# Chapter 9
# Earthquake Risk Reduction: From Scenario Simulators Including Systemic Interdependency to Impact Indicators

**Carlos Sousa Oliveira, Mónica A. Ferreira, and F. Mota Sá**

**Abstract** Earthquakes have a strong effect on the socio-economic well-being of countries; the consequences can lead to a complex cascade of related incidents, expanding across sectors and borders, and in a more serious context, to our basic survivability. An urban area consists on several complex and highly connected systems. A significant loss of housing, education, power outages or other component would have substantial negative impacts. How would constrains in residential areas affect the residential distribution of the region? How would a general change in accessibility due to severe damage affect the population or the economy (employment changes)?

Disasters are still predominantly seen as exogenous events, unexpected and unforeseen shocks that affect normally functioning economic systems and societies rather than as endogenous indicators, an integrated, and mutually influencing process where financial, health, economic and social risks are considered as both facets and at the same time contributing factors in an interdependent process of risk creation, accumulation, mitigation, and transference.

Seismic scenario simulators have been used as tools to estimate damages inflicted by earthquakes in a region. Up to now this powerful simulators calculate and maps the direct damages on urban environment such as the building stock and infrastructures, not including the propagation effects among these components. This paper presents a novel approach to study in a macro scale an urban region, including the systemic interdependencies among urban elements. The methodology allows the observation of urban disruptions caused by the interdependencies and measured through a Disruption index. This index permits to identify the most vulnerable elements, being essential for the risk reduction.

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## 9.1 Introduction

Natural disasters, namely earthquakes have clearly demonstrated that preparedness and disaster management are dynamic processes that require a holistic analysis of critical interdependencies among core infrastructures in order to mitigate the impact of extreme events and improve survivability of our society.

This paper, after a first analysis of the earthquake activity since 1900 and, in particular, in the last 20 years, in relation to the impacts caused to society, describes the main successes achieved to estimate the impact of future events and present a new indicator based on the disruption caused to the population due to not only the direct impact of shaking but also including the effect of interdependences among the various urban systems.

### *9.1.1 Trends of Natural Disasters*

"The so called *natural* disasters, that is, those related to phenomena of Nature, have caused throughout the centuries great convolutions in the process of human development. Even though advances in science and technology have produced a great deal of knowledge on the causes of those disasters, human deaths in the world per million inhabitants are only slightly decreasing with time, but the economic losses have dramatically increased in the last decades. The rise in world population and the complexity of societal organization, among others, are factors that may explain this unfortunate fact. Inadequate non-sustainable use of the territory and present day inadequate construction practices, especially in developing countries, are clear causes of the too frequent "natural" disasters" (Oliveira et al. 2006).

The economic and livelihood losses associated with damaged and destroyed housing, infrastructure, public buildings, businesses and agriculture have been rising at a rapid rate as well as the mortality associated with geological hazards such as earthquakes and tsunamis. How is it possible that progress, which should lead to reduced losses, is actually being accompanied by rising losses?

The concentration of people and values in large conurbations as well as settlement in and industrialization of extremely exposed regions are some reasons to globally increase losses. It is estimated that by 2030 some 60 % of the world's population will live in urban areas and by 2050 this will have risen to 70 % (UN-HABITAT 2008; WDR 2010). Figure 9.1 shows the urban agglomerations with more than five million inhabitants in 2010 together with the zones of higher seismic hazard.

As known, seismic risk is a convolution of Hazard, Exposition and Vulnerability. Looking to the history of earthquakes it is very clear that the higher of one of this variables, the higher the risk.

Figure 9.2 present the evolution of number of victims (a) and economic losses (b) per decade during the twentieth century due to seismic activity. The two decades

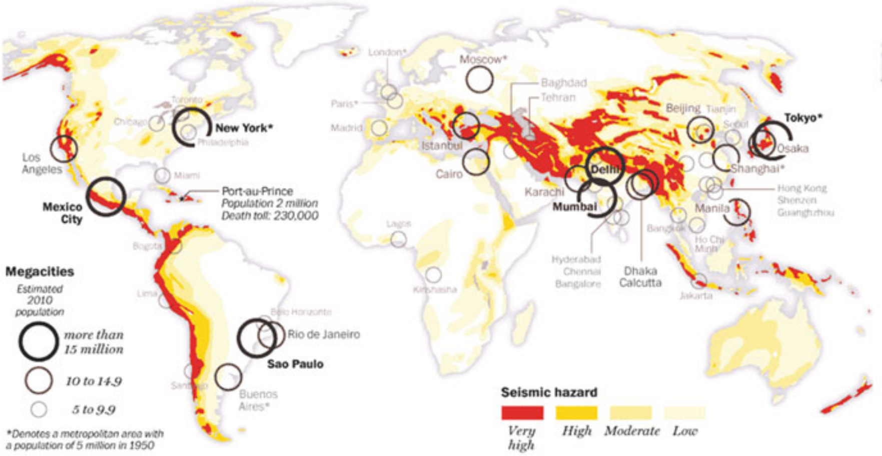


**Fig. 9.1** Urban agglomerations with more than five million inhabitants in 2010 and seismic hazard regions (Karklis 2010)

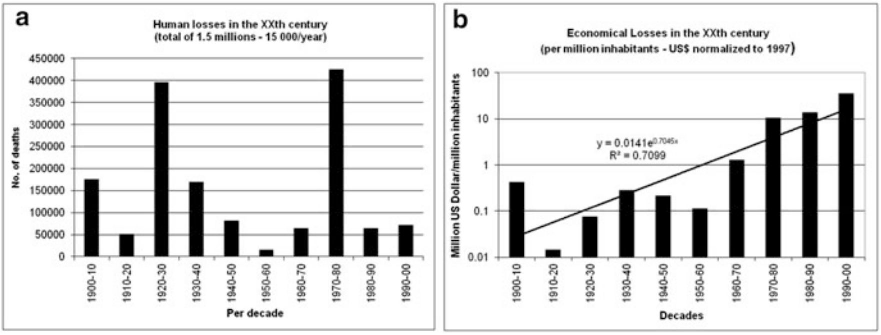


**Fig. 9.2** Evolution of losses during the twentieth century: (**a**) to the population; (**b**) economic (normalized to 1997, per million inhabitants)

with more victims were the 1920–1930 with the Japan Kantõ earthquake and the 1970–1980 with the Chinese Tangshan earthquake. The yearly average of events is three and the average of victims is 15,000 per year. Looking to Fig. 9.2 one observes that even though the number of victims is not a stationary process, the economical losses have increased steadily over the years in an exponential way. This increase is explained by the fact that each time a destructive earthquake strikes the larger the impact in the society, due to the larger assets involved and to the cascade effects of our modern society.

In the last 15 years a similar trend has occurred. Earthquakes and tsunamis such as Sumatra 2004, Sichuan 2008, Haiti 2010 and Tohoku 2011 are extreme events in terms of consequences as shown in Fig. 9.3. In relation to economic losses, the increase trend of Fig. 9.2(b) is similar for the first decade of the twenty-first century.

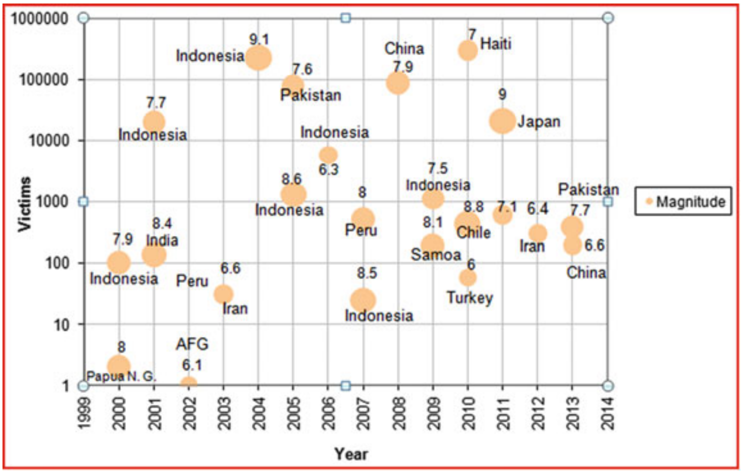


**Fig. 9.3** Victims from earthquakes (and tsunamis) in the last 15 years and corresponding magnitude values

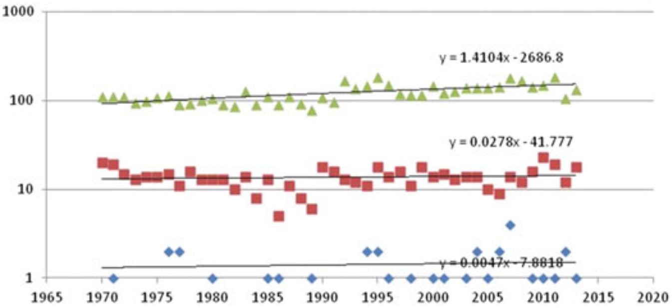


**Fig. 9.4** Annual number of earthquakes in the last 43 years in the World by classes of magnitude; *green triangle* – 6 < M < 6.9; *red squares* – 7 < M < 7.9; *blue diamonds* – 8 < M. (USGS 2012; EMSC 2014)

Figure 9.3 also shows that victims are not only caused by the very large magnitude events. Sometimes a M7, as the case of Haiti, can cause such a large number of victims, naturally due to the way, in many regions, society has dealt with the earthquake threat.

The pattern of earthquake impact cannot be attributed to an increase of seismic activity. In fact in Fig. 9.4 we plot the annual number of earthquakes in the world by classes of magnitude (6 < M < 6.9; 7 < M < 7.9; 8 < M), and it does not seems that seismic activity by itself has been increasing in the last 43 years. The earthquake impact is much more dependent on the increase of assets and of its vulnerability in many urban regions.

We will try to show that the impact of earthquakes is a multi-facet problem with consequences on the population and on the built environment, and demonstrate that in modern societies the effect of systemic dependences is marking with great power the traditional way to look at earthquakes and society.

The figures above show the losses in terms of victims and economic impact, but they not reflect the livelihood impact, the business disruption, the red zone areas or the number of years that this impact will last. Can we get an indicator capable of telling us the "disruption" in a society caused by an earthquake, measuring the state of disorder that was caused?

## 9.2 Scenario Earthquake Simulators. An Evolution

Many different software packages have been produced by different schools around the world in order to provide accurate seismic risk estimates. Table 9.1 presents a review of recent open source software packages.

These powerful seismic risk simulators can compute loss and damage estimate, risk scenarios or the associated benefit by cost of retrofitting, but they do not include the propagation and cascade effects existing in an urban area.

### *9.2.1 QuakeIST®*

An earthquake scenario simulator is produced to assess the impact of future earthquakes on a defined area of exposure, which may be a city, region or country, or a portfolio of buildings and facilities within such a geographical area. This is an ambitious aim since the problem is very complex and there is major uncertainty related to several elements: the ground-motion prediction equations; the ground conditions (site effects); the characterisation of the building stock and infrastructure exposure; the definition of the vulnerability of the exposed elements; the modelling of propagation effects, the estimation of repair costs and human casualties.

Figure 9.5 shows the main modules that constitute an earthquake scenario simulator from hazard definition, exposure, vulnerability, to the loss assessment.

Various approaches exist regarding the damage appraisal, such as financial and economic valuation based on market values (i.e. based on historical values or replacement values) – Today the typical approach is the economic estimation of direct damage. Earthquake scenario simulators developed until now show direct physical damage in terms of victims, buildings, essential facilities and transportation systems, without including estimations of indirect losses or propagated effects (functional interdependencies). For a consistent decision analysis it is desirable to include an holistic approach.

The QuakeIST® is an integrated simulator developed by Instituto Superior Técnico (Mota de Sá, 2012, QuakeIST® software, personal communication), to

**Table 9.1** Synopsis of seismic risk software packages

| Software | Institution | Programming language | Applicability | Availability | Graphical user interface | Type of calculators |
|---|---|---|---|---|---|---|
| ELENA | NORSAR | MATLAB/C | User-defined | OS | Yes | SCN/SDA/PEB |
| EQRM | GA | Python | User-defined | OS | No | SCN/SDA/PEB |
| ELER | KOERI | MATLAB | User-defined | SA | Yes | SCN/SDA |
| QLARM | WAPMERR | Java | World | SC | Yes | SCN/SDA |
| CEDIM | CEDIM | Visual Basic | User-defined | SC | Yes | SCN/SDA/CPB |
| CAPRA | World Bank | Visual Basic | Central America | SC | Yes | SCN/PEB |
| RiskScape | GNS | Java | New Zealand | SA | Yes | SCN/SDA |
| LNECLoss | LNEC | Fortran | Portugal | SC | No | SCN/SDA |
| MAEviz | MAE Center | Java | User-defined | OS | Yes | SCN/SDA/CPB |
| OpenRisk | SPA Risk | Java | USA | SA | Yes | CPB/BCR |
| OpenQuake | GEM | Phyton | World | OS | Yes | SCN/SDA/PEB/CPB/BCR |

Adapted from Silva et al. (2013)
*OS* open-source (code on a public repository), *SA* standard application (available under request), *SC* source code (available under request)
*SCN* scenario risk, *DAS* scenario damage assessment, *PEB* probabilistic event-based risk, *CPB* classical PSHA-based risk, *BCR* benefit-cost ratio

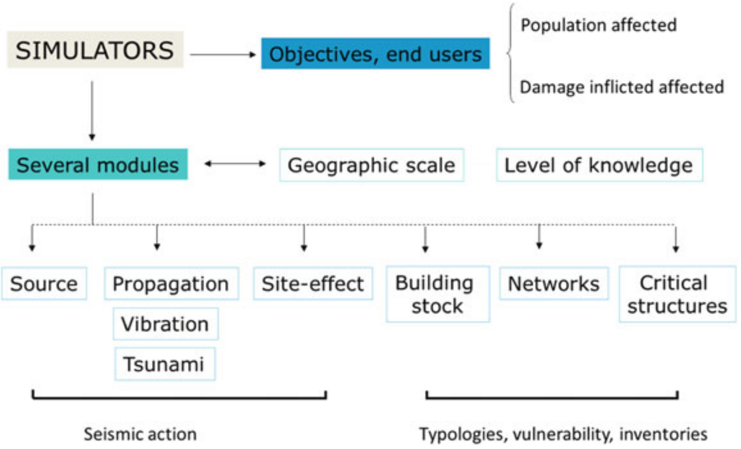


**Fig. 9.5** Schematic structure of earthquake scenario simulators

provide assistance in risk assessment and disaster management to decision makers and other people concerned to take the right decisions related with the topic. This sophisticated software can model physical risk assessment and is the first earthquake risk simulator that offer an integrated cascade-effect approach and a global impact at urban or regional scale (the DI, Disruption index: Oliveira et al. 2012; Ferreira et al. 2014). The results provided by QuakeIST® are capable to identify important factors and systems which contribute to main urban disruptions, providing plans and guidance for short-, medium-, and long-term investment projects to reduce risk.

QuakeIST® software was applied in several countries (Italy, Portugal, Spain and Iceland) during the UPStrat-MAFA Project (2012), to generate and measure risk, quantify the impacts, and improve the capacity to define strategies to address adverse natural events. The locations under study were very important to calibrate and validate several parameters of the model, using real earthquakes (Lorca, Spain 2011; Faial, Azores 1998; Mount Etna, Italy 1914; and Hverageroi, Iceland 2000 and 2008).

A brief description of the key features of the QuakeIST® software is presented below:

- The simulator (QuakeIST®) can handle different ground motion scenarios provided by the user, referring the ground motion values to coordinates, using external scenarios obtained from different software's like SASHA (D'Amico and Albarello 2008), PROSCEN (Rotondi and Zonno 2010), or any historical seismic scenario.
- QuakeIST® contains several well-known attenuation relationships that the user may select or adapt to their own conveniences, in order to calculate ground shaking based on an epicentral position (coordinates) and magnitude.
- QuakeIST® requires shaking intensity, PGA, PGV or PGD as an input parameter to some objects. Conversion between PGA, PGV, PGD and different macroseismic intensity scales was implemented. Soil information can be handled through EC8 soil classes (EC-8 2004), and there are several possible options the user can choose to manage site effects (soil amplification/deamplification).
- QuakeIST® is written in C++ and interacts (but do not rely on them) with virtually all platforms of geographical information system software (GIS), such as ESRI, QuantumGIS, and others, to create maps and measure the possible impact caused by earthquakes in urban systems.
- Various models to calculate direct damages (macroseismic model -Giovinazzi and Lagomarsino 2004), the capacity spectrum (Freeman 2004), N2 (Fajfar 1999) or fragility functions) are included and users can upload their own vulnerability parameters or include new ones.
- Different types of assets can be modeled (buildings, schools, bridges, various types of networks – water, power-electricity, gas, communications-telecom, population, etc.).

- QuakeIST® contains algorithms for propagation effects and earthquake impact assessment.
- Losses maps and maps illustrating the cascade effects can be plotted for a given asset typology.
- The Disruption index can be presented for a city, a region or plotted in a geographic environment. This latest option is very important to share information to general public (people without a scientific background).

Earthquake insurance and compensation systems are important parts of strategies for dealing with seismic risks. They use sophisticated models to price earthquake risk. By using QuakeIST® with the DI calculator can assist in analyzing the damage correlation and interdependence damage propagation; DI can certainly contribute to the development of innovative earthquake insurance systems reducing some of the existing "blind spots" (http://insurance.about.com/).

## 9.3 New Advancements: Interdependences and Cascade Effects

### *9.3.1 Disruption Index*

Where risk analysis looks at the impacts of catastrophic events, the analysis is generally restricted to the immediate effects and impacts rather than to identification of how economic processes generated the risk in the first place and how direct and indirect impacts then run through the economy affecting future development in diverse ways.

Damages and the magnitude of adverse impacts can be categorized as shown below:

- Direct losses: losses resulting from direct impact to buildings and infrastructures.
- Indirect losses: losses resulting from the event but not from its direct impact, for example, transport disruption, business losses that can't be made up, losses of family income, etc.

In both loss categories, there are two sub-categories:

- Tangible losses: loss of things that have a monetary (replacement) value, for example, buildings, livestock, infrastructure, etc.
- Intangible losses: loss of things that cannot be bought and sold, for example, lives and injuries, heritage, and others.

The larger the city, the greater its complexity and the potential for disruptions when facing an adverse event. For example, damage or non-functioning of infrastructure facilities also causes long-term impacts, such as disruptions to clean water

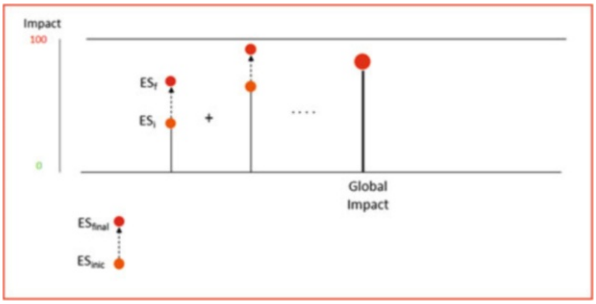


**Fig. 9.6** Effect of interdependences in each sub-system (ES) and on the global impact

and electricity, deterioration of health condition owing to waterborne diseases. Loss of livelihoods, production and other prolonged economic impacts can trigger mass migration or population displacement.

The Disruption Index (DI) was constructed to quantify the state of disorder induced by the disruption of urban structure and its systemic functions. Figure 9.6 presents schematically the earthquake global impacts taking into account the various subsystems and interdependencies among them.

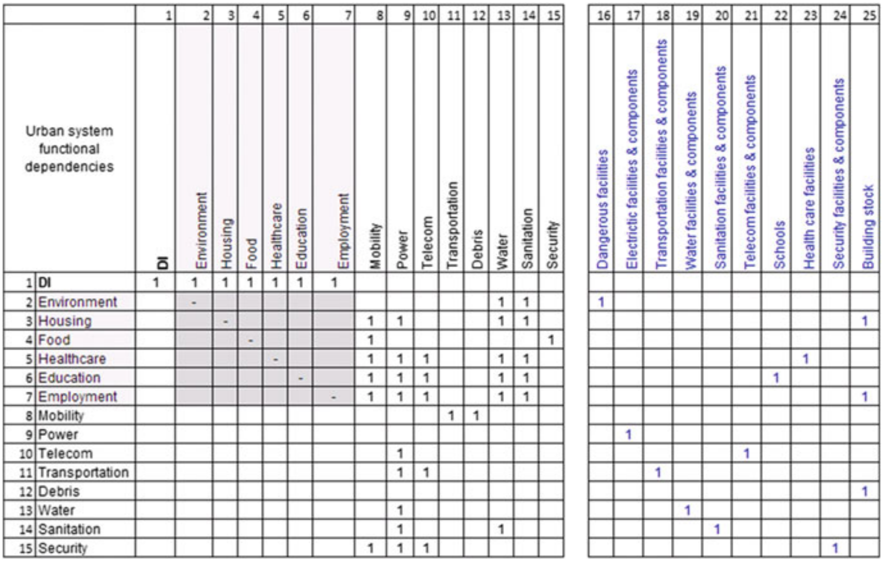
This general model considers a number of subsystems which deals with the allocation of activities and components and their interaction and interdependencies. Crucial to the modelling process of DI was capturing and analysing the systems dependencies and the chain of influences and effects that cross multiple systems (Ferreira 2012).

An urban area consists on complex, dynamic and highly interrelated systems. As mentioned significant loss of housing, education, power or other component would have substantial negative impacts. How would constrains in residential areas affect the residential distribution of the region? How would a general change in accessibility due to severe damage affect the population or the economy (employment changes)?

#### 9.3.1.1 Structuring Disruption Index Model

When experimenting with urban systems, a first difficulty is to define what type of elements can be studied. A crucial part of the modelling process is to develop a general framework capable to clearly identify, capture and analyze each level of organization, the systems dependencies and the chain of influences and failures due to system/component interactions (Ferreira 2012; Ferreira et al. 2014).

In order to identify the most important effects on a society, its economy and other sectors, more than 70 “primary concerns” were found as systematically present in all texts and reports. Following some fundamental rules of decision problem structuring, these primary elements were aggregated in 14 Fundamental Criteria (Fig. 9.7) translating critical dimensions (urban functions) that cooperate in an interdependent fashion. Those dimensions encompass six fundamental human needs: “*Environment*, *Housing, Healthcare, Education, Employment* and *Food*”,



| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Urban system functional dependencies | | DI | Environment | Housing | Food | Healthcare | Education | Employment | Mobility | Power | Telecom | Transportation | Debris | Water | Sanitation | Security | Dangerous facilities | Electrictic facilities & components | Transportation facilities & components | Water facilities & components | Sanitation facilities & components | Telecom facilities & components | Schools | Health care facilities | Security facilities & components | Building stock |
| 1 | DI | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |
| 2 | Environment | | - | | | | | | | | | | | 1 | 1 | | 1 | | | | | | | | | |
| 3 | Housing | | | - | | | | | 1 | 1 | | | | 1 | 1 | | | | | | | | | | | 1 |
| 4 | Food | | | | - | | | | 1 | | | | | | | 1 | | | | | | | | | | |
| 5 | Healthcare | | | | | - | | | 1 | 1 | 1 | | | 1 | 1 | | | | | | | | | 1 | | |
| 6 | Education | | | | | | - | | 1 | 1 | 1 | | | 1 | 1 | | | | | | | | 1 | | | |
| 7 | Employment | | | | | | | - | 1 | 1 | 1 | | | 1 | 1 | | | | | | | | | | | 1 |
| 8 | Mobility | | | | | | | | | | | 1 | 1 | | | | | | | | | | | | | |
| 9 | Power | | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| 10 | Telecom | | | | | | | | | 1 | | | | | | | | | | | | 1 | | | | |
| 11 | Transportation | | | | | | | | | 1 | 1 | | | | | | | | 1 | | | | | | | |
| 12 | Debris | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| 13 | Water | | | | | | | | | 1 | | | | | | | | | | 1 | | | | | | |
| 14 | Sanitation | | | | | | | | | 1 | | | | 1 | | | | | | | 1 | | | | | |
| 15 | Security | | | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | 1 | |

**Fig. 9.7** Disruption index, the adjacency matrix A. In columns, we represent the graph elements. The square matrix contains the six criteria; the other *black rows* contain the services and components, and the right columns (*blue*) show the elements that supports all other functions (Ferreira 2012)

and are conditioned by several other main functions/systems such as mobility, electricity, water, telecoms and others, which in turn are dependent by the reliability of several buildings, equipments and critical or dangerous facilities. To give an example, from Fig. 9.7 we can say that the dependencies of Environment are Water, Sanitation and Dangerous facilities.

Water depends on the operation of the Water system equipment and of the Electricity supply, which depends in turn on the Electric system equipment, and we have a chain of dependencies and interdependencies.

Propagation and cascading effects can be calculated in a bottom – up sequence, starting with the physical damages directly suffered by the exposed assets (nodes with the lowest topological order), proceeding with the impacts that each node has in the functional performance of nodes that depends on them, until reaching the top node, DI (which is the one with higher topological order). Mathematically, the DI can be represented by its Adjacency Matrix of a Directed Graph [G], in which the element Gij equals 1 if row i depends on column j and is zero otherwise.

#### 9.3.1.2 Impact Assessment

It is possible to associate qualitative impacts to each urban function and element (criteria), using a scale, describing as objective as possible all the plausible impacts that may presents.

**Table 9.2** Criteria (*Human needs*) and respective consequence descriptors

| Criteria | Descriptors |
|---|---|
| Environment | Identify materials or elements that can pose a substantial or potential hazard to human health or the environment when improperly managed: soil and water contamination, radiation, radioactive waste, oil spills, etc. It also assess the impact of service disruption of urban hygiene/public health from debris storage (building materials, personal property, and sediment from mudslides), contamination of water (unsafe drinking water and sanitation) and the high concentration of people in the same space |
| Housing | Evaluates whether a particular area may or may not be occupied for housing function as a result of the damage, also indicates alternative housing/shelter |
| Food | Evaluates if the food is accessible to the majority of the population and identifies alternatives to their supply (coping strategies) |
| Healthcare | Determines if the population is served by a sufficient number of health facilities |
| Education | Measures the discontinuity of education and the number of people without school lessons and identifies alternatives for recovery |
| Employment | Evaluates whether a certain area retains its activity as a result of the damage after the earthquake and identify new clusters of jobs that can be generated |

Table 9.2, presents the descriptors associated with each criterion of *human needs*.

The impacts associated with a certain criterion are restricted to a range of plausible levels of impact (Roy 1985), from the more desirable level (normal or I) to a less desirable level (exceptional or IV–V). Taking into account the whole family of criteria, it is possible to define the overall response of the system, originating in the Disruption index, as the result of the interactions between the various systems (the results of sequencing actions are determined by individual actions). The values given for each criterion provide a single value to DI between I and V, a range of impacts of the earthquake in urban systems (Table 9.3).

It is worth noting that these levels have no *cardinal* meaning; these impact scales are only *ordinal* (neither interval nor ratio scales). For example, we can say that impact V is greater than impact IV and that impact III is greater than impact I but, we cannot say that impact IV is twice impact II nor that the difference between impacts IV and III is α times the difference between impact III and impact II.

Each level of DI conveys which are the disruptions and influences (physical, functional, social, economic and environmental) that a given geographic area is subjected when exposed to an adverse event. The enumeration of impact levels of each sub-system is provided in Table 9.4. Using the aforementioned DI, QuakeIST® can also compute impact and plot the respective maps. This is the first time that all the components for impact assessment are integrated and work seamlessly in just one software platform.

**Table 9.3** Qualitative descriptor of disruption index, DI (impact levels are numbered in decreasing order of urban disruption/dysfunction)

| Impact level | Description of the impact level |
|---|---|
| V | From serious disruption at physical and functional level to paralysis of the entire system: buildings, population, infrastructure, health, mobility, administrative and political structures, among others. Lack of conditions for the exercise of the functions and activities of daily life. High cost for recover |
| IV | Starts the paralysis of main buildings, housing, administrative and political systems. The region affected by the disaster presents moderate damage and a slice percentage of total collapse of buildings, as well as victims and injuries and a considerable number of homeless because their houses have been damaged, which, although not collapse, are enough to lose its function of housing. Normal daily activities are disrupted; school activities are suspended; economic activities are at a stand-still |
| III | Part of the population may permanently lose their property and need to permanent be relocated, which means strong disturbances of everyday life. This level is determined by significant dysfunction in terms of equipment's, critical infrastructures and losses of some assets and certain disorders involving the conduct of professional activities for some time. The most affected areas show significant problems in mobility due to the existence of debris or damage to the road network. Starts significant problems in providing food and water, which must be ensured by the Civil Protection |
| II | The region affected by the disaster presents few homeless (about 5 %) due to the occurrence of some damage to buildings, affecting the habitability of a given geographical area. Some people may experience problems of access to water, electricity and/or gas. Some cases require temporary relocation |
| I | The region affected by the disaster continues with their normal functions. No injured, killed or displaced people are registered. Some light damage may occur (non-structural damage) that can be repaired in a short time and sometimes exists a temporary service interruption. The political process begins with an awareness that the problem exists as well as some investments in strengthening policy and risk mitigation is/should be made |

#### 9.3.1.3 DI Application: Portugal

After the briefly description of Disruption index we are able to assess and calculate the earthquake impacts in a holistic approach. The results here presented highlight the potential importance of incorporating dependencies and cascading failures into such models. DI provides the basis for understanding the resource requirements, not only for recovery after events but also to identify, prior to events, the physical elements that contribute most to severe disruptions.

##### 1755 Earthquake Scenario (M 8.7): Algarve Region in Portugal

On November 1st of 1755, three very large earthquakes, centred southwest of the Algarve region (southern Continental Portugal), devastated Algarve and Lisbon regions and was felt throughout Europe and North Africa. Hundreds of aftershocks,

**Table 9.4** Table of impact

| | Environment | Housing | Food | Healthcare | Education | Employment | Mobility | Power | Telecom | Transportation | Debris | Water | Sanitation | Security | Dangerous facilities | Electrictic facilities & components | Transportation facilities & components | Water facilities & components | Sanitation facilities & components | Telecom facilities & components | Schools | Healthcare facilities | Security facilities & components | Building stock |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DI** | | | | | | | | | | | | | | | | | | | | | | | | |
| **I** | | II | | | | | | | | | | | | | | | | | | | | | | |
| **II** | | | | III | III | II | | | | | | | | | | | | | | | | | | |
| **III** | II | III | II | IV | IV | III | | | | | | | | | | | | | | | | | | |
| **IV** | III | IV | | | | IV | | | | | | | | | | | | | | | | | | |
| **V** | IV | V | III | | | | | | | | | | | | | | | | | | | | | |
| Environment | | | | | | | | | | | | | | | | | | | | | | | | |
| I | | | | | | | | | | | | | | | | | | | | | | | | |
| II | | | | | | | | | | | | II | II | | II | | | | | | | | | |
| III | | | | | | | | | | | | III | III | | III | | | | | | | | | |
| IV | | | | | | | | | | | | | | | IV | | | | | | | | | |
| Housing | | | | | | | | | | | | | | | | | | | | | | | | |
| I | | | | | | | | | | | | | | | | | | | | | | | | |
| II | | | | | | | | II | | | | II | II | | | | | | | | | | | II |
| III | | | | | | | III | | | | | | | | | | | | | | | | | III |
| IV | | | | | | | IV | III | | | | III | III | | | | | | | | | | | IV |
| V | | | | | | | | | | | | | | | | | | | | | | | | V |
| Food | | | | | | | | | | | | | | | | | | | | | | | | |
| I | | | | | | | | | | | | | | | | | | | | | | | | |
| II | | | | | | | III | | | | | | | III | | | | | | | | | | |
| III | | | | | | | IV | | | | | | | IV | | | | | | | | | | |
| Healthcare | | | | | | | | | | | | | | | | | | | | | | | | |
| I | | | | | | | | | | | | | | | | | | | | | | | | |
| II | | | | | | | II | | | | | | | | | II | | II | II | II | II | | | |
| III | | | | | | | III | | | | | | | | | III | | III | III | III | III | | | |
| IV | | | | | | | IV | | | | | | | | | | | | | | IV | | | |
| Education | | | | | | | | | | | | | | | | | | | | | | | | |
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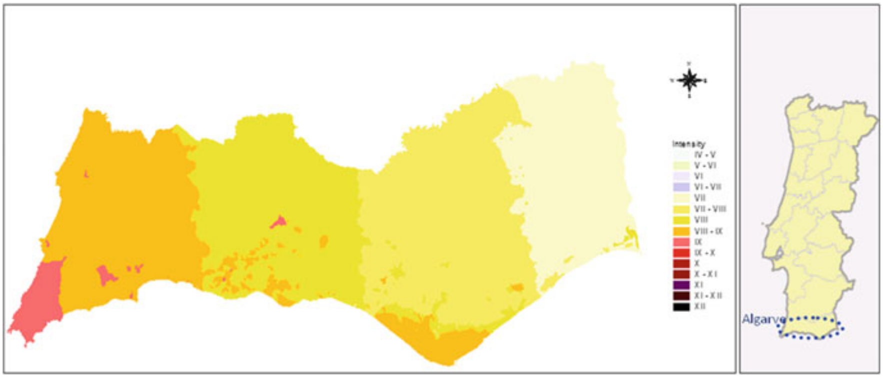


**Fig. 9.8** QuakeIST® intensity distribution for 1755 earthquake scenario

some severely damaging by themselves, continued for years. A devastating fire following the earthquake destroyed a large part of Lisbon, and a very strong tsunami caused heavy destruction along the coasts of Portugal, southwest Spain, and western Morocco (Oliveira 2008).

The Algarve region was selected to demonstrate the regional impact assessment. QuakeIST® software contains detailed information on the geological surface layers, on the building inventory and on population data of the Census (INE 2002), using the statistical sub-section (Census track) as work unit. Soil influence was included through the analysis of upper soil layers classified into several categories; and vulnerability of the building stock was obtained through the analysis of different classes of construction types (55 classes in total). Finally, a pair of coordinates (longitude and latitude) was provided to define the location of each asset (ERSTA 2010).

A vulnerability index was assigned to each typology using the approach of EMS-98 scale based method to calculate expected damages in buildings. The first level of analysis of the QuakeIST® software is based on obtaining intensity (or PGA) distributions analytically (Fig. 9.8) and estimating spatial distribution of the losses (building and lifeline damages) throughout the region of interest. Second level of analysis is intended to propagate effects and earthquake impacts, using DI (Figs. 9.7 and 9.9).

The next figures illustrate how all the referred concepts should be applied and interpreted in our case study areas. Figure 9.10 shows the mean damage grade obtained for each census tract, and Fig. 9.11 illustrates the damages inflicted to bridges and the extend of their sphere of influence.

The obtained results indicate that if we gather together the debris (obtained from the building stock) and the bridges damages, we obtain an impact on Mobility, according to DI methodology (Oliveira et al. 2012; Ferreira et al. 2014) equal to II and III (Fig. 9.12). Mobility equal to III means "Local perturbation on mobility linked with landslide or major damages. Used only by recovery teams. Disruptions to commuting trips, work and nonworking trips" (Ferreira et al. 2014).

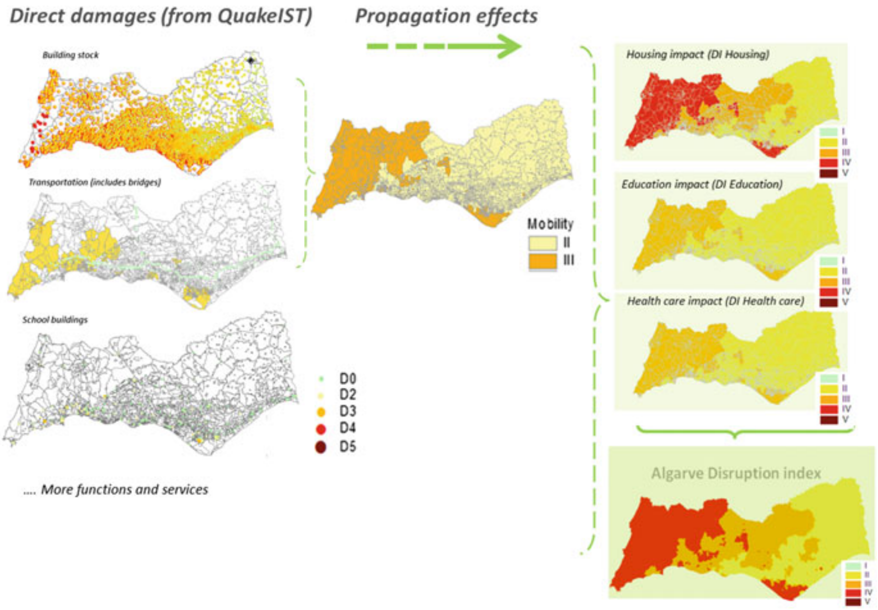


**Fig. 9.9** Disruption index: earthquake impact based on the systemic analysis of the urban components

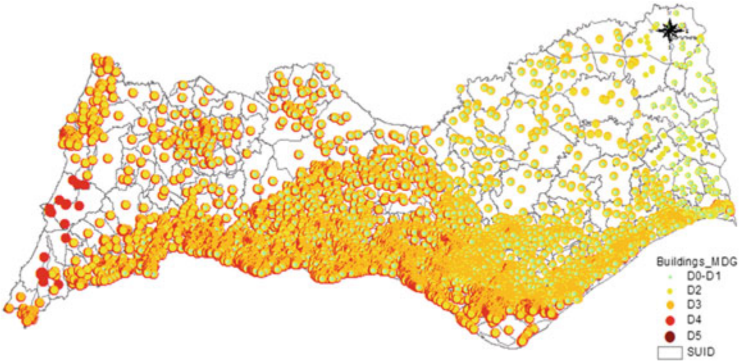


**Fig. 9.10** Distribution of all damaged buildings

The expected school damages associate with the 1755 risk scenario is presented in Fig. 9.13. As shown, most of the school buildings are not affected or present at maximum "moderate damages".

Each impact level is correlated with a severity or grade of damage to either the equipment or function connected with the Education function (Fig. 9.14). By combining the conditions using the logical function OR, we are able to categorize and plot the impact level on Education system (Figs. 9.14 and 9.15).

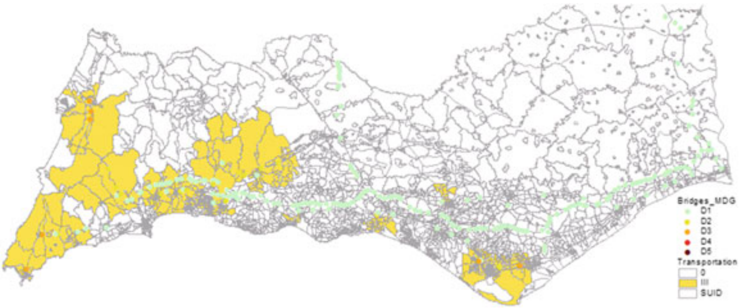


**Fig. 9.11** Intensity-based distribution of all bridges damaged

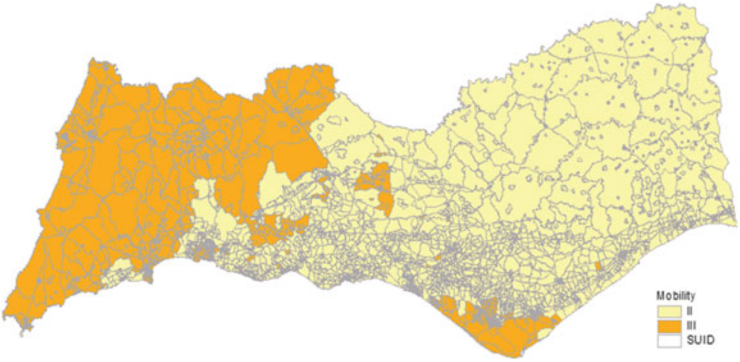


**Fig. 9.12** Impact on mobility

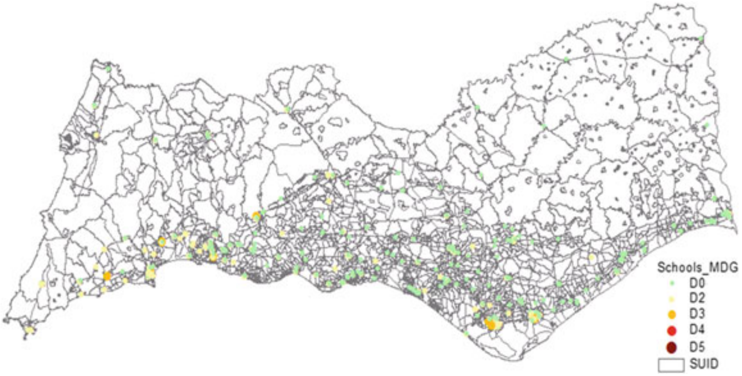
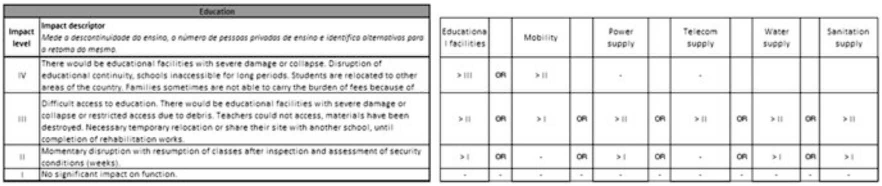


**Fig. 9.13** Direct damages obtained from QuakeIST® – School buildings

The extent of damage to schools and problems on mobility, and the ensuing relocation of people (due to buildings damages), means we cannot restore the education network to its previous state. Figure 9.15 suggests that in this region



| Education | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Impact level | Impact descriptor<br>*Mede o descontinuidade do ensino, o número de pessoas privadas de ensino e identifica alternativas para o retoma do mesmo.* | Educational facilities | | Mobility | | Power supply | | Telecom supply | | Water supply | | Sanitation supply |
| IV | There would be educational facilities with severe damage or collapse. Disruption of educational continuity, schools inaccessible for long periods. Students are relocated to other areas of the country. Families sometimes are not able to carry the burden of fees because of | > III | OR | > II | | - | | - | | | | |
| III | Difficult access to education. There would be educational facilities with severe damage or collapse or restricted access due to debris. Teachers could not access, materials have been destroyed. Necessary temporary relocation or share their site with another school, until completion of rehabilitation works. | > II | OR | > I | OR | > II | OR | > II | OR | > II | OR | > II |
| II | Momentary disruption with resumption of classes after inspection and assessment of security conditions (weeks). | > I | OR | - | OR | > I | OR | - | OR | > I | OR | > I |
| I | No significant impact on function. | - | - | - | - | - | - | - | - | - | - | - |

**Fig. 9.14** Impact on education

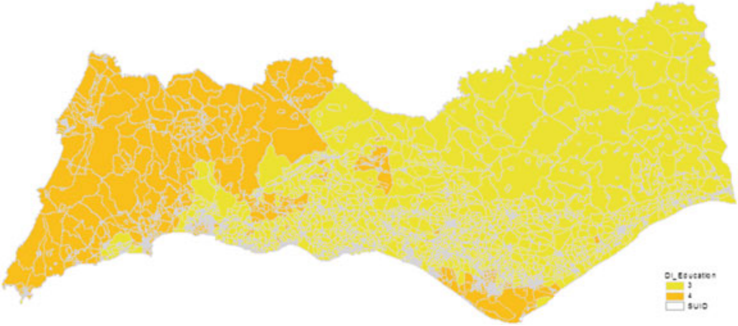


**Fig. 9.15** Education disruption

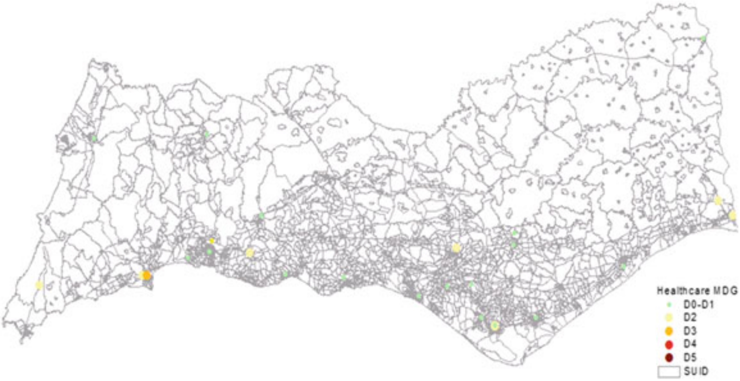


**Fig. 9.16** Direct damages obtained from QuakeIST® – Healthcare buildings

students will experience a prolonged interruption in their education and large numbers of families with school-age children will be forced to relocate either temporarily or permanently as a result of the earthquake.

In terms of physical damage to hospitals and primary health centres, Fig. 9.16 illustrates that were minor damage (D2) and one building with moderate damage (D3). However, the adverse impacts on healthcare system take a large proportion

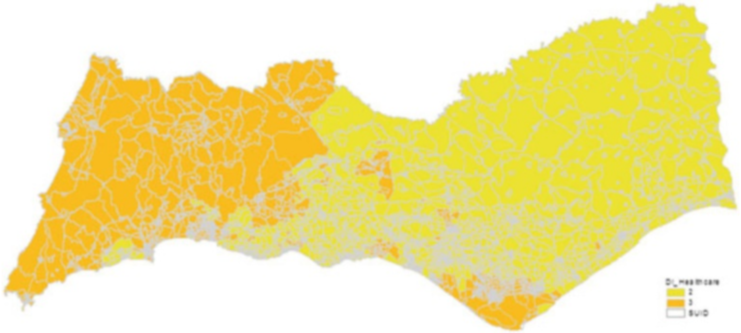


**Fig. 9.17** Impact on healthcare

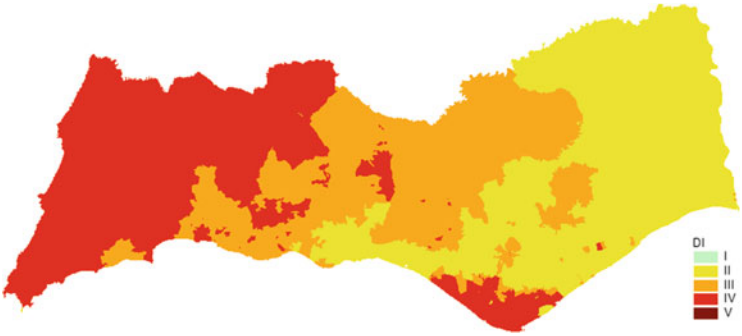


**Fig. 9.18** Global disruption in Algarve region

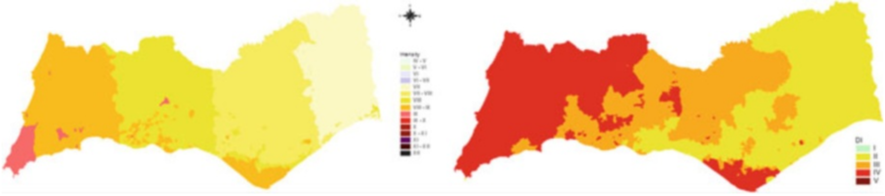


**Fig. 9.19** Comparison between Intensity map (*left* – Fig. 9.8) and DI map (*right* – Fig. 9.18)

due to propagation effects in other important lifelines like power and water systems, and due to the problems on mobility.

As seen on Fig. 9.17 propagation effects severely disrupt the functioning of the health system, being unable to provide emergency services in the region. These impacts may be short- or long-term (DI equal to II or III, respectively), based on the magnitude of the damage to the community and the ability of local resources to readily address and meet the healthcare needs of the community.

It is important to notice that despite high exposure and vulnerability of building and facilities to earthquakes, the propagation effects and the number of chain

**Fig. 9.20** Crises evolution in time

disruptions must be underlined in risk scenarios studies. According to Fig. 9.18, the 1755 Earthquake (not including the possible tsunami) has potential to cause disruption on infrastructure and production capacity of entire Algarve region and consequently to the national level.

Figure 9.19 compares the maps of intensity and of DI if a scenario similar to the 1755 earthquake would happen today, emphasizing the importance of including interdependencies and cascading effects in the analysis of earthquake impact.

From the above maps it is important to highlight that propagation effects due to interdependencies, largely extend the geographical scope and amplify the degree of earthquake impacts (measured by DI). As so, we can expect that zones where macroseismic intensity is low or even very low can be subjected to large disruptions. This situation happens when, for example, a pipeline feeding a region is broken in a section away from it.

The combination of this seismically active area, dense population centres, and aging or fragile infrastructure has the potential to create a massive catastrophe for urban activities (education, business, and so on) located in Algarve region. Loss of life and property damage are the first and foremost concerns for businesses, but the ripple effects of a major seismic event, including business and educational interruption as well as supply chain disruption, could take months or even years of recover.

Looking at the time component, all post-earthquake activities occur in three major phases – during response, recovery and reconstruction – as shown in Fig. 9.20. The DI concept can show the time evolution of decreasing or increasing disruptions according to decisions and reconstruction policies.

The DI concept although developed for a given deterministic seismic scenario can be extended to a set of scenarios representing the seismic activity in the region (hazard, de-aggregation, etc.).

## 9.4 Final Remarks

Living with earthquake risk is a devastating reality for a large and growing number of people in the world. Risk should be seen as a normal and inseparable part of economic activities and development. The construction of disaster risk reduction as an autonomous sector, concerned with protecting economic sectors and society from the impact of exogenous and extreme shocks has isolated it from the mainstream concerns of government in general, including economic growth and employment, or in the case of local governments, water and power supplies, transport and waste management. The lack of real political and economic commitment to disaster risk reduction in many countries reflects its isolation from real political and economic imperatives. This requires awareness of the impact on sectors or territories of any other given sector's policies and/or changes in strategy. As so an important issue should be highlighted; is important to identify communities at direct risk but also those indirectly affected.

The concept of disruption index presented herein can be extended to other earthquake-induced phenomena such as landslides, mudflows, tsunamis, liquefaction and fires, and to other natural or man-made hazards such as typhoons (Ferreira 2012), avalanche, floods and so on.

Fire following earthquake is a significant problem in seismic countries and many people are not aware of this hazard (urban and industrial) resulting from earthquakes and tsunamis. These fires can be classified in "earthquake-induced fires" caused directly by the earthquake, such as fires in oil and gas tanks or in urban areas, and in "tsunami-induced fires", caused by ignition of buildings by burning buildings or debris carried by the tsunami, for example, as observed on 2011 Tohoku earthquake (Yamada et al. 2012) or in the 1755 earthquake (Oliveira 2008).

In the case of insurance policies the various hazards should be taken into account, not only hazard by hazard but also considering the interdependencies among them. Both in urban tissues and in industrial areas the interdependencies are very critical.

The key messages from this work are:

- earthquakes are having a major impact on millions of people every year and therefore earthquake risk management measures need to be implemented in the short term;
- failure to enforce and implement appropriate measures could increase the impact of earthquake events and undermine the resilience of a system;
- promote a risk management approach in dealing with earthquakes, including prevention, mitigation and response;
- continuous communication to raise awareness and reinforce preparedness is necessary.

"Risk communication is successful only if it adequately informs the decision maker" (US Food and Drug Administration 2009). The DI methodology provides useful information in risk perception and risk communication as well as in developing strategies to reduce the consequences of earthquakes and benefits of a decision. This concept offers a comprehensive description of real observed scenarios and permits: (i) to identify the urban system and critical services or elements; (ii) to rank the order of priority of services or elements for continuous operations or rapid recovery; and (iii) to identify internal and external impacts of disruptions. This approach can be also extended to other natural and man-made disasters, and may be used as a tool for optimization resources of system components.

Decisions regarding earthquake risk management are complex and require wide participation and a clear vision of the alternatives from technical personnel and non-specialists. There are now many methods to assist them in making choices. The most popular focuses on evaluating costs and benefits in monetary terms using Cost Benefit Analysis (CBA). However, city managers, urban planners and risk professionals must take a broader view and consider multiple aspects – some of which cannot be quantified. This need can be addressed by the use of Multi-Criteria Analysis (MCA). These decision and risk approaches, capable to use only ordinal scales are very important in order to avoid the endless discussions about the relative weights and utility functions that are the standard procedure used nowadays to assign tangible and intangible values, which may have to be considered in the evaluation of consequences.

Finally, there are many reasons that may result in the priority of earthquake risk management being ignored in favor of more immediate demands. There are financial, practical and psychological factors that come into play here, including the common perception that earthquakes will not happen.

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