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## **SYNER-G**

### **Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain**

Seventh Framework Programme

Priority 1.3.2.2 Vulnerability assessment of buildings, lifelines systems and networks related to earthquakes

### **Deliverable Report**

#### **Deliverable 1.1 – SYNER-G work plan**

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# 1 Concept and objectives, progress beyond state-of-the-art, S/T methodology and work plan

## 1.1 Concept and project objective(s)

### Background and overall objective

The main ideas leading to propose the SYNER-G research project are the following:

(a) Past and ongoing research on the vulnerability assessment and seismic risk analysis of assets and urban systems (buildings, building aggregates, lifeline networks and infrastructures), at international (see HAZUS and MAEviz), European (see RISK-UE and LESSLOSS) and national level [see SRM-LIFE in Greece, VIA in Italy, SDRS in France (2008)], are focused on the vulnerability assessment of individual elements exposed at risk. The uncertainties associated with the proposed empirical, semi empirical and analytical fragility functions and loss estimate models are very important and further research is needed to improve them.

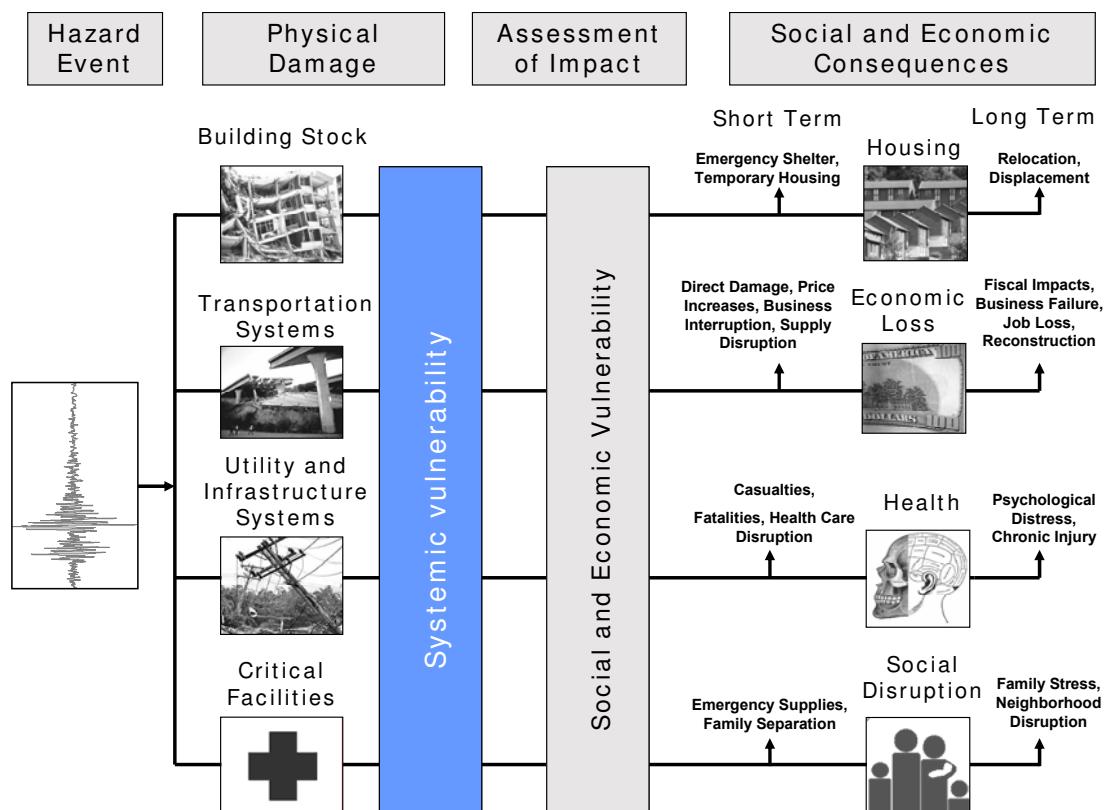
(b) There is an urgent need to develop fragility functions for all elements at risk in the European context respecting the European distinctive features of the elements at risk and the European seismotectonic characteristics.

(c) Systemic vulnerability and the associated increased impact have not been considered so far in a rigorous and unified way for all kind of systems. For example HAZUS, RISK-UE and LESSLOSS projects are focused on the estimation of direct physical damages of the discrete lifeline elements. The importance of the interconnection and interdependencies between elements at risk belonging to the same system and between different networks and systems in urban or regional scale is well known. It is important to evaluate both the vulnerability of independent elements and the systemic vulnerability of systems as well as systems of systems. Furthermore a systemic and holistic approach to loss estimation requires that the loss estimates of the physical elements at risk are connected to the resultant social and economic consequences. Our ability to model damage to non-structural systems and social and economic consequences needs significant improvement. Therefore an important component of the SYNER-G methodology is to capture final loss estimates at the global level (i.e. socio-economic impacts), which depends on the vulnerability and interactions of the whole system and is usually higher than the loss estimates of the sum of its parts.

(d) There is a need in Europe to develop a unified tool to evaluate seismic vulnerability and losses considering both physical and socio-economic aspects that reflect the European communities with their special characteristics as well as the European know-how.

Within this context, the aims of the SYNER-G research project are defined as following: **(a)** To propose and further develop appropriate, in the European context, fragility relationships for the vulnerability analysis and loss estimation of all elements at risk, for buildings, building aggregates, utility networks (water, waste water, energy, gas), transportation systems (road, railways, harbors) as well as complex medical care facilities (hospitals) and fire-fighting systems. **(b)** To develop social vulnerability relationships and other means of quantifying the impact of earthquakes on vulnerable communities. **(c)** To develop the basis and principles of a unified methodology, as well as appropriate tools, for systemic vulnerability assessment accounting for all components (structural and non-structural) exposed to seismic hazard, considering interdependencies within a system unit and between systems belonging to a complex grid that comprises a functioning community (e.g. at city level where building aggregates and different lifeline networks are interacting among themselves and the final loss impact is increased, defined by the individual element losses as well as the losses due to the interaction). Socio-economic issues will be thoroughly considered in the SYNER-G methodology as an impact factor for the holistic evaluation of vulnerability and loss estimates. **(d)** To test and validate the methodology and the particular fragility functions in adequately selected sites (city level) and systems. **(e)** To implement the methodology in an appropriate open source and unrestricted access software tool, to prepare guidelines and to disseminate the results and the developed open-source software in national, European and worldwide level. **(f)** To prepare guidelines and to disseminate the results and output with appropriate dissemination schemes. SYNER-G is a well structured project, integrating across different disciplines all available know-how in Europe, USA and Japan, as necessary for the proposed set of coherent objectives. The objectives and the deliverables are all

well defined and focused to the needs of the administration and local authorities, which are responsible for the management of seismic risk as well as the needs of the construction and insurance industry. Figure 1.1 outlines graphically the concept, the content and the goals of SYNER-G research project.



**Figure 1** General graphical layout of the concept and goals of SYNER-G.

Therefore, the overall objective of SYNER-G is to increase the understanding of the vulnerability of various societal elements at risk belonging to a system (city, region, lifeline network etc) and to propose appropriate methods and tools to consider inter-element and intra-systems interdependencies, including socio-economic features. It will promote the use of modern resources and tools for seismic risk mitigation and it will establish a European reference for seismic societal and physical vulnerability.

To achieve this, the partners in SYNER-G, through an interactive and well structured process will bridge scientific and technology advancement with the development of social-perspective approaches, in order to develop a unified approach.

More precisely, seven main objectives, target areas and key themes will be addressed and achieved by SYNER-G:

The **first** scientific and technical objective of SYNER-G is to encompass all past and ongoing knowledge and know-how on this topic at a European and International level (see Milestone 8 in chapter B.1.3.7);

The **second** objective is to select the most advanced fragility functions and methods to assess the physical and societal-economic vulnerability of assets (buildings, utility systems and transportation infrastructures, society, economy), improving and further developing new ones where necessary, considering European distinctive features (see Milestone 9 in chapter B.1.3.7);

The **third** objective is to propose the most appropriate means of selecting seismic scenarios at system level (see Milestone 8 in chapter B.1.3.7);

The **fourth** and quite innovative objective is to develop a unified methodology to assess vulnerability at a system level considering interdependencies between elements at risk (physical and non-physical), belonging to different systems and between different systems as a whole at city and regional scale (see Milestones 8, 10, 13, 14, 16, 17 in chapter B.1.3.7);

The **fifth** scientific and technical objective is to build an appropriate open-source software and tool to deal with systemic vulnerability in order to improve the seismic risk assessment and management (see Milestone 22 in chapter B.1.3.7);

The **sixth** objective is to validate the effectiveness of the methodology and the tools to specific and well selected case studies at city and regional scale (see Milestone 20 in chapter B.1.3.7);

The **seventh** and final objective is to propose adequate guidelines and to build appropriate dissemination schemes for all products of the project at European and International level (see Milestones 2, 23, 24, 25, 26, 29 in chapter B.1.3.7).

The scientific and technological excellence of the project will be further improved with the active participation in the project of two highly experienced partners from USA and Japan with relevant and long lasting experience in the subject.

The impact of the research and the outcome of the project at a European and international level are consolidated through an appropriate dissemination and educational scheme.

SYNER-G supports and meets the main goals of the ECTP Priority G and contributes efficiently to the Implementation Action of the European Construction Technological Platform.

## **1.2 Progress beyond the state-of-the-art**

### **1.2.1 SYNER-G progress of state of the art**

An evaluation of the risk to an exposed element from a hazardous event requires a consideration of the element's vulnerability, which expresses its propensity to suffer damage, a degree of the system's fragility.

In the Earthquake Engineering approach to vulnerability many relevant bibliographical references are available. From Systems Engineering, the failure events are considered as the result of long chains of failures, finding their way through latent vulnerable elements in the system. Interesting aspects of this approach are related to the need to consider human and physical elements as strictly interconnected and vulnerability as the result of interaction among various systems and subsystems (Lewis, 1999).

In the European research project RISK-UE it was highlighted how the damage and collapse of a building often take place locally, according to the architectonic complexity of some buildings (monuments, hospitals, etc.), to the constructive characteristics (constructive phases, transformations, etc.) and to the poor tensile strength of the masonry. Vulnerability could be assessed by defining a capacity curve for each macro-element identified in the fabric (or for those that seem to be more vulnerable through an appraisal based on experience). Such experimental cases represent a basic floor on which to build a more general methodology. Analogue conclusions have been found for other assets in the more recent LESSLOSS project. Moreover, RISK-UE provided a general methodology for the vulnerability assessment of lifeline systems, mainly based on existing knowledge from USA (i.e. HAZUS), with emphasis to the European typological characteristics. Although it was the first attempt in Europe to bring together all lifeline systems and critical facilities, further improvement was necessary, especially for the derivation of new fragility curves and loss estimation techniques, which was partially within LESSLOSS and other projects.

Systemic vulnerability refers to issues of interdependency, of uniqueness of given functions, and to the possibility to surrogate/transfer/substitute lost functions. The systemic vulnerability introduces generally several new dimensions in the vulnerability evaluation process such as time, space, autohealing, etc. The transient behavior implies the fact that the interaction between sub-systems may dynamically evolve and affect the functionality of the system. The spatial characteristic represents the fact that these vulnerabilities are usually linked to territories. The ongoing European ENSURE project puts emphasis on the identification and integration of different vulnerability concepts embracing physical, systemic and social and economic domains and introduces the territorial vulnerability concept in a multi-risk framework. Hence, the present proposal will be complementary to ENSURE, as it will result in new fragility curves/surfaces for exposed systems and introduce specifically systemic concepts as the transient and adaptativity.

The partner BRGM, in charge of coordination of ENSURE and a partner of MOVE, which adapts a different strategy based mainly on case studies for different natural hazards, will ensure the complementarities between these two projects and the present proposal.

The vulnerability of exposed elements should be studied in the framework of a multi-risk analysis of topologically evolving exposed elements considering not only ground shaking (Bird and Bommer, 2004) but also the impact of other hazard cascading effects, such as earthquake induced landslides, liquefaction or surface rupture (see Dueñas-Osorio and Vemuru, 2008). The software applications developed for the American HAZUS-MH (FEMA, 2003), the New Zealand RiskScape (King and Bell, 2005) and the French ARMAGEDOM (Sedan and Mirgon, 2003) projects are being developed in the direction of multi-risk evaluation. The advantages as well as difficulties associated with a multi-risk analysis are discussed by Douglas (2007) while the vulnerability analysis of topologically evolving systems is still in an inception stage.

### 1.2.2 Introduction and terminology

Three elements are needed to perform a seismic risk analysis for an urbanized / industrialized region. These are the *hazard*, the *inventory* and the *vulnerability*. The hazard is a model describing the seismic threat and its occurrence in a given place. The inventory is the collection of all the assets exposed to hazards in the region. The vulnerability is a model describing the damage-susceptibility of people and the assets. Since uncertainty affects in different ways and to a different extent the three elements above, evaluation of the *socio-economic impact of an earthquake* can only be carried out in probabilistic terms.

The quantification of the socio-economic consequences of a major earthquake is carried out at different levels of complexity. The vast majority of available studies evaluate losses simply as the sum of the monetary value of direct physical damage to the assets in the region (*direct loss*). This approach provides only a first estimate of the *total loss*. In order to evaluate the *indirect loss*, associated for example with economic losses due to business interruption, loss of productivity due to increased travel times on damaged transportation networks, the interruption of harbor activities, etc, it is necessary to move to a much higher level, whereby the (economic) activities of the *society* inhabiting the region, and the *infrastructure* supporting these activities are modeled as a *system of interconnected components*. In the following, a brief overview of the probabilistic seismic risk analysis of such a system is given and relevant terminology used in the proposal is provided.

According to PCCIP (1997) an *infrastructure* is a network of independent man-made *systems*<sup>1</sup> and *processes* that function collaboratively and synergistically to *produce* and *distribute* a continuous flow of essential *goods* and *services*.

According to this definition the infrastructure is the collection of physical elements and procedures that supports the functioning of a society<sup>2</sup>.

Consequently a complex infrastructure may be composed by the following general systems: residential buildings, industrial buildings and processes, electrical power and energy transmission network, water-supply and waste-water network, telecommunication networks, transportation networks .

The term infrastructure is often used to denote only one of the systems, e.g. transportation infrastructure, etc. The term *lifeline* might also be generically used to stress the vital importance of a particular system.

An important element required for the probabilistic evaluation of the performance of a system subjected to an earthquake is an adequate, system-specific probabilistic description of the seismic hazard. The model can range in complexity from a hazard curve and an associated suite

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<sup>1</sup> There appears to be an undifferentiated, somewhat confused use of terms such as “system”, “infrastructure”, “network” and “lifeline”. Among those, the term “system” is ethimologically the one with the widest significance, as it comes from the Greek συν-ιστημι, i.e. put together, i.e. composed of many parts.

<sup>2</sup> According to the Joint Committee on Structural Safety definition (2008), a *society* is a group of people for which common preferences may be identified, exogenous boundary conditions are the same and which share common resources.

of recorded ground motions for a simple structural system (e.g. a building), to a full probabilistic representation of the seismic sources and their activity coupled with either ground-motion prediction equations with distinct terms for the inter- and intra-event dispersion (Crowley and Bommer, 2006; Bommer and Crowley, 2006) or seismological models (e.g. Boore, 2003). Site specific studies based on the principles of seismic scenarios is currently used to assess vulnerability and losses of spatially distributed and extended lifeline systems (Pitilakis et al., 2004a; Faccioli et al., 2007; Pitilakis et al., 2004b). Conventional probabilistic seismic hazard analysis (PSHA) for a single site or using code design spectral values, are of no use for the analysis of spatially distributed systems. Employing PSHA-derived hazard curves at each site in a loss-estimation study leads to a gross over or even underestimation of the expected losses.

A general *system* is made up of *components*. These can often be described themselves as sub-systems made up of elementary components, depending on their complexity. Hence, the analysis of a system starts always with the *identification* of all its components.

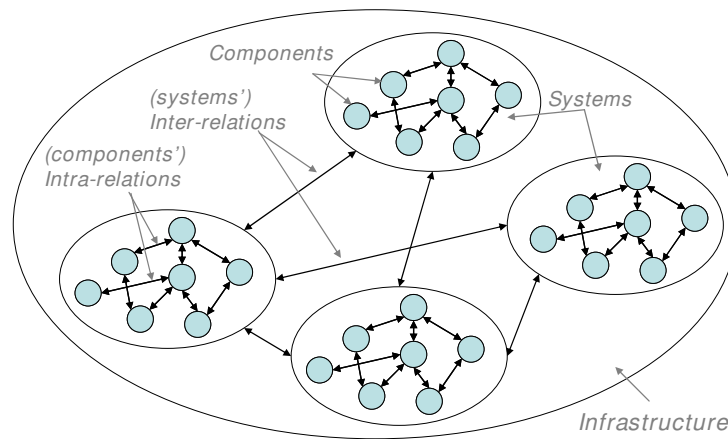
A system of general nature can be decomposed into the following three macro-components according to the system taxonomy proposed by Bea (2003):

- Physical (macro-) component: comprising the structural and non-structural components.
- Human (macro-) component: made of human beings living and using the assets and of the operators (if any), in charge of running/monitoring/maintaining the system.
- Organizational (macro-) component: i.e. the procedures set up for the operators to follow under normal or exceptional (emergency) conditions in order for the system to function properly.

The three macro-components interact in order for the system to function (preserving the well being and producing or delivering goods/services). It can be observed that in different specific systems the above macro-components will have different weights. For example, in a hospital system (Lupoi et al., 2008) all three components are contributing to the delivering of the medical services (the function of the hospital system). In a transportation network the role of the physical macro-component, and in particular of the structural component within the physical component, is dominant (this also depends on the modeling of the network function, as explained later).

The *characterization* of the components is based on the specification for each component type *generic fragility functions* of empirical, analytical or semi-empirical nature (see e.g. HAZUS, NIBS, 2004; RISK-UE, 2001-2004; LESSLOSS, 2004-2007). The refinement in SYNER-G consists of the use of *mechanically-based specific fragility functions* obtained from the analysis of a model of the corresponding physical system, possibly adjusted by Bayesian model updating (e.g. Gardoni et al., 2002) to include empirical evidence from experimental tests and observations of component performance during past earthquakes. Each component will be described in terms of a model which is a function of basic random variables. The latter description, which can be also complemented with correction terms to account for model error and deviations from observations, is the most versatile in the evaluation of all the interdependencies between different components of a system that can have a strong influence on the probability of system performance.

Once all components have been identified and characterized, the system analysis proceeds with the identification and description of the *relation/interactions between the components*. These can be distinguished into *intra-relations* between the components of each system, and *inter-relations* between the systems making up the infrastructure (see Figure 1.2). The ultimate goal of this step is the formulation of a *system function* that allows the evaluation of the state of the system as a function of the states of its components. The availability of such a function is a prerequisite for the evaluation of the system performance.



**Figure 2** Graphical representation of an infrastructure comprising a number of systems with their interactions.

Several approaches are available to help describe the relations existing between a system's components. Some of these are: Graph theory; Fault-tree analysis (FTA); Event-tree analysis (ETA); Series system in parallel (SSP); Agent-based models and Complex Adaptive Systems (Amin, 2001; Little, 2002; Brown et al. 2004; Bernhardt and McNeil, 2004; Tolone et al., 2004).

Once the components and all their relations have been identified and described, the probabilistic evaluation of the performance of the system (PNET) can be carried out employing the methods of System Reliability Analysis. These include expansion methods, such as FORM/SORM or the response surface technique (Ditlevsen and Madsen, 1996), as well as the Monte Carlo simulation methods (Rubinstein, 1981). Depending on the nature of uncertainty and the aptitude to determine them, the probabilistic approach may be replaced or enhanced by possibilistic approaches based on Fuzzy Logics, so-called Fuzzy Networks.

Even if non-simulation methods have recently seen interesting advances, e.g. in the form of Matrix System Reliability Analysis (Song and Der Kiureghian, 2003; Der Kiureghian and Song, 2008), the complexity of civil infrastructural systems, and especially the analysis of capacitive networks such as transportation, power transmission and water-supply networks, leaves simulation methods as the only viable option. Also due to the increasingly quantitative approach to the evaluation/prediction of the behavior of other complex systems, of economic or social nature, the simulation approaches have undergone most significant progresses. These new developments, collectively denoted as *Modern simulation methods* (as opposed to conventional simulation largely established before 1980), consist of smart techniques dealing with sensitivity analysis and stochastic optimization of computer simulation models (Rubinstein and Melamed, 1998) or Neural networks (NN).

The probabilistic assessment of the seismic performance of any system must yield as outcome a quantity that is meaningful to the decision-makers and the stake-holders (JCSS, 2008). The definition of the most appropriate quantity for each system, denoted as "*performance measure*", is itself a challenging task. For example, measures have been proposed to quantify the reduced performance of a damaged/congested transportation network in the form of a "Driver's Delay" (Shinozuka et al., 2003 a) or, to quantify the performance of a health-care facility, in the form of the "Hospital Treatment Capacity" (HTC) i.e. the number of patients that can be given surgical treatment per hour (Lupoi et al., 2008) and, for electric power transmission or water supply networks, in the form the "Service Flow Reduction", i.e. the amount of flow that can be delivered to users compared to the amount prior to the damage/disturbance (Dueñas-Osorio et al., 2007).

For the purpose of comparison and optimal allocation of retrofit/mitigation and restoration resources, the different performance measures must be homogenized. This is commonly done in monetary terms. With reference to structures such as buildings, bridges etc a methodology for the probabilistic evaluation of losses has been developed in the context of a ten years long research endeavor within the Pacific Earthquake Engineering Research Centre (Cornell and Krawinkler, 2000). The simple summation of the monetary losses separately incurred by the various systems does not represent, however, the actual total loss suffered by a society hit by an earthquake. Loss can be subdivided into *direct* and *indirect*. The former correspond to direct

*damage* to the *physical components* of the system, while the latter stem from *loss of function* resulting from the physical damage. Even if indirect loss can likely be the dominant contributor to total loss, it is usually estimated in approximate ways, since an accurate estimation of the economic consequences of the loss of function of one system requires the evaluation of its impact on the other systems of the infrastructure. Studies that attempt to tackle the problem of interacting systems are still few, limited in scope and in early stages of development (e.g. limited to the one-way influence of the electrical transmission network on the water-supply system, as in Dueñas-Osorio et al., 2007 or Kim et al., 2007). Perhaps the most comprehensive study available, albeit including only a part of the vulnerable systems, is the one in Karaca (2005), which explores the consequences of a major earthquake in the Central-Eastern US by modelling the economic activity in the whole US and its disruption due to the event.

### 1.2.3 International state-of-the-art

The following section provides a very brief overview of the most significant studies mainly in USA and Europe covering parts or attempting to tackle the whole problem of the vulnerability assessment and the evaluation of the socio-economic impact of earthquakes in buildings, urban systems, lifelines and infrastructures.

This state-of-the-art is structured as follows. Section 1.2.3.1 summarizes studies on the probabilistic characterization of *components'* fragility /vulnerability. Section 1.2.3.2 illustrates some selected studies on the estimation of the impact of an earthquake on a region, where direct loss is estimated as a simple summation over the system components. These two sections pave the way for the presentation in section 1.2.3.3 of some selected studies dealing with the more complex problem of accounting for the interaction between system components in the estimation of the total loss due to an earthquake.

#### 1.2.3.1 Element fragility studies

Fragility functions (curves) describe the probability of an element reaching a certain damage state given a specific ground motion parameter; they usually referred to groups of structures with similar typology. Fragility functions of structural and non-structural components belong to three general classes: (a) generic fragility based on expert judgment, (b) empirical fragilities based on experimental tests of components or on damage surveys after earthquake events, (c) fragilities based on physical models of the components and a probabilistic characterization of the corresponding parameters. ATC-13 (1985) and ATC-25 (1991) followed the type (a) approach for the evaluation of damage probability matrices, evaluation of loss functions and restoration times and finally determination of fragility curves for different elements at risk. Models in the software package HAZUS (NIBS, 2004) are mostly of type (a) and can be used mainly for large-scale preliminary loss-assessment. Models of type (b) have been developed both for non-structural components (e.g. partitions, window-panes, etc), as well as for entire structural systems (e.g. bridges, as in Basoz and Kiremidjian, 1998; Shinozuka et al., 2003b; Saxena et al 2000, tunnels, water system elements as in ALA, 2001 a, b). Fragility of types (b) and (c) lead to more reliable loss estimates, however several uncertainties are involved in empirical models related to the inconsistency or heterogeneity of damage data, the lack of ground motion records, the subjectivity of damage descriptions or the statistical analysis method. Fragility of type (c) can be obtained with a variety of methods. Recent reviews of these methods, ranging from response surface, to advanced simulation, etc, can be found in RISKUE and LESSLOSS, 2004-2007<sup>3</sup>; Pinto et al., 2004; Calvi et al., 2006. Few examples of analytically derived fragility curves are given herein: Kappos et al. (2006) for common R/C buildings in Greece; Iervolino et al. (2007); Polese et al. (2008); Borzi et al. (2008a,b) for RC and masonry buildings in Italy; Gencturk et al. (2007) for buildings in USA; Shinozuka et al. (2003b); Gardoni et al. (2002); Elnashai et al. (2004); Nielson and DesRoches (2007) for R/C bridges; Argyroudou et al. (2007) for shallow tunnels in alluvial deposits. The principles of fragility curves have been recently studied by Seyedi et al. (2007; 2008) and Chalmers (2008). Douglas and Gehl (2008) and Khair (2008) propose

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<sup>3</sup> Several partners of SYNER-G took part in the EU-funded project LESSLOSS (FP6), whereby component and structural systems vulnerability assessment was the specific object of Sub-project 9 led by UROMA, while vulnerability assessment of lifelines in Sub-project 11 (AUTH).

instead of “curves” the “fragility surfaces” by use of which the shortcomings of representing the seismic threat by only one parameter may be overcome.

### **1.2.3.2 Loss estimation studies**

Large destructive earthquakes occurred worldwide in highly urbanized areas in the last twenty years or so, (Loma Prieta, CA, 1989; Northridge, CA, 1994; Kobe, Japan 1995; Izmit, Turkey and Chi-Chi, Taiwan, 1999) have prompted governments to undertake large-scale studies on the expected losses due to a major earthquake. Studies of this type serve the main purposes of designing mitigation strategies and of planning emergency and recovery measures. They do not consider the inter- or intra-dependence of the components and systems making up the infrastructure, they simply evaluate the degree of damage to all assets exposed to risk by overlaying seismic hazard for selected scenarios with vulnerability maps. Damage ratios thus obtained are then converted in monetary terms by means of loss functions. Few selected case studies are presented herein mainly to highlight the state-of-the art and practice.

#### **1.2.3.2.1 Studies on the Italian building stock**

Various projects in Italy over the past 10 years have considered the problem of defining the levels of seismic risk to residential buildings at a national scale. The SAVE Project (Zuccaro, 2004), the SSN Rischio Sismico 2001 project (Lucantoni et al., 2001) and studies by the Italian Department of Civil Protection (Bramerini and Di Pasquale, 2008) have all tackled this problem, producing maps which generally present the annual risk in terms of the percentage/number of residential buildings or dwellings exceeding a given damage state within each of the 8101 municipalities in Italy. All of the aforementioned maps were produced utilizing seismic hazard studies carried out at the end of the 1990's, with empirical descriptions of the vulnerability (based on observed damage data from a number of large Italian earthquakes) and with census data from the 1991 Census of the Population and Dwellings. A recent study by Crowley et al. (2008) presents seismic risk maps which combine the most up-to-date seismic hazard maps for Italy with mechanics-based vulnerability assessment methods.

#### **1.2.3.2.2 Studies on the Istanbul area**

Istanbul has been the focus of a number of scenario-based damage assessment studies following the 1999 Kocaeli earthquake which raised the level of awareness of seismic risk in the area. According to the recent study by Parsons et al. (2000) there is a heightened probability of a magnitude  $M_w \geq 7$  earthquake effecting Istanbul over the next 30 years and thus many analyses have been carried out considering the effects of a deterministic scenario earthquake beneath the Sea of Marmara (e.g. Erdik, 2007; Spence, 2007; Pyper Griffiths et al., 2007; Sözen, 2006; Bal et al., 2008). Many of these studies have used the building inventory developed by KOERI who compiled the 2000 Building Census data with the footprints of buildings from aerial photos of the greater Istanbul area taken between 1995 and 1998 on a 500m by 500m grid. The day- and night-time population within each grid was also estimated. The building and population exposure databases have allowed estimates of the percentage of damaged buildings, the number of casualties and injured persons and the displaced population following the scenario earthquake to be estimated. The estimates from the aforementioned studies vary from 100,000 to 250,000 for the number of severely damaged or collapsed buildings, whilst for the number of deaths, estimates between 0.3 - 1.2% of the population have been found. A current study being conducted in Istanbul by KIT-U is investigating the underlying factors of social vulnerability (i.e. poverty, age, disability, lack of risk awareness and preparedness measures, etc.) through the use of indicators (derived from a survey of 36,500 households) and linking their aggravating impact to the physical loss estimates obtained for Istanbul .

#### **1.2.3.2.3 Study on the Thessaloniki area**

A general modular methodology for the vulnerability assessment and seismic risk management of lifelines and infrastructures has been recently developed in Greece, with application in the city of Thessaloniki, in the framework of national and EU research projects (SRMLIFE, RISKUE, LESSLOSS). The vulnerability of buildings and lifeline systems in the city has been assessed for different seismic scenarios (Pitilakis et al., 2006a,b; Pitilakis et al., 2007a,b; Argyroudis et al., 2005). A hierarchy model has been proposed to evaluate and quantify the relative importance of various elements at risk and systems as well as city regions (see Global Value approach in

RISKUE) The hazard analysis is based on seismic scenarios, and a detailed microzonation study (Anastasiadis et al., 2001; Pitilakis et al., 2007a). Given the spatial distribution of the characteristics of earthquake motion, loss scenarios for buildings, utility and transportation systems, critical facilities and strategic buildings are produced, using inventory data and adequate fragility relationships. The assessment of the “global value” (physical and non-physical) is performed (a methodology developed in RISKUE), in order to classify the importance of each lifeline element in different periods (normal, crisis and recovery) and thus to prioritize in a more efficient way the pre-earthquake retrofitting actions and the post earthquake restoration efforts. Based on the hierarchy of importance of lifeline components, as well as available techniques, man-power, material and equipment, estimates of the restoration process are performed.

#### **1.2.3.2.4 Study on the Central-Eastern USA**

Recently the Impact of Earthquakes on the Central USA has been the object of the “New Madrid Seismic Zone Catastrophic Earthquake Response Planning Project” funded by FEMA and carried out by the Mid-America Earthquake Center (MAEC, 2008). This project comprises a multi-phase investigation of possible earthquake scenarios, analytical earthquake impact assessments, and social impact estimates that will assist federal, state, and local governments to develop coordinated response plans for a catastrophic earthquake in Central USA. The primary objective of this multi-phase project is to provide scientifically defensible earthquake impact assessments with the most up-to-date hazard, inventory and fragility data in order to save lives and protect property. The earthquake impact assessment of direct damage to infrastructure, social impacts and economic losses for the individual states has been compiled. Hazard, inventory and fragility are integrated to determine direct damage, direct economic loss and functionality of infrastructure components. The results of this direct damage assessment are then used to determine social impacts such as displaced population and sheltering requirements.

Hazard has been modeled considering ten scenarios for three seismogenic sources. Inventory includes all components of the built environment as well as demographic data, which includes estimates of total population, and various group classifications within the general population, broken down by income, ethnicity, education and age. Inventory, or assets, in the built environment includes a wide variety of infrastructure with commonly used inventory types listed below: Essential Facilities (Schools and Hospitals, Police and Fire Stations, Emergency Operation Centers), Transportation Lifelines (Highway Bridges and Roads, Railway Bridges, Tracks and Facilities, Airport, Port, Bus and Ferry Facilities), Utility Lifelines (Potable Water Facilities and Networks, Waste Water Facilities and Networks, Natural Gas Facilities and Pipelines, Oil Facilities and Pipelines, Electric Power and Communication Facilities), High Potential-Loss Facilities (Dams and Levees, Hazardous Materials Plants, Nuclear Power Plants).

The study makes use in Phase I of the HAZUS-MH MR2 software package (NIBS, 1999, 2004), replacing almost all the generic hazard and fragility data with specific data appropriate for the study region and derived specifically taking the region’s characteristics into account. The Phase II effort of this large FEMA-funded project focuses on several issues, like inventory and hazard improvement, further development of fragility curves for different assets, network modeling (transportation and utility) and social vulnerability. MAE Viz, the MAE Center open source, web-enabled impact assessment software package is used as well as HAZUS.

#### **1.2.3.2.5 Studies in Japan**

In the case of the 1995 Hyogo-ken Nanbu (Kobe), Japan, earthquake, many lives were lost under completely collapsed buildings having no survival spaces. Most methods of formulation of vulnerability functions are based on statistical functions obtained from actual earthquake damage survey results, but enough data sets have not been collected to formulate the vulnerability functions for completely collapsed buildings, because of the difficulty of damage surveys focusing on those buildings. At the Research Center for Urban Safety and Security (RCUSS) of Kobe University (UKOBE), a modified seismic risk assessment method using vulnerability functions, reflecting structural damage levels and focusing on completely collapsed damage, has been developed. Building damage patterns have been classified using more than 11,000 photographs linked to a GIS database of the Hyogo-ken Nanbu earthquake, and the relationship among the building damage patterns, the intensity of seismic ground motion and building characteristics such as the building construction year has been analyzed. The new method will be a useful tool

for promoting countermeasures to mitigate building damage, which is a main factor of human casualty, and contribute to further development of similar methods under this EU project.

#### 1.2.3.2.6 Study on the South-Western France (Lourdes area)

The microzonation of Lourdes area has been carried out in order to assess the seismic risk of the city and its suburbs. Adequate seismic inputs have been identified in parallel with the inventory of existing buildings covering around 150 building polygons delimited on the basis of different GIS layers and satellite imagery (see Carnec et al. 2005) and considering the period of construction, the density and the position in the city. Based on the structural survey sheet the vulnerability of the current buildings was assessed according to "RISK-UE Level I" method. Seismic hazard and the vulnerability were combined by means of the Armagedom software (Sedan and Mirgon 2003). Building damage estimation was performed for each scenario earthquake based on the damage function, the vulnerability of each structural typology and intensity of ground motion in each 250 meter square grid cell. Building damage is expressed in terms of EMS92 damage grade from 1 to 5. Finally, information obtained from 17 November 2006 earthquake was used to compare and validate the results of the analysis.

#### 1.2.3.3 Loss-estimation studies of systemic nature

This section provides a brief overview of selected international studies which go beyond the simple summation of direct loss and include consideration of the interactions between system components in determining the deterioration of the system function due to an earthquake.

##### 1.2.3.3.1 Studies on transportation networks

###### Roadway networks

A fundamental distinction among the studies related to the seismic vulnerability of transportation networks can be made based on the importance of the role played by the network itself. In a way of simplification, available studies can be assigned to the following three levels:

- **Level I** is focused on the functioning of the network in terms of pure connectivity (Franchin et al., 2006; Nuti and Vanzi, 1998). The considered vulnerable elements are those internal to the network itself, which generally consists of bridges, viaducts, tunnels, retaining structures, etc, and other elements of the surrounding environment, such as residential buildings and hospitals. This type of studies focuses on just one of the services provided by the network, e.g. most typically the rescue function immediately after the earthquake, and may be of interest in identifying portions of the network which are critical with respect to the continued connectivity of the network and allows the determination of *direct* economic loss. Social loss is evaluated in terms of increased number of fatalities due to either hospital collapse or road interruption (Franchin et al., 2006).
- **Level II** is further considering the network capacity to accommodate traffic flows (Basoz and Kiremidjian, 1996, Werner et al., 1999, Shinozuka et al., 2003 a). In the latter study the damage to the network (determined based on Monte Carlo simulation of probabilistically defined seismic scenarios and fragility curves of the bridges) causes traffic congestion, resulting in increased travel time which is in turn translated into monetary terms. The latter is a first approximation of the indirect loss caused by the earthquake. The analysis is repeated at fixed interval of times after the event taking into account the repair process to evaluate the distribution of increased travel time (driver's delay) with time elapsed from the event. Sensitivity studies to seismic upgrading scenarios are also carried out by employing fragility curves of upgraded bridges. Modaressi and co-workers (see Douglas et al. 2007) developed a similar tool for evaluation of the loss in monetary terms due to the interruption of a trans-border road between France and Italy caused by earthquake and/or landslide.
- **Level III** is the most general approach, which aims at obtaining a realistic estimate of total loss, inclusive of direct physical damage to the built environment (residential and industrial buildings as well as network components), network-related loss (increased travel time) and loss due to reduced activity in the economic sectors (industry, services) (Karaca, 2005; Veneziano et al., 2002). Economic interdependencies are accounted for, such as the reduction in demand and supply of commodities (due to damaged factories, etc.), hence in the demand for travel, and due

to the increased travel costs. At this level the relevance and the complexity of the economic models become dominant over that of the transportation network.

Analysis at the third level involves reaching beyond the area of structural engineering and requires important inputs from the economic disciplines, like data for demand and supply of goods, commodities and services disaggregated by economic sector and spatial location. Collection of this information requires the involvement of governmental bodies.

Finally, the studies for the seismic risk analysis of roadway networks in terms of road closures due to collapsed buildings and/or adjacent lifelines (e.g. damaged water or gas pipes beneath the roadways) are limited. Goretti (2005) proposed a probabilistic approach for the analysis of the seismic behavior of the road network, buildings and emergency services in urban areas of South Italy, combining the probabilities of building collapse and road blockades. A similar study has been performed in Thessaloniki (Anastassiadis & Argyroudis, 2007).

### **Harbor systems**

Harbors are complex systems including several structural components, utilities and infrastructures, thus concentrating various activities in a limited area. Damages sustained by port facilities during past earthquakes throughout the world, led to a wide range of direct and indirect losses, with serious impacts in economic, operational and emergency management of modern societies. The port of Kobe lost almost 50% of its commercial flow after the strong M=7.5 earthquake in 1995 and besides the important retrofitting works it has not recovered yet. HAZUS (NIBS, 2004) proposed empirical fragility curves in respect to permanent ground displacements (PGD) and/or peak ground acceleration (PGA) for waterfront structures (e.g., wharfs, piers and seawalls), cranes and cargo handling equipment, fuel facilities and warehouses. Several fragility curves have been proposed especially for different waterfront structures, (Ichii, 2003; 2004) while few attempts to consider the SSI effects can be found in Roth et al. (2003), Roth and Dawson (2003) Pasquali et al. (2008) and Kakderi et al. (2006). The HAZUS method has been applied in Greece for the port of Thessaloniki (Pitilakis et al., 2007b).

Pachakis and Kiremidjian (2003, 2004) presented a methodology to simulate the seismic response, planning and risk management of port facilities based on previously described HAZUS curves. The types of earthquake related losses include: direct property losses, net income losses, liability losses to third parties and employees and indirect losses. Werner et al. (1999) proposed a method based on the concept of "acceptable seismic risk" for the reduction of seismic risk in ports lifelines. The Port of Los Angeles has developed and recently revised guidelines for the design, upgrade and seismic strengthening of wharf structures (Yin et al., 2003).

#### **1.2.3.3.2 Studies on electrical power distribution networks**

Cesi (2001) has collected numerical and experimental studies on electrical equipment in a database, aimed at providing data for the definition of fragility curves. Similarly, in USA, the PEER has developed databases collecting the main dynamic characteristics of electrical equipment (Filiatrault and Stearns, 2003), and the damage data surveyed in substations after Californian earthquakes (Anagnos, 2003). The data have been used to assess seismic fragility curves (Der Kiureghian, 1999). In Nuti et al. (2007) a numerical procedure for the assessment of a single piece of electrical equipment has been developed based on the application of Cornell's method (Cornell et al., 2002).

For what concerns past and on-going research on electrical power networks, realistic modeling can only be of the capacitive type, which makes use of power-flow equations and/or Monte Carlo analysis within the network (Shinozuka et al., 1999; Liu et al., 2004; Ostrom, 2003). For each scenario, seismic hazard curves relating the annual probability of exceedance with the functionality indices of the system are estimated to derive the type and level of induced damages, the systems' functionality and mitigation priorities. American Lifelines Alliance (ALA, 2005a,b) proposes a method for the assessment of electric power systems in natural hazard and human threat events consisting of a screening phase and an analysis process based on scoring.

Probably the most accurate model of the equipment and the network, the Ask4elp procedure (and software) (Vanzi, 1996; Giannini et al., 1999; Vanzi, 2000) makes use of the Monte Carlo procedure to conciliate the capability to consider the main sources of uncertainty under which the

analysis is conducted, the need to treat the network as capacitive and a reasonable computational effort. Applications have included two-thirds of the Italian high tension network (Vanzi, 1996), the medium and high tension networks of Sicily (Giannini et al., 1999; Vanzi, 2000) and the medium tension network serving the city of Catania (Nutti et al., 2007).

#### **1.2.3.3.3 Studies on water and waste-water networks**

The vulnerability of water and waste-water networks in strong earthquakes is strongly dependent on their distinctive features (i.e. oldness, corrosion, and typology) and the inherent uncertainties of earthquake loading (permanent ground displacements, ground shaking) which are strongly influenced by the local soil conditions. Moreover, the lack of well-validated damage data from strong earthquakes, the difficulty in the definition of damage states, and the strong influence of interdependencies impede a reliable and homogeneous estimation of the vulnerability.

Empirical relations have been proposed for pipe damage, which relate peak ground velocity (PGV, due to wave propagation) or permanent ground deformation (PGD) to the Repair Rate/km [RR/km], i.e. the expected number of repairs per km of pipe. Macroseismic intensities were also used as an appropriate indicator. For water and gas pipelines, O'Rourke and Ayala (1993); Eidinger (1998); Eidinger and Avila (1999); Isoyama et al. (1998) and ALA (2001a,b) developed damage relations in terms of Repair Ratio/km, using estimated and recorded values of peak ground velocity (PGV) and data from USA, Mexico and Japan. Honegger and Eguchi (1992); Eidinger and Avila (1999) and ALA (2001a, b) produced relationships that correlate PGD with pipeline failures. The scatter between the various approaches is very important (an order of magnitude!) A major conclusion derived from this remark is that fragility relations should be specifically defined at European and/or national level with respect to the design-construction practice, the seismotectonic background and the local soil conditions. The latter two parameters modify considerably the ground velocity (and strains) for large earthquake and consequently the fragility relations expressed in terms of ground velocities (and strains). Recently validation studies after the Lefkas, Greece (2003) and Duzce, Turkey (1999) earthquakes have been performed (Pitilakis et al., 2005). A detail analysis of the spatial distribution damages has been performed for the Thessaloniki's water system for the 475 years scenario (Pitilakis et al., 2007 b). A new method for the seismic verification of pipelines subjected to fault rupture is presented recently (Faccioli et al., 2007). Finally, vulnerability relations based on the ground strains as appropriate indicators have been proposed by O'Rourke and Deyoe (2004) and Paolucci and Pitilakis (2007).

#### **1.2.3.3.4 Studies tackling the interaction of two networks**

Several researchers have proposed different types of interdependency simulation models:

- Physics-based models (Tang et al., 2004; Wong and Isenberg, 1995). Interactions among lifeline systems are defined based on functions, spatial coexistence, and conditionality in recovering procedure. The Fault Tree Analysis (FTA) is often used for the estimation of their seismic performance.
- Nodal analysis models (Giannini and Vanzi, 2000; Peerenboom et al., 2001). The reliability analysis of systems is usually performed with a Monte-Carlo simulation tool to assess the statistics of the network performance.
- Agent-based models (complex systems) (Amin, 2001; Little, 2002; Brown et al., 2004; Bernhardt and McNeil, 2004; Tolone et al., 2004). Infrastructures are studied as Complex Adaptive Systems (CASs), which are complex collections of interacting components in which change often occurs as a result of learning processes (emergent behaviour).
- Stocks-and-flows models (Haines and Jiang, 2001; Santos and Haines, 2004). They are based on Input-Output economic models to address the multiple interactions between infrastructures, assuming that the level of economic dependency is the same as the level of physical dependency and using flows of products between the systems in economic (monetary) terms.
- Network models (Dueñas-Osorio et al., 2007; Yao et al., 2004; Tang et al., 2004; Tang and Wen, 2008; Li and He, 2002). Infrastructures' interdependencies are addressed through network analysis. Graph theory is adopted by several researchers. The Bayesian approach is often used for network analysis. The function states of the systems are also analyzed using flow analysis

and connectivity analysis. Network models are classified in random networks, small-world networks, scale-free networks and interdependent infrastructure network.

However very few studies can be found in the literature dealing with the highest level problem of multiple systems interaction in the case of seismic vulnerability and loss estimates. They have still an exploratory character and are based on rather extreme simplifications, being limited to the analysis of at most two systems.

Dueñas-Osorio et al. (2007) proposed a very simple model for interdependent lifeline systems in which the interdependency was determined by geographical immediacy. In particular, the study focuses on the dependence of a water system on the power grid.

The main limitation of the study is that the modeling of the networks is of the pure-connectivity type and the links are bi-directional (whereas in most networks, and in the two networks studied they are either unidirectional or both uni- and bi-directional). Kim et al. (2007) built on the work cited above by introducing many refinements and in particular directional modeling of links, capacitive modeling of the networks and a more efficient representation of the networks topology, which turns out to be essential for large scale networks of regional size.

Finally some recent studies have been focused on the proposal of a methodology to evaluate the associated losses of interacting lifeline elements for various strong motion intensities and the estimation of complex fragility curves of interdependent components (Kakderi et al., 2007; Kakderi et al., 2008; Alexoudi et al., 2008a,b). The estimation of the expected seismic performance of interdependent infrastructures is performed based on a probabilistic approach and using adequate interdependency indices to quantify the level of interaction. These indices are evaluated using an economic approach, a decision making procedure, and a fuzzy reasoning.

#### **1.2.3.3.5 Studies on the vulnerability of essential (critical) facilities**

Essential facilities include schools, hospitals, police and fire stations and emergency centers. Hospitals play a crucial role in “emergency” conditions in the aftermath of a natural disaster and they may represent the more complex paradigmatic examples of this kind of facility. The indirect consequences of a health care system failure include both human costs, in terms of deaths, and intangible costs, such as loss of confidence in governments and fear for safety.

The standard procedures which regulate the hospital-system functioning have to be significantly modified to positively respond to the disaster through a concise emergency plan. Simplified but comprehensive models of social-complex system for seismic assessment have yet to be developed. A proposal for hospitals, based on the taxonomy of complex systems by Bea (2003) has been recently advanced in Lupoi et al. (2008) taking in account three active components of the medical services (operators, organization and facilities). All external influences to the functioning of a hospital system are represented by the *environment* component, which encompasses such diverse factors varying from cultural background to soil conditions.

The main challenges (Lupoi et al., 2008) in the seismic performance evaluation of health-care facilities consist of:

1. The definition of a meaningful measure to express the performance encompassing technical, organizational as well as societal considerations.
2. The development of a methodology for assessing the performance in terms of the above measures, accounting not only for the physical factors involved, but also for human and organizational factors, with adequate consideration of all the different sources of uncertainties.
3. The definition of the mutual relations between the system components.

According to Lupoi et al. (2008) a performance measure is expressed as the Hospital Treatment Capacity (HTC), derived in a probabilistic way on the basis of past experiences and responses of hospital systems. The HTC measures the amount of medical services provided by the hospital following an earthquake in terms of number of patients that can be given surgical treatment per hour. The consequences of the earthquake on the hospital and its functioning in the aftermath of the event have been identified by a *system analysis*; the identification of possible failure modes has been dealt by *fault tree analysis* (FTA) approach (NUREG-0492, 1981). The vulnerability of non-structural physical components has been assessed employing state-of-the-art models (ATC 51-2, 2003), (Shinozuka, 2000). The Hospital Treatment Capacity is compared with the Hospital

Treatment demand (HTD). Both depend on the intensity of the earthquake (HPC is decreasing and HPD is increasing).

Kuwata and Takada (2008), proposed a seismic risk assessment method for hospital lifeline as a part of the Seismic Risk Management method. The purpose was to evaluate the availability of hospital systems, considering damage probability of building and lifeline facilities, and the loss related to pipeline damage. The proposed method has been applied to ten hospitals in Osaka. The methodology was based on developing fragility curves of components of hospital lifelines and where the components are made of subcomponents (i.e., outside water pipeline, receiver tank, elevated tank, house pipes), their damage were obtained using a probabilistic combination of subcomponent fragilities using the fault tree logic.

#### 1.2.3.3.6 Studies attempting the estimation of total socio-economic losses

Research on estimating socio-economic losses often has to deal with elements that are difficult to measure – either because data is unavailable or because the factor of interest is difficult to quantify. Until recently, research in this field has described many case studies and local observations on social and economic vulnerability. What is needed now is a set of methodologies that can be used to extrapolate the appropriate findings from the existing body of case studies on social vulnerability, to other geographical areas and to other dimensions of vulnerability (e.g. economic, physical, institutional, etc.). Furthermore, there is a demand through multidisciplinary research to transfer the differential impact and interdependencies of social and economic components into measurable indicators and values of socio-economic losses and integrate them into loss estimation methodologies, upon which political decisions can be based.

Several notable studies dealing with hazard loss estimation and the quantification of socio-economic effects have recently been undertaken. These include studies on the aggravating impact of social vulnerability and (e.g. Cardona et al., 2005 and Carreno et al., 2007); studies on the recovery potential of communities from an earthquake impact (e.g. Miles and Chang, 2006); studies on the economic impact of earthquakes on lifelines (e.g. Tatano and Satoshi, 2008); and studies on business interruption losses from natural hazards (e.g. Rose and Lim, 2002). Some novel approaches also exist that attempt to account for socio-economic interdependencies within regional earthquake loss methodologies.

One such study was carried out by Karaca (2005) where realistic estimates of economic interaction were obtained for a scenario earthquake from the New Madrid Seismic Zone, by investigating the spatial interactions (through the transportation network) and business interactions (through an input-output model) and extending the socio-economic consequences geographically to the entire conterminous U.S. The losses reflect damage to buildings and transportation components, reduced functionality, changes in the level of economic activity in different economic sectors and geographical regions, and the speed of the reconstruction/recovery process.

#### 1.2.4 Limitations in the state of the art

Three main limitations of the existing know-how can be identified:

The first one is that, despite the large investment in several EU and national projects in EU Member States, and other countries (USA, Japan and elsewhere) in the vulnerability assessment of particular assets (residential and public buildings, lifeline systems and infrastructures like bridges), little work has been done to assess the *systemic vulnerability* of all these systems especially considering the interdependencies among elements at risk belonging to different systems and/or intra-dependencies within each system. The system's vulnerability is always higher than the sum of individual component's vulnerability

The second is that the physical and **socio-economic vulnerability** of independent elements at risk is far from being studied in a homogenous and coherent way. Socio-economic impact is not currently systematically included in vulnerability and risk assessment studies. As a consequence the results from various studies cannot be easily integrated in a consistent large-scale loss assessment.

Finally, existing **fragility relationships and loss models** have been mostly derived outside Europe - with the exception for buildings and partially for bridges - and must be adapted to the

**European context** and construction practice before use in a loss assessment study. There is an urgent need for identification and characterization of all the components/elements for all systems, in order to select and possibly to improve or even propose new adequate fragility relationships in the European context, reducing at the same time the uncertainties. Damage-Functionality relationships are also required in conjunction with the fragility relationships to assess the indirect losses associated to an earthquake event.

SYNER-G is proposing to tackle these needs in order to improve the European know-how and to propose a unified methodology for the vulnerability assessment and loss estimate at system level.

## **1.2.5 Proposed research and progress beyond the state-of-the-art**

Based on the above remarks SYNER-G proposes to develop an integrated general methodology and a comprehensive simulation framework for the vulnerability assessment and the evaluation of the physical and socio-economic impact of an earthquake, allowing also for consideration of multiple interdependent systems within the infrastructure. The end result will be implemented into an open, modular and expandable software package for effective seismic risk management. The main innovative contributions of SYNER-G are briefly summarized in the following sections. A detailed description of the work plan and its break-up into work-packages with planned contributions from each partner is given in the following section.

### **1.2.5.1 Development of an enhanced seismic hazard model for spatially-distributed systems (Part of WP2)**

When dealing with the seismic risk to spatially distributed systems, the joint seismic hazard at a number of geographically spaced locations needs to be estimated. Hence, site-specific seismic hazard assessment and the maps which are often produced by combining the ground motions at a given return period cannot be used for this purpose. One of the simplest ways of modeling the joint seismic hazard at a number of locations is to generate a synthetic catalogue of earthquakes which is consistent with the seismicity of the region, and then generate random ground-motion fields for each scenario using ground-motion prediction equations where the temporal and spatial correlation of the ground motions due to the inter-event (earthquake-to-earthquake) and intra-event (site-to-site) variability, respectively, is accounted for. However, other more direct methods are also available and thus a number of methodologies will be reviewed and compared in terms of computational efficiency and ease of integration within the software.

Alternatively, probabilistic seismic hazard analysis (PSHA) may be adapted to account for the spatial correlation of ground motion and site effects, preliminary literature studies exist in this respect proposing different approaches to extend PSHA to territorial seismic hazard assessment. These procedures will also be reviewed compared and, if possible, exploited in the framework of the project. This will be useful in both the territorial risk assessment of building stocks and vulnerability analysis of lifelines and distribution networks.

The most adequate and enhanced seismic hazard model for spatially distributed systems will be implemented in SYNER-G methodology and tools.

### **1.2.5.2 Development of improved technologies for setting up and maintaining elements inventory (Part of WP2)**

The typical characteristics of all elements at risk (structural and non-structural) within European infrastructures will be defined based on inventory data, which may be constructed based on two sources: (a) from data collected from census and residing in cadastral offices, in the case of buildings and building aggregates, or from owners/operators, in the case of utility and transportation systems and networks, and of critical facilities; (b) when data is scarce or difficult to gather from ground based activities, data may be collected from remote sensing or aerial photographs. Current methodologies for remote sensing include the derivation of building height and building outlines from quantitative and qualitative validation of digital surface models from VHR stereo satellite data. The procedure consists in using orthorectification methods based on either empirical or rigorous, physical models and on the theoretical aspects of digital surface model extraction. The methodology proposed in the scientific literature for performing inventories of exposed elements using remote sensing techniques consists in identifying homogeneous

inhabited large zones by spatial imagery, evaluating sociological and local urban characteristics and finally relating the homogeneous inhabited zones to vulnerability classes (see for instance Taubenböck et al., 2006). Recently BRGM has developed a methodology for identifying the classes of buildings using the spectral property and the texture of spatial images. For this purpose, the Kalideos images (4-band multispectral images with 10m resolution) have been used for a semi-automatic classification of landcover in the Archachon area in France and THX (3-band spectral images with 2.5m resolution) for the La Réunion Island. Automatic classification (K-means) gives the surface occupied by the building while using a Laplace filter it is possible to extract road networks.

The work carried out in WP2 will focus on refining the available technologies to determine, with a sufficient level of reliability, the height, the in-plan geometry, and the age of construction (by comparing subsequent image layers at different intervals in time) of building structures. On-going research based on building outline extraction based on watershed segmentation will be further developed for improving accuracy and to overcome the problems related to extracting complicated building outlines and shapes. Likewise, in the case of bridge structures, it is proposed to test the ability of such systems to identify the location and length of bridge structures, which may be particularly useful in large cities with a vast array of bridge structures belonging to different owners. In building and maintaining the inventory data, appropriate methods for archiving and processing the collected data will be developed, taking into account the requirements for the definition of the fragility functions of WP3 (individual elements) and WP5 (systems).

### **1.2.5.3 Development of Europe-specific fragility functions for elements at risk (WP3)**

A plethora of fragility functions and curves currently exists for buildings, utility and transportation components as well as critical facilities. These formulations (generic-analytical/numerical, empirical and semi-empirical) mainly developed in USA, Japan and in Europe, based on different approaches and assumptions, according to the needs, available data and tools. Thus, each set of fragility functions is characterized by important uncertainties and limitations which should be considered before their application. An effort to overcome some of the uncertainties has been made in ANR 05 VEDA project where Seyedi et al., proposed a methodology for generating fragility surfaces for reinforced concrete buildings. The main idea is to represent the probability of exceedance of damage in the building with respect to uncorrelated parameters representing the strong ground motion. The damage is assessed following the EMS98 and is based on the maximum inter-story relative displacement (Rossetto and Elnashai, 2003). The obtained results show that the use of only one parameter representing the ground motion may not be conservative. However, the use of fragility surfaces in practical applications is complicated. Therefore, Khier (2008) proposed a fragility curve in which the probability of exceeding damage is plotted against a multiparameter function combining the initial uncorrelated parameters. The same approach is being applied to masonry buildings in ANR 07 EVSIM project. In the present proposal, this methodology will be applied to some of the elements of the studied systems and its interest will be evaluated.

Within SYNER-G, appropriate fragility curves/functions or surfaces will be proposed for each element at risk (buildings, building aggregates, utility and transportation components and critical facilities) according to the typological features of European construction and practice.

In particular the vulnerability of masonry building aggregates, which is particularly important for Europe, has been considered in the RISK-UE project with both empirical and mechanics-based methods, with more detailed emphasis on the former. Following the identification of information on both the isolated buildings (e.g. roofs, foundations, materials etc.) and the aggregates (e.g. connection between buildings, differences in height between buildings, location of building within the aggregate), empirical vulnerability indices can be defined for each single building based on building-by-building data, or an average index for the aggregate can be obtained based on the statistics for the aggregate. By relating the vulnerability index to the ground motion intensity through detailed observed damage data, vulnerability (fragility) functions can be defined. More research is needed on the mechanics-based methods which identify the most probable out-of-plane mechanism based on the characteristics of the building within the aggregate (masonry typology, building geometry including differences between adjacent buildings, construction

characteristics such as openings). Once the mechanism has been identified (including in-plane mechanisms), capacity curves can be calculated from simple structural mechanics principles and material and geometrical properties; these curves could then be compared with response spectra to generate fragility functions.

#### **1.2.5.4 Development of Europe-specific loss models for elements at risk (WP4)**

Casualties and direct impact to “at risk” populations (e.g. shelter needs, hospital capacity, mobility impediment, etc.) will be estimated based on secondary data and fragility curves for buildings. Additionally, a set of social context conditions that aggravate the physical damages will be developed as indirect “impact” factors. The strategic and economic importance of each utility and transportation element will be defined and connected with the physical damage and the most critical elements of each network will be defined.

#### **1.2.5.5 Development of a general methodology for systemic vulnerability assessment (WP2)**

In SYNER-G, the conceptual basis and general principles of a unified methodology will be developed, as well as the appropriate tools and methods for the probabilistic assessment of the seismic vulnerability of a *system of general nature* accounting for all elements exposed to seismic risk, considering their interdependence and following the consequences of failure to the evaluation of the socio-economic impact.

Systemic methodology does require a considerable effort and the likely development of ad hoc tools for each system, providing an important innovative contribution throughout the project. The purpose is to assess the resilience of a system but also to minimize potential loss by identifying, prioritizing and safeguarding those assets that are most valuable and that need the most protection. For this purpose, several techniques may be employed: for example an approach proposed by Bryson et al. (2002) following original works by Tamura and co-workers (2000), where a DRP (Disaster Recovery Plan describing feasibility, completeness, consistency, and reliability) based on a formal operating systems/management science (OR/MS) modelling may be used. According to this approach the starting point will be to construct a paradigm representing the events and their effects and associated probabilities as in a decision tree graph. Then for each event a set of recovery sub-plans and solution resources are established. Finally, the value is optimized under constraints (risks) and possible uncertainties.

##### **1.2.5.5.1 Development and improvement of methods and tools for the vulnerability assessment of the main systems in a urban infrastructure (WP2 and WP5)**

The main innovative constituents of the procedure to be developed are the following: **(1)** Selection and definition of new performance measures on a system-specific basis, e.g. the HTC for health-care facilities, the number of displaced people for building aggregates, the percentage loss of electric power for electric power transmission networks, etc. **(2)** Formulation of a general system function that allows the evaluation of the state of the system, in terms of the appropriate performance measure, as a function of the states of its components under seismic action, accounting for the intra-dependencies. **(3)** Homogenization of the fragility functions and the loss curves employed in systemic vulnerability studies by selecting and detailing a unique general procedure for the production and updating of such curves for all components' types.

##### **1.2.5.5.2 Extension the methods to include interactions between systems (WP2, WP5)**

The contribution of SYNER-G will be to identify the common characteristics of the available techniques for the analysis of the interaction between different systems and to formalize and include them in the general methodology. More specifically, two-systems interactions will be principally dealt with, as for example in the case of electric power transmission and water-supply networks, with consideration also of multiple systems, as for example the case of building aggregates, the system of hospitals, emergency centers and the transportation network.

##### **1.2.5.6 Specification of the general methodology to particular systems (WP5)**

The general methodology presented in the two previous paragraphs should be specified and detailed for the four main categories of systems (1) buildings, aggregates, urban systems (2) utilities (water, waste water, gas, oil, electricity, telecommunication) (3) transportation (roadways, railways, harbors) and (4) critical facilities (hospital complex). Systems may be affected by

several factors associated to the external aggression or internal deficiency. Hence, the idea of fragility surfaces or fragility multi-parameter functions will be very useful for representing the probability of damage. It will be also very useful for integrating social and economic vulnerabilities that inherently depend on a large number of parameters.

It is common to represent each system as a combination of nodes, connections and incoming/outgoing flows. This “standard” representation will be adopted not only for physical but also functional, societal and economic systemic vulnerability evaluation. The vulnerability of the system is related to different parameters that could impact its performance. This latter may be defined by the **ratio between the Demand and Capacity** where both may be affected by the seismic event. The capacity of a system may be reduced due to the deficiency of its elements (nodes and/or connections), while the increase of demand may be internal (evolution of the system) or external. The advantage of using this ratio rather than the reduced flow as proposed in Dueñas-Osorio et al. (2007) is that, in this way, it is possible to identify the origin of fragility of the system. The notion of reduced flow, implicitly assumes that the capacity is unchanged during the seismic threat. The probability that the measure of the performance ratio exceeds a fixed threshold will correspond to a measure of the propensity of the damage to the system.

The application of a general methodology of WP2 to all systems studied in this proposal is not straightforward and requires further work. Examples of the difficulties which shall be overcome in WP5 are the following:

- The tolerance grade towards losses as well as the definition of the capacity/demand is easier to define for systems such as water, oil or gas pipelines or transportation lifelines than for more complex systems such as cities or harbor systems.
- The interdependencies between systems may be almost inexistent (roadways with water supply network), loose (roadways with electricity network) to very strong (Urban and critical health facilities with other networks).
- The disaggregation degree of a system to sub-systems may be straightforward (road network) to very complex (urban system).
- Some elements of a system may be affected by the seismic ground motion directly (rupture of a road, a pipeline) or indirectly (failure of an electric pillar).

#### **1.2.5.7 Development of an open-source software tool (WP7)**

A number of attempts has been taken after the earthquakes in 1999 (Turkey and Taiwan), where several studies were carried out to satisfy the needs of loss assessment. However, none of the studies were able to provide an integrated system that could be updated and run with most current data and models. In a GIS environment geologic, geodetic, geotechnical and structural studies were combined to derive a modern loss assessment procedure. A number of independent tools have been created to meet the needs of specific regions and areas of study, however, many were built as proprietary environments and were not designed to be easily extended or customized. A popular system built in the United States for emergency management (HAZUS) provides good generalized results at the regional level, but it was not designed to provide specific results for points of interest where each point takes into consideration the inventory item type, its fragility and geologic location. As a consequence the cost of creating proprietary solutions and maintaining the existing capabilities is high. Thus, the next generation of software needs to move beyond a proprietary approach to a model that is open, extensible and evolvable, and where costs can be shared across communities.

To respond to this complex nature of high consequence earthquakes MAE has developed a holistic approach towards seismic risk assessment and mitigation, termed Consequence based Risk Management (CRM, Elnashai and Hajar, 2006). CRM is a framework for the execution of loss assessment and alternatives with the goal of reducing the assessed losses to an acceptable level. The CRM paradigm provides a philosophical as well as a practical framework for the assessment of the dynamic interdisciplinary relationship between causes, effects and effect mitigation features of major events or disaster management. It addresses the following fundamental questions: (a) what are the estimated losses? (b) which are the losses that the region can sustain without irrevocable consequences? (c) which are the options, and associated costs in time and money, for loss reduction? The system places decision makers into a position to take the most appropriate action. Considering the fact that the characteristic of European

regions is considerably different from this U.S. application this newly developed tools will provide the ideal starting point for the toolbox to be developed within SYNER-G. The deliverable will provide exceptionally effective needs of planning research and education activities, a framework for asset management and a framework for test bed application.

Based on the above remarks a new generation of tools is needed to allow owners, practicing engineers and researchers the means to carry out realistic risk assessment and to provide the ability to leverage investment in new methodologies and software infrastructure while enabling customization to local conditions. SYNER-G represents such a next generation of seismic risk assessment open source software, based on global existing knowledge and is designed to be extended, customized, and involved to meet the needs of specific organizations and regions.

#### 1.2.5.8 Application and validation (WP6)

SUNER-G integrated methodology will be validated through the application in appropriately selected and well constrained test sites in city scale (Thessaloniki, Vienna), regional scale (a transportation network in North-Eastern Italy, an electric power transmission network in Central Italy and a gas pipeline network) and in complex systems (the harbor of Thessaloniki and a large hospital facility in Reggio di Calabria, Italy). The efficiency of SYNER-G will be measured largely in these engineering applications which surpass the present state-of-the-art.

#### 1.2.6 Performance / research indicators for the project for measuring results, progress and impact of the project

The type of result that is expected from this research project is on one hand an identified product (development of an open-source software tool) and on the other hand to develop the basis and principles of a unified methodology for systemic vulnerability assessment accounting for all components (structural and non-structural) exposed to seismic hazard, considering interdependencies within a system unit and between systems and accounting for socio-economic issues as well.

The following performance indicators can be proposed:

- Capacity of the final framework to accommodate in a comprehensive way different aspects of physical and societal vulnerability, existing within a system and between systems, showing common elements existing between interpretations and definitions provided by various scientific communities (WP2, WP3, WP4 and WP5);
- Production of several scientific articles, and possibly of a book, illustrating the advancement in interpreting and understanding the various aspects of vulnerability at system level as accommodated in the framework to be produced (WP2, WP3, WP4 and WP5).
- The developed methodology for assessing vulnerability at system level should be (WP2, WP3, WP4 and WP5):
  - manageable in the various steps to be carried out to assess systemic vulnerability; the steps to be followed will be clearly identified and described in such a way that a person not participating to the research may be able to apply the method on his/her own;
  - transparency of the assessment process, including the explicit declaration of assumptions, simplifications, and recognition of gaps, limits, and uncertainty of the method itself;
  - as far as products are concerned, an important element for evaluating the degree of concordance and integration among the various partners will be the capacity to produce several scientific articles and manuals for educational purposes written by groups of partners in a collaborative form, illustrating the various aspects of the methodology along with its implications for future risk assessment models and practice.

- An important indicator of the quality of what will be obtained both from the methodological part and from its applications and validation of the methodology and tools refer to the (WP6):
  - Possibility to compare the assessment process and results deriving from its application according to a predefined and common set of criteria.
  - Use of the results for efficient risk mitigation studies in the specific study areas.
- An identified product of the project will be the development of a prototype software tool for the systemic vulnerability assessment and loss estimation. The indicator thus proposed is the implementation of the methodology in an appropriate open source and unrestricted access software tool, the software release and validation by a user group (WP7).
- Another identified product will be the development of the SYNER-G Web portal; the web-portal is going to be periodically upgraded and extended until the end of the project, including plan for its maintenance and operation beyond the project end (WP1, WP8).
- Regarding the potential impact of what will be achieved by the research project on selected stakeholders, such as public administrators in charge of risk mitigation at various levels, a group of End Users will ensure a wide applicability of the methodology and the deliverables arising from the project; technical workshops illustrating the methodology being proposed will be organised and 7 reference reports will be produced (WP8).
- In the field of dissemination, the development of e-learning tools addressing the specific needs in training and understanding systemic vulnerability can be considered as another important result to be monitored by performance indicators. Also, in the same direction is the preparation of project newsletters (3 issues), project leaflet and project presentation, high-quality brochure, describing the main project products and the key results of the applications to the two European urban, infrastructure and network sites and a web portal structure and implementation. The capacity to develop such tools, thus translating into educational terms results of scientific endeavours can be considered an important indicator of the progress made by the research project in the field of seismic societal and physical risk assessment (WP8).

## 1.3 S/T methodology and associated work plan

### 1.3.1 Overall strategy and general description

#### Overall strategy

SYNER-G aims at building a unified European methodology and tools (software, guidelines) to evaluate physical and societal vulnerability and losses at system level. The systems that will be considered are building aggregates, lifeline networks (energy, transportation, water and waste water) and infrastructures. It is proposed to develop appropriate fragility curves considering the interdependency and interaction among different elements at risk belonging to different systems and/or the intra-connections of different systems). The overall strategy of SYNER-G is described through seven scientific-technical objectives.

Starting from the evaluation of the past and ongoing knowledge we proceed to the development of a unified methodology to assess the physical and societal/economic vulnerability and losses of interconnected and intra-connected systems for the given seismic scenarios (**WP2**). We propose well calibrated and improved fragility functions and damage state indices for all elements at risk considering the European distinctive features (**WP3**) and the socio-economic impact (**WP4**). We adapt then the general methodology to the specific assets considered in SYNER-G (building aggregates in urban scale, utility and transportation systems, critical facilities) (**WP5**), and we validate the unified methodology to five well selected case studies in the European context (**WP6**). We are proposing to build a user friendly tool (open-source software) of the whole methodology (**WP7**). Finally we will prepare several guidelines to use in practice and we are proposing to build appropriate dissemination schemes at European and International level for the entire community and administration entities (**WP8**). SYNER-G is designed according to the following principles:

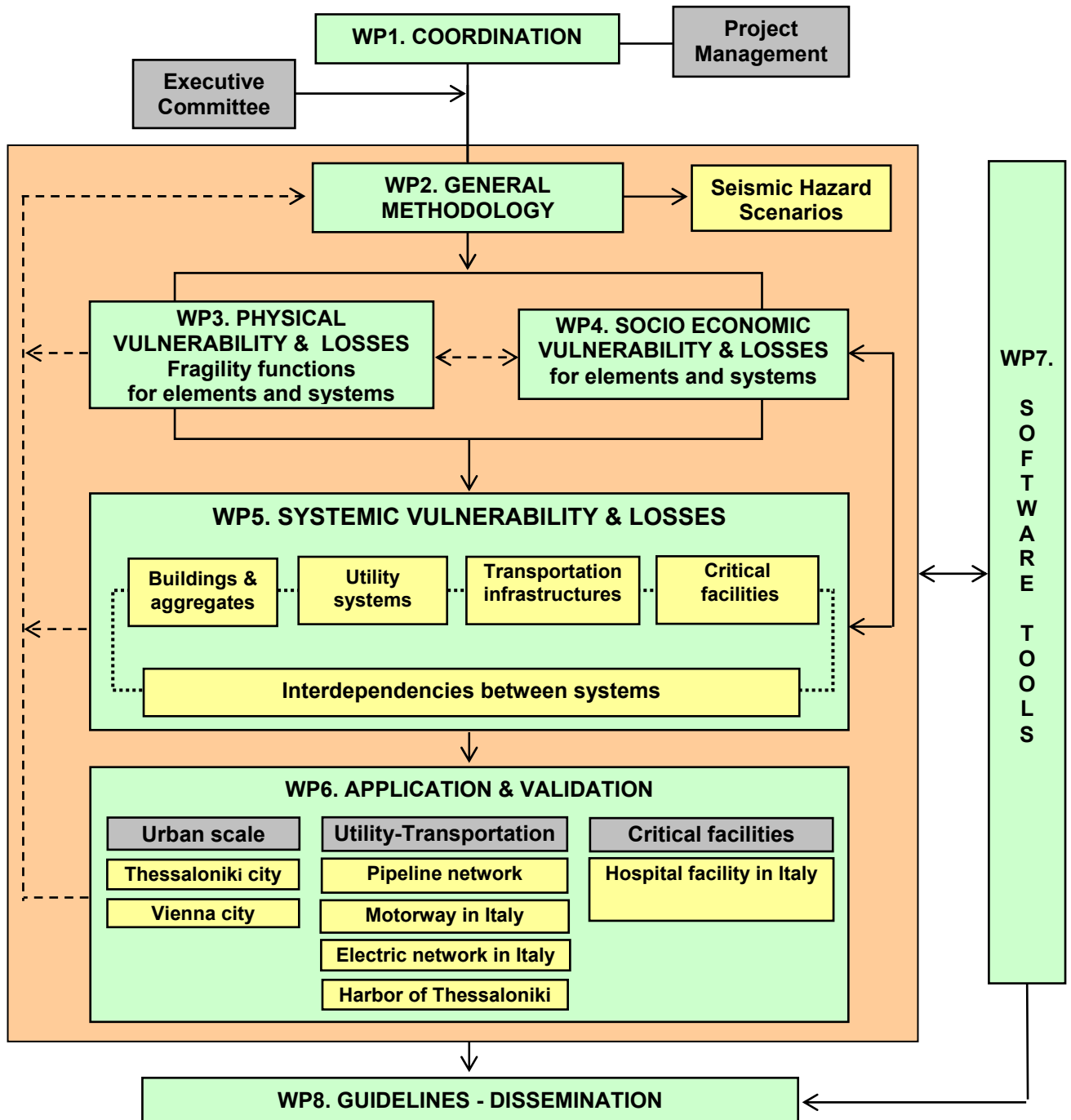
- Ensure **integration across disciplines** by involving participants, competences and experts spanning all fields from earthquake structural and geotechnical engineering, engineering seismology, risk managers, insurances and administration, to pursue high scientific and technical standards and better practice.
- Build a framework for **cooperation across national and international borders** to exchange knowledge and know-how as well as data and tools, to move beyond the national dimension in building a real European vulnerability and risk assessment and losses evaluation for complex systems and networks presenting important synergetic features.
- **Build on past and ongoing European (national and EU) and international projects**, know-how and tools (e.g. RISKUE, HAZUS, SRM-LIFE, LESSLOSS, ANR 07 EVSIM, ANR 05 VEDA), and enable the integration of ongoing and future EC projects (e.g. NERIES, SHARE, SAFER, SAFELAND, SERIES, ENSURE, MOVE) as well as on-going national and regional efforts (e.g. RELUIS, FIRB-Turkey, DORII).
- Pursue **scientific and technical innovation** by including the most recent developments in the probabilistic vulnerability and loss assessment of elements at risk and systems.
- Build a well controlled computational tool to assess the systemic vulnerability.
- Maintain a direct connection with **ECTP and risk management authorities** at National and European level.
- Produce **direct output and deliverables** concerning the general methodology and the validation applications in several case studies.
- Establish an **effective dissemination scheme** for the entire community, the administration, the construction and insurance industry and relevant potential stakeholders in the context of prevention efforts.

SYNER-G is designed with **eight work packages**: **WP1**-Project coordination and management; **WP2** - Development of a methodology to evaluate systemic vulnerability; **WP3**- Fragility functions of elements at risk; **WP4** - Socio-economic vulnerability and losses; **WP5** - Systemic vulnerability specification; **WP6** - Validation studies; **WP7** - Build prototype software; **WP8** - Guidelines, recommendations and dissemination.

The following test sites and systems are selected for application and to validate the efficiency of the methodology and tools: Thessaloniki in Greece; Vienna in Austria; Messina in Italy (for

calibration of census and remote sensing data); a motorway system in North-East Italy (regional scale); an electric power network of regional extension in Central Italy; a gas/oil pipeline; the harbor of Thessaloniki and a hospital facility in South Italy (Reggio di Calabria).

The SYNER-G work packages, deliverables and timescale are linked in a logical workflow illustrated in the diagrams and Gantt chart below. The total duration of the project is three years which is coherent with the content the objectives and extent of the project, the proposed structure of the different work packages and the number of deliverables.



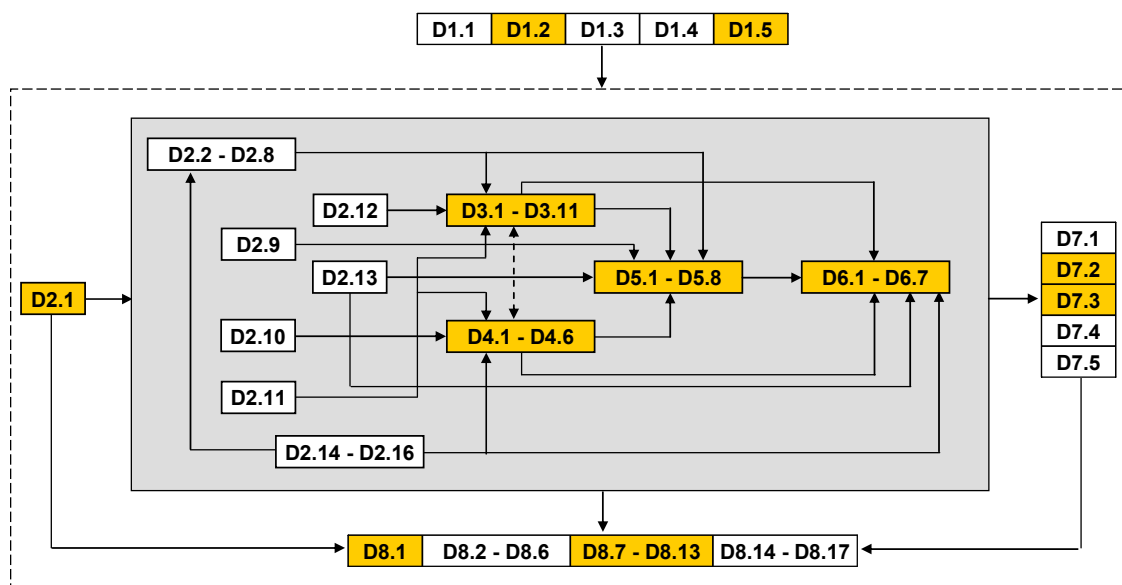
**Figure 3** SYNER-G project workflow.

WP2 defines the basis and principles of a unified methodology for the systemic vulnerability assessment accounting for all elements (structural and non-structural) exposed to seismic risk, considering interdependencies as well as socio-economic issues. WP3 develops various sets of fragility functions for the physical vulnerability assessment of all elements at risk, while WP4 includes the modeling of the various socio economic losses for elements and systems. WP5 performs the systemic vulnerability evaluation and loss evaluation of each system with inputs

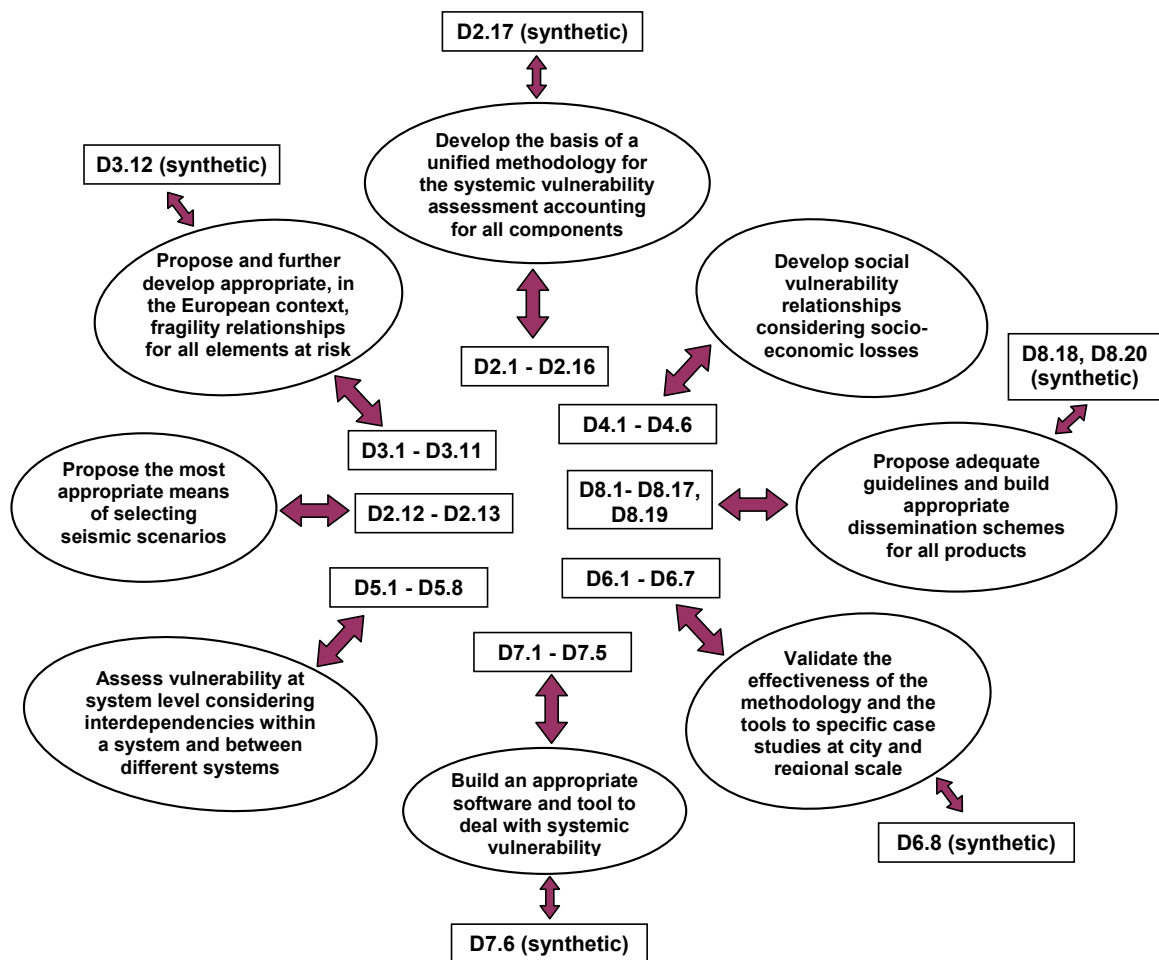
from WP3 and WP4, and moreover, assesses the interdependencies between different systems. The interactions between WP5 and WP2 will be very strong. The adaptation of the WP2 methodology in WP5 systems does require a considerable effort and the likely development of ad hoc tools for each system, providing an important innovative contribution throughout the project. WP2 loops through Physical (WP3) and socio-economic vulnerability assessment to be applied and developed in WP5. The methodology will be validated in WP6 and applied in two cities (Thessaloniki and Vienna), two main lifeline networks in regional scale (a motorway and a gas pipeline route) as well as a complex harbor system and a large hospital facility within WP6. The methodology will be implemented in appropriate software tools (WP7). A set of guidelines will be exported, while various dissemination actions are foreseen (WP8).

### Graphical presentation of the components showing their interdependencies

The seven main objectives/goals are closely interrelated and the research will be done concurrently, and in an iterative manner, adjusting methodologies and strategies as progress provides new knowledge in each of the work packages. Figure 1.4 shows the interrelationship among the main deliverables. The key deliverables of SYNER-G are indicated in the dark boxes. Figure 1.5 shows the interrelationship among the scientific-technical objectives and the project's deliverables.



**Figure 4** Interrelationships among deliverables.



**Figure 5** Interrelationship among scientific-technical objectives and deliverables.

## General Description

A detailed description of WPs and relative tasks is described below. WP and task leaders are indicated. The participants of tasks (listing them after each task name) and their respective roles (at the end of the task descriptions) can be found in the WP description in Section B.1.3.5.

### **WP1: Project coordination and management (WP leader: AUTH, Participant: VCE)**

WP 1 is related to project management and coordination.

This work package will ensure scientific/ technical coordination and oversee the administrative and financial management, project planning and evaluation of the project in progress. It is also going to ensure frictionless management and coordination of the project, efficient planning, coordination, monitoring, fostering the flow of information between participants and between work packages, efficient steering of the activities, and efficient conflict management and establishment of a clear decision making process. In addition the project coordination and management will provide the communication to the European Commission.

The duties and rights of the coordinator (AUTH) and the project manager (VCE) are described in detail in the Consortium Agreement (CA).

In particular, the Coordinator (AUTH) will:

- Ensure that the specific technical and scientific targets of the project will be duly met; monitor and evaluate progress according to the work plan and schedule, ensuring that milestones and deliverables are achieved.
- Oversee science and society issues related to the research activities conducted within the project.

- Conclude a Consortium Agreement with partners, ensure that it is followed and maintain it (through updates, if needed) during the course of the project.
- Receive all payments from Commission and distribute to the partners without unjustified delay the sums allocated among the Contractors as per the provisions stated in the contract.
- Oversee the promotion of gender equality in the project.
- Timely submit reports and other deliverables to the Commission.
- Timely deliver cost and other statements as well as financial audit certificates from the Contractors to the Commission.
- Call, chair, administrate and provide the secretary for the minutes of the Contractors Assembly and of the Executive Committee; ensure that the decisions are implemented.
- Organize, call and chair of the plenary meetings, the General Assembly, the Executive Committee meetings and the meetings of the International Advisory Committee.
- Provide the secretary of the International Advisory Committee meetings, ensure the preparation of the minutes and that guidance and proposals by IAC are followed.
- Assist Contractors following-up the performances of the Work Packages, activities and deliverables to be provided by the Contractors under the Contract as well as information of any-non performance.
- Collect the work records of the Contractors on a monthly basis (collection quarterly).
- Transmit any documents and information of relevance for the overall management of the project to and between the Work Package Leaders and the Contractors concerned.
- Issue of periodic and final financial and management reports according to the Contract.
- Collect from Contractors the Audit Certificates when requested by EC.
- Perform in due diligence its tasks in the proper administration of any funds and maintenance of financial accounts.
- Manage the overall legal, contractual, ethical, financial and administrative issues of the project.
- Coordinate knowledge management and other innovation-related activities.

The Coordinator shall neither be entitled to act or neither to make legally binding declarations on behalf of any other Contractor nor to enlarge their role beyond the one described herein and in the Contract.

The management of SYNER-G will be focused on several aspects: organization, time and budget, quality, process, risks and communication. The overall duties of the Project Manager (VCE) are:

*(1) Operational planning:*

*Overall financial and accounting management.*

*Collective technical coordination administrative coordination.*

*Controlling of the project resources and the compliance of the budget.*

*Time management and compliance of the time schedule.*

*Support the Coordinator for the organization and management of the meetings.*

*(2) Project steering and assessment:*

*Overall planning and steering of the activities in the project.*

*Regular coordination with the work package leaders (milestones).*

*Control and assess activities within the independent work packages.*

*(3) Project documentation and controlling:*

Support the Coordinator in the regular reporting to the Scientific Officer of the European Commission.

*(4) Decision making and conflict management:*

Establishment of the decision making rules in the project.

Conflict management tools.

*(5) Communication management:*

- Establish of clear communication channels within the project.
- Establishment and maintenance of a project web server of the project.
- Management of the mailing lists.
- Moderation of the meetings.

The web portal will be promptly set up by VCE, for communication and exchange of information in all parts of the project. The portal will be continuously upgraded during the project and maintained after its end for a certain time. It will support controlled access of various groups of partners to strictly administrative, financial or confidential information, or project results considered immature for public release. The portal will provide access to several user categories. Individual beneficiary pages will be accessible only by the beneficiary, the coordinator and the project manager. Partner-only pages will provide beneficiary mailing lists and details, work package teams, past and upcoming meetings (including presentations and public reports). The public pages will provide information, data and deliverables of the project according to the dissemination plan.

The Coordinator is Contractor No. 1 — **AUTH – Prof. Kyriazis Pitolakis** and the Project Manager is Contractor No. 2 - **VCE Holding GmbH (VCE) — Dr. Helmut Wenzel**.

*Significant risks of this work package and contingency plan*

The project will meet important management challenges, because of the complexity of the project and the large aperture of the research plan and dissemination scheme. A detailed management structure is planned to allow flexible and rapid response to situations or challenges as they arise. A hierarchical management structure is stated to enable a successful project management and to secure the achievement of the results envisaged by the project. In order to maintain the research group homogeneous and cohesive, SYNER-G has structured a well-balanced management team with the definition of several management roles with clear and distinctive roles and obligations. Furthermore, a continuous review of the progress of work and capability for decisions concerning alterations or additions to the work plan are on the agenda of the project in order to meet any inconsistencies and risks (See Section: Implementation).

**WP2: Development of a methodology to evaluate systemic vulnerability (WP leader: UPAV, Participants: AUTH, VCE, BRGM, JRC, NGI, UROMA, METU, AMRA, KIT-U, UPAT, WILLIS, UKOBE)**

Within this work package the conceptual basis and general principles of a unified methodology will be developed, as well as the appropriate tools and methods for the probabilistic assessment of the seismic vulnerability of a *system of general nature* accounting for all elements exposed to seismic risk, considering their interdependence and following the consequences of damage to the evaluation of the socio-economic impact (i.e. human and economic losses).

A “heavy-duty” methodology will be prepared, which will also be as flexible as possible in order to be applied to several systems with different characteristics. Systemic vulnerability specification shall identify general specificities for each kind of system, and these specification characteristics should be considered in the development of the global methodology as well as together with the associated socio-economic vulnerability indexes. The development of an enhanced seismic hazard model for spatially-distributed systems is also going to be incorporated, along with the development and improvement of methods and tools for the vulnerability assessment of the main systems in a urban infrastructure (buildings and building aggregates, electric power systems, gas

and oil pipeline networks, water and waste-water systems, transportation infrastructures, ports, critical facilities) and the extension of the methods to include interactions between systems.

WP2 has been developed into five tasks described as follows:

- Task 2.1: Development of the general methodology of the systemic vulnerability accounting for all elements at risk, considering interdependences (Leaders: UPAV, UROMA, Participants: all partners)

This task will begin by identifying and characterizing the components within different types of systems (e.g. industrial buildings and processes, electrical power generation plants, electrical power transmission network, water-supply networks, telecommunication networks, residential buildings, transportation networks) such that the vulnerability of these individual elements can be considered in WP3. Once all components have been identified and characterized, the system analysis will proceed with the identification and description of the *relation/interactions between the components*. The ultimate goal of this step is the formulation of a system function that allows the evaluation of the performance state of the system as a function of the states of its components. The developed methodology for each system will then be applied within WP5. Similar processes can be applied when the system under consideration is the infrastructure itself, i.e. a number of interacting systems. Current available studies, where the object of the analysis is a “system of systems”, are characterized by a cruder description of each of the interacting systems. A state-of-the-art review of these methods for a “system of systems” will be undertaken within this task with the aim of identifying those which can be applied in WP5.

- Task 2.2: Methods to consider socio-economic issues and evaluation of losses (Leader: KIT-U, Participants: UPAV, NGI, AMRA, WILLIS)

This task will review the current methods for considering social and economic losses within systems for use in WP4 and as a novel methodological approach this task will also look at using indicators for the assessment of loss to commercial facilities, indirect loss due to business interruption, loss of life etc., wherever they cannot be evaluated by more quantitative methods. As basic input data to any kind of vulnerability evaluation at a city or country-scale, a quantitative estimate of damage ratios for one group of assets must be available, e.g. residential buildings. Any other damaged set of elements at risk can then be evaluated with reference to this by indicators that quantify the role of lifeline failure, loss of commercial assets, loss of life, environmental damage, etc. as a function of value (relative to proxy), restoration time, impact, etc.

In particular, physical losses evaluated as a damage ratio or monetary quantity of primary damage are aggravated by indirect economic damage, by socio-economic factors (reduced resilience of low-income groups, lack of organization within poorly educated groups, etc.) and by the interdependency of lifeline networks, and the socio-economic factors. The task aims at identifying (a) the factors of aggravation (what constitutes the aggravation), (b) the determination of the factors (stakeholder approach, empirical data), (c) the utilization for risk assessment in probabilistic and deterministic (scenario-based) frameworks. The key of the methodology is the assessment by indicators for each risk component and their interaction.

- Task 2.3: Typology definitions of European elements at risk (including data collection, archiving and processing) (Leader: JRC, Participants: AUTH, UPAV, NGI, BRGM)

This task will look at the data which should be collected in order to define the typical characteristics of structural and non-structural elements within European systems and propose a harmonized template for data collection after reviewing different methods for data collection (census, owner/operator data, surveys, remote sensing, aerial photographs) and methods for archiving and processing this data. These procedures will then be used to collect the data required for the vulnerability assessments in WP3 (individual elements) and WP5 (systems).

- Task 2.4: Seismic scenarios (Leader: UPAV, Participants: AUTH, BRGM, AMRA, METU, WILLIS)

This task will begin by proposing efficient intensity measures (i.e. PGA, PGV, spectral ordinates, permanent ground displacements, ground strains etc.) for use with various systems through literature reviews (i.e. RISKUE and LESSLOSS “seismic scenario” type of approaches) and preliminary studies on each of the elements at risk. These intensity measures will then be used in WP3 when defining the vulnerability functions of the individual elements at risk. When dealing with the seismic risk of spatially distributed systems, the seismic hazard should consider the macroseismic spatial correlation of the ground motion residuals at pairs of sites due to similar azimuth and directivity effects of the propagating waves, similar geological profiles, etc. Hence this task will look at how ground motion fields can be simulated in an efficient manner for spatially distributed systems and outline methodologies for direct use within WP5.

- Task 2.5: Remote sensing for systemic vulnerability analysis (Leader: UPAV, Participants: BRGM, KIT-U, JRC, WILLIS)

Sub-Task 2.5.1 Identification and calibration of inventory data (Leader: UPAV, Participants: JRC, BRGM, WILLIS)

This task will demonstrate how a database of key physical, social and economic inventory measures can be developed through the integration of physical variables (e.g. location and dimensions of physical structures) derived from both optical satellite images and radar images coupled with secondary sources including census data, localized knowledge, socio-economic and demographic data. These ancillary data provide information that are not directly available through the satellite image, but when combined with the remote sensing data yield a new/additional family of measures. The data from census and from owner/operators of transportation networks will be mutually calibrated with data from remote sensing, using as a reference the two case studies (Vienna and Thessaloniki) chosen for the project, whilst a third case study for the city of Messina will look at calibrating remote sensing data for buildings and building aggregates.

Sub-Task 2.5.2 Potential of vulnerability assessment by optical satellite imagery (Leader: KIT-U, Participants: JRC, BRGM, UPAV)

This will explore and develop a systemic framework on the options to develop or support vulnerability models from optical satellite imagery combined with vulnerability information and socio-economic ground data. The input parameters for accessibility analysis will be performed in GIS environment in order to address: Structural Exposure: Number of structures, built-up density, building height, roof type, building age, urbanization rate, sealed areas, open spaces, etc., critical Infrastructure (transportation, infrastructure, harbors, lifelines, etc.); population structure (occupancy (for residential and commercial areas), population estimates (bottom-up and top-down approaches), and other demographic proxies such as economic wealth or poverty; population development (population growth rates, migration rates, etc.)

#### *Significant risks of this work package and contingency plan*

Difficulties may be encountered in integrating different types of methodologies for the vulnerability assessment of the main systems in an urban infrastructure and the extension of the methods to include interactions between systems. What can be envisaged as a contingency plan is providing integration for those aspects where it is possible at the end of the research activity in this work package and to highlight and explain where and why it is not possible. Previous and ongoing research and pioneering work that has been carried out in the field of systemic and social vulnerability to earthquakes (see state of the art section) will be integrated and connected to the proposed methodology.

**WP3: Fragility functions of elements at risk (WP leader: NGI, Participants: AUTH, VCE, BRGM, JRC, UPAV, UROMA, METU, UPAT, WILLIS, UILLINOIS, UKOBE)**

The work which will be performed within this work package is going to:

- (i) Compile the existing fragility functions for the various elements at risk including buildings, and elements within utility lifeline networks and transportation infrastructures.
- (ii) Adapt, improve and, if necessary, develop new fragility functions for these elements considering their distinctive European features and typological characteristics.
- (iii) Harmonize the fragility functions for their systematic incorporation in the following WP.

Appropriate fragility curves/functions or surfaces will be proposed for each element at risk (buildings, building aggregates, utility networks, transportation components infrastructures and critical facilities) according to the typological features of European construction and practice. The fragility relationships will be proposed after an extensive review of existing studies, considering the inventory and typology of elements at risk in Europe, together with validation studies (for example using real data when available in Europe from recent strong earthquakes). In some cases the fragility curves will be appropriately modified and adapted, while in other cases new fragility functions will be developed (for example for masonry buildings and building aggregates, for the electric power substations as a combination of building and installations fragilities or for tunnels, underground structures and gravity quay walls).

The fragility functions will give an estimation of the damage and therefore direct losses associated for a given element at risk. Damage-functionality relationships will also be proposed in conjunction with the fragility functions in order to assess the indirect losses associated with an earthquake event.

WP3 has been developed into four tasks described as follows:

- Task 3.1: Fragility of buildings and building aggregates (Leader: UPAV, Participants: UPAT, BRGM, JRC, METU, WILLIS, VCE, UILLINOIS, UKOBE).

Based on existing methodologies, databases and standards (Eurocode), a system of fragility curves will be compiled for the most common building types in Europe (Reinforced concrete, masonry). Results from previous projects (RISKUE, LESSLOSS, ANR 07 EVSIM, ANR 05 VEDA, HAZUS), will be combined with data from experimental tests and data generated through numerical simulations and post-earthquake field investigations to update/improve the fragility curves. In these studies, the influence of regional variation and historical development will be considered. The methodology will be based on a Bayesian approach and will determine the most appropriate attributes of exposure derived from the seismic scenarios. A concerted description of damage states will be defined, considering the robustness of the building when defining the collapse limit state. Where the building is part of agglomerate, the fragility functions will be defined based on the interdependent behavior of single buildings considering the characteristics of the agglomerate. The possibility of generating the fragility curves of the more general classes by aggregating the information contained in subclasses of buildings, based on assumptions made on spatial variation and variation of parameters, will also be explored. Fragility curves for monumental buildings will be also proposed as the building stock of many European cities includes such structures. Rapid and detailed methods will be developed and verified, for different levels of granularity of developments.

Sub-Task 3.1.1 Fragility of common RC and steel buildings and building aggregates (Leader: UPAV, Participants: UPAT, JRC, METU, BRGM, UKOBE, UILLINOIS)

Fragility curves for reinforced concrete buildings for a number of limit states from a number of European and national studies (e.g. RISKUE, RELUIS, LESSLOSS, ANR 05 VEDA) will be reviewed and compared. State-of-the-art mechanics-based methodologies will also be employed for the development of fragility curves and comparisons with observed damage data will be made. The aim will be to assemble as many definitions of the vulnerability of European buildings and building aggregates as possible in order to define the epistemic (i.e. knowledge-based) uncertainty in this fundamental component of a seismic risk analysis. The

final goal is to propose the most improved fragility functions for RC buildings and building populations in the European context

Sub-Task 3.1.2 Fragility of masonry buildings and aggregates (Leader: JRC, Participants: UPAV, VCE, UPAT, BRGM, UKOBE)

In a similar manner to the study on reinforced concrete buildings in Sub-Task 3.1.2, a number of fragility functions for masonry buildings and buildings aggregates in historical centers will be compiled, generated and compared with the aim of identifying the epistemic uncertainty in the vulnerability assessment and finally to propose adequate fragility functions for masonry buildings and aggregates..

- Task 3.2: Fragility of elements/components within utility networks (Leader: AUTH, Participants: NGI, UROMA, BRGM, WILLIS, UILLINOIS).

Task 3.2 will suggest classification of infrastructure elements considering relevant factors including standards/regulations, construction materials/design, age vs operating time. Appropriate indicators of seismic damage will be defined and damage states will be described for each element of utility networks based on past experience, previous research projects and studies as well as new studies where necessary. Fragility functions and damage-functionality relationships will be developed for all elements based on available data and experience. Damage based on both ground shaking and large and permanent ground deformation will be accounted for.

Sub-Task 3.2.1 Fragility of elements of electric power systems (Leader: UROMA, Participant: AUTH)

Fragility methods that were developed in Europe, USA and Japan will be reviewed and further improved in order to propose appropriate fragility functions for all elements of power supply networks (transformers, substations, electrical lines). For example for the energy substations comprised by electrical equipment and building facilities, new fragility curves will be proposed using fault tree analysis considering the typology and appropriate operational structure of the substation, as well as the typology and fragility of buildings in Europe (described in Sub-Task 3.1). Physical damage states will be related to loss of function levels in order to perform systemic vulnerability and loss analyses (WP5).

Sub-Task 3.2.2 Fragility of elements of gas and oil pipeline systems (Leader: BRGM, Participants: AUTH, UILLINOIS)

Existing fragility formulations for gas and oil pipelines will be compared and evaluated in order to propose the most reliable ones according to the typological features in Europe. Both peak ground strain and peak ground velocity will be introduced in the fragility functions, while the effect of soil properties and non-linearity to the ground response will be studied. Physical damage states will be related to loss of function levels in order to perform systemic vulnerability and loss analyses (WP5).

Sub-Task 3.2.3 Fragility of elements of water and waste-water systems (Leader: AUTH, Participant: UILLINOIS)

Empirical and analytical fragility functions for water and waste-water pipelines will be compiled and evaluated based on European typological features and past earthquake damages in Europe. Both ground failure (described by permanent ground deformation) and ground shaking (described by peak ground velocity or acceleration) will be considered. Fragility functions and damage-functionality relationships will be proposed for pipelines, tanks, pumping stations and other water and waste-water system components.

- Task 3.3: Fragility of elements within transportation infrastructures (Leader: AUTH, Participants: BRGM, JRC, NGI, UPAV, UROMA, METU, UPAT, VCE, WILLIS, UILLINOIS).

Based on schemes for damage states, and transportation typologies/classifications reported in literature, including the RISK-UE and LESSLOSS projects, fragility functions will be developed both for shaking and permanent ground displacements (lateral spreading, landslides, fault crossing) according to the nature of each element at risk. Seismic damage indicators based on traffic capacity degradation will be suggested in order to establish

damage-functionality relationships. The important consideration of how damage to link affects the functionality of the links will be thoroughly investigated.

Sub-Task 3.3.1 Fragility of elements of roadway bridges (Leader: UPAV, Participants: UPAT, VCE, JRC, UROMA, BRGM, METU, UILLINOIS)

State-of-the-art-fragilities that are based on the response of bridge components and their interaction during earthquake ground motion will be researched and implemented from the published literature. Mechanics-based methods which employ simplified nonlinear static analysis to define the capacity of bridges and bridge components for use in vulnerability assessment will also be studied. These nonlinear static analyses will be compared with more complex nonlinear dynamic analyses to identify the uncertainty in the response of bridges to ground shaking. Data from experimental results on bridge components will be integrated into the numerical fragility analyses. Improved fragility functions will be finally proposed for bridges.

Sub-Task 3.3.2 Fragility of elements of road networks (Leader: NGI, Participants: AUTH, BRGM)

Fragility functions for road network elements like roads, embankments, tunnels and slopes, will be reviewed and evaluated in order to adapt, modify or even improve them according to the distinctive inventory and typology features. Appropriate parameters of the seismic ground shaking and/or ground failure will be assigned, while different damage states will be defined and related to loss of function and restoration time. In some cases such as the shallow tunnels, new fragility curves will be developed considering soil conditions. In the case of urban roads indirect damages and functionality loss due to the collapse of buildings will be examined.

Sub-Task 3.3.3 Fragility of elements of railway networks (Leader: NGI, Participants: UPAT, VCE, METU)

Although many aspects of railway vulnerability are similar to road networks, most railway elements have lower damage tolerance levels (hence, more vulnerable) than road elements. To facilitate the establishment of network performance degradation functions, separate sets of fragility functions will therefore be compiled for railway network elements like tracks, bridges, embankments, retaining walls, tunnels, signal and power supply systems. Curves will be established based on existing data and Bayesian approaches, using relevant experience from other lifeline networks where possible.

Sub-Task 3.3.4 Fragility of elements of harbor systems (Leader: AUTH)

Fragility functions for all elements within harbor facilities (wharfs, cranes, warehouses, buildings, utility and transportation networks etc) will be evaluated and finally proposed. Appropriate parameters of the seismic ground shaking and/or ground failure (mostly due to the occurrence of liquefaction phenomena) will be assigned. Damage states will be described based on past earthquake experience and studies (in Europe and abroad), while functionality levels will be assigned to each damage state. Validation studies and additional analyses will be performed in order to improve existing fragility functions and/or propose new ones for the case of the quay walls.

- Task 3.4: Fragility of elements within critical facilities (Leader: UROMA, Participant: AUTH).

Amongst critical facilities, two are chosen for their special importance and the peculiarity of their equipment.

Sub-Task 3.4.1 Fragility of elements within health-care facilities (Leader: UROMA)

The probabilistic analysis of the seismic performance of facilities (buildings, operating theaters, medical gas supply, etc) requires, apart from the fragilities of structural and non-structural components (partitions, ceilings, elevators, lighting, etc), which are common to all building structures, the fragility of specific equipment such as operating theaters, medical gas supply systems, which in turn is itself a system comprising such elements as tanks, distribution lines and other pieces of equipment (electric pumps).

#### Sub-Task 3.4.2 Fragility of elements of fire-fighting system. (Leader: AUTH)

The typology of fire-station buildings is usually similar to that of common buildings, however their importance is much higher and thus the functionality losses should be appropriately assigned. The consistency of fragility functions of fire fighting and common water pipes and tanks will be examined. Fragility formulations for water supply points will be proposed in relation to the water pipeline functionality and damage states.

#### Significant risks of this work package and contingency plan

Difficulties are expected to arise in the attempt to develop an integrated model for various vulnerability aspects taking also into consideration the indirect losses. In some cases lack of adequate data allowing for the identification and characterization of all the components/elements could impede the proposal of new adequate fragility relationships in the European context, reducing at the same time the uncertainties. For this, all partners will be involved and arrial meetings will be organised in order to overcome problems that may arise on specific issues. The consortium as a whole represents some of the best available expertise in different aspects of earthquake vulnerability assessment; thus enabling an effective integration of such research challenges. Also connection to previous and on-going research activities will be made.

#### **WP4: Socio-economic vulnerability and losses (WP leader: KIT-U, Participants: NGI, METU, AMRA, WILLIS, UILLINOIS)**

Within this work package an estimation of socio economic losses due to physical damages on buildings will be performed in terms of casualties, displaced population, and other socio economic impacts. Furthermore, the social and economic impact due to seismic damages on utility networks, transportation infrastructures and critical facilities is going to be assessed through an indicator system that considers the strategic and economic importance of each element and system, and the interdependencies between elements and systems.

Casualties and direct impact to “at risk” populations (e.g. shelter needs, hospital capacity, mobility impediment, etc.) will be estimated based on secondary data and fragility curves for buildings. Additionally, by considering the inherent factors of fragility of a person or community (i.e. age, disability, income, etc.) a set of social context conditions that aggravate the physical damages will be developed as indirect “impact” factors. The methodology will combine the direct impact of expected physical damage to buildings, infrastructure and society, and indirect “impact” factors that account for the socio-economic fragility and resilience within the community or region. Furthermore, the strategic and economic importance of each utility and transportation element will be defined and connected with the physical damage based on appropriate classification schemes and indicators which describe the interdependence between the systems and the society. As such, the most critical elements of each network will be defined based on distribution and level of expected damages, geographical importance measures (populations and activities affected, interconnection with other systems etc) and network characteristics measures (capacity, flows etc).

WP4 has been developed into four tasks described as follows:

- Task 4.1: Buildings and buildings aggregates (local to city scale) (Leader: KIT-U, Participants: UILLINOIS, METU, AMRA, WILLIS)

Utilizing demographic data and fragility functions developed for buildings and building aggregates in Task 3.1, appropriate methodologies for estimating casualties, displacements and demand for temporary housing will be contributed. Furthermore, a system of indicators related to the fragilities and coping capacities of the affected population will be developed to capture the aggravating impact of direct damages to buildings at the local and city scale.

- Task 4.2: Utility networks (Leader: KIT-U, Participants: NGI, WILLIS)

Task 4.2 will suggest the development of an indicator-based methodology relating direct damages of utility infrastructure (developed in Task 3.2) to the socio-economic importance of each element at risk. A system of strategic and economic indicators will be derived from relevant input parameters, including production loss associated with utility disruptions, dependency structure of various industrial sectors on water and energy supply, and the

interdependencies in the utility network themselves. Additionally, a set of social impact indicators will be derived by considering the impact of sustained disruptions (extended period of time) in electricity, water and gas to vulnerable households. Furthermore, experience from MOVE (Methods for the Improvements of Vulnerability Assessments in Europe) will be used to contribute to the development of indicators representing economic and social vulnerability in lifeline disruptions. The systems to be considered are: energy distribution systems, gas and oil pipeline systems, water and waste-water systems.

- **Task 4.3: Transportation infrastructures** (Leader: KIT-U, Participants: NGI, WILLIS)

Utilizing regional traffic flow models the most critical parts, hubs, knots in the road network will be identified. The greater the importance of a transportation network component, the greater the impact will be to the whole network or region when the component is removed. Furthermore, the criticality of the transportation network will be modeled on such varied parameters as costs of hampered rescue and relief efforts (GIS-based accessibility analysis), missed business opportunities or delayed deliveries of goods and services. In general the transportation criticality indicators are divided in two categories capturing: geographical importance measures and network characteristics measures, where the latter measures the network efficiency drop due to the disruption of the network. The criticality of the transportation network is then related to the seismic damage estimates of network elements (Task 3.3) to obtain an assessment of the socio-economic impact of disruptions to transportation infrastructure.

- **Task 4.4: Critical facilities** (Leader: KIT-U, Participant: WILLIS)

Task 4.4 will suggest the development of appropriate indicator-based methodologies accounting for the aggravated impact of damaged critical facilities such as health care facilities and fire stations on “at risk” populations. Similar to Task 4.1 a system of indicators related to the fragilities and coping capacities of the affected population will be used to determine the social impact of the loss of critical facilities. Furthermore, the impact of disruptions to utility and transportation networks on healthcare facilities and firefighting systems will be considered.

#### **Significant risks of this work package and contingency plan**

Another constraint is represented by the challenging attempt to study and capture the physical and socio-economic vulnerability of independent elements at risk in a homogenous and coherent way. Socio-economic impact is not currently systematically included in vulnerability and risk assessment studies. As a consequence the results from various studies cannot be easily integrated in a consistent large-scale loss assessment. In order to achieve WP4 objectives the adopted approach will be to initially disaggregate issues and then combine them in workable modules. The complexity of integrating different types of socio-economic vulnerability and losses will be assisted by the quality and experience of the consortium in the field of integration of multi-discipline and multi-scale approaches.

#### **WP5: Systemic vulnerability specification (WP leader: BRGM, Participants: AUTH, NGI, UPAV, UROMA, METU, AMRA, UPAT, WILLIS)**

The general methodology which will be developed within WP2 should be specified and detailed for the four main categories of systems. (1) buildings, aggregates, urban systems (2) utilities (water, waste water, gas, oil, electricity, telecommunication) (3) transportation networks (roadways, railways and harbor systems) and (4) critical facilities (fire fighting, and health care facilities).

WP5 is divided in five tasks:

- **Task 5.1: General identification of each system specificities** (Leader: BRGM, Participant: NGI)

The parameters governing the general methodology presented in WP2 have to be specified for each system in hand. The physical fragility functions developed in WP3 and social and economic consequences of any damage resulting in a partial or total performance loss of

each system studied in WP4 will be integrated in the general methodology. When necessary the methodology will be refined for a better adjustment to each system to be analyzed.

The overall vulnerability will be examined in the light of the performance of the system expressed by the ratio between the Demand and Capacity where both may be affected by the seismic event. Depending on the nature of the system, the evaluation of the performance may need specific definitions and characterization. The weak or strong interdependencies and interconnections between sub-systems will be studied. For the case of complex systems (urban, harbor or health care) in a deterministic and probabilistic framework. In the latter, the combination of different probabilities for capacity modulation (e.g. failure of components) or for demand modulation (e.g. seismic input, flow variation) will be addressed.

- Task 5.2: Systemic vulnerability assessment and loss of buildings and aggregate (city scale) (Leader: BRGM, Participants: UPAV, UPAT, AMRA, METU, WILLIS)

The systemic vulnerability assessment of buildings and building aggregates at the city scale may only be performed by representing the city as a set of homogeneously vulnerable zones (HVZs). The standard methodology consists in identifying the areas with almost similar building typologies to which a fragility curve may be attributed deterministically or randomly. This methodology is appropriate for sectors with more or less isolated buildings where interaction between constructions may be neglected. In many European cities, and more specifically in city centers, the buildings are aggregated in blocks. In this case it is difficult to directly establish a fragility curve for a building aggregate. The purpose of this task is to establish fragility functions for a building aggregate by considering it as a system in which the components are buildings with usually -but not always- strong interconnections and to finally come up with a systemic fragility function for the whole aggregate (or system). Then the standard methodology may be applied in order to break up the vulnerability of the city in which the HVZs are made of either series of similar buildings or building aggregates. The fragility functions will be then attributed to each HVZ deterministically or randomly. The propagation of uncertainties of different origin (fragility functions, interconnections, spatial positioning) to the final result may be carried out by a possibilistic/probabilistic approach already developed by BRGM for vulnerability assessment of HVZ made up of isolated buildings.

- Task 5.3: Systemic vulnerability assessment of utility networks (Leader: UROMA, Participants: AUTH, BRGM, AMRA, WILLIS)

Sub-Task 5.3.1: Systemic vulnerability assessment and loss of electrical power networks (Leader: UROMA)

So far the outcome of the studies has been mainly concentrated on technical aspects, in the effort to measure the network service level (namely the probability of outage of electrical power). Research within the project will be directed at modeling the consequences in terms of (indirect) costs of the power outage within the struck region on an activity basis (industry, residential, services, transport, commerce, water-distribution). This will allow the development of a computational tool for the decision makers for the selection of the optimal upgrading/retrofitting strategy for an electric network. An attempt to detect possible effects over the community served by the electric utility has been already made. For instance in (Vanzi, 2000) the 'unfed casualties', i.e. the number of people injured by the earthquake left without electricity service (necessary for rescue and sanitary activities) is assessed.

Along the above direction of enhancement is the study of the interaction between the electrical network and the other networks serving the region. So far the research efforts have been addressed mainly on the response of the single system, neglecting the interconnectedness among systems. The increasing interconnection of these systems is such that a failure in one system can propagate through many systems and trigger a domino-like effect. Within this project an attempt will be made to extend the interaction analysis to include capacitive modeling of the interacting systems, with a focus on the interaction of the electrical power network with the water supply network (Nutti et al., 2008).

Sub-Task 5.3.2: Systemic vulnerability assessment of gas and oil networks (Leader: AMRA, Participants: AUTH, BRGM)

The work to be carried out in this sub-task will be based on the methodology developed in WP2 and the results of WP3 and WP4. It will start from the basis of recent studies such as Adachi (2007) and Adachi and Ellingwood (2008) who forecast the serviceability of distributed civil infrastructure systems under severe earthquakes. This sub-task is aimed at assessing the serviceability of a distribution network of gas/oil system (i.e., pressurized and non-pressurized). Spatial correlation in seismic intensity and demand is the key feature of the seismic risk assessment for distributed systems.

The specific goals of the sub-task are:

1. To derive closed-form upper and lower bound approximations to the component failure probabilities, functionality of components within the system that have been damaged by an earthquake and network serviceability;
2. To derive a comprehensive model for the probabilistic systemic seismic vulnerability and risk assessment of gas and oil networks in the framework of performance-based earthquake engineering;
3. To consider the case in which the earthquake damage of a portion of the networks may trigger explosions interacting with a building/structure having reduced seismic capacity because of the earthquake. This latter part will be aimed at determining the risk of this explosion-induced collapse of the building and will be carried out adapting and extending the approaches of Fabbrocino et al. (2005) and Asprone et al. (2008).

Sub-Task 5.3.3: Systemic vulnerability assessment of water and waste-water networks (Leader: AUTH, Participant: AMRA)

Within this project, appropriate system performance criteria for water and waste-water systems will be assigned based on reliability analysis. Based on the general methodology developed within WP2, the seismic reliability analysis of the water and waste-water networks will be given in terms of density of damage (%), connectivity or serviceability analysis. Water system functionality (i.e. the percentage of customers served immediately after the event) will be determined from a hydraulic model of the damaged system. Considering that in the aftermath of an earthquake event, the capacity to serve open-spaces, shelter areas and critical or essential facilities is extremely important. The general methodology will be specialized in order to develop a method to evaluate the systems' behavior in respect to the serviceability level to specific points will be proposed based on connectivity analysis.

Multiple existing interdependencies with other lifelines and infrastructures will be treated on the basis of the analysis of the "system of systems" proposed in WP2. Adequate interdependency indices between water and waste-water systems and other lifelines (electrical power supply system) will be estimated using different techniques (economic approach, decision making, fuzzy logic or complex approaches). The general methodology to evaluate "systemic vulnerability" of interdependent lifelines will be specified in the specific case of systems based on the systems' global performance and level of interdependence. Special interest will be given to the interaction with the electric power supply network due to strong interdependency (for example malfunction of the water-supply system due to supply disruption of electric power).

- Task 5.4: Systemic vulnerability assessment of transportation infrastructures (Leader: UROMA, Participants: AUTH, NGI, BRGM)

Sub-Task 5.4.1: Systemic vulnerability assessment of transportation systems (Leader: UROMA, Participants: AUTH, NGI, BRGM)

The transportation networks are roadway and railway systems. The proposed research starts from the Level I work in (Franchin et al., 2006) and aims at expanding it along several lines to make it a Level II decision-making tool for emergency managers during the aftermath of an earthquake. The original study evaluates the probability of loss of connectivity between struck

municipalities and hospitals in the region, leading to a measure of the increase in casualties due to the hospitals unavailability.

In particular, the aspects that will be introduced or improved upon are the following:

- 1) Consideration of the increased seismic risk due to the aftershock sequence. To this end input is needed from: a) probabilistic modeling of the aftershock sequence b) fragility curves of bridges for the transition between intermediate damage states (e.g. the probability of a bridge damaged by the main-shock collapsing during an aftershock).
- 2) Introduction of the traffic flow evaluation over the damaged network (switching from a purely connective to a capacitive modeling of the network).
- 3) Integration with vulnerability assessment of building aggregates in order to establish realistic estimates of casualties and injured people that constitute one of the main inputs to the traffic demand evaluation during the emergency phase.
- 4) Integration with the evaluation of the fragility of each of the hospitals in the health-care network in the affected area. Health-care demands will be redirected towards farther hospitals when the reduced capacity of a hospital cannot cope with it. The health-care capacity of each hospital will be treated as time-dependent, as a function of direct damage to the hospital and time-varying emergency response (fatigue of staff, incoming aid and repairing work).

The study, carried out for a number of significant probabilistically defined seismic scenarios, will constitute an example of analysis of interaction between different systems and will allow the identification of the critical elements of both the transportation and the hospitals network from the point of view of emergency management. This will be a valuable tool for the rational seismic upgrading of these two networks to limit socio-economic consequences.

Moreover, SYNER-G (partner AUTH) will develop an approach for the seismic risk assessment of urban road networks, considering the interactions with collapsed or heavily damaged buildings and other lifelines in order to make a probabilistic estimation of urban road system functionality for different seismic scenarios, considering the damage states of adjacent lifeline networks and buildings. Despite its complicated nature the specific issue will be achieved based on the results of the vulnerability analysis and damages of building aggregates and other lifeline elements (water, waste water, gas, pipes) establishing correlation between collapsed building volumes and reduced debris volume based on simplified engineering approaches or empirical data.

Sub-Task 5.4.2: Systemic vulnerability assessment and loss of harbor system (Leader: AUTH)

Ports are complex facilities comprised of different structural and non structural components concentrated in a limited area. In general there is a strong level of interdependence between all components of a port facility. According to the general methodology developed within WP2, adequate interdependency indices between port facilities and with other lifelines will be estimated using different techniques (economic approach, decision making, fuzzy logic or complex approaches). Economic losses will be estimated according to the models developed in WP4. A methodology to evaluate “systemic vulnerability” of interdependent lifelines will be proposed specifically for the complex harbor facility, based on the systems’ global performance and level of interdependence. Special interest will be given to the interaction with the electric power supply network due to strong interdependency (for example malfunction of the cargo handling equipment due to supply disruption of electric power). Finally, the functionality of the port’s complex facility in terms of cargo and/or people traffic will be defined through the reliability analysis of each component (based on appropriate system performance criteria) and a simulation framework of the port’s operations, extending the work of Pachakis and Kiremidjian (2004) (input from WP3 and WP4).

- Task 5.5: Systemic vulnerability assessment and loss of critical facilities (Leader: UROMA and AUTH)

Sub-Task 5.5.1: Systemic vulnerability assessment of health-care facilities (Leader: UROMA)

The procedure developed in Lupoi et al. (2008) will be modified and integrated into the framework of the general methodology to assess systemic vulnerability developed in WP2:

1) The fragility curves of non-structural elements, such as operating theatres, elevators, etc. as well as those of installation plants (e.g. medical gas supply) developed based on mechanical models will be employed. This will represent a major step forward with respect to the models based on empirical observations (e.g. HAZUS type) available at present time.

2) The possibility of broadening the scope of the presently employed performance measure will be investigated. In this direction, a first important refinement will be the explicit modeling of the human and organizational components to the whole system vulnerability. At present the response of both components is deterministically evaluated according to expert opinion; analytical models, similar to those employed for the (probabilistic) assessment of the physical component have still to be derived.

3) Finally, the assessment methodology will be applied in the evaluation of the performance of the health care system at the regional level, where unbalances from a hospital facility can be absorbed by the others located nearby. This extension will feature a close interaction with Task 5.4, since the possibility of redirection to nearby hospitals is conditional on the availability of a functional non-congested route between the hospitals.

Sub-Task 5.5.2: Systemic vulnerability assessment of fire fighting system (Leader: AUTH)

The fire fighting network in an urban area is a complex system of buildings (stations), warehouses, water reservoirs and water supply points distributed within the city. Manpower is also a very crucial parameter especially during a crisis period. Moreover, there is also a very strong interdependence with the telecommunication and the transportation system while the unimpeded function of the fire brigade allows for the elimination of the earthquake consequences on a series of other networks especially related to gas and power supply. The functionality of the fire-fighting system is in most cases closely connected to the serviceability of the water supply system, defined through a reliability system analysis. In SYNER-G, appropriate system performance criteria will be defined, and the seismic vulnerability of the system will be defined in relation to the serviceability level of the water supply system (connection with WP2 and Sub-Task 5.3.3). Interactions with other infrastructures in cases of high danger of fire ignition, and especially with the natural gas system, will be studied through the reliability analysis of the fire-fighting system (both in cases of coupled and un-coupled system with the water supply network).

*Significant risks of this work package and contingency plan*

Difficulties are expected to arise in the attempt to develop an integrated model for the systemic vulnerability assessment of each lifeline system due to the complexity and distinct features of the networks. However, the development of a general methodology in WP2 will constitute the basis for the systemic vulnerability assessment of the different systems. Moreover, partners will be involved and partial meetings will be organised in order to overcome problems that may arise on specific issues. There are some international examples that have been described in the state of art section that may constitute a reference, even though the project aims at developing a more comprehensive tool, including the inter- or intra-dependence of the components and systems. The complexity of integrating different types of vulnerabilities, interactions and components will be assisted by the quality and experience of the consortium in the field of seismic risk assessment. In some cases the adopted approach will be initially disaggregate issues and then combine them in workable modules in order to achieve WP5 objectives.

**WP6: Validation studies (WP leader: AUTH, Participants: VCE, BRGM, NGI, UROMA, AMRA, UPAT)**

Within this WP the SUNER-G integrated methodology will be validated through the application in appropriately selected and well constrained test sites. The methodology and tools developed in WP2, 3, 4 and 5 will be applied and validated at a city scale in urban areas of high and low seismicity (Thessaloniki in Greece and Vienna in Austria, respectively) and potentially in other sites as well (L' Aquila, Turkey). The basic criteria for the selection of these two test sites are the availability of detailed databases in GIS for all elements at risk. All necessary seismological and geotechnical information to perform the seismic hazard assessment according to the methodology outlined herein is also available. The variety in typological features like building type and population, construction materials, age, level of seismic intensity, capacity etc has been also considered for the selection of the sites. The systemic physical and socio-economic vulnerability analysis will cover building aggregates, utility and transportation systems and their interdependencies.

The methodology will be also applied and validated in complex lifeline systems and infrastructures such as the harbor of Thessaloniki, a hospital facility in South Italy, an electric power network in Central Italy, a motorway network in North-East Italy as well as a gas pipeline network.

This activity will be undertaken in seven tasks:

- Task 6.1: Application and validation study in the city of Thessaloniki (Greece) (Leader: AUTH, Participants: UPAT and BRGM).

Thessaloniki with a population of one million inhabitants is an important administrative, economic, industrial, academic and cultural centre at national scale. Located at one of the most seismically active regions in Europe, it has a long seismic history and has been heavily damaged through the centuries and therefore the estimation of seismic risk of buildings, lifelines and infrastructures is an important issue.

Thessaloniki has a complete database in a uniform GIS platform for all utility systems (electric power, potable water, waste-water, gas, telecommunication) transportation infrastructures (roadways, railways, port) and critical facilities (fire-fighting system), together with detailed topographic, geological, geophysical and geotechnical information and maps. The seismic hazard has been investigated in previous national and European research projects, while a detailed microzonation study is available for the metropolitan city of Thessaloniki for different seismic scenarios. All relevant data are available to perform a probabilistic seismic hazard analysis or scenario type analysis, according to SYNER-G methodology. Thessaloniki has been used in the past as a case study for the vulnerability and seismic risk assessment of buildings and lifeline elements under different seismic scenarios (RISK-UE, 2001-2004; SRMLIFE 2003-2007; LESS-LOSS, 2004-2007).

Within this task the developed methods and tools will be applied in order to estimate the systemic vulnerability and losses of building population and, utility networks, transportation systems. Direct damages and socio-economic losses will be estimated for all systems. Systemic vulnerability analyses will be carried out for utility, roadway networks and the fire fighting system. Connectivity performance of the utility systems will be examined. Interdependences between networks will be considered based on the methodology developed in WP2 and the specifications in WP5.

- Task 6.2: Application and validation study to the city of Vienna (Austria) (Leader: VCE, Participant: UPAT).

The city of Vienna has a detailed GIS database of buildings, utility and infrastructure systems. It is characterized by low seismic hazard, however the global risk and social losses are expected to be higher when the interconnections and/or intra-connections between systems will be considered. Besides the seismic design of lifeline elements is limited or missing. Thus it will be interesting to check the applicability and compatibility of the developed methodology and tools in an urban area with such characteristics.

Based on the unique data source of the Viennese digital city model, validation of the SYNER-G development will be done close to practice. The approach will be based on existing development of a similar kind. A full set of HAZUS-MH is available to the Consortium and VCDECIS, the decision support system of the lead partner of this work package (VCE) will be checked on their applicability for the SYNER-G toolbox. It can be considered a major advantage for this Consortium that these approaches are fully available allowing the start of the works from a high level. A challenge will be to model the interdependencies of the elements at risk without getting trapped in various uncertainties and accumulated standard deviations. The work concept therefore concentrates on the collection of knowledge and approaches, the modelling of a discrete number of understood systems, the formulation of the developed methodologies and the user interface based on a GIS surface.

The deliverables form partial elaborations of the SYNER-G toolbox. They will be developed following the progress of the development of the methodology.

- Task 6.3: Application and validation study to a transportation network (Italy) (Leader: UROMA, Participants: NGI and BRGM).

Within this task the methodology and tools of SYNER-G will be validated through an application to a transportation system. The considered network includes most of the road network across the two regions of Veneto and Trentino. Data are available for the bridges on the network as well as for the traffic flows. Both connectivity (level I) and flow analyses (level II) will be carried out under selected scenario earthquakes, with the goals of planning emergency response and identify priorities of retrofit interventions, respectively.

- Task 6.4: Application and validation study to an electric power network (Italy) (Leader: UROMA).

This validation study will model the high- and medium-tension electric power network in Central Italy, with capacitive network modeling, explicit modeling of the stations logical functioning, capable of insulating short-circuits, as well as the fragility of all electric equipment. Monte Carlo simulation will be used to compute the statistics of the network seismic safety, with reasonable computational times, and advanced simulation techniques will be used to evaluate sensitivities of the results with respect to components fragilities. A seismic retrofitting procedure will be also set up, with the aim of minimizing upgrading cost over the whole network.

- Task 6.5: Application and validation study to a gas pipeline network (Leader: AMRA, Participants: AUTH, NGI and BRGM).

A pipeline network in Europe, will be used as a case study for the application of the vulnerability and loss assessment methods and tools that will be developed in SYNER-G. Expected direct damages to all elements of the system, functionality losses and social impact due to disruption of the network will be estimated. Interdependencies with other networks will also be examined.

- Task 6.6: Application and validation study to a harbor system (Thessaloniki, Greece) (Leader: AUTH).

The port of Thessaloniki is a complex system that includes several structural components, utilities and infrastructures, thus concentrating various activities in a limited area. It covers an area of 1,500,000 m<sup>2</sup> and trades approximately 15,000,000 tons of cargo annually. Complete typological and functional information are available for each element at risk and compiled in GIS format, including cargo and handling equipment, waterfront structures, electric power, potable and waste water, telecommunication, railway and roadway systems, as well as buildings, warehouses and critical infrastructures. Previous studies showed a high risk of port components due to ground shaking and especially due to ground failure (liquefaction phenomena) in the specific area. However, the global risk and the total losses will be much higher when the interdependencies will be considered in a systemic vulnerability and loss analysis.

Within this task the developed methods and tools will be applied in order to estimate the vulnerability and losses of all infrastructure and systems within the harbor of Thessaloniki for

appropriate seismic hazard scenarios. The socioeconomic impact will be estimated based on the results of WP4. The systemic vulnerability of each system and infrastructure and the interdependences between the different systems will be examined based on the deliverables of WP5 in order to estimate the harbor's vulnerability as a whole. Possible weaknesses and limitations of the tools and methods will be identified through this application in order to further improve the overall methodology.

- Task 6.7: Application and validation study to a hospital facility (Italy) (Leader: UROMA).

In this last task, a probabilistic assessment of the seismic performance of the main hospital of Reggio di Calabria will be performed by comparing the hospital treatment capacity with the corresponding demand. The former is the number of seriously injured patients that can receive surgical treatment in an hour following a scenario event, the latter is the number per hour of injured people in need of treatment arriving at the hospital. Data on the structures and equipment of the hospital are available and contacts with the medical staff will be established to understand and model the functioning of the hospital system under the specific working conditions in the aftermath of a major earthquake.

#### Significant risks of this work package and contingency plan

Although the test sites were mainly selected based on the availability of data, difficulties may be encountered during the applications, due to inconsistency of the data format and the requirements or limitations of the developed software and tools. To overcome these difficulties, appropriate modification in the format will be performed, with the technical support of infrastructure managers (for example city of Vienna Administration). Moreover, the lack of specific data that will be necessary for the implementation of discrete tools is possible (for example the data for the definition of a specific social indicator). As there are many case studies, the option might be considered to split some parts of the assessment in the application, prioritizing for example on physical and systemic vulnerability in one case study and focussing on social and economic impact in the other in order to get a feedback on all parts of the methodology from at least one case study. Another solution is to estimate the missing data based on reliable qualitative approaches and judgments.

#### **WP7: Build prototype software (WP leader: VCE, Participants: AUTH, BRGM, JRC, UPAV, KIT-U, WILLIS, UILLINOIS)**

A new generation of tools is needed to allow owners, practicing engineers and researchers the realistic risk assessment and to provide the ability to leverage investment in new methodologies and software infrastructure while enabling customization to local conditions. SYNER-G represents such a next generation of seismic risk assessment software, based on global existing knowledge and is designed to be extended, customized, and involved to meet the needs of specific organizations and regions. SYNER-G helps to bridge the gap between researchers, practitioners and policy makers by integrating the latest research findings and most accurate data, state of the art methodologies into an extensible software platform. The open source approach of building software has proven to be successful in delivering reliable and extensible solutions to meet the needs of diverse communities. The availability of open source tools, frameworks and codes provides the means to create extensible and evolvable solutions to meet general needs and can be extended to meet unique requirements.

The creation of this toolbox will be based on existing works within the Consortium (UPAV, BRGM, AUTH and VCE) as well as the open source solutions offered by the American colleagues engaged to collaborate with SYNER-G (MAEviz developed by UIUC, Prof. A. Elnashai, and Opensees offered by the University of Berkeley, CAL,USA). SYNER-G will take an open source approach based on pre-existing works in Europe and overseas under the consideration of risk based management. The deliverable will be an open source application and environment for loss assessment that is designed to be extended to meet the evolving needs of the earthquake engineering community.

The seventh workpackage will synthesize the results of the workpackages 2 till 6 in order to develop a software package. The prototype package will consider the following objectives:

- (1) Intelligent Fragility Curve Archive.

- (2) Code for Routines in System Modelling Simulation and Assessment.
- (3) Development of a Toolbox for Systemic Seismic Vulnerability and a Risk Analysis.
- (4) Web GIS Interface.

The WP7 will be developed in the following five tasks:

- Task 7.1 Collection and intelligent management of existing and newly developed fragility functions (Leader: VCE, Participants: all)

It will enable the collection and intelligent management of existing and newly developed fragility curves. Results from the previous work packages will be considered and implemented.

- Task 7.2 Modelling and functional simulation of building, lifelines and infrastructure systems (Leader: VCE, Participants: all)

Buildings, lifelines and infrastructure systems will be modelled and functionally simulated. A selection can be made from the fragility curve archive for elements for system assessment. Open source software will be used for implementation like Opensees, and Scilab.

- Task 7.3 Compilation of the methodologies and production of toolbox (Leader: VCE, Participants: all)

Comprises the compilation of the methodologies and collected sampled into a toolbox as a useful product for the construction sector (ECTP).

- Task 7.4 Geo-referencing and assignment of used surface into a web GIS solution (Leader: VCE, Participants: all)

Available data are generally geo-referenced. Therefore the used surface will be put into a web GIS solution. The creation of this toolbox will be based on existing works within the Consortium (Pavia, Thessaloniki and VCE) as well as the open source solutions offered by the American colleagues engaged to collaborate with SYNER-G (MAEviz developed by UIUC, Mr. Elnashai, and Opensees offered by the University of Berkley).

- Task 7.5 Indicator Software (Leader: KIT-U, Participant: VCE)

To interactively demonstrate the variability of the results to different indicators, a software system based on "multi-attribute decision theory" will be used. The Logical Decisions for Windows (LDW) application has been used in previous applications with risk indicators and is conceived as an effective tool which enables the interactive evaluation of the sensitivity of the indicator systems to their weights and transformation functions. The software also allows uncertainty analyses to be performed on the input data using Monte Carlo simulations. A versatile menu of interactive output and display functions make this tool suitable for risk communication with stakeholders.

#### Significant risks of this work package and contingency plan

Difficulties may be arised during the implementation of the developed methodology in a software package. The experience of the MAE Centre in buildings its earthquake impact software based on open source tools, and utilizing workflow concepts, as well as being web-enabled will be employed here to develop the next generation impact assessment software for SYNER-G.

Moreover, the work will be based on existing development of a similar kind. A full set of HAZUS-MH is available to the Consortium and VCDECIS, the decision support system of the lead partner of this work package (VCE) will be checked on their applicability for the SYNER-G toolbox. It can be considered a major advantage for this Consortium that these approaches are fully available allowing the start of the works from a high level. A challenge will be to model the interdependencies of the elements at risk without getting trapped in various uncertainties and accumulated standard deviations. The work concept therefore concentrates on the collection of knowledge and approaches, the modelling of a discrete number of understood systems, the formulation of the developed methodologies and the user interface based on a GIS surface.

**WP8: Guidelines, recommendations and dissemination (WP leader: JRC, Participants: AUTH, VCE, BRGM, NGI, UPAV, UROMA, METU, AMRA, KIT-U, UPAT, WILLIS)**

Guidelines, recommendations and dissemination activities are crucial for the longlasting effect of the project. Dissemination serves to promote and stimulate the wide participation of relevant European actors in the research process and, in due course, achieving the practical implementation of project outcomes. The dissemination activities and educational materials will be developed in the context of seismic risk prevention and mitigation efforts.

The two main objectives of WP8 are:

(i) To prepare technical guidelines and recommendations in the form of European Reference Reports concerning the fragility and loss assessment of individual elements at risk (buildings, utility and transportation network components, critical facilities) and the systemic vulnerability and losses of the entire networks and of system of networks (in city and regional scale) considering inter-element and intra-systems interactions.

(ii) To develop and implement a dissemination plan for the output from the project, which encompasses: (1) Knowledge (new methodology for systemic vulnerability assessment); (2) Products from Research (Prototype software for systemic vulnerability analysis and loss estimation, Classification of European physical assets and Guidelines for further development and deployment) and Demonstration activities, and (3) Involvement of Stakeholders and User Communities (ranging from European to Local Authorities, Technical and Scientific Communities). Special attention deserves exploitation of the Prototype software to be developed during the project.

The following tasks will respond to the above objectives:

- Task 8.1: Writing, review and production of (7) European reference reports, considered as guidelines and recommendations for Europe (Leader: JRC, Participants: all)

The developed methodology and tools will be presented in seven European reference reports intended as state-of-the-art guidelines, manuals and recommendations in order to be usable for the end-users (such as governmental/public authorities and organizations managing/owning lifelines, local communities/municipalities, construction/consulting companies, insurance companies). These reports will include the principals and methods for the vulnerability and loss assessment of buildings, utility and transportation network components and critical facilities (in city and regional scale) considering inter-element and intra-systems synergies; examples and applications from the selected case studies will be also presented. In order to secure a balanced and high-level quality, a review process will be considered.

Sub task 8.1.1: Consolidated list of the SYNER-G reference reports (titles, editors, reviewers, addresses, publisher) (Leader: JRC, Participants: UPAV, AUTH, VCE).

Set-up of a final list of the reference reports. Agreement on the process of writing (including the template) and production of the reports, as well as on the final list of editors, reviewers and publisher.

Sub task 8.1.2: Guidelines for editors, reviewers and production (Leader: JRC)

Issuing of the guidelines for writing, reviewing and production of the SYNER-G Reference Reports. These guidelines will define the specific tasks and responsibilities in the process of production of the reports.

Sub task 8.1.3: Drafting of version 1 of the reference reports (structure, contents, contributors, etc) (reference report editors and contributors, JRC)

Editors will provide a version 1 of the reports, specifying their structure, contents, and contributor partners.

Sub task 8.1.4: Production of the final version of the reference reports (ready for printing) (reference report editors, contributors and reviewers, JRC)

The final version of the reports will be produced by the contributor partners identified in Task 8.3 under the leadership of the editors. The reports will be ready for printing only after the review process is completed.

Sub task 8.1.5: Printing of the reference reports (Leader: JRC)

Production and printing of the reports in electronic form is foreseen towards the end of the project, in order to have them available at the final workshop.

Sub task 8.1.6: Distribution of the reference reports (Leader: JRC)

The reports will be distributed to members of the scientific community, end users, public administration and policy makers identified in Sub-Task 8.2.4.

- Task 8.2: Dissemination schemes for all products and tools (Leader: JRC, Participants: all)

Sub task 8.2.1: Development of communication, awareness and dissemination material and tools (Leader: VCE, Participants: JRC, AUTH, UPAV).

(1) Development of the project web server (website, document archive and exchange platform with public, restricted parts); (2) Project leaflet (3) Project presentation (4) Project Newsletters. All material will be in electronic form except for the publications in journals or other scientific editions.

Sub task 8.2.2: Organization of project workshops (Leader: JRC, Participants: VCE, AUTH)

(1) Two technical workshops in the cities chosen for pilot applications, namely: Vienna (AT) and Thessaloniki (GR); (2) Organization of the final international workshop involving potential end-users and stakeholders and contributions from 3<sup>rd</sup> countries (USA, Japan, China, etc.)

Sub task 8.2.3: Other awareness and dissemination activities (Leader: JRC, Participants: VCE, AUTH, all)

(1) Development of appropriate awareness material for the project products, such as e-booklets, leaflets and multi-media both for the scientific community, the administration and the great public; the type of material that will be produced will be defined in D8.4 "Final plan for the use and dissemination of foreground" (2) Participation in key international events related to the project, namely the European Conference on Earthquake Engineering (Skopje, FYROM, 2010) and the World Conference on Earthquake Engineering (Lisbon, PT, 2012); (3) Publication of scientific results in peer reviewed journals and magazines; (4) Production of a high-quality brochure, describing the main project products and the key results of the applications to the two European urban, infrastructure and network sites. Most of the material will be in electronic form except for the brochure and the publications in journals or other scientific editions.

Sub task 8.2.4: Involvement of potential users to achieve utilization (Leader: JRC, Participants: VCE, all)

(1) Identification of stakeholders and potential end-users of the project knowledge and products, namely the scientific and technical communities, national authorities, civil protection agencies, industry (insurance and re-insurance companies), relevant European technology platforms and European associations and federations for infrastructures and networks; (2) Collection and analysis of feedback from key events (questionnaire) for up-dating the implementation plan and set-up an effective exploitation plan ; (3) Training courses; the possibility for their implementation will be explored based on the disposed capabilities in national and regional scale.

Sub task 8.2.5: Development of detailed dissemination and exploitation plans (Leader: JRC, Participants: VCE, AUTH)

Development of a detailed implementation plan for dissemination, which will be updated regularly and will constitute the basis of the project exploitation plan to be ready at the end of the project.

Finally, joint activities are envisaged with other existing EU projects on vulnerability, especially with the ENSURE and MOVE projects. As some of the SYNER-G beneficiaries participate in the consortium of these two projects it would be feasible to exchange information and results of the applied methodologies during the planned meetings. This allows a learning process for all consortia.

*Significant risks of this work package and contingency plan*

Significant risks for this work package include difficulties in achieving awareness amongst key stakeholders and potential end-users across Europe and achieving their participation in the workshops. In order to address these risks, it will be important for dissemination to start early in the project period with the active participation of all the partners. For this reason a webpage and other promotion materials (newsletters etc) are foreseen. Moreover, a list of End-Users has been already established and will be further completed, as they will be an important body of SYNER-G that will help to keep the progress and the technical developments within SYNER-G close to the “real-world” requirements and will contribute to the success of local dissemination activities. The workshops will be run at a time and locations that will maximize participation, particularly linking up with ongoing policy developments during the project period highlighting the role of or need for vulnerability assessment. The International Advisory Committee will also stimulate the international cooperation and international dissemination of results and knowledge. Finally, cooperation with relative ongoing EC projects (ENSURE, MOVE etc) will further enhance the dissemination of the results, through joint workshops or other activities.

### 1.3.2 Timing of work packages and their components

The timing of the 8 Work Packages is shown in the diagram below. The scheduled Consortium project meetings (plenary meetings) are also shown in the diagram. Mid-term meetings between the plenary meetings among partners of particular work packages will be also organized, if necessary.

The duration of the total project is estimated to be 36 months. One consequence of the proposed duration of the project is that it may be difficult to perform a full PhD program within the project's premises. A rather extensive use of PhD candidates in SYNER-G is envisaged by some partners. The SYNER-G partners are committed to provide supplementary support for the PhD-candidates who do not conclude their studies before the project termination.

Work Packages	Duration (Months)																	
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
<b>WP1:</b> Project coordination and management																		
<b>WP2:</b> Development of a methodology to evaluate systemic vulnerability																		
<b>WP3:</b> Fragility functions of elements at risk																		
<b>WP4:</b> Socio-economic vulnerability and losses																		
<b>WP5:</b> Systemic vulnerability specification																		
<b>WP6:</b> Validation studies																		
<b>WP7:</b> Build prototype software																		
<b>WP8:</b> Guidelines, recommendations and dissemination																		
<b>Milestones</b>	☼	☼	☼			☼		☼	☼			☼		☼	☼		☼	☼
<b>Progress report</b>																		
<b>Final report</b>																		

#### LEGEND

			Work package duration
☼	Milestone		
☰	Progress report		
☰	Final report		

**Figure 6** Timing schedule. For interrelationships between WPs refer to figures 1.3 to 1.5.

### 1.3.3 Work package list /overview

Work package list						
WP No.	Work package title	Type of activity	Lead beneficiary No.	Person-months	Start month	End month
1	Project coordination and management	MGT	AUTH(1), VCE(2)	34	1	36
2	Development of a methodology to evaluate systemic vulnerability	RTD	UPAV(6)	129.5	1	24
2.1	Development of the general methodology of the systemic vulnerability accounting for all elements at risk, considering interdependences	RTD	UPAV(6)	57	1	24
2.2	Methods to consider socio-economic issues and evaluation of losses	RTD	KIT-U(10)	14.5	1	18
2.3	Typology definitions of European elements at risk (including data collection, archiving and processing)	RTD	JRC(4)	19	1	24
2.4	Seismic scenarios	RTD	UPAV(6)	23	1	18
2.5	Remote sensing for systemic vulnerability analysis 2.5.1 Identification and calibration of inventory data 2.5.2 Potential of vulnerability assessment by optical satellite imagery	RTD	UPAV(6)	16	1	24
3	Fragility functions of elements at risk	RTD	NGI(5)	142	1	18
3.1	Fragility of buildings and building aggregates 3.1.1 Fragility of common RC and steel buildings and building aggregates 3.1.2 Fragility of masonry buildings and aggregates	RTD	UPAV(6)	57.5	1	12
3.2	Fragility of elements/components within utility networks 3.2.1 3.2.1 Fragility of elements of energy systems 3.2.2 Fragility of elements of gas and oil pipeline systems 3.2.3 Fragility of elements of water and waste-water systems	RTD	AUTH(1)	17	1	18
3.3	Fragility of elements within transportation infrastructures 3.3.1 Fragility of elements of roadway bridges 3.3.2 Fragility of elements of road networks 3.3.3 Fragility of elements of railway networks 3.3.4 Fragility of elements of harbor systems	RTD	AUTH(1)	60.5	1	18
3.4	Fragility of elements within critical facilities 3.4.1 Fragility of elements within health-care facilities 3.4.2 Fragility of elements of fire-fighting system	RTD	UROMA(7)	7	1	18
4	Socio-economic vulnerability and losses	RTD	KIT-U(10)	45	1	24
4.1	Buildings and buildings aggregates (local to city scale)	RTD	KIT-U(10)	24	1	18
4.2	Utility networks	RTD	KIT-U(10)	7	1	24
4.3	Transportation infrastructures	RTD	KIT-U(10)	8	1	24
4.4	Critical facilities	RTD	KIT-U(10)	6	1	24
5	Systemic vulnerability specification	RTD	BRGM(3)	91.5	12	27
5.1	General identification of each system specificities	RTD	BRGM(3)	6	12	20
5.2	Systemic vulnerability assessment and loss of buildings and aggregate (city scale)	RTD	BRGM(3)	29.5	12	27
5.3	Systemic vulnerability assessment of utility systems 5.3.1 Systemic vulnerability assessment and loss of energy systems 5.3.2 Systemic vulnerability assessment of gas and oil systems 5.3.3 Systemic vulnerability assessment of water and waste-	RTD	UROMA(7)	26	12	27

WP No.	Work package title	Type of activity	Lead beneficiary No.	Person-months	Start month	End month
	water systems					
5.4	Systemic vulnerability assessment of transportation infrastructures 5.4.1 Systemic vulnerability assessment of transportation systems 5.4.2 Systemic vulnerability assessment and loss of harbor system	RTD	UROMA(7)	17.5	12	27
5.5	Systemic vulnerability assessment and loss of critical facilities 5.5.1 Systemic vulnerability assessment of health-care facilities 5.5.2 Systemic vulnerability assessment of fire fighting system	RTD	UROMA(7)	12.5	12	27
6	Validation studies	RTD	AUTH(1)	92.5	18	34
6.1	Application and validation study in the city of Thessaloniki (Greece)	RTD	AUTH(1)	23	18	34
6.2	Application and validation study to the city of Vienna (Austria)	RTD	VCE(2)	19	18	34
6.3	Application and validation study to a transportation network (Italy)	RTD	UROMA(7)	11	18	34
6.4	Application and validation study to an electric power network (Italy)	RTD	UROMA(7)	8	18	34
6.5	Application and validation study to a gas pipeline network (Italy)	RTD	AMRA(9)	11.5	18	34
6.6	Application and validation study to a harbor system (Thessaloniki, Greece)	RTD	AUTH(1)	11	18	34
6.7	Application and validation study to a hospital facility (Italy)	RTD	UROMA(7)	9	18	34
7	Build prototype software	RTD	VCE(2)	49.5	3	36
7.1	Collection and intelligent management of existing and newly developed fragility functions	RTD	VCE(2)	5	3	24
7.2	Modelling and functional simulation of building, lifelines and infrastructure systems	RTD	VCE(2)	10.5	12	30
7.3	Compilation of the methodologies and production of toolbox	RTD	VCE(2)	26	20	36
7.4	Geo-referencing and assignment of used surface into a web GIS solution.	RTD	VCE(2)	5	3	12
7.5	Indicator software	RTD	KIT-U(10)	3	12	24
8	Guidelines, recommendations and dissemination	OTH	JRC(4)	30.5	1	36
8.1	Writing, review and production of (7) European reference reports, considered as guidelines and recommendations for Europe 8.1.1 Consolidated list of the SYNER-G reference reports 8.1.2 Guidelines for editors, reviewers and production 8.1.3 Drafting of version 1 of the reference reports 8.1.4 Production of the final version of the reference reports 8.1.5 Printing of the reference reports 8.1.6 Distribution of the reference reports	OTH	JRC(4)	24	1	34
8.2	Dissemination schemes for all products and tools 8.2.1 Development of communication, awareness and dissemination material and tools 8.2.2 Organization of project workshops 8.2.3 Other awareness and dissemination activities 8.2.4 Involvement of potential users to achieve utilization 8.2.5 Development of detailed dissemination and exploitation plans	OTH	JRC(4)	6.5	1	36
	TOTAL			614.5		

### 1.3.4 Deliverables list

Del. No.	Deliverable Name	WP No.	Lead beneficiary	Estimated indicative person-months	Nature	Dissemination level	Delivery date (project month)
D1.1	SYNER-G work plan	1	AUTH (1)	1	R (report)	PU (public)	1
D1.2	SYNER-G Consortium Agreement	1	AUTH (1)	2	R/O	PU	1
D1.3	Project meetings and minutes, General Assembly and International Advisory Committee meetings	1	AUTH (1)	9	R	PU	1, 12, 18, 24, 30, 36
D1.4	Progress and management technical and administrative reports as requested by the Commission. Scientific and technical final report and final management report.	1	AUTH (1)	7	R	PU	6, 12, 18, 24, 30, 36
D1.5	Web-portal periodically upgraded and extended until the end of the project, including plan for its maintenance and operation beyond the project end	1	VCE (2)	15	O(Other)/D(Demonstrator)	PU/CO	3, 36
D2.1	General methodology for systemic seismic vulnerability assessment	2	UROMA(7)	5	R	PU	18
D2.2	Definition of system components and the formulation of system functions to evaluate the performance of buildings and building aggregates	2	UPAV(6)	7	R	PU	18
D2.3	Definition of system components and the formulation of system functions to evaluate the performance of electric power systems	2	UROMA(7)	6	R	PU	20
D2.4	Definition of system components and the formulation of system functions to evaluate the performance of gas and oil pipeline networks	2	AMRA(9)	6	R	PU	20
D2.5	Definition of system components and the formulation of system functions to evaluate the performance of water and wastewater systems	2	AUTH(1)	6	R	PU	20
D2.6	Definition of system components and the formulation of system functions to evaluate the performance of transportation infrastructures	2	UROMA(7)	7	R	PU	20
D2.7	Definition of system components and the formulation of system functions to evaluate the performance of ports	2	AUTH(1)	6	R	PU	18
D2.8	Definition of system components and the formulation of system functions to evaluate the performance of critical facilities	2	UROMA(7)	6	R	PU	18

D2.9	State-of-the-art literature review of methodologies to assess the vulnerability of a “system of systems”	2	AUTH(1)	8	R	PU	24
D2.10	Development of an innovative methodology to assess socio-economic losses based on indicators	2	KIT-U(10)	14.5	R	PU	18
D2.11	Methods for collecting, archiving and processing data on the typical European elements at risk within systems	2	JRC(4)	19	R	PU	24
D2.12	Efficient intensity measures for components within a number of infrastructures	2	UPAV(6)	10	R	PU	18
D2.13	A review and preliminary application of methodologies for the generation of earthquake scenarios for spatially distributed systems	2	UPAV(6)	12	R	PU	18
D2.14	Methods for remote sensing of infrastructures and processes to combine the data with ancillary information	2	UPAV(6)	5	R	PU	24
D2.15	Mutual calibration of census and remote sensing data for three case study areas (Vienna, Thessaloniki and Messina)	2	JRC(4)	6	R	PU	24
D2.16	Vulnerability assessment by optical satellite imagery	2	KIT-U(10)	5	R	PU	24
D2.17*	SYNER-G methodology for systemic analysis, performance and loss estimates	2	UPAV(6)	1	R	PU	36
D3.1	Fragility functions for common RC and steel building types and aggregates in Europe	3	UPAV(6)	34	R	PU	12
D3.2	Fragility functions for masonry buildings and aggregates in Europe	3	JRC(4)	23.5	R	PU	15
D3.3	Fragility functions for electric power system elements	3	UROMA(7)	5.5	R	PU	12
D3.4	Fragility functions for gas and oil network elements	3	BRGM(3)	6	R	PU	12
D3.5	Fragility functions for water and waste-water system elements	3	AUTH(1)	5.5	R	PU	12
D3.6	Fragility functions for roadway bridges	3	UPAV(6)	19	R	PU	18
D3.7	Fragility functions for roadway system elements	3	NGI(5)	14	R	PU	18
D3.8	Fragility functions for railway system elements	3	NGI(5)	9	R	PU	18
D3.9	Fragility functions for harbor elements	3	AUTH(1)	17.5	R	PU	12
D3.10	Fragility functions for elements within health care facilities	3	UROMA(7)	5	R	PU	18
D3.11	Fragility functions for fire fighting system elements	3	AUTH(1)	2	R	PU	18
D3.12*	SYNER-G fragility curves for all elements at risk	3	NGI(5)	1	R	PU	36

D4.1	Assessment of indicators representing socio-economic impact for losses from buildings and building aggregates and their interactions	4	KIT-U(10)	23	R	PU	12
D4.2	Assessment of indicators representing socio-economic impact for losses from utility networks and their interactions	4	KIT-U(10)	6	R	PU	18
D4.3	Assessment of indicators representing socio-economic impact for losses from transportation infrastructures (roadway, harbor) and their interactions	4	KIT-U(10)	7	R	PU	18
D4.4	Assessment of indicators representing socio-economic impact for losses from critical facilities (health care facilities, fire fighting system) and their interactions	4	KIT-U(10)	7	R	PU	18
D4.5	Collection of data for indicators determined in D4.1-4.4 through existing and/or inferred data (e.g. surveys with experts, empirical data, remote sensing, etc.)	4	KIT-U(10)	2	R	PU	24
D4.6	Utilization of socio-economic indicators for risk assessment in probabilistic and deterministic (scenario-based) frameworks	4	KIT-U(10)	2	R	PU	24
D5.1	Systemic vulnerability and loss for building aggregates in urban scale	5	BRGM(3)	30.5	R	PU	24
D5.2	Systemic vulnerability and loss for electric power systems	5	UROMA(7)	10	R	PU	24
D5.3	Systemic vulnerability and loss for gas and oil networks	5	AMRA(9)	9.5	R	PU	24
D5.4	Systemic vulnerability and loss for water and waste-water systems	5	AUTH(1)	9.5	R	PU	24
D5.5	Systemic vulnerability and loss for transportation systems	5	UROMA(7)	10.5	R	PU	27
D5.6	Systemic vulnerability and loss for harbors	5	AUTH(1)	9	R	PU	27
D5.7	Systemic vulnerability and loss for health care facilities	5	UROMA(7)	8	R	PU	27
D5.8	Systemic vulnerability and loss for fire fighting systems	5	AUTH(1)	4.5	R	PU	27
D6.1	Application and validation study to the city of Thessaloniki (Greece)	6	AUTH(1)	22	R	PU	34
D6.2	Application and validation study to the city of Vienna (Austria)	6	VCE(2)	19	R	PU	34
D6.3	Application and validation study to a motorway system (Italy)	6	UROMA(7)	11	R	PU	34
D6.4	Application and validation study to an electric power system (Italy)	6	UROMA(7)	8	R	PU	34
D6.5	Application and validation study to a gas and oil pipeline network (Italy)	6	AMRA(9)	11.5	R	PU	34
D6.6	Application and validation study to a harbor system (Thessaloniki, Greece)	6	AUTH(1)	11	R	PU	34

D6.7	Application and validation study to a hospital facility (Italy)	6	UROMA(7)	9	R	PU	34
D6.8*	Pilot studies and application of SYNER-G methodology	6	AUTH(1)	1	R	PU	36
D7.1	Functional fragility curve archive	7	VCE (2)	5	O	PU	24
D7.2	Code for the SYNER-G methodology	7	VCE (2)	10.5	O	PU	30
D7.3	SYNER-G toolbox	7	VCE (2)	25	O	PU	36
D7.4	Web GIS interface	7	VCE (2)	5	O	PU	12
D7.5	Indicator software	7	KIT-U(10)	3	O	PU	24
D7.6*	SYNERG-G tool-box and web portal	7	VCE (2)	1	R	PU	36
D8.1	Web portal structure and implementation of the part concerned with general information on the project	8	VCE(2)	3	D	PU	3
D8.2	Project newsletter issue 1, issue 2 and issue 3	8	JRC(4)	1	R	PU	3, 15, 27
D8.3	Project leaflet and project presentation (slides set)	8	JRC(4)	1	R	PU	3
D8.4	Final plan for the use and dissemination of foreground (implementation details, including dates, and location of project events, etc)	8	JRC(4)	1.5	R	PU	12
D8.5	Consolidated program for the production of the SYNER-G reference reports	8	JRC(4)	1	R	PU	12
D8.6	Guidelines for editors, reviewers and production of the SYNER-G reference reports	8	JRC(4)	1	R	PU	12
D8.7	Report 1: Methodology for systemic seismic vulnerability assessment of buildings, infrastructures, networks and socio-economical impacts	8	JRC(4)	2.5	R	PU	34
D8.8	Report 2: Guidelines for typology definition of European physical assets for earthquake risk assessment	8	JRC(4)	1.5	R	PU	34
D8.9	Report 3: Remote sensing and integration of secondary data sources for earthquake loss estimation	8	JRC(4)	1.5	R	PU	34
D8.10	Report 4: Guidelines for deriving fragility functions of elements at risk: buildings, lifelines, transportation networks and critical facilities	8	JRC(4)	2	R	PU	34
D8.11	Report 5: Guidelines for the consideration of socio-economic impacts	8	JRC(4)	2	R	PU	34
D8.12	Report 6: Systemic seismic vulnerability assessment: Validation studies	8	JRC(4)	2	R	PU	34
D8.13	Report 7: Systemic seismic vulnerability assessment: Software users manual	8	JRC(4)	2	R	PU	34
D8.14	Technical workshops conclusions and recommendations	8	JRC(4)	2	R/O	PU	36
D8.15	Final workshop conclusions and	8	JRC(4)	2	R/O	PU	36

	recommendations						
D8.16	Exploitation plan	8	JRC(4)	1	R	PU	36
D8.17	High-quality brochure, describing the main project products and the key results of the applications to the two European urban, infrastructure and network sites	8	JRC(4)	1.5	R	PU	36
D8.18*	Brochures, guidelines, manuals for dissemination purposes	8	JRC(4)	1	R	PU	36
D8.19	Awareness and wider societal implications	8	JRC(4)	1	R	PU	36
D8.20*	SYNER-G synthetic document extracted from D2.17, D3.12, D6.8, D7.6, D8.18 and Vision Paper	8	AUTH(1)	1	R	PU	36

\* **Synthetic deliverables:** Considering the fact that there is a large number of technical deliverables, which have been assigned to correspond to the different activities within the various work packages and tasks, five synthetic deliverables have been proposed (D2.17, D3.12, D6.8, D7.6, D8.18) which will present in a more consolidated way the main results and products of the project. They will all be delivered at the end of the project (Month 36).

Moreover it is proposed to prepare a unique synthetic document extracted from the previous five synthetic deliverables, which will outline in a comprehensive manner the scientific achievements and findings highlighting the usefulness of the research output for Policy or other users. The effort will be to communicate key messages and explanations about the main results of SYNER-G and present the step forward for knowledge and practice. Finally a vision paper (final deliverable) will be prepared giving an opinion and recommendation on the way forward. Both are delivered at the end of the project under a single deliverable number D8.20.

### 1.3.5 Work package descriptions

<b>Work package number</b>	1	<b>Start date or starting event</b>	Month 1				
<b>Work package title</b>	<b>Project coordination and management</b>						
<b>Activity Type</b>	<b>Consortium management</b>						
<b>Participant number</b>	1	2					
<b>Participant short name</b>	<b>AUTH</b>	<b>VCE</b>					
<b>Person-months per participant</b>	24	10					

#### Objectives

- To ensure scientific/ technical coordination.
- To oversee the administrative and financial management, project planning and evaluation.
- To ensure frictionless management and coordination of the project, efficient planning, coordination, monitoring, fostering the flow of information between participants and between work packages, efficient steering of the activities, and efficient conflict management and establishment of a clear decision making process.
- To provide communication to the European Commission.

#### Description of work

The overall duties of the Coordinator (AUTH) are to:

- Ensure that the specific technical and scientific targets of the project will be duly met; monitor and evaluate progress.
- Oversee science and society issues related to the research activities.
- Conclude a Consortium Agreement with partners, ensure that it is followed and maintain it.
- Receive all payments from Commission and distribute to the partners.
- Oversee the promotion of gender equality in the project.
- Timely submit reports and other deliverables to the Commission.
- Timely deliver cost and other statements as well as financial audit certificates from the Contractors to the Commission.
- Call, chair, administrate and provide the secretary for the minutes of the Contractors Assembly and of the Executive Committee; ensure that the decisions are implemented.
- Organize, call and chair of the plenary meetings, the General Assembly, the Executive Committee meetings and the meetings of the International Advisory Committee.
- Provide the secretary of the International Advisory Committee meetings, ensure the preparation of the minutes and that guidance and proposals by IAC are followed.
- Assist Contractors following-up the performances of the Work Packages, activities and deliverables to be provided by the Contractors under the Contract as well as information of any-non performance.
- Collect the work records of the Contractors on a monthly basis (collection quarterly).
- Transmit any documents and information of relevance for the overall management of the project to and between the Work Package Leaders and the Contractors concerned.
- Issue of periodic and final financial and management reports according to the Contract.
- Collect from Contractors the Audit Certificates when requested by EC.
- Perform in due diligence its tasks in the proper administration of any funds and maintenance of financial accounts.
- Manage the overall legal, contractual, ethical, financial and administrative issues of the project.

- Coordinate knowledge management and other innovation-related activities.

The overall duties of the Project Management (VCE) are:

- Operational planning: Overall financial and accounting management; Collective technical coordination administrative coordination; Controlling of the project resources and the compliance of the budget; Time management and compliance of the time schedule; Support the Coordinator for the organization and management of the meetings.
- Project steering and assessment: Overall planning and steering of the activities in the project; Regular coordination with the work package leaders (milestones); Control and assess activities within the independent work packages.
- Project documentation and controlling: Support the Coordinator in the regular reporting to the Scientific Officer of the European Commission.
- Decision making and conflict management: Establishment of the decision making rules in the project; Conflict management tools.
- Communication management: Establishment of clear communication channels within the project; Establishment and maintenance of a project web server of the project; Management of the mailing lists; Moderation of the meetings.

**Role of Participants:**

AUTH (1) will coordinate the project

VCE (2) will play a key role as the Project manager.

**Deliverables**

- D1.1: SYNER-G work plan (approved in the EC negotiation prior to project start). (AUTH, Month 1)
- D1.2: SYNER-G consortium agreement (signed by Consortium prior to project start). (AUTH, Month 1)
- D1.3: Project meetings and minutes, General Assembly and International Advisory Committee meetings. (AUTH, VCE, Months 1, 12, 18, 24, 30, 36)
- D1.4: Progress and management technical and administrative reports as requested by the Commission. Scientific and technical final report and final management report. (AUTH, VCE, Months 6, 12, 18, 24, 30, 36)
- D1.5: Web-portal (Month 3) periodically upgraded and extended until the end of the project, including plan for its maintenance and operation beyond the project end (Month 36). (VCE, Months 3, 36)

<b>Work package number</b>	2			<b>Start date or starting event</b>					Month 1					
<b>Work package title</b>	<b>Development of a methodology to evaluate systemic vulnerability</b>													
<b>Activity Type</b>	RTD													
<b>Participant number</b>	6	1	2	3	4	5	7	8	9	10	11	12	14	
<b>Participant short name</b>	UPAV	AUTH	VCE	BRGM	JRC	NGI	UROMA	METU	AMRA	KIT-U	UPAT	WILLIS	UKOBE	
<b>Person-months per participant</b>	35	12	3	7	13.5	3	18	8	14	5	1	2	8	

## Objectives

- Development of the conceptual basis and general principles of a unified methodology.
- Development of the appropriate tools and methods for the probabilistic assessment of the seismic vulnerability of a *system of general nature*.

## Description of work

### **Task 2.1: Development of the general methodology of the systemic vulnerability accounting for all elements at risk, considering interdependences (UPAV, UROMA and all partners)**

- Identification and characterization of the components within different types of systems (industrial buildings and processes, electrical power generation plants, electrical power transmission network, water-supply networks, telecommunication networks, residential buildings, transportation networks).
- Identification and description of the *relation/interactions between the components*.
- Formulation of a system function that allows the evaluation of the performance state of the system as a function of the states of its components.
- Application of similar processes for infrastructures, i.e. a number of interacting systems.
- State-of-the-art review of the methods for a "system of systems" analysis and identification of those which can be applied in WP5.

### **Task 2.2: Methods to consider socio-economic issues and evaluation of losses (KIT-U, UPAV, NGI, AMRA, WILLIS)**

- Review the current methods for considering social and economic losses within systems.
- Definition of the indicators for the assessment of loss to commercial facilities, indirect loss due to business interruption, loss of life etc.
- Quantitative estimations of damage ratios for selected group of assets, e.g. residential buildings.
- Identification of the factors of aggravation of physical losses evaluated as a damage ratio or monetary quantity of primary damage (what constitutes the aggravation).
- Determination of the factors (stakeholder approach, empirical data) for each risk component and their interaction.
- Utilization for risk assessment in probabilistic and deterministic (scenario-based) frameworks.

### **Task 2.3: Typology definitions of European elements at risk (including data collection, archiving and processing) (JRC, AUTH, UPAV, NGI, BRGM)**

- Definition of the typical characteristics of structural and non-structural elements within European systems.
- Review of different methods for data collection (census, owner/operator data, surveys, remote sensing, aerial photographs) and methods for archiving and processing this data.
- Proposal of a harmonized template for data collection.

### **Task 2.4: Seismic scenarios (UPAV, AUTH, BRGM, AMRA, METU, WILLIS)**

- Proposal of efficient intensity measures for use with various systems through literature reviews and preliminary studies on each of the elements at risk.
- Simulation of ground motion fields in an efficient manner for spatially distributed systems. Outline

methodologies for direct use within WP5.

**Task 2.5: Remote sensing for systemic vulnerability analysis** (UPAV, BRGM, KIT-U, JRC, WILLIS)

**Sub-Task 2.5.1** Identification and calibration of inventory data (UPAV, JRC, BRGM, WILLIS)

- Demonstration of how a database of key physical, social and economic inventory measures can be developed through the integration of physical variables derived from both optical satellite images and radar images coupled with secondary sources including census data, localized knowledge, socio-economic and demographic data.
- Mutual calibration of the data from census and from owner/operators of transportation networks with data from remote sensing, using as a reference the two case studies of Vienna and Thessaloniki.
- Calibration of remote sensing data for buildings and building aggregates in the city of Messina.

**Sub-Task 2.5.2** Potential of vulnerability assessment by optical satellite imagery (KIT-U, JRC, BRGM, UPAV)

- Exploration and development of a systemic framework on the options to develop or support vulnerability models from optical satellite imagery combined with vulnerability information and socio-economic ground data.
- Performance of the input parameters for accessibility analysis in GIS environment in order to address structural exposure, population structure and population development.

**Role of Participants:**

AUTH (1) will actively contribute to the development of the general methodology of the systemic vulnerability (Task 2.1) and the studies of seismic hazard issues (Task 2.4). It will also support the definition of typology and inventory for utility and transportation systems (Task 2.3).

VCE (2) will support the development of the general methodology especially for bridges, masonry buildings and general infrastructure lifelines.

BRGM (3) will contribute to the development of the general methodology through a systemic approach and the introduction of inter-element and interdependency issues (Task 2.1). As BRGM is explicitly recognized for its seismic expertise within the Consortium, it will provide inputs on seismic scenarios (Task 2.4). Finally it will participate in Task 2.5: Remote sensing methods for loss assessment.

JRC (4) will have an active contribution in the inventory and typology issues (Task 2.3) and on application of remote sensing methods for the calibration of inventory data of the test sites (Task 2.5).

NGI (5) will actively contribute to the development of a methodology to assess systemic vulnerability, particularly (Task 2.1 and Task 2.2) using amongst other experiences and framework from ongoing EU project Move (Methods for the Improvement of Vulnerability Assessment in Europe).

UPAV (6) will play a key role as a leader of WP2.

UROMA (7) will play a key role in Task 2.1 together with UPAV (in the definition of the general methodology for systemic vulnerability assessment).

METU (8) will contribute to the development of general methodology for the systemic vulnerability (Task 2.1) and seismic scenarios (Task 2.4) with emphasis on ground motion prediction equation derivation and effect of local geology.

AMRA (9) will contribute to the methodology for systemic structural-non-structural loss assessment in specific buildings; methodology for seismic risk assessment of lifelines (Tasks 2.1, 2.2). It will actively participate to the methodology for the definition of spatially correlated hazard scenarios (Task 2.4).

KIT-U (10) will contribute to the development of methodology to explore and evaluate interdependences (Task 2.1) and as a leader of Task 2.2 to the development of methodology to consider the socio-economic issues. It will also contribute to remote sensing methods for loss assessment (Task 2.5).

UPAT (11) will contribute to the development of the general methodology of the systemic vulnerability (Task 2.1).

WILLIS (12) will have a supporting role, provide a review of methodologies, in particular in relation to tasks 2.1, 2.2, 2.4 and 2.5, including the consideration of research findings from the Willis Research

Network where appropriate. Willis will expect to provide an industry-focused overview of economic modeling / loss estimation methods, reflecting the general approach and views of the global financial services industry, to enable the outcomes of this research to be most applicable to the development of effective financial risk transfer mechanisms.

## **Deliverables**

- D2.1: General methodology for systemic seismic vulnerability assessment. (UROMA, UPAV and all partners, Month 18)
- D2.2: Definition of system components and the formulation of system functions to evaluate the performance of buildings and building aggregates. (UPAV, UPAT, JRC, METU, BRGM, UKOBE, VCE, Month 18)
- D2.3: Definition of system components and the formulation of system functions to evaluate the performance of electric power systems. (UROMA, AUTH, Month 20)
- D2.4: Definition of system components and the formulation of system functions to evaluate the performance of gas and oil pipeline networks. (AMPRA, BRGM, AUTH Month 20)
- D2.5: Definition of system components and the formulation of system functions to evaluate the performance of water and waste-water systems. (AUTH, Month 20)
- D2.6: Definition of system components and the formulation of system functions to evaluate the performance of transportation infrastructures. (UROMA, NGI, AUTH, UPAV, UPAT, JRC, BRGM, METU, VCE, Month 20)
- D2.7: Definition of system components and the formulation of system functions to evaluate the performance of ports. (AUTH, Month 18)
- D2.8: Definition of system components and the formulation of system functions to evaluate the performance of critical facilities. (UROMA, AUTH, Month 18)
- D2.9: State-of-the-art literature review of methodologies to assess the vulnerability of a “system of systems”. (AUTH and all, Month 24)
- D2.10: Development of an innovative methodology to assess socio-economic losses based on indicators. (KIT-U, UPAV, NGI, AMRA, WILLIS, Month 18)
- D2.11: Methods for collecting, archiving and processing data on the typical European elements at risk within systems. (JRC, AUTH, UPAV, NGI, BRGM, Month 24)
- D2.12: Efficient intensity measures for components within a number of infrastructures. (UPAV, AUTH, BRGM, AMRA, METU, WILLIS, Month 18)
- D2.13: A review and preliminary application of methodologies for the generation of earthquake scenarios for spatially distributed systems. (UPAV, AUTH, BRGM, AMRA, METU, WILLIS, Month 18)
- D2.14: Methods for remote sensing of infrastructures and processes to combine the data with ancillary information. (UPAV, BRGM, KIT-U, JRC, WILLIS, Month 24)
- D2.15: Mutual calibration of census and remote sensing data for three case study areas (Vienna, Thessaloniki and Messina). (JRC, UPAV, BRGM, WILLIS, Month 24)
- D2.16: Vulnerability assessment by optical satellite imagery. (KIT-U, JRC, BRGM, UPAV, Month 24)
- D2.17: SYNER-G methodology for systemic analysis, performance and loss estimates. (UPAV, all, Month 36) (synthetic deliverable)

<b>Work package number</b>	3			<b>Start date or starting event</b>					Month 1			
<b>Work package title</b>	<b>Fragility functions of elements at risk</b>											
<b>Activity Type</b>	RTD											
<b>Participant number</b>	5	1	2	3	4	6	7	8	11	12	13	14
<b>Participant short name</b>	NGI	AUTH	VCE	BRGM	JRC	UPAV	UROMA	METU	UPAT	WILLIS	UILLINOIS	UKOBE
<b>Person-months per participant</b>	7	16	3	8	11	25	6	16	34	2	7	7

### Objectives

- Compilation of the existing fragility functions for the various elements at risk including buildings, and elements within utility lifeline networks and transportation infrastructures.
- Adaptation, improvement and, if necessary, development of new fragility functions for these elements considering their distinctive European features and typological characteristics.
- Harmonization of the fragility functions for their systematic incorporation in the following WP.

### Description of work

#### **Task 3.1 Fragility of buildings and building aggregates (UPAV, UPAT, BRGM, JRC, METU, WILLIS, VCE, UILLINOIS, UKOBE).**

- Compilation of a system of fragility curves for the most common building types in Europe (Reinforced concrete, masonry).
- Determination of the most appropriate attributes of exposure derived from the seismic scenarios.
- Definition of a concerted description of damage states considering the robustness of the building when defining the collapse limit state.
- Exploration of the possibility of generating fragility curves for more general classes by aggregating the information contained in subclasses of buildings.
- Proposal of fragility curves for monumental buildings using rapid and detailed methods.

##### **Sub-Task 3.1.1 Fragility of common RC and steel buildings and building aggregates (UPAV, UPAT, JRC, METU, BRGM, UKOBE, UILLINOIS)**

- Review and comparison of fragility curves for reinforced concrete buildings for a number of limit states from a number of European and national studies.
- Employment of state-of-the-art mechanics-based methodologies for the development of fragility curves.
- Comparisons with observed damage data.
- Definition of the epistemic uncertainty in this fundamental component of a seismic risk analysis.
- Proposal of the most improved fragility functions for RC buildings and building populations in the European context.

##### **Sub-Task 3.1.2 Fragility of masonry buildings and aggregates (JRC, UPAV, VCE, UPAT, BRGM, UKOBE)**

- Compilation, generation and comparison of a number of fragility functions for masonry buildings and buildings aggregates in historical centers
- Identification of the epistemic uncertainty in the vulnerability assessment.
- Proposal of adequate fragility functions for masonry buildings and aggregates.

#### **Task 3.2 Fragility of elements/components within utility networks (AUTH, NGI, UROMA, BRGM, WILLIS, UILLINOIS).**

- Suggestion of a classification of infrastructure elements considering relevant factors.
- Definition of appropriate indicators of seismic damage.

- Description of damage states for each element of utility networks.
- Development of fragility functions and damage-functionality relationships for all elements due to ground shaking and large and permanent ground deformation.

**Sub-Task 3.2.1** Fragility of elements of electric power systems (UROMA, AUTH)

- Review and further improvement of available fragility methods.
- Proposal of appropriate fragility functions for all elements of power supply networks (transformers, substations, electrical lines).
- Relation of physical damage states to loss of function levels in order to perform systemic vulnerability and loss analyses (WP5).

**Sub-Task 3.2.2** Fragility of elements of gas and oil pipeline systems (BRGM, AUTH, UILLINOIS)

- Comparison and evaluation of existing fragility formulations for gas and oil pipelines.
- Proposal of the most reliable ones according to the typological features in Europe.
- Introduction of both peak ground strain and peak ground velocity in the fragility functions and study of the effect of soil properties and non-linearity to the ground response.
- Relation of physical damage states to loss of function levels in order to perform systemic vulnerability and loss analyses (WP5).

**Sub-Task 3.2.3** Fragility of elements of water and waste-water systems (AUTH, UILLINOIS)

- Compilation and evaluation of empirical and analytical fragility functions for water and waste-water pipelines based on European typological features and past earthquake damages in Europe.
- Consideration of both ground failure and ground shaking.
- Proposal of fragility functions and damage-functionality relationships for pipelines, tanks, pumping stations and other water and waste-water system components.

**Task 3.3 Fragility of elements within transportation infrastructures** (AUTH, BRGM, JRC, NGI, UPAV, UROMA, METU, UPAT, VCE, WILLIS, UILLINOIS).

- Development of fragility functions both for shaking and permanent ground displacements according to the nature of each element at risk.
- Suggestion of seismic damage indicators based on traffic capacity degradation in order to establish damage-functionality relationships.

**Sub-Task 3.3.1** Fragility of elements of roadway bridges (UPAV, UPAT, VCE, JRC, UROMA, BRGM, METU, UILLINOIS)

- Review and implementation of the state-of-the-art-fragilities that are based on the response of bridge components and their interaction during earthquake ground motion.
- Study of mechanics-based methods which employ simplified nonlinear static analysis to define the capacity of bridges and bridge components for use in vulnerability assessment.
- Comparison with more complex nonlinear dynamic analyses to identify the uncertainty in the response of bridges to ground shaking.
- Integration into the numerical fragility analyses of data from experimental results on bridge components.
- Proposal of improved fragility functions for bridges.

**Sub-Task 3.3.2** Fragility of elements of road networks (NGI, AUTH, BRGM)

- Review and evaluation of fragility functions for road network elements like roads, embankments, tunnels and slopes, in order to adapt, modify or even improve them according to the distinctive inventory and typology features.
- Assignment of appropriate parameters of the seismic ground shaking and/or ground failure.

- Definition of different damage states and relation to loss of function and restoration time.
- Development of new fragility curves in some cases such as the shallow tunnels, considering soil conditions.
- Examination of indirect damages and functionality loss of urban roads due to the collapse of buildings.

**Sub-Task 3.3.3** Fragility of elements of railway networks (NGI, UPAT, VCE, METU)

- Compilation of separate sets of fragility functions for railway network elements like tracks, bridges, embankments, retaining walls, tunnels, signal and power supply systems.
- Establishment of curves based on existing data and Bayesian approaches, using relevant experience from other lifeline networks where possible.

**Sub-Task 3.3.4** Fragility of elements of harbor systems (AUTH)

- Evaluation and proposal of fragility functions for all elements within harbor facilities (wharfs, cranes, warehouses, buildings, utility and transportation networks etc).
- Assignment of appropriate parameters of the seismic ground shaking and/or ground failure.
- Description of damage states based on past earthquake experience and studies and assignment of functionality levels to each damage state.
- Performance of validation studies and additional analyses in order to improve existing fragility functions and/or propose new ones for the case of the quay walls.

**Task 3.4** Fragility of elements within critical facilities (UROMA, AUTH).

**Sub-Task 3.4.1** Fragility of elements within health-care facilities (UROMA)

- Probabilistic analysis of the seismic performance of facilities (buildings, operating theaters, medical gas supply, etc).
- Definition of the fragilities of structural and non-structural components as well as specific equipment such as operating theaters, medical gas supply systems.

**Sub-Task 3.4.2** Fragility of elements of fire-fighting system. (AUTH)

- Examination of the consistency of fragility functions of fire fighting and common water pipes and tanks.
- Proposal of fragility formulations for water supply points in relation to the water pipeline functionality and damage states.

**Role of Participants:**

AUTH (1) will actively contribute to the definition of fragility functions for elements of energy system (Sub-Task 3.2.1), gas and oil pipelines (Sub-Task 3.2.2), water and waste-water system (Sub-Task 3.2.3), telecommunication system (Sub-Task 3.2.4), road network (Sub-Task 3.3.2), harbor (Sub-Task 3.3.4) and fire fighting system (Sub-Task 3.4.2).

VCE (2) will support the definition of fragility functions for bridges, masonry buildings and general infrastructure lifelines.

BRGM (3) will provide fragility curves and surfaces for masonry and reinforced concrete buildings (Task 3.1) based on previous work. It will also have a supportive role in Task 3.2: Fragility of elements/components within utility networks and provide expertise in vulnerability of roadway bridges (Sub-Task 3.3.1) and underground-tunnel interaction analysis (Sub-Task 3.3.2), together with inputs through past work on road networks (Task 3.3).

JRC (4) will review/propose methodologies/gy for the generation of fragility curves of buildings (Task 3.1) and bridges (Task 3.3.1) based on available data.

NGI (5) will play a key role as WP3 leader, and actively contribute to sub-tasks 3.2.2, 3.3.1 and 3.3.2.

UPAV (6) will actively contribute through vulnerability curves and simplified methods for scenario damage prediction in Task 3.1 (Buildings and building aggregates), Sub-Task 3.3.1 (Bridges).

UROMA (7) will have a supporting role in Task 3.2 and Task 3.3 (in the development of fragility curves for electric power systems and bridge structural systems) and Sub-Task 3.4.1 (development of fragility

curves for elements within health-care facilities).

METU (8) will contribute to the development of fragility curves for buildings and components (Task 3.1) and elements of road networks (Task 3.3.1)

UPAT (11) will play a key role in the development of fragility curves for buildings (reinforced concrete and masonry in Task 3.1) and bridges (Sub-Task 3.3.1).

WILLIS (12) will have a supporting role, provide a review of specific methodologies and contribution to the design of fragility function outputs, in relation to economic and insured loss calibrations (WP3).

UILLINOIS (13) will participate actively in the WP3. UILLINOIS will contribute to the review of US research on fragility relationships for buildings, bridges, pipelines, network facilities, major bridges and river crossings and the selection and further development of required 'consistent' fragilities sets to arrive at uniform reliability loss assessment (Tasks 3.1, 3.2, 3.3). It will also provide information on transportation network modeling and validation examples (Task 3.3).

UKOBE (14) will contribute to the review of Japanese research on fragility relationships for buildings, especially those for traditional and modern Japanese structures (Task 3.1). It will provide information on the vulnerability and loss estimates associated with the 1995 Hyogo-ken Nanbu (Kobe), Japan, Earthquake.

### **Deliverables**

D3.1: Fragility functions for common RC and steel building types and aggregates in Europe. (UPAV, UPAT, JRC, METU, BRGM, UKOBE, UILLINOIS, Month 12)

D3.2: Fragility functions for masonry buildings and aggregates in Europe. (JRC, UPAV, VCE, UPAT, BRGM, UKOBE, Month 15)

D3.3: Fragility functions for electric power system elements. (UROMA, AUTH, Month 12)

D3.4: Fragility functions for gas and oil system networks. (BRGM, AUTH, UILLINOIS, Month 12)

D3.5: Fragility functions for water and waste-water system elements. (AUTH, UILLINOIS, Month 12)

D3.6: Fragility functions for roadway bridges. (UPAV, UPAT, VCE, JRC, UROMA, BRGM, METU, UILLINOIS, Month 18)

D3.7: Fragility functions for roadway system elements. (NGI, AUTH, BRGM, Month 18)

D3.8: Fragility functions for railway system elements. (NGI, UPAT, VCE, METU, Month 18)

D3.9: Fragility functions for harbor elements. (AUTH, Month 12)

D3.10: Fragility functions for elements within health care facilities. (UROMA, Month 18)

D3.11: Fragility functions for fire fighting system elements. (AUTH, Month 18)

D3.12: SYNER-G fragility curves for all elements at risk. (NGI, all, Month 36) (synthetic deliverable)

<b>Work package number</b>	<b>4</b>	<b>Start date or starting event</b>					Month 1		
<b>Work package title</b>	<b>Socio-economic vulnerability and losses</b>								
<b>Activity Type</b>	RTD								
<b>Participant number</b>	10	5	8	9	12	13			
<b>Participant short name</b>	<b>KIT-U</b>	NGI	METU	AMRA	WILLIS	UILLINOIS			
<b>Person-months per participant</b>	21	3	6	8	3	4			

### Objectives

- Estimation of socio economic losses due to physical damages on buildings in terms of casualties, displaced population, and other socio economic impacts.
- Assessment of social and economic impact due to seismic damages on utility networks, transportation infrastructures and critical facilities through an indicator system.
- Consideration of the strategic and economic importance of each element and system, and the interdependencies between elements and systems.

### Description of work

#### **Task 4.1 Buildings and buildings aggregates (local to city scale) (KIT-U, UILLINOIS, METU, AMRA, WILLIS)**

- Establishment of appropriate methodologies for estimating casualties, displacements and demand for temporary housing based on demographic data and fragility functions developed for buildings and building aggregates.
- Development of a system of indicators related to the fragilities and coping capacities of the affected population, to capture the aggravating impact of direct damages to buildings at the local and city scale.

#### **Task 4.2 Utility networks (KIT-U, NGI, WILLIS)**

The following systems are going to be considered: energy distribution systems, gas and oil pipeline systems, water and waste-water systems.

- Development of an indicator-based methodology relating direct damages of utility infrastructure to the socio-economic importance of each element at risk.
- Derivation of a system of strategic and economic indicators, including production loss associated with utility disruptions, dependency structure of various industrial sectors, and the interdependencies in the utility network themselves.
- Derivation of a set of social impact indicators by considering the impact of sustained disruptions.
- Connection with on-going European research projects (MOVE, ENSURE) for the development of indicators representing economic and social vulnerability in lifeline disruptions.

#### **Task 4.3 Transportation infrastructures (KIT-U, NGI, WILLIS)**

- Identification of the most critical parts, hubs, knots in the road network based on regional traffic flow models.
- Modeling of the criticality of the transportation network based on varied parameters.
- Definition of the transportation criticality indicators in two categories: geographical importance measures and network characteristics measures.
- Assessment of the socio-economic impact of disruptions to transportation infrastructure based on the relation of the criticality of the transportation network to the seismic damage estimates of network elements.

#### **Task 4.4 Critical facilities (KIT-U, WILLIS)**

- Development of appropriate indicator-based methodologies accounting for the aggravated impact of damaged critical facilities such as health care facilities and fire stations on "at risk" populations.

- Determination of the social impact of the loss of critical facilities based on a system of indicators related to the fragilities and coping capacities of the affected population.
- Consideration of the impact of disruptions to utility and transportation networks on healthcare facilities and firefighting systems.

**Role of Participants:**

NGI (5) will play a supporting role in WP4, specifically Task 4.2, bringing in seismic case study experience from EU project Move.

METU (8) will contribute to the socioeconomic and loss assessment of buildings and aggregates (tasks 4.1)

AMRA (9) will contribute in socioeconomic issues of buildings and buildings aggregates (Task 4.1)

KIT-U (10) will lead WP4 and play a key role in organizing the issue of socio-economic vulnerability within SYNER-G.

WILLIS (12) will take a supporting role in the review of methodologies in relation to economic and financial impacts (WP4). Willis expects to contribute mainly to task 4.1 as this is currently the focus for quantitative risk assessment within the insurance and reinsurance industry. Outcomes of tasks 4.2, 4.3 and 4.4 are becoming increasingly relevant, particularly in heavily industrialised countries, in terms of business interruption costs. Willis will therefore provide appropriate review of these tasks in relation to the insurance and reinsurance industries.

UILLINOIS (13) will have a supporting role in WP4, through contributing to the modeling of social impact, dislocation and temporary housing for optimization of housing allocations, balancing social, economic and environmental impact (Task 4.1).

**Deliverables**

- D4.1: Assessment of indicators representing socio-economic impact for losses from buildings and building aggregates and their interactions. (KIT-U, UILLINOIS, METU, AMRA, WILLIS, Month 12)
- D4.2: Assessment of indicators representing socio-economic impact for losses from utility networks and their interactions. (KIT-U, NGI, WILLIS, Month 18)
- D4.3: Assessment of indicators representing socio-economic impact for losses from transportation infrastructures (roadway, harbor) and their interactions. (KIT-U, NGI, WILLIS, Month 18)
- D4.4: Assessment of indicators representing socio-economic impact for losses from critical facilities (health care facilities, fire fighting system) and their interactions. (KIT-U, WILLIS, Month 18)
- D4.5: Collection of data for indicators determined in D4.1-4.4 through existing and/or inferred data (e.g. surveys with experts, empirical data, remote sensing, etc.) (related to Task 2.5). (KIT-U, AMRA, WILLIS, Month 24)
- D4.6: Utilization of socio-economic indicators for risk assessment in probabilistic and deterministic (scenario-based) frameworks (see Task 2.2). (KIT-U, NGI, AMRA, WILLIS, Month 24)

<b>Work package number</b>	5		<b>Start date or starting event</b>				Month 12			
<b>Work package title</b>	<b>Systemic vulnerability specification</b>									
<b>Activity Type</b>	RTD									
<b>Participant number</b>	3	1	5	6	7	8	9	11	12	
<b>Participant short name</b>	<b>BRGM</b>	AUTH	NGI	UPAV	UROMA	METU	AMRA	UPAT	WILLIS	
<b>Person-months per participant</b>	15	20	3.5	5	18	10	16	1	3	

## Objectives

- (i) Identify the parameters governing the general methodology for each system based on the characterization of systems performed in WP2
- (ii) Assess the systemic vulnerability and evaluate the loss related to the different systems studied in the frame work of this proposal, i.e. Buildings, building aggregates, networks (electrical power, gas and oil, water and waste water), transportation infrastructure, roadway, fire fighting and harbor systems and health care facilities.

## Description of work

### Task 5.1 General identification of each system specificities (BRGM, NGI)

- Incorporation of the outcomes of WP2, 3 and 4.
- Examine of the overall vulnerability in the light of the performance of the system expressed by the ratio between the Demand and Capacity. Specific definitions and characterization of the performance depending on the nature of the system
- Study of the weak or strong interdependencies and interconnections between sub-systems for the case of complex systems (urban, harbor or health care) in a deterministic and probabilistic framework.

### Task 5.2 Systemic vulnerability assessment and loss of buildings and aggregate (city scale) (BRGM, UPAV, UPAT, AMRA, METU, WILLIS)

- Definition of homogeneously vulnerable zones (HVZs) for the systemic vulnerability assessment of buildings and building aggregates at the city scale.
- Establishment of systemic fragility functions for building aggregates which will be then attributed to each HVZ deterministically or randomly.
- Estimation of uncertainties of different origin (fragility functions, interconnections, spatial positioning) to the final result through a possibilistic/probabilistic approach.

### Task 5.3 Systemic vulnerability assessment of utility networks (UROMA, AUTH, BRGM, AMRA, WILLIS)

#### Sub-Task 5.3.1 Systemic vulnerability assessment and loss of electrical power networks (UROMA)

- Modeling of the consequences in terms of (indirect) costs of the power outage within the struck region on an activity basis (industry, residential, services, transport, commerce, water-distribution).
- Study of the interaction between the electrical network and the other networks serving a region.

#### Sub-Task 5.3.2 Systemic vulnerability assessment of gas and oil networks (AMRA, AUTH, BRGM)

- Estimating closed-form upper and lower bound approximations to the component failure probabilities, functionality of components within the system that have been damaged by an earthquake and network serviceability
- Developing a comprehensive model for the probabilistic systemic seismic vulnerability and risk assessment of gas and oil networks in the framework of performance-based earthquake engineering
- Considering of the case in which the earthquake damage of a portion of the networks may trigger explosions interacting with a building/structure having reduced seismic capacity because of the earthquake.

**Sub-Task 5.3.3** Systemic vulnerability assessment of water and waste-water networks (AUTH, AMRA)

- Determine appropriate system performance criteria for water and waste-water systems based on reliability analysis and on the general methodology developed within WP2,
- Specialize the general methodology in order to develop a method to evaluate the systems' behavior in respect to the serviceability level to specific points based on connectivity analysis.
- Treat the multiple existing interdependencies with other lifelines and infrastructures on the basis of the analysis of the "system of systems" proposed in WP2. Adequate interdependency indices between water and waste-water systems and other lifelines (electrical power supply system) will be estimated using different techniques (economic approach, decision making, fuzzy logic or complex approaches).

**Task 5.4** Systemic vulnerability assessment of transportation infrastructures (UROMA, AUTH, NGI, BRGM)

**Sub-Task 5.4.1** Systemic vulnerability assessment of transportation systems (UROMA, AUTH, NGI, BRGM)

- Introduction and improvement of previous work (Franchin et al., 2006)
- Consideration of the increased seismic risk due to the aftershock sequence. To this end input is needed from: a) probabilistic modeling of the aftershock sequence b) fragility curves of bridges for the transition between intermediate damage states (e.g. the probability of a bridge damaged by the main-shock collapsing during an aftershock).
- Evaluation of the traffic flow over the damaged network (switching from a purely connective to a capacitive modeling of the network).
- Integration with vulnerability assessment of building aggregates in order to establish realistic estimates of casualties and injured people that constitute one of the main inputs to the traffic demand evaluation during the emergency phase.
- Integration with the evaluation of the fragility of each of the hospitals in the health-care network in the affected area.
- Development of a seismic risk assessment approach for urban road networks, considering the interactions with collapsed or heavily damaged buildings and other lifelines.

**Sub-Task 5.4.2** Systemic vulnerability assessment and loss of harbor system (AUTH)

- Estimation of adequate interdependency indices between port facilities and other lifelines according to the general methodology developed within WP2, using different techniques (economic approach, decision making, fuzzy logic or complex approaches).
- Estimation of economic losses according to the models developed in WP4.
- Development of "systemic vulnerability" for the complex harbor facility, based on the systems' global performance and level of interdependence.
- Functionality and reliability analysis of each component (based on appropriate system performance criteria) and a simulation framework of the port's operations (input from WP3 and WP4).

**Task 5.5** Systemic vulnerability assessment and loss of critical facilities (UROMA, AUTH)

**Sub-Task 5.5.1** Systemic vulnerability assessment of health-care facilities (UROMA)

- Integration and improvement of previous work Lupoi et al. (2008).
- Development of fragility curves of non-structural elements, such as operating theatres, elevators, etc. as well as those of installation plants (e.g. medical gas supply) based on mechanical models.
- Measuring of system performance, modeling of the human and organizational components to the whole system vulnerability (expert opinion and analytical models).
- Application of the assessment methodology in the evaluation of the performance of the health care system at the regional level, through a close interaction with Task 5.4, since the possibility of redirection to nearby hospitals is conditional on the availability of a functional non-congested route between the

hospitals.

**Sub-Task 5.5.2** Systemic vulnerability assessment of fire fighting system (AUTH)

- Definition of appropriate system performance criteria.
- Definition of seismic vulnerability of the system in relation to the serviceability level of the water supply system (connection with WP2 and Sub-Task 5.3.3).
- Study of interactions with other infrastructures in cases of high danger of fire ignition, and especially with the natural gas system, through the reliability analysis of the fire-fighting system (both in cases of coupled and un-coupled system with the water supply network).

**Role of Participants:**

AUTH (1) will actively contribute to the development of systemic fragility assessment of water and waste-water networks (Sub-Task 5.3.3), harbor system (Sub-Task 5.4.2) and fire fighting system (Sub-Task 5.5.2).

BRGM (3) will play a key role as Leader of WP5.

NGI (5) will contribute with transfer of aggregated knowledge from WP3 to WP5, in particular active contribution to Tasks 5.1 and 5.4.

UPAV (6) will play a supporting role in WP5, systemic vulnerability of buildings and building aggregates.

UROMA (7) will play an active role in WP5 in the particularization of the general methodology to three systems (transportation networks SubTask 5.4.1, electrical power networks SubTask 5.3.1, health-care facilities SubTask 5.5.1)

METU (8) will contribute to the systemic vulnerability and loss assessment of buildings and aggregates (Task 5.2)

AMRA (9) will contribute to the systemic vulnerability assessment and loss of buildings and aggregates (Task 5.2) and actively participate to the systemic vulnerability assessment of gas and oil networks (Task 5.3).

UPAT (11) will contribute to the systemic vulnerability and loss assessment of building aggregates (Task 5.2).

WILLIS (12) will have a supporting role in tasks 5.2 and 5.3, advising on the insurance-related application of systemic vulnerability to urban structures and utilities.

**Deliverables**

D5.1: Systemic vulnerability and loss for building aggregates in urban scale (BRGM, UPAV, UPAT, AMRA, METU, WILLIS, Month 24).

D5.2: Systemic vulnerability and loss for electric power systems (UROMA, Month 24).

D5.3: Systemic vulnerability and loss for gas and oil networks (AMRA, AUTH, BRGM, Month 24).

D5.4: Systemic vulnerability and loss for water and waste-water systems (AUTH, AMRA, Month 24).

D5.5: Systemic vulnerability and loss for transportation systems (UROMA, AUTH, NGI, BRGM, Month 27).

D5.6: Systemic vulnerability and loss for harbors (AUTH, Month 27).

D5.7: Systemic vulnerability and loss for health care facilities (UROMA, Month 27).

D5.8: Systemic vulnerability and loss for fire fighting systems (AUTH, Month 27).

<b>Work package number</b>	6		<b>Start date or starting event</b>	Month 18										
<b>Work package title</b>	Validation studies													
<b>Activity Type</b>	RTD													
<b>Participant number</b>	1	2	3	5	7	9	11	4	6	8	10	12	13	14
<b>Participant short name</b>	AUTH	VCE	BRGM	NGI	UROMA	AMRA	UPAT	JRC	UPAV	METU	KIT-U	WILLIS	UILLINOIS	UKOBE
<b>Person-months per participant</b>	26	12	2	3.5	22	8	8	2	2	2	2	1	1	1

## Objectives

To apply and validate the methodology and the different tools developed in WP2, 3, 4 and 5 in selected test sites:

- in city / urban scale (Thessaloniki-high seismicity, Vienna-low seismicity),
- regional scale (a transportation network in North-Eastern Italy, an electric power transmission network in Central Italy and a gas pipeline network)
- complex systems (the harbor of Thessaloniki and a large hospital facility in Reggio di Calabria, Italy).

## Description of work

### Task 6.1 Application and validation study in the city of Thessaloniki (Greece) (AUTH, UPAT, BRGM)

- Preparation and data setting according to the specifications of the developed tools.
- Application of the developed methods and tools in order to estimate the systemic vulnerability, direct and socio-economic losses of building population and, utility networks, transportation systems of Thessaloniki city.
- Systemic vulnerability analyses for utility, roadway networks and the fire fighting system.
- Connectivity performance of the utility systems, considering the interdependences between networks based on the methodology developed in WP2 and the specifications in WP5.

### Task 6.2 Application and validation study to the city of Vienna (Austria) (VCE, UPAT)

- Preparation and data setting according to the specifications of the developed tools.
- Application of the SYNER-G toolbox to the city of Vienna in order to estimate the expected global risk and social losses for buildings, utility and infrastructure systems considering the interconnections and/or intra-connections between systems.
- Check the applicability and compatibility of the developed methodology and tools in an urban area

### Task 6.3 Application and validation study to a transportation network (Italy) (UROMA, NGI, BRGM)

- Preparation and data setting for the bridges and the traffic flows of the road network across the two regions of Veneto and Trentino.
- Application of the developed tools and methods.
- Connectivity (level I) and flow analyses (level II) under selected scenario earthquakes, with the goals of planning emergency response and identify priorities of retrofit interventions, respectively.

### Task 6.4 Application and validation study to an electric power network (Italy) (UROMA)

- The study will model the high- and medium-tension electric power network in Central Italy, with capacitive network modeling, explicit modeling of the stations logical functioning, capable of insulating short-circuits, as well as the fragility of all electric equipment.
- Monte Carlo simulation will be used to compute the statistics of the network seismic safety, with reasonable computational times, and advanced simulation techniques will be used to evaluate sensitivities of the results with respect to components fragilities.
- A seismic retrofitting procedure will be also set up, with the aim of minimizing upgrading cost over the whole network.

### **Task 6.5 Application and validation study to a gas pipeline network (AMRA, AUTH, NGI, BRGM)**

A pipeline network in Europe, will be used as a case study for the

- Application of the vulnerability and loss assessment methods and tools to a pipeline network in Europe
- Estimation of expected direct damages to all elements of the system, functionality losses and social impact due to disruption of the network considering the interdependencies with other networks.

### **Task 6.6 Application and validation study to a harbor system (Thessaloniki, Greece) (AUTH)**

- Preparation and data setting of the available GIS database of Thessaloniki Harbor
- Application of the developed methods in order to estimate the vulnerability and losses of all infrastructure and systems within the harbor of Thessaloniki for appropriate seismic hazard scenarios.
- Estimation of the socioeconomic impact based on the results of WP4.
- Estimation of the systemic vulnerability of each system and infrastructure considering the interdependences between the different systems based on the results of WP5
- Identification of possible weaknesses and limitations of the tools and methods.

### **Task 6.7 Application and validation study to a hospital facility (Italy) (UROMA)**

- Preparation and data setting of the available data for the main hospital of Reggio di Calabria. Establishment of contacts with the medical staff in order to understand and model the functioning of the hospital system in the aftermath of a major earthquake.
- Application of developed tools and methods. Probabilistic assessment of the seismic performance by comparing the hospital treatment capacity with the corresponding demand.

### **Role of Participants:**

AUTH (1) will play a key role as a leader of WP6 and it will be the main responsible of the application in the Thessaloniki city (Task 6.1) and harbor system in Thessaloniki (Task 6.6).

VCE (2) will actively participate in the validation studies for the city of Vienna (Task 6.2)

BRGM (3) will contribute to the validation of the methodology developed in WP2 and specified in WP5 through the case studies that will be carried out in Tasks 6.1, 6.3 and 6.5.

NGI (5) will contribute to the development of the motorway system case study and exchange of experience with the other case studies.

UROMA (7) will play a key role in WP6 with the development of three validation studies on transportation network (Task 6.3), electrical power networks (Task 6.4) and health-care facilities (Task 6.7) respectively.

AMRA(9) will play a key role in the application and validation study to a gas pipeline network (Task 6.5).

UPAT (11) will contribute to the validation studies in Thessaloniki and Vienna (Task 6.1 and 6.2).

JRC, UPAV, METU, KIT-U, WILLIS, UILLINOIS and UKOBE will also have a supporting role.

### **Deliverables**

D6.1: Application and validation study to the city of Thessaloniki (Greece) (AUTH, UPAT, BRGM, Month 34).

D6.2: Application and validation study to the city of Vienna (Austria) (VCE, UPAT, Month 34).

D6.3: Application and validation study to a motorway system (Italy) (UROMA, NGI, BRGM, Month 34).

D6.4: Application and validation study to an electric power system (Italy) (UROMA, Month 34).

D6.5: Application and validation study to a gas and oil pipeline network (Italy) (AMRA, AUTH, NGI, BRGM, Month 34).

D6.6: Application and validation study to a harbor system (Thessaloniki, Greece) (AUTH, Month 34).

D6.7: Application and validation study to a hospital facility (Italy) (UROMA, Month 34).

D6.8: Pilot studies and application of SYNER-G methodology (AUTH, all, Month 36). (synthetic deliverable)

<b>Work package number</b>	<b>7</b>	<b>Start date or starting event</b>						Month 3	
<b>Work package title</b>	<b>Build prototype software</b>								
<b>Activity Type</b>	RTD								
<b>Participant number</b>	2	1	3	4	6	10	12	13	
<b>Participant short name</b>	VCE	AUTH	BRGM	JRC	UPAV	KIT-U	WILLIS	UILLINOIS	
<b>Person-months per participant</b>	28	4	1	0.5	6	3	3	4	

### Objectives

- To develop a new generation of seismic risk assessment software, based on the results of the development within the work packages 2 till 6. The software aims to allow owners, practicing engineers and researchers the realistic risk assessment and to provide the ability to leverage investment in new methodologies and software infrastructure while enabling customization to local conditions.

- The prototype package will consider the following objectives:

- (1) Intelligent Fragility Curve Archive.
- (2) Code for Routines in System Modelling Simulation and Assessment.
- (3) Development of a Toolbox for Systemic Seismic Vulnerability and a Risk Analysis.
- (4) Web GIS Interface.

### Description of work

#### **Task 7.1 Collection and intelligent management of existing and newly developed fragility functions (VCE, all)**

- Collection and intelligent management of existing and newly developed fragility curves.
- Implementation of the results from the previous work packages.

#### **Task 7.2 Modelling and functional simulation of building, lifelines and infrastructure systems (VCE, all)**

Buildings, lifelines and infrastructure systems will be modelled and functionally simulated. A selection can be made from the fragility curve archive for elements for system assessment. Open source software will be used for implementation like Opensees, and Scilab.

#### **Task 7.3 Compilation of the methodologies and production of toolbox (VCE, all)**

Compilation of the methodologies and collected fragility curves into a toolbox as a useful product for the construction sector (ECTP).

#### **Task 7.4 Geo-referencing and assignment of used surface into a web GIS solution (VCE, all)**

Geo-referencing and assignment of used surface into a web GIS solution based on existing works within the Consortium (Pavia, Thessaloniki and VCE) as well as the open source solutions offered by the American colleagues engaged to collaborate with SYNER-G (MAEviz developed by UIUC, Mr. Elnashai, and Opensees offered by the University of Berkley).

#### **Task 7.5 Indicator Software (KIT-U, VCE)**

- Development of an interactive indicator software system based on "multi-attribute decision theory"
- Evaluation of the sensitivity of the indicator systems based on the Logical Decisions for Windows (LDW) application
- Uncertainty analyses on the input data using Monte Carlo simulations.

#### **Role of Participants:**

AUTH (1) will have a supportive role in building the software (WP7)

VCE (2) will play a key role as a leader of WP7 through conception and design of the prototype, collection of the contributions from other work packages, production of a code for implementation, discussion and coordination of the interfaces between methodologies and approaches.

BRGM (3) will transfer of prototype software developed in WP2 and WP5 for industrial implementation

in WP7.

JRC (4) will play a supportive role for the open source software and development of web GIS.

UROMA (7) will have a supporting role for the open source software and development of web GIS.

KIT-U (10) will contribute to build prototype indicator based software (Task 7.5).

WILLIS (12) will have a supporting role, possibly provide testing resources (user tests) for beta software (WP7), subject to this being appropriate to Willis' business approach and industry practice.

UILLINOIS (13) will offer the considerable experience in developing its open source, cyberinfrastructure-enabled system MAEviz in providing software architecture and advice on the best open source platforms to use and what worked and what did not work. Also, compare the developed software with MAEviz as a stable leading edge earthquake impact software system.

### **Deliverables**

SYNER-G will take an open source approach based on pre-existing works in Europe and overseas under the consideration of risk based management. The deliverables will be an open source application and environment for loss assessment that is designed to be extended to meet the evolving needs of the earthquake engineering community.

The deliverables form partial elaborations of the SYNER-G toolbox. They will be developed following the progress of the development of the methodology.

D7.1: Functional fragility curve archive (VCE, all, Month 24)

D7.2: Code for the SYNER-G methodology (VCE, Month 30)

D7.3: SYNER G toolbox (VCE, Month 36)

D7.4: Web GIS interface (VCE, Month 12)

D7.5: Indicator software (KIT-U, VCE, Month 24)

D7.6: SYNERG-G tool-box and web portal (VCE, all, Month 36) (synthetic deliverable)

<b>Work package number</b>	8		<b>Start date or starting event</b>					Month 1				
<b>Work package title</b>	<b>Guidelines, recommendations and dissemination</b>											
<b>Activity Type</b>	OTH											
<b>Participant number</b>	4	1	2	3	5	6	7	8	9	10	11	12
<b>Participant short name</b>	JRC	AUTH	VCE	BRGM	NGI	UPAV	UROMA	METU	AMRA	KIT-U	UPAT	WILLIS
<b>Person-months per participant</b>	1.5	4	1	2	1	8	2	4	2	2	1	2

## Objectives

(i) Preparation of technical guidelines and recommendations in the form of European Reference Reports concerning the fragility and loss assessment of individual elements at risk (buildings, utility and transportation network components, critical facilities) and the systemic vulnerability and losses of the entire networks and of system of networks (in city and regional scale) considering inter-element and intra-systems interactions.

(ii) Development and implementation of a dissemination plan for the output from the project, which encompasses: (1) Knowledge (new methodology for systemic vulnerability assessment); (2) Products from Research (Prototype software for systemic vulnerability analysis and loss estimation, Classification of European physical assets and Guidelines for further development and deployment) and Demonstration activities, and (3) Involvement of Stakeholders and User Communities (ranging from European to Local Authorities, Technical and Scientific Communities). Special attention deserves exploitation of the Prototype software to be developed during the project.

## Description of work

### Task 8.1 Writing, review and production of (7) European reference reports, considered as guidelines and recommendations for Europe (JRC, all)

**Sub task 8.1.1** Consolidated list of the SYNER-G reference reports (titles, editors, reviewers, addresses, publisher) (JRC, UPAV, AUTH, VCE).

- Set-up of a final list of the reference reports. Agreement on the process of writing (including the template) and production of the reports, as well as on the final list of editors, reviewers and publisher.

**Sub task 8.1.2** Guidelines for editors, reviewers and production (JRC)

- Issuing of the guidelines for writing, reviewing and production of the SYNER-G Reference Reports.

**Sub task 8.1.3** Drafting of version 1 of the reference reports (structure, contents, contributors, etc) (reference report editors and contributors, JRC)

- Editors will provide a version 1 of the reports, specifying their structure, contents, and contributor partners.

**Sub task 8.1.4** Production of the final version of the reference reports (ready for printing) (reference report editors, contributors and reviewers, JRC)

- The final version of the reports will be produced by the contributor partners identified in Task 8.3 under the leadership of the editors. The reports will be ready for printing only after the review process is completed.

**Sub task 8.1.5** Printing of the reference reports (JRC)

- Production and printing of the reports is foreseen towards the end of the project, in order to have them available at the final workshop.

**Sub task 8.1.6** Distribution of the reference reports (JRC)

- The reports will be distributed to members of the scientific community, public administration and policy makers identified in Sub-Task 8.2.4.

### Task 8.2 Dissemination schemes for all products and tools (JRC, all)

**Sub task 8.2.1** Development of communication, awareness and dissemination material and tools (VCE, JRC, AUTH, UPAV).

- Development of the project web server (website, document archive and exchange platform with public, restricted parts)
- Project leaflet
- Project presentation
- Project Newsletters.

**Sub task 8.2.2** Organization of project workshops (JRC, VCE, AUTH)

- Two technical workshops in the cities chosen for pilot applications, namely: Vienna (AT) and Thessaloniki (GR)
- Organization of the final international workshop involving potential end-users and stakeholders and contributions from 3<sup>rd</sup> countries (USA, Japan, China, etc.)

**Sub task 8.2.3** Other awareness and dissemination activities (JRC, VCE, AUTH, all)

- Development of appropriate awareness material for the project products, such as booklets, leaflets and multi-media
- Participation in key international events related to the project, namely the European Conference on Earthquake Engineering (Skopje, FYROM, 2010) and the World Conference on Earthquake Engineering (Lisbon, PT, 2012)
- Publication of scientific results in peer reviewed journals and magazines
- Production of a high-quality brochure, describing the main project products and the key results of the applications to the two European urban, infrastructure and network sites.

**Sub task 8.2.4** Involvement of potential users to achieve utilization (JRC, VCE, all)

- Identification of stakeholders and potential end-users of the project knowledge and products, namely the scientific and technical communities, national authorities, civil protection agencies, industry (insurance and re-insurance companies), relevant European technology platforms and European associations and federations for infrastructures and networks
- Collection and analysis of feedback from key events (questionnaire) for up-dating the implementation plan and set-up an effective exploitation plan.

**Sub task 8.2.5** Development of detailed dissemination and exploitation plans (JRC, VCE, AUTH)

- Development of a detailed implementation plan for dissemination, which will be updated regularly and will constitute the basis of the project exploitation plan to be ready at the end of the project.

**Role of Participants:**

All partners will contribute to the setup of guidelines and recommendations for Europe (Task 8.1) and the preparation and implementation of dissemination actions (Task 8.2).

AUTH (1) will actively participate in the setup of guidelines and recommendations for Europe (Task 8.1) and the preparation and implementation of dissemination actions (Task 8.2).

VCE (2) will actively participate in public dissemination campaigns and preparation of guidelines and recommendations (WP8).

JRC (4) will play a key role as a leader of WP8

NGI (5) will actively participate in the SYNER-G dissemination activities

UPAV (6) will have an active role through contribution to guidelines, development of web server and preparation of dissemination material.

UPAT (11) will support the preparation of guidelines and recommendations (Task 8.1) and the dissemination actions (Task 8.2).

WILLIS (12) will contribute to financial services industry focus for WP8 in the drafting of appropriate guidelines for EU. As a supporting member, provide appropriate insurance industry participation in knowledge transfer events.

## Deliverables

- D8.1: Web portal structure and implementation of the part concerned with general information on the project (VCE, JRC, AUTH, UPAV, Month 3).
- D8.2: Project newsletter issue 1, issue 2 and issue 3 (VCE, JRC, AUTH, UPAV, Month 3, Month 15, Month 27).
- D8.3: Project leaflet and project presentation (slides set) (VCE, JRC, AUTH, UPAV, Month 3).
- D8.4: Final plan for the use and dissemination of foreground (implementation details, including dates, and location of project events, etc) (VCE, JRC, AUTH, UPAV, Month 12).
- D8.5: Consolidated program for the production of the SYNER-G reference reports (JRC, Month 12).
- D8.6: Guidelines for editors, reviewers and production of the SYNER-G reference reports (JRC, Month 12).
- D8.7: Report 1: Methodology for systemic seismic vulnerability assessment of buildings, infrastructures, networks and socio-economical impacts (UPAV, UROMA, KIT-U, NGI, AMRA, WILLIS, AUTH, BRGM, METU, JRC, Month 34).
- D8.8: Report 2: Guidelines for typology definition of European physical assets for earthquake risk assessment (JRC, AUTH, UPAV, NGI, BRGM, Month 34).
- D8.9: Report 3: Remote sensing and integration of secondary data sources for earthquake loss estimation (UPAV, BRGM, KIT-U, JRC, WILLIS, Month 34).
- D8.10: Report 4: Guidelines for deriving fragility functions of elements at risk: buildings, lifelines, transportation networks and critical facilities (NGI, AUTH, BRGM, JRC, UPAV, UROMA, METU, KIT-U, UPAT, WILLIS, Month 34).
- D8.11: Report 5: Guidelines for the consideration of socio-economic impacts (KIT-U, JRC, NGI, METU, AMRA, WILLIS, Month 34).
- D8.12: Report 6: Systemic seismic vulnerability and loss assessment: Validation studies (AUTH, VCE, BRGM, JRC, NGI, UROMA, UPAT, Month 34).
- D8.13: Report 7: Systemic seismic vulnerability and loss assessment: Software users manual (VCE, AUTH, BRGM, JRC, UPAV, KIT-U, WILLIS, Month 34).
- D8.14: Technical workshops conclusions and recommendations (JRC, VCE, AUTH, Month 36).
- D8.15: Final workshop conclusions and recommendations (JRC, VCE, AUTH, Month 36).
- D8.16: Exploitation plan (JRC, VCE, AUTH, Month 36).
- D8.17: High-quality brochure, describing the main project products and the key results of the applications to the two European urban, infrastructure and network sites (JRC, Month 36).
- D8.18: Brochures, guidelines, manuals for dissemination purposes (JRC, all, Month 36). (synthetic deliverable)
- D8.19: Awareness and wider societal implications (JRC, all, Month 36).
- D8.20: SYNER-G synthetic document extracted from D2.17, D3.12, D6.8, D7.6, D8.18 and Vision Paper (AUTH, all, Month 36). (synthetic deliverable)

### 1.3.6 Efforts of the full duration of the project (given in man-months)

Project number (acronym): **SYNER-G (244061)**

**Table 4** Summary of staff effort list.

#### Project Effort Form 1 – Indicative efforts per beneficiary per WP

Beneficiary no./short name	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	TOTAL per beneficiary
1. AUTH	24	12	16	0	20	26	4	4	106
2. VCE	10	3	3	0	0	12	28	1	57
3. BRGM	0	7	8	0	15	2	1	2	35
4. JRC	0	13.5	11	0	0	2	0.5	1.5	28.5
5. NGI	0	3	7	3	3.5	3.5	0	1	21
6. UPAV	0	35	25	0	5	2	6	8	81
7. UROMA	0	18	6	0	18	22	0	2	66
8. METU	0	8	16	6	10	2	0	4	46
9. AMRA	0	14	0	8	16	8	0	2	48
10. KIT-U	0	5	0	21	0	2	3	2	33
11. UPAT	0	1	34	0	1	8	0	1	45
12. WILLIS	0	2	2	3	3	1	3	2	16
13. UILLINOIS	0	0	7	4	0	1	4	0	16
14. UKOBE	0	8	7	0	0	1	0	0	16
<b>Total</b>	<b>34</b>	<b>129.5</b>	<b>142</b>	<b>45</b>	<b>91.5</b>	<b>92.5</b>	<b>49.5</b>	<b>30.5</b>	<b>614.5</b>

#### Project Effort Form 2 – Indicative efforts per activity type per participant

Activity Type	AUTH	VCE	BRGM	JRC	NGI	UPAV	UROMA	METU	AMRA	KIT-U	UPAT	WILLIS	UILLINOIS	UKOBE
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RTD/Innovation Activities														
WP2	12	3	7	13.5	3	35	18	8	14	5	1	2	0	8
WP3	16	3	8	11	7	25	6	16	0	0	34	2	7	7
WP4	0	0	0	0	3	0	0	6	8	21	0	3	4	0
WP5	20	0	15	0	3.5	5	18	10	16	0	1	3	0	0
WP6	26	12	2	2	3.5	2	22	2	8	2	8	1	1	1
WP7	4	28	1	0.5	0	6	0	0	0	3	0	3	4	0
<b>Total 'research'</b>	<b>78</b>	<b>46</b>	<b>33</b>	<b>27</b>	<b>20</b>	<b>73</b>	<b>64</b>	<b>42</b>	<b>46</b>	<b>31</b>	<b>44</b>	<b>14</b>	<b>16</b>	<b>16</b>

Demonstration Activities														
<b>Total 'demonstration'</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>

Consortium Activities														
WP1	24	10	0	0	0	0	0	0	0	0	0	0	0	0
<b>Total 'management'</b>	<b>24</b>	<b>10</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>

Other activities														
WP8	4	1	1	1.5	1	8	2	4	2	2	1	2	0	0
<b>Total 'other'</b>	<b>4</b>	<b>1</b>	<b>2</b>	<b>1.5</b>	<b>1</b>	<b>8</b>	<b>2</b>	<b>4</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>0</b>	<b>0</b>

<b>TOTAL BENEFICIARIES</b>	<b>106</b>	<b>57</b>	<b>35</b>	<b>28.5</b>	<b>21</b>	<b>81</b>	<b>66</b>	<b>46</b>	<b>48</b>	<b>33</b>	<b>45</b>	<b>16</b>	<b>16</b>	<b>16</b>
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### 1.3.7 List of milestones and planning of reviews

List and schedule of milestones					
Milestone no.	Milestone name	Work package (s) involved	Lead beneficiary	Delivery date from Annex I	Comments
1	Kick-off meeting: project and research management, knowledge management	All	AUTH	1	Concretization and establishment of project, research and knowledge management. Finalization of the organizational structure and the ground rules for the cooperative research, review and agree on extent and deadlines for deliverables, key technical personnel responsible for work packages and work tasks and finalizations of details around milestones, deliverables and management reviews. Report, Consortium Agreement.
2	SYNER-G Web portal	1	VCE	3	Communication and exchange of information in all parts of the project. The portal will provide access to several user categories (beneficiaries, public).
3	Project newsletter issue 1 and project leaflet and presentation	8	VCE, JRC	3	Development of communication, awareness and dissemination material and tools
4	1 <sup>st</sup> Work progress control	1	AUTH, VCE	6	Internal review, technical and scientific assessment
5	2 <sup>nd</sup> Work progress control	1	AUTH, VCE	12	Report on progress until month 12 Internal review
6	Kick of meeting on WP5	5	BRGM	12	Work plan of WP5 (systemic vulnerability). Connection with WP2, 3 and 4.
7	Project newsletter issue 2	8	VCE, JRC	15	Development of communication, awareness and dissemination material
8	Methodology for assessing vulnerability at system level	2	UPAV	18	Report: Review of current state of the art, understanding of systemic vulnerability and development of a general methodology.
9	Fragility functions for all elements at risk and all systems in the European context	3	NGI	18	Reports: Review of existing fragility curves, homogenization and adaptation or improvement considering the distinctive European features
10	Seismic socio-economic loss for European distinctive feature	4	KIT-U	18	Reports: Indicator system for the socio economic losses assessment of buildings, utilities, critical facilities and infrastructures
11	1st Financial control	1	VCE	18	Cost statements Month 18
12	1 <sup>st</sup> review	1	AUTH, VCE	18	Evaluation of external reviewers (IAC)
13	Systemic analysis of the vulnerability and loss for urban building aggregates	5	BRGM	24	Report: Incorporation of WP2, 3 and 4 outcomes into an integrated approach for the systemic vulnerability assessment of urban building aggregates
14	Systemic analysis of the vulnerability and loss for utility systems	5	BRGM	24	Report: Incorporation of WP2, 3 and 4 outcomes into an integrated approach for the systemic vulnerability assessment of utility systems
15	3 <sup>rd</sup> Work progress control	1	AUTH, VCE	24	Report on progress until month 24 Internal review
16	Systemic analysis of the vulnerability and loss for	5	BRGM	27	Reports: Incorporation of WP2, 3 and 4 outcomes into an integrated approach for the

	transportation systems				systemic vulnerability assessment of transportation systems.
17	Systemic analysis of the vulnerability and loss for critical facilities	5	BRGM	27	Reports: Incorporation of WP2, 3 and 4 outcomes into an integrated approach for the systemic vulnerability assessment of critical facilities.
18	Project newsletter issue 3	8	VCE, JRC	27	Development of communication, awareness and dissemination material.
19	4 <sup>th</sup> Work progress control	1	AUTH, VCE	30	Internal review, technical and scientific assessment
20	Applications and validation of the methodology and tools	6	AUTH	34	Verify how the systemic vulnerability assessment approach can be applied at the selected case studies. Measure the efficiency of SYNER-G methodology and software tools.
21	Reference reports	8	JRC	34	Technical guidelines and recommendations in the form of 7 European Reference Reports concerning the fragility and loss assessment of individual elements at risk and the systemic vulnerability and losses of the entire networks and of system of networks
22	Prototype software tool for the systemic vulnerability assessment and loss estimation	7	VCE	36	Software released and validated by a user group
23	Dissemination material of all products and tools	8	JRC	36	Reports, high-quality brochure, scientific papers
24	Technical workshop A	8	AUTH	36	SYNER-G presentation and application in Thessaloniki
25	Technical workshop B	8	VCE	36	SYNER-G presentation and application in Vienna
26	Final international workshop	8	JRC	36	General presentation of SYNER-G and discussion with IAC and stake holders
27	2 <sup>nd</sup> review	1	AUTH, VCE	36	Report on progress until month 36 Evaluation of external reviewers (IAC)
28	2 <sup>nd</sup> Financial control	1	VCE	36	Cost statement Month 36
29	SYNER-G Web portal	8	VCE	36	The public pages will provide information, data and deliverables of the project according to the dissemination plan.

**Table 6** Tentative schedule of project reviews.

<b>Tentative schedule of project reviews</b>			
<b>Review no.</b>	<b>Tentative timing, i.e. after Month X = end of a reporting period</b>	<b>planned venue of review</b>	<b>Comments , if any</b>
<b>Internal 1</b>	After project month: 12	Meeting	Internal review of progress until month 12, technical and scientific assessment
<b>Formal 1</b>	After project month: 18	Meeting	Report on progress until month 18 Evaluation of external reviewers (IAC)
<b>Internal 2</b>	After project month: 24	Meeting	Internal review of progress until month 24, technical and scientific assessment
<b>Formal 2</b>	After project month: 36	Meeting	Report on progress until month 36 Evaluation of external reviewers (IAC)

### **1.3.8 Forms of measurement and verification**

Forms of measurement will be established to control the above milestones and the actions prioritized to meet the project's objectives and to ensure completion of the deliverables. A detailed description will be made in the "Measurement and Verification Plan", which will be one of the outcomes of the kick-off meeting and which will follow the EC rules. The plan will contain all technical and administrative elements as well as all the details of project management practice, from task description and evaluation principles and methodologies to deadlines and documentation. The project participants have prioritized 29 milestones and 4 review meetings. The measurement and verification process will monitor the progress and fulfillment of these milestones and meetings. The verification of progress will be done at project plenary meetings, and if necessary between plenary meetings among partners within each work package.

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