

- initially, all natural and anthropic factors of a territory are considered as potentially exposed to hazards; it is possible to evaluate the vulnerability of each element considering its intrinsic characteristics referred to a specific vulnerability domain (structural, functional, economic, social, etc.);
- in the first instance, all existing resources may be taken into account, regardless of the levels of hazard, while the optimal allocation of new resources depends on the hazard zonation for all dangerous events.

The adoption of the “universalistic” approach leads to define a set of intermediate information elements, particularly important in the overall process of Civil Protection. The content of these elements and their role in the process are defined as it follows:

- **the system of hazards**

  It contains the analytical information related to existing hazards on the territory. In order to create this information layer, it is necessary to:
  - take into account simultaneously every hazardous phenomenon acting on a territory and to assess overlaps;
  - analyze and classify all the investigated territory, regardless of the actual conditions of risk, in order to identify the "safe territorial system" for emergency management.

  This information, in a virtuous relationship between Civil Protection planners and figures in charge of monitoring the development of the territory, is strategically useful to orientate urban planning decisions.
- **the safe territorial system**

  It identifies safe areas, not subject to any kind of hazard. The availability of this layer is fundamental in order to identify those portions of territory which are "safe" and therefore usable for the allocation of strategic resources for emergency management (in particular for fixed resource allocation).
- **the vulnerable territorial system**

  It localizes and describes vulnerable elements in a territory, classified by level of intrinsic vulnerability. Given the uncertainty in the evaluation of hazard scenarios, this information layer have to be defined regardless of hazard zonation and so the availability of this information enables a precautionary assessment of potential damage in the whole considered territory. In forecasting and preventive activities, this synthesis allows to immediately identify the areas more sensitive to be damaged by events.
- **the system of resource allocation**

  This information synthesis contains the spatial description of all potential resources for emergency management (strategic resources located on the territory in the planning stage and territorial structures, which can provide services useful to emergency management).

4.2. *The analysis of the territorial system: the “systemic” approach*

In order to evaluate damage caused by a dangerous event, Tor Vergata University defined the set of natural and anthropic elements in a territory as a "vulnerable territorial system”, considering not only the single territorial entities, but also the complex of functional relationships among specific elements (Minciardi, 2006).

Therefore, in order to develop a risk analysis, it is necessary to assess not only the potential damage associated to the presence of exposed elements, but also the damage in elements functionally joined to the directly damaged ones. These elements could play a fundamental role because of their high capacity to interact with other parts of the system and so they could be defined as “strategic elements”, such as the infrastructure or the electricity network, and then all potential resources in emergency (hospitals, accommodation, etc.).

When strategic elements stop working, significant damage (frequently greater than the damage on single elements) can be caused on a plurality of other elements, including human beings. Therefore, it seems fundamental to define a type of risk related to the systemic vision of the territory, and not only to the overlapping of hazard and vulnerability.

Referring to the interruption of the functionality of a strategic element, it is possible to define different kinds of systemic risks, depending on which category of strategic elements is damaged (e.g. road systemic risk if the systemic element is an arc of the road network). The elements involved in the systemic risk are all those functionally connected to particular strategic elements, and their location provides the zoning of systemic risk.

In order to assess the systemic risk it is necessary to analyze all functional connections among strategic elements and others as well as the level of these relationships, defining a model of functional relationship. For this purpose, it is necessary both to identify all the alternative connections among single and strategic elements and to assess, for each element, its level of relationship with all the strategic elements belonging to the "strategic sub-system".

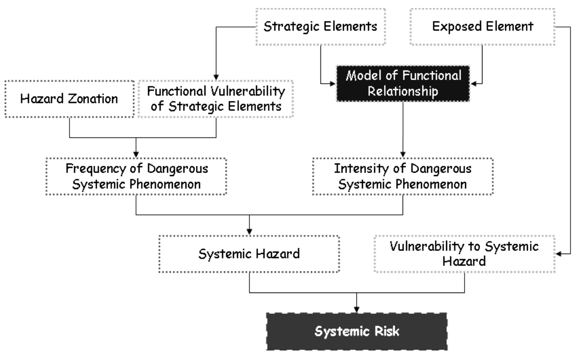

Fig. 1. Logical model for systemic risk assessment

In analogy with the local risk approach it is then possible to define, for a set of elements, other types of dangerous phenomena that we have already defined “systemic”, as the loss of the functional relationships with a specific type of strategic elements. These phenomena occur, differently from the local risk approach, depending on relationship features within the territorial system.

The level of systemic hazard is assessed for vulnerable elements, referring to a specific systemic dangerous phenomenon, in function of:

- the frequency of the phenomenon, which results from the level of local functional risk connected to the single strategic elements, and then from:

· the level of local hazard to which the single strategic element is exposed;
· the functional vulnerability of the single strategic element;

- the intensity of the phenomenon, which stems from the level of relationship among single strategic elements and the exposed one.

The systemic hazard is estimable for every exposed element, by overlapping the levels of frequency and intensity of each dangerous phenomenon.

The systemic risk derives from the combination of systemic hazard and the intrinsic vulnerability of the exposed elements to the systemic hazard.

The assessment of systemic risk allows to:

- characterize the connected elements with the level of systemic risk, for the purpose of strategically localizing resources on a territory for emergency management;
- immediately assess, in the instance of an event involving a strategic element, the potential damage on the other connected elements.

Finally, a particular attention should be reserved for the evaluation of the systemic risk involving strategic elements functionally related to other strategic elements (e.g. an electricity breakdown could endanger the function of elements for the supplying of drinking water).

4.3. *The knowledge system: the "incremental" approach*

The amount of data necessary for a comprehensive and detailed knowledge of a territorial system, which can be hit by a dangerous phenomenon, is quite huge; the more analytical the identification of vulnerability factors of each element is, the more that is true.

In many instances the system of needed data is not available; it is also possible that these data exist, but they are not easily integrable into a single information system because of their heterogeneous origin. For all these reasons, it is necessary that the design of the knowledge system supporting the Civil Protection processes is oriented by an "incremental" approach. By assuming this approach, that states "a quick Emergency Plan is better than no Plan" (Regione Lombardia, 2007) it is possible to draft the plan on the basis of the available knowledge system, preserving the possibility to later specify the information layers of the plan.

From a technical point of view, it means that the system of data capture and processing has to be oriented in a way that information layers are interchangeable and data can gradually be replaced with more specific ones. In order to ensure the data interchangeability, both data structure and processing have to be designed in such a way to minimize the influence of the data scale.

Talking about data scale, we intend, for example, the different detail by means of which it is possible to describe a single spatial element, moving from the single indication of existence (presence/absence) to the specification of its functional, structural or dimensional feature. Talking about interchangeability, we intend that a specific information layer can be updated, replaced or added at any time, not significantly modifying the data flow structure.

By adopting the "incremental" approach, it is possible, of course, to obtain different levels of information support to the analytical or decision process, depending on data scale. The main advantage of this approach lies in the possibility to not modify the structure of the data analysis process when more detailed data are available.

Moreover, this approach allows to manage all instances in which one or more elements play different role in the general Civil Protection process. This is true, for instance, for buildings such as schools, which represent vulnerable elements, but, if described in a very detailed and structural way, they should be considered as resources in managing emergencies. The different levels of description (the scale of data) are assumed, by this approach, as two different data layers implemented in the same data structure and managed by the same data analysis process.

4.4. *The "decision-oriented" approach*

Risk assessment is of primary importance to carry out the Civil Protection tasks, therefore, in order to manage the described uncertainty, it seems necessary to strengthen the relationship between risk analysis and Civil Protection processes, using an approach that we can call "decision-oriented".

As described above, on one hand a quantitative risk assessment is not completely possible, on the other hand a totally empirical approach is not useful to achieve Civil Protection aims on the whole. For this reason we have to support the potential integration, in the risk assessment process, between the quantitative and the empirical approach. In this way, even giving up to calculate a totally quantitative risk index, the aim is to employ as much as possible the risk analysis to effectively support the Civil Protection activities. From the cognitive point of view, it means that all the quantitative information, both for hazard and vulnerability, has to be conserved in the most analytical way, for each spatial units, in order to assure the possibility to compare the risk's components under a specific cognitive objective and to support a specific decision hypothesis. By adopting the "decision - oriented" approach, the traditional activities of reducing the different spatial conditions in a finite number of risk classes (by incorporating in this class both the consistence of the hazard and the value (quantitative or qualitative) of vulnerable elements) losses its relevance.

Furthermore, this kind of approach can be useful to manage emergency raising from (totally or partially) unforeseen events.

In the emergency managing, the main field of application of this approach concerns the localization and quantification of the different types of resources (means, human resources, emergency centres, etc.). In this case the specific cognitive objectives are defined by the type of resource and on the basis of the political aims. Reducing the problem complexity to the identification of where one type of resource is needed (and sometimes to its quantification), it is easy to compare in a meaningful manner value and vulnerability of different territorial elements as "demand of resource". Following this approach risk analysis change into the assessment of where, and eventually how much of, one type of resource is needed. In this way it is possible to combine more than one event, numerous territorial elements and their relationships.

5. Technical implementation of the defined approaches

The defined approaches were technically implemented through the design of a GIS-based information product in which territory is divided into square cells, each of them is codified with the information about:

- level of hazard for each considered dangerous event, homogeneously classified into four levels (high, medium, low, negligible);
- quantity of vulnerable elements, classified by a general typology (e.g. people, residential buildings, schools, hospitals, streets, museums, etc.) and types related to the specific vulnerability class we adopt in the vulnerability analysis.
- Because of the different scales of the dangerous events, two matrixes of codified cells were created, differing by the size of the cells' side (100 metres and 30 metres).

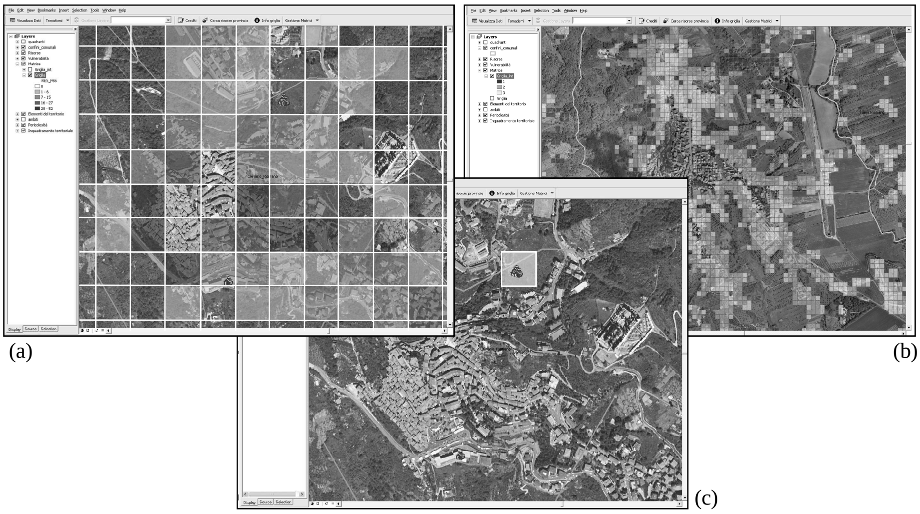

Fig. 2. Examples of use of matrixes: number of people 65 years old and over (classified) (a); levels of interface fire hazard (b); elementary school exposed to flood hazard (c)

On one hand matrixes can contain (and make easily available both for visualization and processing) analytic and totally quantitative information. On the other hand matrixes are synthetic instruments, in which a big amount of heterogeneous information coexists, keeping their independence. In this way it seems possible to implement the "universalistic approach".

Besides from the logical-physical structure of the matrixes it is possible to define analytical processes, independent of contents and specific modelling methodologies. In this way it's possible to add, replace or modify information layers without (or partially) modifying the processing methods to build matrixes and to use them.

By the use of matrixes, it is possible to easily and quickly combine information about both hazard and vulnerability aspects on the basis of the specific cognitive objectives of the decision processes.

Finally matrixes allow to easily integrate the systemic concept into the analytical process, simply adding the systemic hazards as information layers.

As described in par. 4.2, these data layers stem from the necessity of estimate damage induced from the break of strategic elements, such as an arc of the road network, in elements also significantly distant from the event. We tested the designed methodology for systemic risk evaluation, by considering the arcs of the road network as strategic elements and the possibility that some vulnerable elements may be closed off because of the break of the network.

The considered element, vulnerable to systemic hazard, is population living in inhabited sites.

In order to evaluate systemic hazard, a model of functional relationship among arcs of the road network and population living in inhabited sites was firstly defined, in order to quantitatively assess the functional relevance of each arc for each inhabited site. To do this we identified arcs fundamental to ensure the connection, by modeling paths between the gates (access points to the considered area) or strategic elements (hospital, etc.) and inhabited sites, through two complementary methodologies:

- estimation of "best" paths; this type of routing models the use of road network in function of speed travel. This allows to analyze the level of relationship among roads and inhabited sites if it is possible to choose the optimum route and no arc is interrupted.
- estimation of "alternative" paths, aimed to search for more alternative routes between each origin-destination pair, in order to evaluate the importance of each arc in relation to the presence or absence of alternative routes usable to connect the same pairs origin-destination.

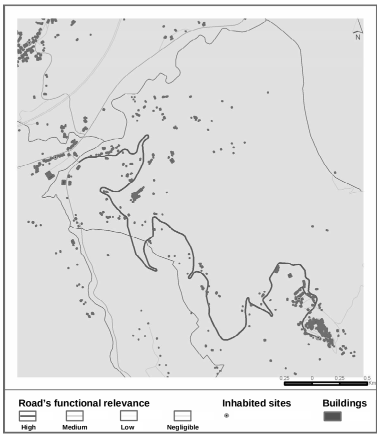

Fig. 3. Road's functional relevance: example of inhabited site connected by a unique road

Once classified each arc of the road network by the level of systemic relevance for each inhabited site, we classified each linear element by the level of local hazards acting on it. Finally, considering road function completely vulnerable to all local hazards, we combined these two information layers in order to:

- evaluate systemic hazard for each inhabited site;
- classify the road network by systemic hazard potentially caused to all inhabited sites. This was done for the events which imply, by a convenient and appropriate Civil Protection policy, interventions to prevent systemic risk directly on the streets.

6. Conclusion

In this work a new approach to risk assessment is defined, in order to better meet the needs of the Civil Protection activities. The adopted analysis process is not aimed to the punctual damage assessment, but rather to supply the Civil Protection activities with support instruments. Adopting this approach, risk analysis changed into the assessment of the "demand" of one type of action, in a certain "quantity" and in a certain localization. In this way, the occurrence of more than one event is considered by means of the definition of scenarios of event. Reducing the complexity of the problem to the identification of where one type of resource is needed (and sometimes to its quantification), it is possible to take significantly into account numerous territorial elements and their relationships.

In order to identify the scenarios to consider, the corresponding resources and operating procedures to use, technical modelling is not sufficient, but political decisions concerning the concrete objectives have to be made. The information product defined, the matrix, allows to support this definition, easily supplying the decision-makers with the information synthesis they may need in the manifold combinations of hazard and vulnerability levels. Following the decision process, matrixes can also be used to immediately localize (and eventually quantify) the action and the resources to apply in the defined scenarios.

In this way, it seems that risk assessment is closer to the needs of the Civil Protection activities.

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