MATRIX

New Multi-Hazard and Multi-Risk Assessment Methods for Europe

MATRIX Reference Reports

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Preface

The *Multi-HAzard and MulTi-RIsK Assessment MethodS for Europe* or *MATRIX* project (01.10.2010 to 31.12.2013), coordinated by the GFZ, set out to tackle some of the issues associated with multi-hazard and risk assessment. Disaster risk reduction (DDR) activities generally treat different natural hazards and their associated risks separately within what may be termed a "single-type" approach. However, this ignores the spatial and temporal interactions that often arise along the disaster risk chain. For instance, one hazardous event may trigger others, e.g., earthquakes causing tsunamis, or several different types may occur concurrently, e.g., severe weather and earthquakes. Considering vulnerability, an initial event would leave a community more susceptible to future, possibly different, hazards, e.g., an earthquake weakening buildings which are damaged further by windstorms. The temporal dimension may include changes in exposure, e.g., increased urbanisation, altering the total risk to an area, while repeated events lessen a community's resilience. Meanwhile, although losses are estimated by usually only considering direct economic losses or casualties, this ignores less tangible losses such as reduced business activity or the loss of cultural heritage. In short, the total risk estimated when incorporating interactions between multiple hazards and risks is likely to be greater than the sum of the individual parts.

Hence, for a more comprehensive risk assessment paradigm, these, and other, interactions need to be considered. Therefore, MATRIX set out to develop concepts, methods, frameworks and tools for dealing with risk assessment within a multi-hazard and risk environment. The focus was on the hazards that most affect Europe, namely earthquakes, landslides, volcanos, tsunamis, wild fires, storms and fluvial and coastal flooding. Interactions at all the different levels were considered, such as cascading events and time dependency in vulnerability. The resulting products were applied at three test cases: Naples, Italy, the French West Indies, and Cologne, Germany. Considerable interaction with end-users was also undertaken, including identifying biases at the individual and institutional level which may hinder employing a multi-type framework for risk governance.

This Scientific Technical Report presents two so-called "Reference reports" produced during the MATRIX project. These reports were provided to the European Commission as deliverables, namely D8.4 "MATRIX Results I and Reference Report" and D8.5 "MATRIX Results II and Reference Report". D8.4 presented a series of specific reports outlining the results of the project, written in a manner accessible not only to the specialist but with a broader audience in mind. D8.5 deals with the risk governance within a multi-hazard and risk context and has since been published. We therefore divide with document in two, where part 1 represented the outcomes presented in D8.4 while D8.5 forms part 2.

We believe the MATRIX project was a very important step towards the goal of establishing the multi-hazard and risk environment as the norm within a European context, and we hope that the reader will benefit from the results presented here.

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PART 1 - Deliverable D8.4 “MATRIX Results I and Reference Report”

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Introduction

“The New Multi-HAzard and MulTi-RIsK Assessment MethodS for Europe” or MATRIX project is by definition a multi-disciplinary program, whose results and outcomes, again by default, cross many boundaries in terms of their relevance. Natural disasters by their very nature show no regard for national, social or economic borders, and therefore efforts to mitigate against their negative consequences need to include the ability to communicate the findings of projects such as MATRIX to the broadest possible cross-section of the community. This not only includes other research scientists and engineers, but also civil protection authorities, decision and policy makers, as well as the general public.

It is for this reason that this deliverable, D8.4 “MATRIX results I and reference report”, has been produced. In it are relatively short, but specific descriptions of some of the outcomes of the MATRIX project, presented in a manner that would appeal to a wide audience. While these reports generally follow the themes pursued in the work packages into which MATRIX was organized, some effort has been expended in showing how the results from the different work packages relate to each other.

The first report by Parolai et al. details the importance of harmonizing single-type risk assessments, in terms of presenting the risk arising from different hazards in a consistent and comparable form. This is followed by Garcia-Aristizabal et al., who outline the various cascading scenarios that have been identified for the MATRIX test cases. Desramaut et al. next present their assessment of the temporal variations of vulnerability from a systems point of view for the case of Guadeloupe, French West Indies, one of the MATRIX test sites. A multi-level multi-risk framework developed within MATRIX is then described by Nadim et al. The MATRIX-CITY tool and Virtual City concept developed within the project is summarized by Mignan, while Komendantova et al. provide an outline of their results dealing with the multi-risk assessment tools and the response of end-users. A preliminary application of the framework developed by Nadim et al. to the MATRIX test cases is outlined by Fleming et al., with this document concluding with a discussion of the issue of multi-risk and governance provided by Scolobig et al.

We believe the variety of reports presented in this document, while by no means exhausting the outcomes of the MATRIX project, nonetheless provides a sound overview of the project’s achievements, allowing the reader (be they researchers, practitioners, or the public) to gain some understanding of the challenges involved in, and need for, a multi-risk approach. The MATRIX consortium is under no delusion that much work is still required, but we are confident that a multi-hazard and risk approach will be of fundamental value to future efforts in disaster risk reduction, especially within the context of the post-Hyogo Framework for Action era.

Comparing and harmonizing single-type risks.

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Introduction

Although the MATRIX project has as its primary concern the interactions between hazards and their associated risks, and how this impacts upon all manner of potential losses, this by no means is meant to replace the assessment of single-type risks. In fact, the project has been at pains to point this out, even while endeavouring to convince various members of the disaster risk reduction community of the necessity for a multi-type approach. For example, following an expert meeting conducted by the European Commission Directorate-General Humanitarian and Civil Protection (ECHO) on risk assessment and mapping for disaster management (Brussels, July 2011) where MATRIX was represented, while the project presentation was well received, one participant commented “I would be happy if I could manage a simple risk assessment. Multi-risk is far away from the reality on the ground.”

Hence, considerable efforts within MATRIX were spent in better understanding the means by which different hazards and risks can be presented in a harmonized and comparable manner, including how individual risks can be combined, and how the associated uncertainties should be presented. Such ability is essential in that it allows a means of comparing the relative importance of different hazards and risks in order to assist decision makers in their prioritizing of mitigation activities.

Risk metrics and scale factors

The first question is therefore what should be employed as the most appropriate risk metric (a matter of “comparing apples with apples”), which would allow the losses from different types of disaster to be meaningfully compared. For example, considering Germany, although the summer 2003 heat wave resulted in the highest number of deaths from an extreme natural event for the period 1980-2010 (9,355 people), the associated economic losses were relatively low (1.65 billion Euros) compared to the floods of 2002 (11.6 billion Euros) which caused the deaths of 27 people[1].

Another problem concerns the spatial and/or temporal scales being dealt with, each of which is, naturally, a function of the hazard in question. Considering spatial scales, different hazards have their own spatial pattern, for example, direct losses from floods are only of a concern to lower-lying areas close to water bodies, and so a flood may be rather localised. By contrast, a major earthquake will affect a much wider area, although again, depending upon geological conditions, there may be considerable spatial variability in the resulting ground shaking (e.g., Parolai et al., 2007).

Similarly for temporal scales, some hazards display a more obvious degree of regularity, such as seasonal winter storms or hurricanes, while others must be considered over much longer time periods, for example, earthquakes and volcanos. The problem, however, is that historical records may not be adequate to gain a proper understanding of what is to be expected over a given time period, let alone potential extreme events. This may lead to the problem where more familiar events (e.g., hurricanes) are seriously considered, while rarer ones (e.g., earthquakes) are neglected, as was the case of older buildings in Kobe, Japan, whose heavy roofs were suitable for seasonal typhoons, but not for rare earthquakes (Otani, 1999).

It was therefore decided within the MATRIX project to generally concentrate on direct losses arising from direct damage to residential buildings over annual time scales and urban spatial scales. The estimated losses or risk curves will then (usually) be expressed in the form of expected loss per annum (in Euros) versus probability. However, alternate means of presenting risk will be mentioned below.

Combining and comparing risks

In the following we call upon the example of Cologne, Germany (see MATRIX deliverables D2.3, Parolai et al., 2014, and D7.5, Fleming et al., 2014) to show how the risk arising from different hazards can be combined and compared. Considering first the risk curves derived for Cologne by Grünthal et al. (2006), who did not take into account potential interactions, we can obtain some idea of what the total risk may be due to several different hazards by employing the following simple formulation:

[1] http://www.preventionweb.net/english/countries/statistics/?cid=66

$$P_{tot} = 1 - \prod (1 - P_i) \qquad (1)$$

where P_{tot} is the total annual probability of exceedance of a given risk (expressed as Euros), and P_i is the probability of exceedance of a given risk i (i.e., here represented by earthquakes, landslides and floods). The original three curves of Grünthal et al. (2006), along with the various combinations, are presented in Figure 1 (note, because of limitations in the original results, we cannot combine these risks for the entire range of losses covered).

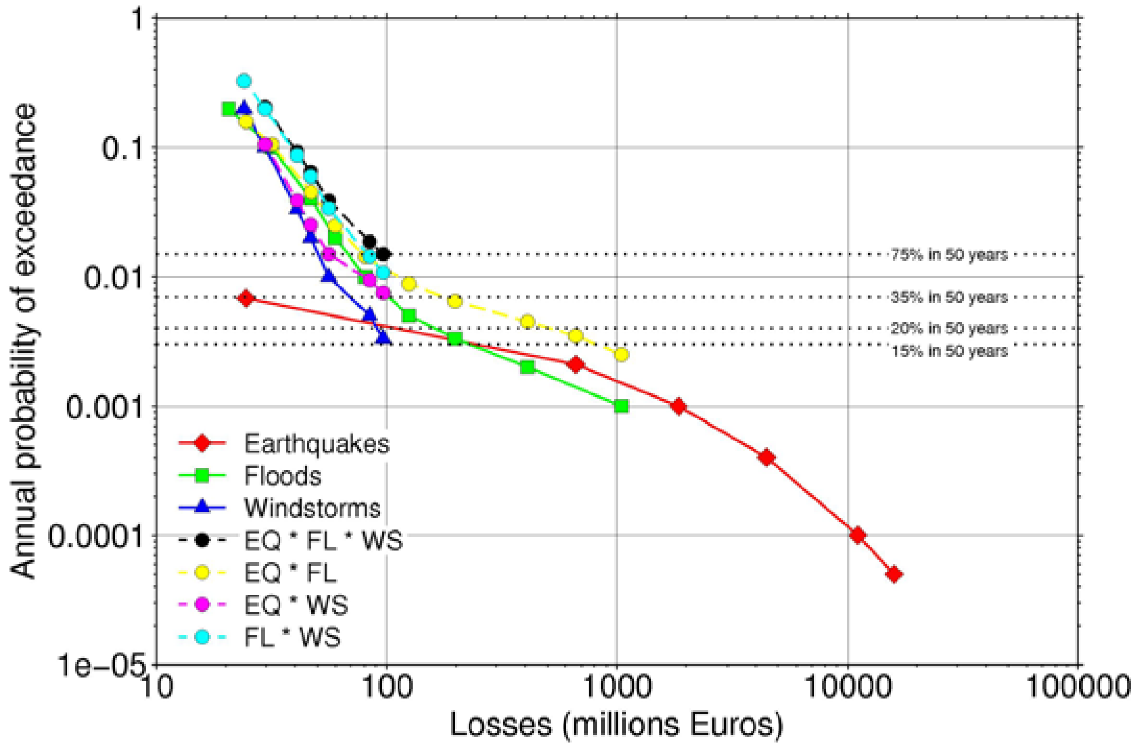

Figure 1: The individual risk curves for the three main hazards (earthquakes – EQ, floods – FL, windstorms – WS) that affect Cologne and their various combinations derived using equation 1.

We note that for the loss range over which all hazards have results, the resulting combination of the three curves differs little from combining only flood and windstorm (the dominate risks for higher probability/lower loss events). However, if we were to consider, for example, all risk-types where losses are of the order of 100 million Euros, we see that the combination of curves will significantly increase the probability of such a level of loss, from 15 to 35% in 50 years for the individual hazards, to around 75% in 50 years when combined.

Another way in which such changes in risk may be presented is by a risk matrix[2]. In fact, as commented upon in Komendantova et al., (2014), end-users tend to prefer such a format as

[2] This matrix follows approximately that employed by the German Federal Office of Civil Protection and Disaster Assistance (BBK, http://www.bbk.bund.de/). See also "Risk Mapping and Assessment Guidelines for Disaster Management", SEC(2010), Brussels, 21.12.2010, European Commission.

opposed to risk curves. Figure 2 shows an example of a risk matrix for Cologne using examples of the risk arising from the three hazards shown in Figure 1. Included is the summation of the three risks that give an approximate loss of 100 million Euros. These examples are outlined by the ellipse, where the result of combining the windstorm (triangle), earthquake (diamond) and flood (square) is shown by the circle. One can see how the total risk has increased by its movement towards the right, in the case of this figure, moving from “Quite likely” to “Likely”. While it must be kept in mind that this figure is only intended for illustrative purposes, one can imagine, based on expert opinion, how the relative distribution of the risks (i.e., the colour scheme) could be altered to better reflect the case at hand.

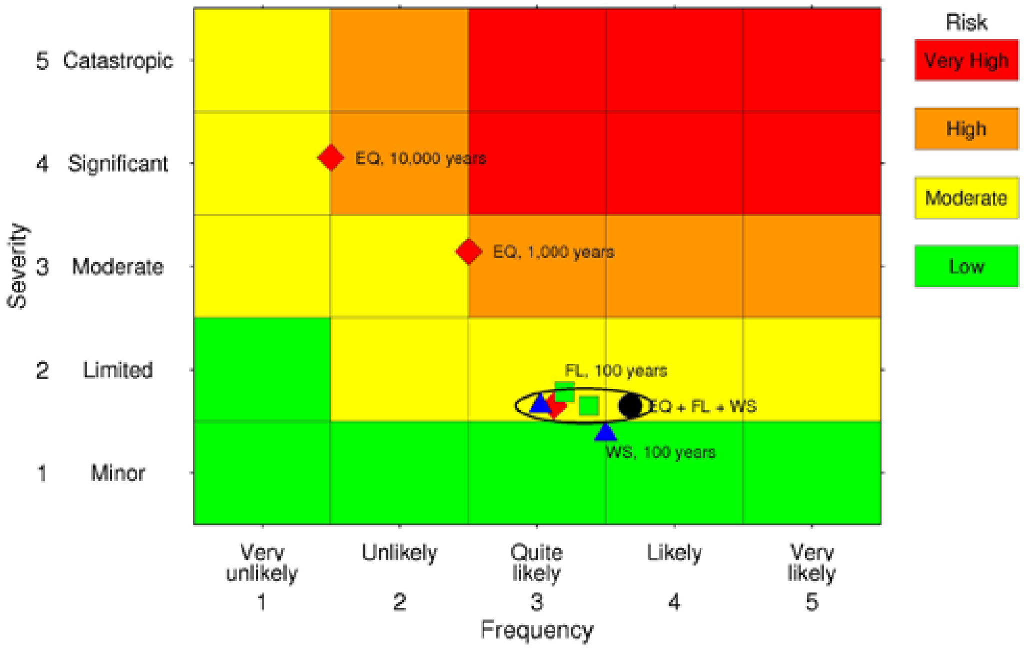

Figure 2: Risk matrix showing how combining the risk associated with individual risks (EQ – earthquake, FL – flood, WS – windstorm, see area) can lead to a significant increase in overall risk. The risk estimates discussed in the text (corresponding to losses of ca. 100 million Euros) are outlined by the ellipse. Note, we divided the loss and probability ranges in Figure 1 into 5 and allocated the frequency and severity accordingly, while the colour scheme employed is purely illustrative and would require expert judgement to properly be assigned.

Next we compare for specific return periods the range of results for each risk type newly calculated for the Cologne test case. For the seismic risk, this involved a logic tree approach that considers a range of hazard input parameters and damage and vulnerability models, resulting in 180 estimates per return period (Tyagunov et al., 2013). The flood estimates employed a hybrid probabilistic-deterministic coupled dyke breach/hydrodynamic model (IHAM, Vorogushyn et al., 2010), run in a Monte Carlo simulation. The windstorm risk was found using the Vienna Enhanced Resolution Analysis or VERA tool (Steinacker et al., 2006) and the building damage estimation method of Heneka and Ruck (2008). All three employed the same metric (direct damage, residential buildings) and total costs (see D7.5 details).

Again, we employ a simple means of determining if the risk arising from two independent hazards for specific return periods are the same. This involves the Wilcoxon's test, a distribution free ranking test that asks the specific question "Are the medians of the two distributions the same?" (Barlow, 1989). We compare a range of values for each pair of hazards (earthquake – flood, earthquake – windstorm, flood – windstorm) and apply a null hypothesis (to 0.05) that the question's answer is in the affirmative. The test involves taking 20 random samples from each pair of distributions, applying the Wilcoxon's test, and doing so 10000 times. This is to reduce the consequence of situations where the random selections of samples are clustered in some way. The return periods we examine are 200, 500 and 1000 years for comparing earthquakes and floods, and 200 and 500 years for floods and windstorms, and windstorms and earthquakes (Figure 3).

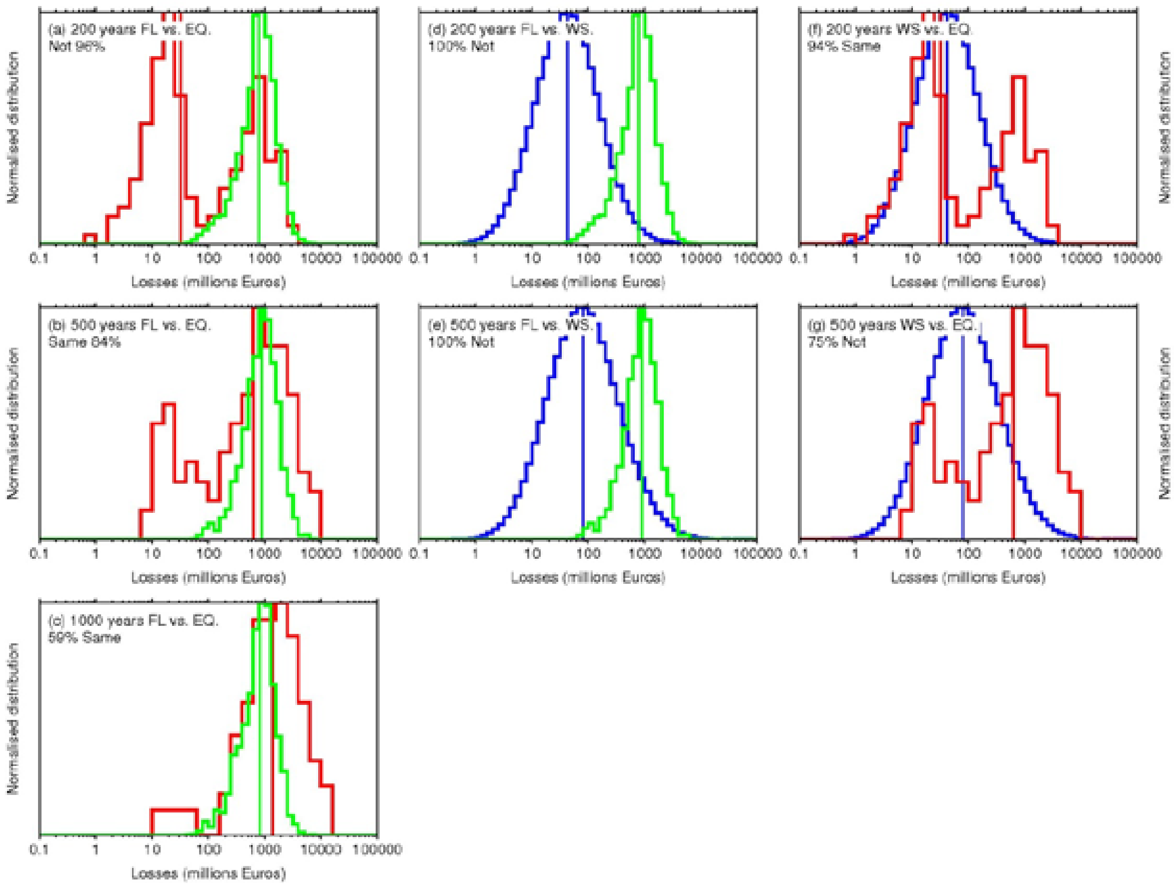

Figure 3: Comparing the distribution of results for each pair of risks. (a-c) Floods (green, FL) and earthquakes (red, EQ) for (a) 200, (b) 500 and (c) 1000 years return periods, (d-e) floods and windstorms (blue, WS) for (d) 200 and (e) 500 years, (f-g) windstorms and earthquakes for (f) 200 and (g) 500 years. The vertical lines of the same colours are the respective medians.

Considering first the earthquake distribution, we see that its bimodal character (a product largely of the choice of the ground motion predictive equations, see D7.5) immediately adds an additional element of uncertainty as to whether the risks it is compared to are equivalent. Considering the results of the Wilcoxon's test, we note for the 200 year return period (Figure 3a) that earthquakes and floods are not equivalent (in contrast to Grünthal et al., 2006, where they appear very similar), but can be considered comparable for 500 years (Figure 3b, in agreement with Grünthal et al., 2006), although for 1000 years (Figure 3c), a definitive comment cannot be made. For the windstorms and floods (Figure 3d-e), for both the 200 (Figure 3d) and 500 (Figure 3e) years return periods, it is obvious (even without applying this test) that windstorms and floods are not equivalent, with floods being of greater concern in both cases. Finally, for earthquakes and windstorms (Figure 3f-g), for 200 year return period (Figure 3f), these appear to be of equivalent importance, while for 500 years (Figure 3g), this does not appear to be the case (with earthquakes of greater importance), in both cases consistent with Grünthal et al. (2006).

Closing comments

We have presented here for the case of Cologne simple methods for combining risk curves, along with a means of graphically showing (risk matrix) how total risk changes as one combines the individual components. Such a presentation scheme is useful in showing how risk changes when interactions are considered (as shown by Mignan in this document[3]. We also examined a means of seeing if a pair of risks is equivalent to one another when considering a range of plausible values for a given return period. The relevance of such an exercise is to do with the decision making process, whereby if the risk associated with two types of hazard is "equivalent", then the required mitigation schemes may need to consider both, or at least help decision makers when deciding on how to allocate resources. For example, while for 200 years return periods, earthquakes and windstorms appear to be equivalent, one would imagine that implementing mitigation actions for earthquake would be much more expensive than those for windstorms. It also shows that one needs to accommodate uncertainties, since simply using, for example, average curves, may yield misleading conclusions about the relative importance of a given combination of hazard types. However, it is also important to note that the actual results would vary as the range of employed input models and parameters are updated and refined (as would be apparent in the earthquake case).

[3] Mignan, A. MATRIX Common IT sYstem (MATRIX CITY) Generic multi-hazard and multi-risk framework - the concept of Virtual City - IT considerations, this document.

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Identifying and structuring scenarios of cascade events in the MATRIX project

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Introduction

The core of the probabilistic assessment of cascading effects within a multi-hazard problem consists of identifying the possible interactions that are likely to happen and that may result in an amplification of the expected damages within a given area of interest. After a detailed review of the state of the art in multi-hazard assessment (MATRIX deliverable D3.1, Garcia-Aristizabal et al., 2013a) and an exercise in defining the cascading effect scenarios of interest for the test cities of the MATRIX project (MATRIX deliverable D3.3, Garcia-Aristizabal et al., 2013b), we have developed a procedure for classifying the main kinds of interactions that can be considered for the quantitative assessment of cascading effects in a multi-risk analysis. In particular, we have identified two possible kinds of interactions, namely: (1) interactions at the hazard level, in which the occurrence of a given initial 'triggering' event, entails a modification to the probability of the occurrence of a secondary event, and (2) interaction at the vulnerability (or damage) level, in which the main interest is to assess the effects that the occurrence of one event (the first one occurring in time) may have on the response of the exposed elements against another event (that may be of the same kind as the former, but also a different kind of hazard). Implicitly, a combination of both kinds of interactions is another possibility, hence in the discussion of the interactions at the vulnerability level, both dependent and independent hazards have been considered.

Identification and structuring of scenarios

A fundamental initial step towards assessing cascading effects is the identification of possible scenarios. The term "scenario" is used in a wide range of fields, resulting in different interpretations in practical applications. In general, a scenario may be considered as a synoptic, plausible and consistent representation of an event or series of actions and events (e.g., MATRIX deliverable D3.3). In particular, it must be plausible because it needs to fall within the limits of what might conceivably happen, and must be consistent in the sense that the combined logic used to construct a scenario must not have any built-in inconsistencies.

To achieve the required complete set of scenarios, different strategies can be adopted, ranging from event-tree to fault-tree strategies. In many applications, an adaptive method combining both kinds of approaches is applied in order to ensure the exhaustive exploration of scenarios. From the multi-risk assessment point of view, the cascading effects scenarios of primary interest are those that produce an amplified total risk when compared to the effects produced by the individual events. With an appropriate set of cascading scenarios, their quantification can be achieved by adopting different strategies, for example, analysing databases of past events, performing physical modelling for the propagation of the intensity measures of interest, and/or by performing expert elicitations in order to obtain information for extremely complex problems, or in these cases with poor data or needing rapid analysis.

Identification of scenarios in the MATRIX test cases

To define some possible cascade scenarios, the 'primary' interactions between hazards were identified. These can be understood as the pairs of hazards where it is theoretically possible to define an event that has the capacity to directly trigger another one (interaction at the hazard level), or in which the additive effects of the loads may lead to a risk amplification. In the matrix-like Table 1, the different hazards considered in the MATRIX project are classified as triggering (running in the x-axis) against the 'triggered' (running in the y-axis) events. In this case, all the possible 'direct' triggering effects are considered. It would also be obvious that it is physically impossible for some hazards to trigger another, e.g., wildfires and volcanoes (although the other way around is certainly a concern, especially for Naples).

Table 2 is a modification of the previous one, where we try to highlight more complex cascade effects. In this case, the number refers to the 'level' (i.e., the position in the sequence of events) at which the given phenomena may be triggered, starting from the initial event being defined as level 0. The numbers in this table are an attempt to represent the different possible sequences of events that can produce different chains of cascade events. Figure 1 in turn allows us to understand better the existing relationships between the different kinds of events and, their relative level in the chain. In this way, the occurrence of different phenomena may be considered from the possible triggering factors.

Table 1: Matrix of all possible direct interactions among the hazards considered within the MATRIX project.

		Triggering -> (cause) *Considered hazards* **Triggered** (result)	**Triggering events**													
						Volcanic								Meteorological events		
			Earthquakes	Landslides	**Volcanic eruption**	*Tephra fall*	*Pyroclastic flows*	*Lava flows*	*Lahars*	*Volcanic earthquakes*	floods	Tsunami	Wildfires	Extreme wind	Heavy precipitation	Extreme temperature
Triggered events		Earthquakes			1[b]											
		Landslides	1		1								1?		1	
	Volcanic	**Volcanic eruption**	1													
		Tephra fall														
		Pyroclastic flows														
		Lava flows														
		Lahars													1	
		Volcanic earthquakes	1													
		Floods		1[a]				1[c]							1	
		Tsunami	1	1	1											
		Wildfires			1			1								1

[a, c] *In specific cases such as, for example, when a landslide (a) or a lava flow (c) reaches and blocks a river.*
[b] *For example, a volcanic edifice collapse.*

Summary of scenarios identified for the MATRIX test cases

Naples test case.

The possible cascading scenarios for the Naples test case are summarized in Table 3. Naples is in fact the test case that may have the largest collection of possible cascade events, with, as can be seen, cascades up to level 4 (landslides from volcanic eruptions) being identified. The most serious interactions appear to be volcanic-seismic relations, with a number of volcanic-related hazards possibly occurring or triggered.

Table 2: Cascades of more than 2 events for the hazards considered in the MATRIX project.

Triggering -> (cause) *Considered hazards* **Triggered** (result)			Earthquakes	Landslides	**Volcanic eruption (in general)**	floods	Tsunami	Wildfires	Meteorological events: Extreme wind	Meteorological events: Heavy precipitation	Meteorological events: Extreme temperature
Triggered events	Earthquakes				1						
	Landslides		1		1,4			1?		1	
	Volcanic	**Volcanic eruption**	1[d]								
		Tephra fall	2		1						
		Pyroclastic flows	2		1						
		Lava flows	2		1						
		Lahars	2,3		2					1	
		Volcanic earthquakes	2		1						
	Floods		2	1	3					1	
	Tsunami		1	1	1						
	Wildfires		3		3						1

[d] *In this case, it may be more properly defined as the triggering of volcanic unrest that eventually leads to an eruption.*

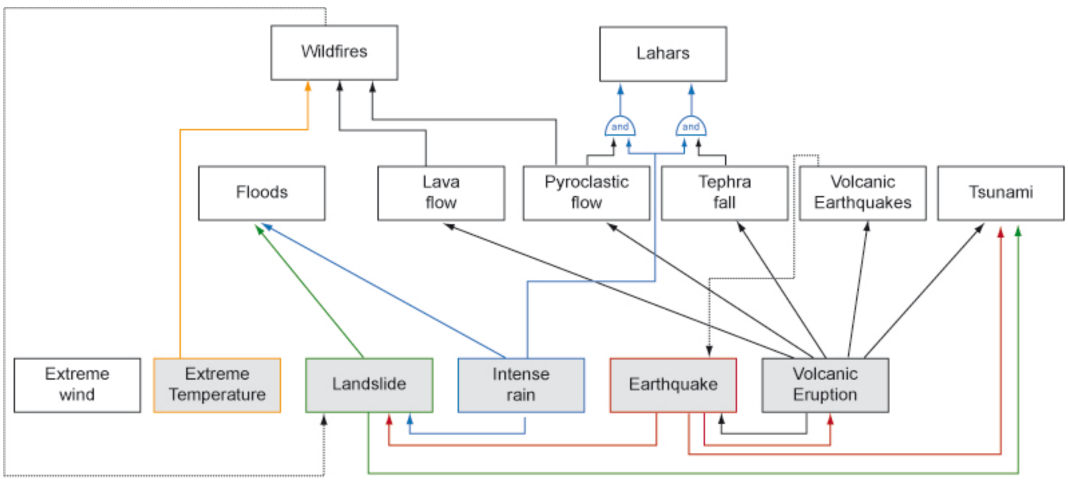

Figure 1: Diagram showing the possible scenarios of cascading events among the hazards considered in the MATRIX project.

Cologne test case:

The next case is Cologne, whose sequence of possible cascading effects scenarios is summarized in Table 4. Cologne is in fact a much simpler example of cascading potential than either Naples or Guadeloupe, but nonetheless, earthquakes and floods display a potential interaction arising from the possibility of an earthquake damaging the flood defences along the River Rhine, hence increasing flood risk.

Table 3: Possible event cascade scenarios for the Naples test case.

									Meteorological events		
			Earthquakes	**Landslides**	**Volcanic eruption (in general)**	floods	Tsunami	**Wildfires**	Extreme wind	Heavy precipitation	Extreme temperature
Triggered events		**Earthquakes**			1						
		Landslides	1		1,4			1?		1	
	Volcanic	**Volcanic eruption**	1[d]								
		Tephra fall	2		1						
		Pyroclastic flows	2		1						
		Lava flows	2		1						
		Lahars	2,3		2					1	
		Volcanic earthquakes	2		1						
		Floods									
		Tsunami									
		Wildfires	3		3						1

[d]In this case, it may be more properly defined as the triggering of volcanic unrest that eventually leads to an eruption.

Guadeloupe islands: French West Indies

The final test case, the island of Guadeloupe (French West Indies), is of a similar level of cascade event potential as Naples, although, for example, wild fires are not considered a serious danger. The possible cascading effect scenarios for this case are summarized in Table 5. Again, the earthquake-volcano interactions appear to be the most serious.

Table 4: Possible event cascade scenarios for the Cologne test case.

							Meteorological events

									Extreme wind	Heavy precipitation	Extreme temperature
Triggered events		**Earthquakes**									
		Landslides									
	Volcanic	**Volcanic eruption**									
		Tephra fall									
		Pyroclastic flows									
		Lava flows									
		Lahars									
		Volcanic earthquakes									
		Floods	2*							1	
		Tsunami									
		Wildfires									

**Possible cascade effects proposed (GFZ): Earthquake -> Dyke damage -> Flooding*

Table 5: Possible event cascade scenarios for the French West Indies test case.

									Meteorological events		
			Earthquakes	**Landslides**	**Volcanic eruption (in general)**	**floods**	Tsunami	Wildfires	**Extreme wind (hurricane)**	**Heavy precipitation**	Extreme temperature
Triggered events		**Earthquakes**			1						
		Landslides	1		1,4					1	
	Volcanic	**Volcanic eruption**	1[d]								
		Tephra fall	2		1						
		Pyroclastic flows	2		1						
		Lava flows	2		1						
		Lahars	2,3		2					1	
		Volcanic earthquakes	2		1						
		Floods	2	1	3					1	
		Tsunami									
		Wildfires									

[d]In this case, it may be more properly defined as the triggering of volcanic unrest that eventually leads to an eruption.

Final comments

From the different cascading scenarios identified in each test case, a set of specific scenarios of interest were selected for more quantitative analyses. For example, in the Naples test case, two scenarios were analysed in quantitative terms: first, the effects of simultaneous loads caused by volcanic ash-fall (first effect) and earthquakes (second effect); second, the effects on the seismic hazard of the volcanic seismicity triggered during a volcanic unrest. The results of these analyses are summarized in greater detail in the Naples test case deliverable (D7.3, Garcia-Aristizabal et al., 2013c). In the Guadeloupe (French West Indies) test case, a scenario consisting of landslides triggered by the occurrence of earthquakes after a cyclonic event or a heavy rainfall period was considered. The detailed analysis of this scenario is described in the Guadeloupe test case deliverable D7.4, Monfort and Lecacheux (2013). Finally, in the Cologne test case, a scenario consisting of earthquake-triggered embankment failures and subsequent inundation of the City of Cologne has been analysed, with a detailed description of this scenario found in the Cologne test case deliverable D7.5, Fleming et al. (2013).

The cascading scenarios identified for each test case were important input information to implement the multi-hazard and multi-risk framework developed within MATRIX. This framework (MATRIX deliverable D5.2, Nadim et al., 2013) indeed provides a useful and valuable scheme within which to identify the characteristics of interactions between a given area's hazard and risk environment, and an appropriate identification of interaction scenarios is a fundamental step in this process.

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The temporal dimension in multi-risk assessment: Effects of antecedent conditions and simultaneous events on the functional vulnerability of critical infrastructures.

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Introduction

The MATRIX project aimed to develop methodologies to assess and compare some of the different natural risks that society has to face. Hence, in order to address multi-risks, one has to take into account the different interactions that might exist between the risks. These interactions, at the hazard and the vulnerability levels, might happen with different delays. It is, therefore, necessary to consider the temporal aspect of such interactions to properly assess multi-risk. The time dependencies might involve the following:

- The repetition of events over time.
- The concomitance of simultaneous-yet-independent events.
- The succession of dependent phenomena (cascading events).

The study of the time-dependency of vulnerability was the objective of work package 4 of the MATRIX project.

Repetition of the same hazard events over time

The effects of the repetition of a type of event have been studied by following a seismic example. The effects of fatigue due to the repetition of seismic shocks (the first mentioned above) within a physical vulnerability assessment have been analysed through two mechanical methodologies. The first approach, proposed by BRGM (Reveillere et al., 2012), developed damage-state dependent fragility functions (Figure1), while the second approach, performed by AMRA (Iervolino et al., 2014), analysed the multiple shock capacity reduction for non-evolutionary structural system (Figure 2).

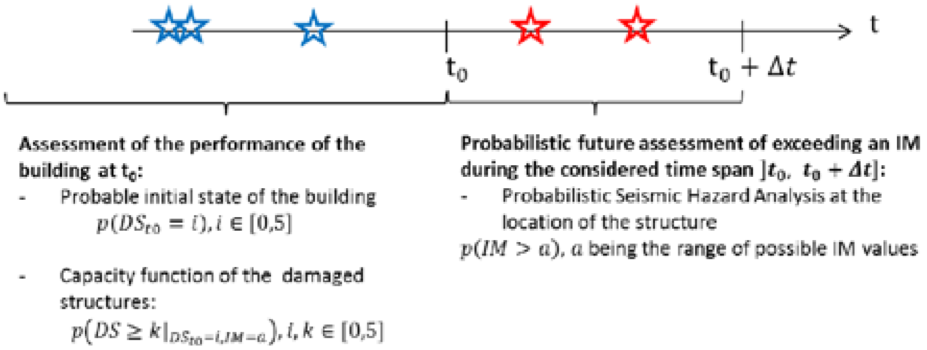

Figure 1: Scheme of the time-dependent risk assessment methodology at a time t0.

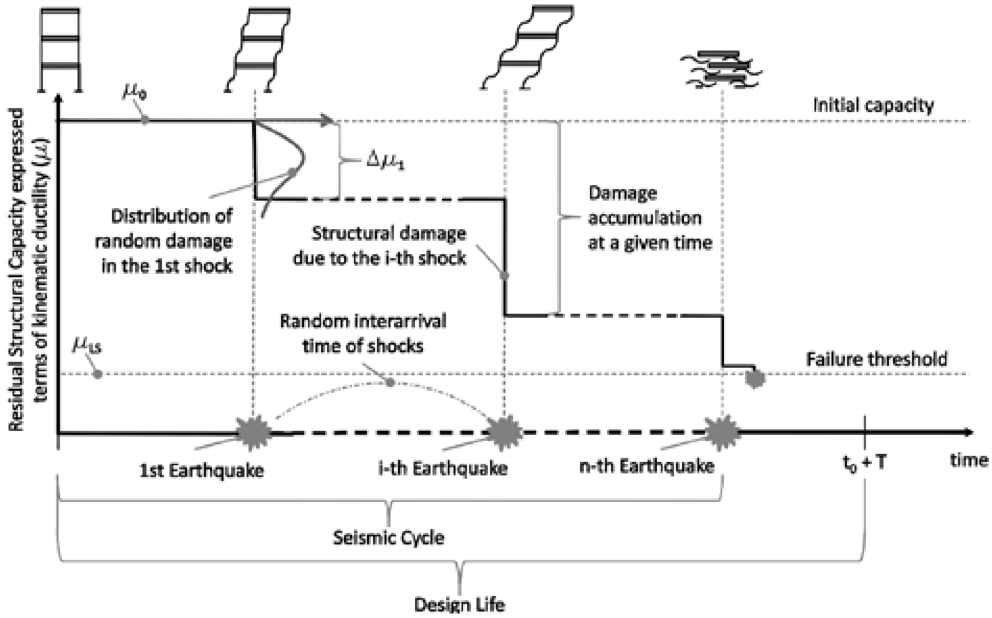

Figure 2: Cumulated damage evolution in the life-cycle.

Concomitance of independent events and cascading scenario

Another study within this work package developed a methodology to take into account the two other types of temporal dependency in societal impact studies. It has been applied to cascading events for illustrative purposes, but it could also be employed for concomitant, yet independent events. The major concern of the study was the integration of two different types of hazards into the evaluation of emergency system functionality during a crisis. The two hazards considered are earthquakes and induced landslides: the first one heavily damages the built environment, whereas the other only impacts upon the road network. The functionality of the road network as a function of these events is modelled using the I2Sim[4]

[4] http://www.i2sim.ca/

platform developed at the University of British Columbia. This tool simulates the interdependencies between infrastructures and among them (Marti et al., 2008).

The first step was the definition of a deterministic disaster scenario using several simulation tools to present a realistic earthquake and landslides scenario for the study area, which was Guadeloupe, Basse-Terre. The hazard cascading scenario consisted of a M6.3 earthquake striking Basse-Terre Island, and triggering landslides in the mountainous areas where previous rainfall events have made the area prone to mass movement (Figure 3). Damage due to the earthquake has been estimated for 5 considered systems (buildings, healthcare system, electrical network, water supply network and transportation, Figure 4). In our scenario, landslides mainly affect transportation networks, resulting in the closure of some roads. This physical damage was then introduced into the lifelines simulation tool (I2Sim), to convert the impacts on the physical integrity of the built environment (number of collapsed buildings, number of victims) into functional consequences (quantity of water and power available in the different cities, accommodation capacities, hospital treatment capacity and capacity of the transportation network to carry injured people to operational hospitals).

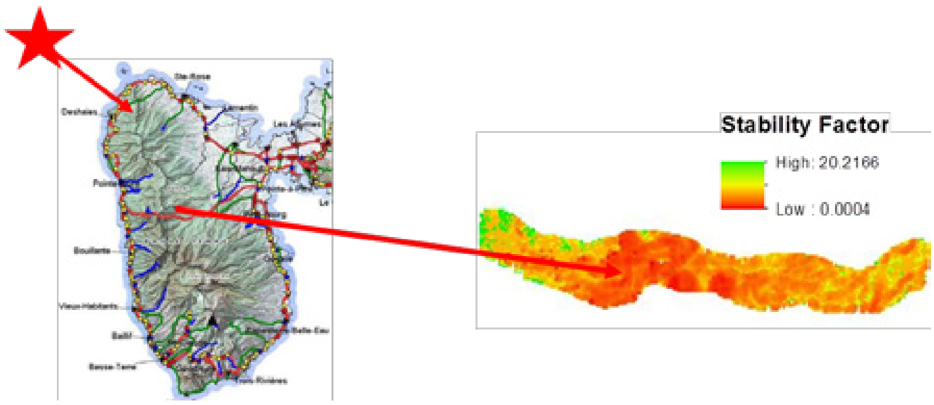

Figure 3: Hazard cascading scenario: an earthquake (star, left) strikes and triggers landslides (resulting slope stability map, right) in the vicinity of the important RD23 road. The stability factors relate to the potential for landslides along a slope, with values lower than 1 indicating a significant landslide hazard.

Systemic vulnerability: inter and intra dependencies between systems

Using the I2Sim tool, the functionality of each element is therefore the combination of the physical (direct damage), as well as functional (indirect) damage. Analyses were performed for different strategies of resource allocations, with one of the final results being the impact of the induced landslides upon the health care treatment capacity of the island. It was found that some systems were very resilient, while others were more vulnerable during disaster situations.

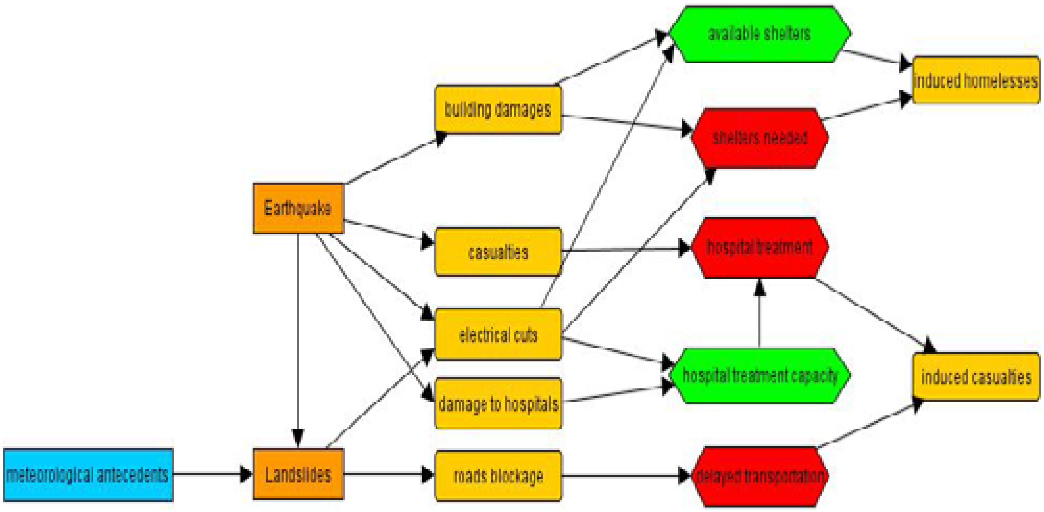

Figure 4: Interactions between hazards at the different levels (physical and functional vulnerability) as examined in the scenario described in this work.

By examining all of the simulation results, several conclusions can be made for the particular earthquake scenario simulated. It was found that the transportation system in Guadeloupe proved to be a major weak point during disaster response. The only route connecting the east and west sides of the Basse-Terre Island, the RD23 road (see Figure 3) is vulnerable to landslides. The simulations proved that, combined with the increased levels of congestion, the evacuation speed would decrease dramatically with virtually no remedy available. Due to the characteristics of the island: i.e., a closed system with mountains in the centre, both the road network and the health care system have a low level of redundancy.

General remarks

Lifelines play a vital role, even under normal conditions. Therefore, during a crisis, the dependency on critical infrastructures is likely to be exacerbated. Indeed, systems have to be functional to provide rapid emergency responses. However, the different systems are interdependent and even if not directly damaged, they can have their functionality seriously reduced and even stopped due to damaged elements of other systems. Thus, it is necessary to take functional vulnerability into account in order to have a comprehensive multi-risk approach and to improve the robustness of assessments of the impact of natural hazards on society.

For example, the impacts of individual hazards, taken separately, might not significantly affect societies or alter system functionality, but might reduce redundancy, and therefore could increase the functional vulnerability of the system to another hazard. This work undertaken within the MATRIX project therefore aimed to analyse the effects of cascading events on interdependent systems and on the capacities of the health care system to treat the victims under damaged-lifeline conditions. Further details may be found in MATRIX deliverable D7.4, Monfort and Lecacheux (2013).

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MATRIX Framework for multi-risk assessment

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Introduction

Many regions of the world are exposed to and affected by several types of natural hazard. The assessment and mitigation of the risk posed by multiple natural and man-made threats at a given location requires a multi-risk analysis approach that is able to account for the possible interactions among the threats, including possible cascade events. Performing quantitative multi-risk analysis using the methodologies available today presents many challenges (e.g., Kappes et al., 2012, Marzocchi et al., 2012). The risks associated with different types of natural hazards, such as volcanic eruptions, landslides, floods, and earthquakes, are often estimated using different procedures and the produced results are not comparable. Furthermore, the events themselves could be highly correlated (e.g., floods and debris flows could be triggered by an extreme storm event), or one type of threat could be the result of another (e.g., a massive landslide that is triggered by an earthquake, an example of a cascade effect).

It is obvious that a mathematically rigorous approach to multi-risk assessment that addresses all the challenges named above, as well as the uncertainties in all steps of the analysis, will be complicated and require resources and expertise. On the other hand, in many situations, the decision-maker in charge of risk management can identify the optimum alternative among the possible options without undertaking a detailed, rigorous multi-risk analysis. Therefore, the framework recommended herein is based on a multi-level approach where the decision-maker and/or the risk analyst will not need to use a more sophisticated model than what is required for the problem at hand, or what would be reasonable to use given the available information.

The recommended three-level framework for multi-risk assessment

The recommended multi-risk assessment framework is a multi-level process which assumes that the end-user (decision-maker or risk analyst) has identified the relevant threats and has carried out an assessment of the risk(s) (again at the level of sophistication required for the problem at hand) associated with each individual hazard. Figure 1 shows the general steps of our multi-risk assessment framework. The overall multi-risk assessment process comprises the following stages: (1) risk assessment for single hazards, (2) level 1: qualitative multi-risk analysis, (3) level 2: semi-quantitative multi-risk analysis, and (4) level 3: quantitative multi-risk analysis. The details are described below.

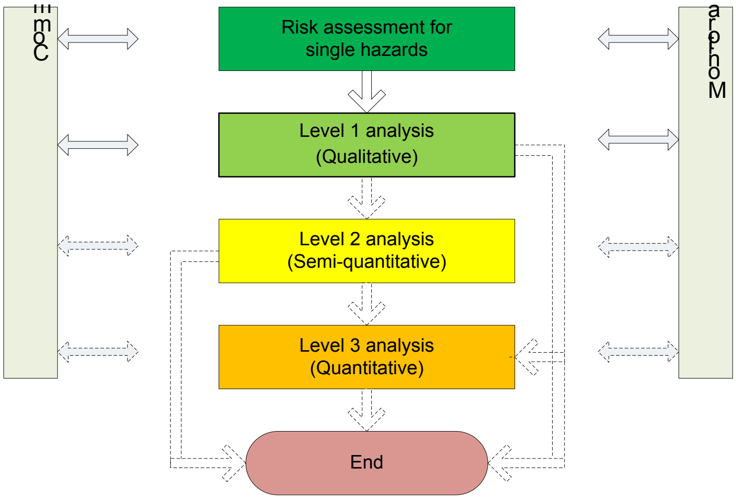

Figure 1: Schematic view of the steps followed in the proposed multi-risk assessment framework.

Level 1 Analysis

Level 1 analysis comprises a flow chart type list of questions that guides the end-user as to whether or not a multi-type assessment approach is required. These questions explicitly account for cascading hazards and dynamic vulnerability within the context of conjoint or successive hazards. Each question is supplied with an exhaustive list of answers that the user can choose from. This process is shown schematically in Figure 2.

If the Level 1 results strongly suggest that a multi-type assessment is required, then the end-user moves on to Level 2 to make a first-pass assessment of the effects of dynamic hazard and time-dependent vulnerability (see Figure 3). If cascading events are potentially a concern, the user goes directly to the Level 3 analysis.

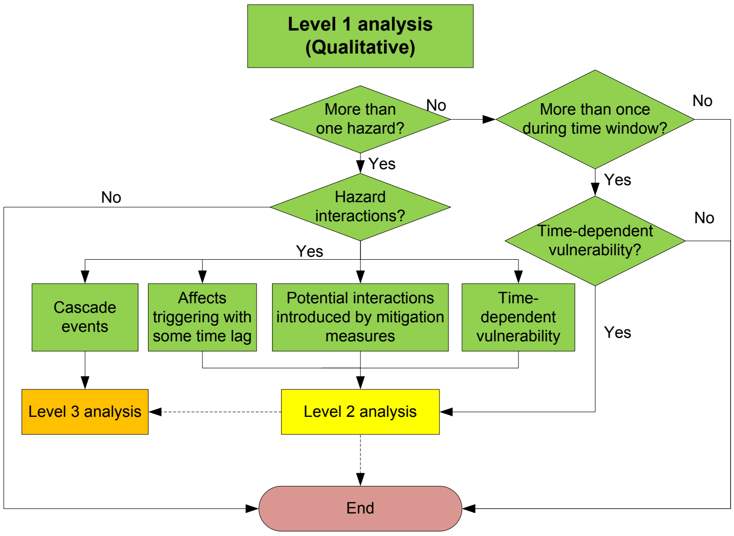

Figure 2: The steps involved in the Level 1 multi-risk analysis.

Level 2 Analysis

In the Level 2 analysis, the interactions among hazards and dynamic vulnerability are assessed approximately using semi-quantitative methods. The steps involved in the Level 2 analysis are shown in Figure 3a.

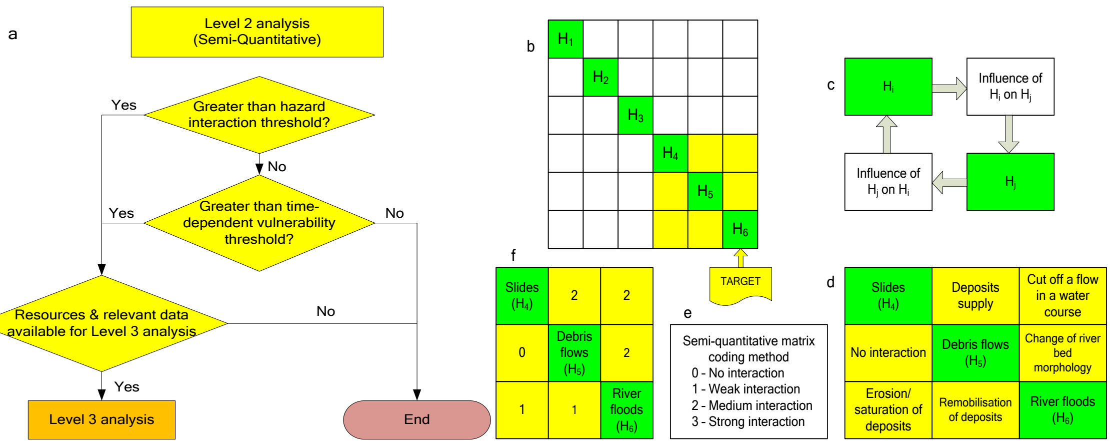

Figure 3: Level 2 multi-risk analysis. (a) The steps involved in the process. (b) The matrix approach followed. (c) The types of interactions that may arise. (d) Description of the mutual influences. (e) The "scoring" system. (f) The matrix with the resulting scores.

To consider hazard interactions and time-dependent vulnerability, the suggested method in the Level 2 multi-risk analyses is a matrix approach based on system theory. Figure 3b-f shows an example to explain this approach (Modified after de Simeoni et al., 1999 and

Kappes et al., 2010). First, a matrix is developed by means of the choice of a pair of hazards, considered as the basic components of the system (Figure 3b). It will be followed by a clockwise scheme of interaction (Figure 3c), with the description of the mutual influence between different hazards (Figure 3d). After the descriptions contained in the matrix, they are assigned numerical codes varying between 0 (No interaction) and 3 (Strong interaction) with intervals of 1, as a function of their degree of the interaction intensity (Figure 3e). Once all the hazards in the matrix are filled (Figure 3f), it is possible to verify the degree of the impact of each hazard on the others and the effect from other hazards. In order to avoid the excessive weighting of a single hazard, the hazard interaction index H_I, which is the sum of the codes for all the off-diagonal terms, is evaluated and compared to a threshold value.

The maximum possible value for the total sum of causes and effects is:

$$H_{I,\,max} = 2 \cdot 3 \cdot n \cdot (n-1) = 6 \cdot n \cdot (n-1) \qquad (1)$$

where n is the number of hazards and H_I is the hazard interaction index.

Given the uncertainties and possible excessive or moderate weighting of single hazards, a threshold hazard interaction index H_I equal to 50% of $H_{I,max}$ is recommended for considering a detailed Level 3 analysis. If the hazard interaction index is less than this threshold, Level 3 analysis is not recommended because the additional accuracy gained by the detailed analyses is most likely within the uncertainty bounds of the simplified multi-risk estimates. Otherwise, if the hazard interaction index is greater than the threshold value, a detailed Level 3 analysis is recommended.

Level 3 Analysis

In the Level 3 analysis, the interactions among hazards and dynamic vulnerability are assessed quantitatively with as high accuracy as the available data allow.

A new quantitative multi-risk assessment model based on Bayesian networks (BaNMuR, outlined in MATRIX deliverable D5.2, Nadim and Liu, 2013) is introduced to both estimate the probability of a triggering/cascade effect and to model the time-dependent vulnerability of a system exposed to multi-hazard. A conceptual Bayesian network multi-risk model may be built as shown in Figure 4. To determine the whole risk from several threats, the network takes into account possible hazards and vulnerability interactions. This would include events that are:

(1) *Independent*, but threatening the same elements at risk with or without chronological coincidence (the column marked in orange in Figure 4), or

(2) *Dependent* on one another or caused by the same triggering event or hazard; this is mainly the case for cascading or domino events (i.e., the column marked in green in Figure. 4).

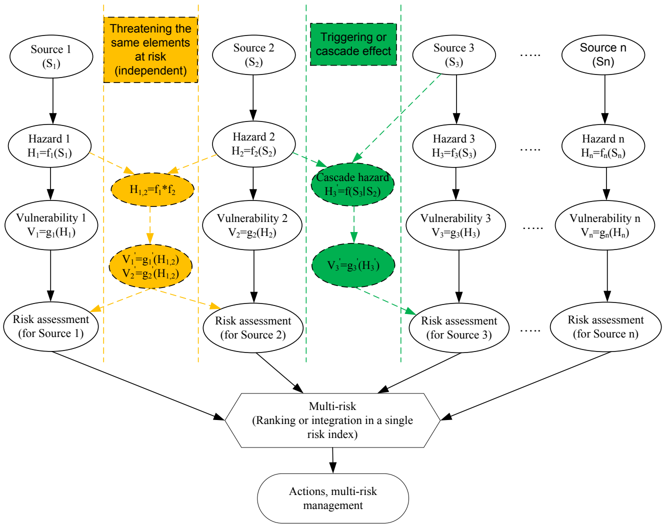

Figure 4: Bayesian network for quantitative multi-risk assessment.

Final Comments

The framework presented in this chapter provides, at the very least, a starting point from which a decision-maker, risk-analyst etc., can proceed from their initial single-type assessment to a more comprehensive (if necessary) analysis. In a later report in this document (Fleming et al., 2013, "The MATRIX framework applied to the test cases of Naples, Guadeloupe and Cologne"), aspects of the framework described here will be applied to the MATRIX test cases, namely Naples, Italy, French West Indies, and Cologne, Germany.

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MATRIX Common IT sYstem (MATRIX CITY) Generic multi-hazard and multi-risk framework - the concept of Virtual City - IT considerations

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Summary

Dynamic risk processes have yet to be clearly understood and properly integrated into probabilistic risk assessments. While much attention has been given to this issue in recent times, most studies remain limited to specific multi-risk scenarios. Here we present the MATRIX Common IT sYstem (MATRIX-CITY), developed within the scope of work package 7 of MATRIX (details are presented in MATRIX deliverable D7.2, Mignan, 2013). MATRIX-CITY is a first step towards a more general use of multi-risk tools in decision-making, and encompasses 3 major advances in the implementation of a multi-risk framework:

1. The development of a generic probabilistic framework based on the sequential Monte Carlo method to implement coinciding events and triggered chains of events, as well as time-dependent vulnerability and exposure (Mignan et al., 2014),
2. The proposition of guidelines for the implementation of multi-risk, using the concept of the "Virtual City" to test basic multi-risk concepts in a controlled, yet realistic, environment (Mignan et al., 2014),
3. A better understanding of the IT requirements for the widespread use of multi-risk tools, based on the lessons learned from the development of an IT platform prototype (the "original MATRIX-CITY", Mignan, 2013) and from interactions with stakeholders.

A generic multi-hazard and multi-risk framework: A "blue print" for extreme event assessment

A sequential Monte Carlo method was proposed to generate a large number of risk scenarios (i.e., the generation of hazardous events and the computation of associated losses). The analysis of these simulated risk scenarios then allowed us to assess losses in a probabilistic way and to recognize more or less probable risk paths, including extremes or low-probability high-consequences chains of events. We finally found that "black swans", which refer to unpredictable outliers, can only be captured by adding more knowledge about potential interaction processes to the computation process. However, this can only be achieved over time by following a “brick-by-brick” approach given the considerable effort that is required.

To quantify hazard interactions, we introduced the concept of the hazard correlation matrix (Figure 1a). We considered three categories of interactions: event repeat (e.g., $A_i \rightarrow A_i$; C $\rightarrow$ C), intra-hazard interaction (e.g., $A_i \rightarrow A_j$) and inter-hazard interaction (e.g., $A_i \rightarrow B_j$). The effect could be positive (i.e., probability increase) or negative (i.e., probability decrease), and temporary or long lasting. Time-dependent vulnerability and exposure are not described here, but are taken into account within the framework at a later stage of the calculations. To evaluate how multi-risk participates in the emergence of extremes, we additionally introduced the concept of the risk migration matrix and showed that risk migration and risk amplification are the two main causes for the occurrence of extremes (Figure 1b).

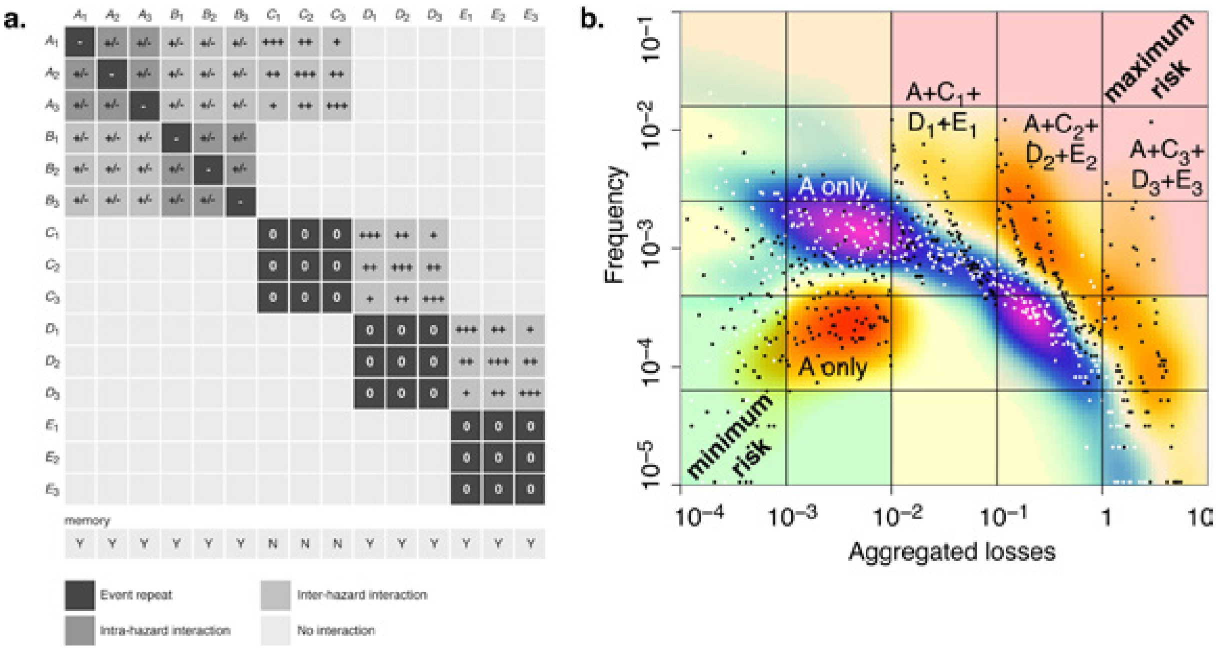

Figure 1: Main results from the proposed generic multi-risk framework. **a.** The concept of the hazard correlation matrix. Trigger events are represented in rows i and target/triggered events in columns j. Each cell indicates the 1-to-1 conditional probability of occurrence Pr(j|i). The n-to-1 conditional probability is considered by incorporating a memory element to the correlation matrix. The identifiers A, B, C, D and E represent different types of perils. **b.** The risk migration matrix, a multi-risk metric that shows how risk changes as a function of frequency and aggregated losses when new information is added to the system (here adding cascading effects A $\rightarrow$ C $\rightarrow$ D $\rightarrow$ E as defined in **a.**). An increase of risk is represented in red and a decrease in blue. The points represent the individual risk scenarios, where black indicates those where interactions are considered and white where they are not. Source: Mignan et al. (2014). Figure 1b is also available from the Appendix of Komendantova et al. (2014).

The Virtual City concept: Guidelines for shifting from abstract processes to realistic processes

The multi-risk framework was developed and tested based on generic data and processes generated following the heuristic method. This strategy, which involves the use of intuitive judgment and simple rules, allows for the solving of problems that are otherwise difficult to consider. Our approach follows the existing recommendations on extreme event assessment, which involves the use of inductive generalizations and "scientific imagination" to include known examples of extremes, as well as potential "surprise" events within the same framework. However, abstract concepts, such as the definition of generic perils (e.g., A to E, Figure 1), remain difficult to comprehend and we therefore proposed some guidelines to help risk modellers and decision-makers apply this approach to realistic cases. For this purpose, we developed the concept of the Virtual City (Figure 2). Within this concept or tool, the perils A, B, C, D and E are no longer simply abstract concepts, but are replaced, for instance, by earthquakes, volcanic eruptions, tsunamis, fluvial floods and storms. Hazard, exposure and vulnerability data, as well as details about possible interacting processes, are based on real examples obtained from the scientific literature.

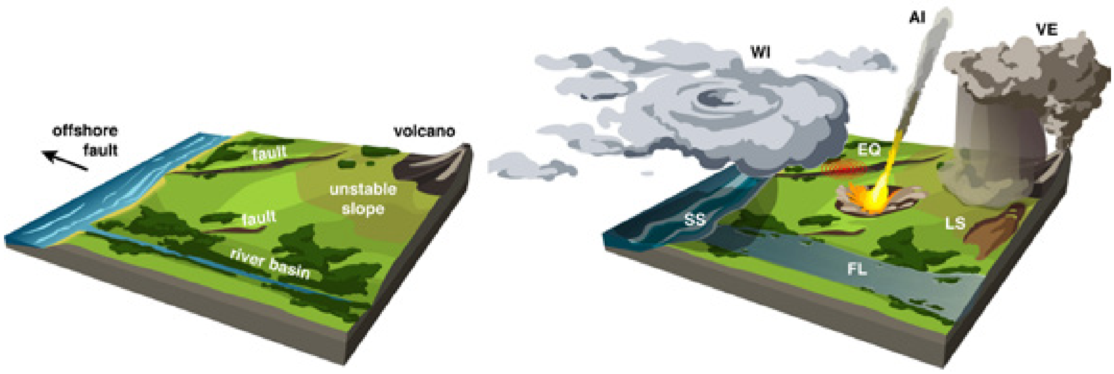

Figure 2: (left) The virtual region in which the Virtual City is located. (right) The considered perils include: earthquakes (EQ), volcanic eruptions (VE), landslides (LS), fluvial floods (FL), wind events (WI), sea submersion (SS, e.g., storm surge or tsunami) and asteroid impacts (AI). Also included, but not shown, are NaTech (Natural Technological) events, i.e., technological accidents triggered by a natural event. Source: Mignan et al. (in preparation). A previous, simpler, version is shown in Komendantova et al. (2014).

IT considerations: Planning the widespread use of multi-hazard and multi-risk tools by decision makers

A prototype version of an IT platform for multi-risk loss estimations was developed during the first part of the project, the so-called MATRIX Common IT sYstem - or MATRIX-CITY

(Mignan, 2013). While based on state-of-the-art software engineering and a Python-based code, it was rapidly observed that multi-risk software would need to have all the functionalities of existing risk tools, on top of the innovative multi-risk framework described previously. Such a task would require significant resources and a commitment of modellers used to other types of risk modelling tools (including various procedures and formats). At this present stage, we recommend the exporting of the method developed for this IT tool to existing risk tools, which would facilitate its implementation and potentially encourage the widespread use of the proposed approach, as explained in Figure 3.

Concluding comments

The present work should be seen as a proof-of-concept, as we did not intend to fully resolve the complex problem of low probability-high consequence events. We only considered a selected number of possible interactions, where naturally adding more perils and interactions would yield more complex risk patterns. We thus recommend a brick-by-brick approach to the modelling of multi-risk, to progressively reduce epistemic uncertainties. A more realistic modelling of low-probability high-consequences events would also require the consideration of additional aspects, such as uncertainties, domino effects in socio-economic networks and long-term processes, such as climate change, infrastructure ageing and exposure changes. While the concepts developed in the present study outline the theoretical benefits of multi-risk assessment, identifying their real-world practicality will require the application of the proposed framework to real test sites.

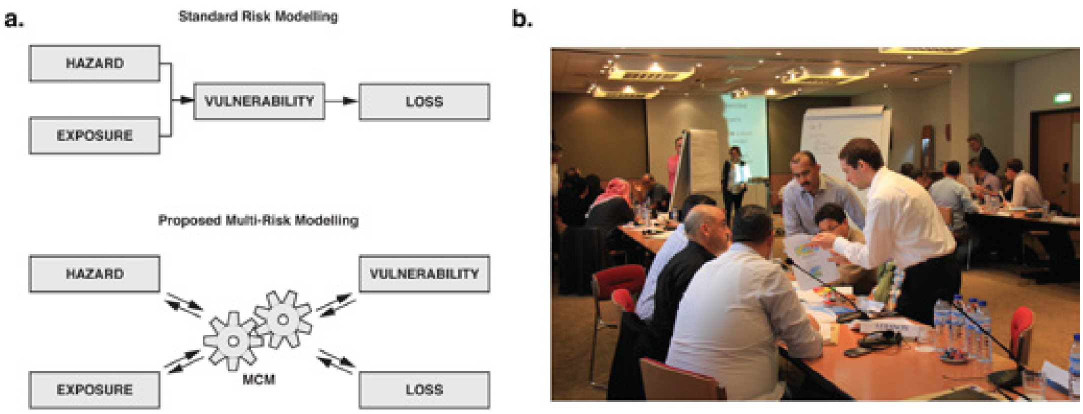

Figure 3: A paradigm shift in risk assessment? **a.** The structural differences between standard risk modelling and the newly proposed multi-risk approach. MCM refers to the sequential Monte Carlo Method. Such an approach could be exported to existing risk tools. Source: Mignan et al. (2014); **b.** Discussion with stakeholders at the PPRD[5] South 2012 Lisbon workshop on multi-risk. The needs of

[5] http://www.euromedcp.eu/index.php

decision makers must be taken into account to facilitate the communication and use of multi-risk approaches (see also Komendantova et al., 2014).

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Multi-risk and multi-hazard decision support models and the needs of stakeholders from practice

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Introduction

Existing risk assessment methods integrate large volumes of data and sophisticated analyses, as well as different approaches to risk quantification. However, the key question is why do losses from natural disasters continue to grow if our scientific knowledge on multi-risk is increasing? (White et al., 2001). As Kappes et al. (2012) stated in their review on multi-hazard risk assessment, to be able to understand this question, we need to also examine the frameworks employed in the field of risk management, as well as the interactions between science and practice in terms of knowledge transfer and the applicability of results. Our work deals with the questions of communication and the transfer of scientific knowledge on multi-risk and its underlying drivers to stakeholders within the decision-making process. A two-way communication process has allowed us to not only collect feedback from stakeholders (i.e., civil protection offices) across Europe on the usability of the multi-risk decision–support tools that have the potential to benefit decision-makers and to provide them with information on mitigation measures, but also to integrate their feedback into improving the tools themselves.

The theoretical background of our work involves the concept of risk governance, which takes into account cultural and political factors when implementing risk mitigation measures and emphasizes the role of participation and communication. The risk governance concept is concerned with such issues as how information is perceived, collected and communicated, and, based on these factors, how management decisions are made (IRGC, 2005). Participatory modelling is an important part of risk governance and allows us to take into consideration not only facts, but also values by collecting feedback from stakeholders (Forester, 1999). The process of interacting with stakeholders leads to an enhanced understanding of the views, criteria, preferences and trade-offs employed in decision-making (Antunes et al., 2006). Also, as social science scholars argue, because the development of scientific tools is also a social process, it is essential to involve relevant stakeholders who will be using the tools in the design process through the collection and integration of their feedback (Tesh, 1990).

Two complementary decision-making tools developed within the context of the MATRIX project are discussed here:

(1) A generic framework developed by ETH Zurich and which is the subject of another report in this deliverable (MATRIX deliverable D7.2, Mignan, 2013, Mignan, 2014, this report), and

(2) An evaluation methodology based on the concept of the risk matrix that incorporates expert knowledge through stakeholder interactions into multi-hazard scenario development, developed by the Karlsruhe Institute of Technology (KIT) (Wenzel, 2012).

Feedback for decision-making tools

This research was motivated by the gap in the scientific literature about feedback with respect to the usability of decision-support tools. While the use of feedback for the development of decision-support tools for environmental issues has been reported (Constanza and Ruth, 1998), as well as there being multi-risk decision–support tools that have the option of collecting feedback (T6, 2007), there is no evidence or analysis of the feedback from stakeholders from practice on the usability of multi-risk decision-support tools. During our work, we not only collected such feedback from civil protection officers, but we also used this information to improve the developed decision-making tools, directly integrating stakeholders' perceptions into the model by attributing different weights to loss parameters according to preferences from stakeholders. The information was gained during two workshops, namely a MATRIX stakeholders' meeting in Bonn (July, 2012) and a workshop on urban multi-hazard risk assessment in Lisbon[6] (October, 2012), and from a

[6] Multi-hazard Risk Assessment in Urban Environment, 18-19 October 2012, Lisbon, Portugal, PPRD South program

questionnaire distributed prior to the first workshop. The selection of the stakeholders forms a representative sample, given the fact that our stakeholders´ consultation process covered most European countries, with a majority of them representing National Platforms, as well as the UNISDR.

A presentation of the generic multi-risk framework (tool #1) in Lisbon involved a half-day exercise, where one of the tasks required investigating the different hazards presented in the used examples, based on data such as hazard maps and to give some score to their severity and frequency within the concept of the risk matrix - hence combining the tool #1 core modelling concept with a visualization and ranking of multi-risk similar to tool #2. In fact, this represented an upgrade of tool #1, based on feedback obtained during the Bonn workshop. An exercise involving tool #2 was presented at the Bonn workshop, in which stakeholder input was needed to identify the weights with which the impact of particular components of the model are specified in a participatory fashion (i.e., what is the relative importance of the different loss parameters in the risk ranking?). Thus, the primary difficulty in gathering stakeholder input involved creating a "value model" that would support stakeholders in assessing problems and expressing their views more explicitly.

The general results show that for the usage of multi-risk decision-support tools, two areas are most problematic. These are (1) the absence of clear definitions and (2) the lack of information on the added value of multi-risk assessment. Multi-risk is not systematically addressed among the EU countries for all hazards, but is only singularly integrated into risk assessment approaches. Some examples include the superposition of existing single hazard risk prevention plans for all hazards, for example, combining flood and landslide hazards and flood risks with wind effects, the application of which is within the context of risk assessment of critical infrastructure, in particular the combination of meteorological and technological risks. Generally, multi-risk analysis is barely or not at all integrated into decision-making processes, and only around half of stakeholders were aware of methodologies and tools to assess multi-risk.

The reaction of stakeholders to the multi-risk assessment and decision-making tools presented at the both workshops was optimistic. Several stakeholders invited the developers of these tools to give presentations and to conduct training on the tools at their home institutions. The majority of stakeholders would consider the use of the generic multi-risk framework (tool #1) and the decision-making tool (tool #2) after their testing phase. However, the usability of the tools in practice is complicated by such factors as the required large

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volume of input parameters, which involves cumbersome data gathering to consider multiple hazards and risks in a given region, and that their possible application is limited to only a narrow number of experts as high-level expertise is required to assess the dynamic multi-hazard and multi-risk processes, taking into account the complexity of the models and the required parameters.

The consultation process with stakeholders also showed significant variation in perceptions between stakeholders in academia and in practice. While both academicians and practitioners agreed that the decision-support tools are useful for understanding losses and their contributions in a risk scenario, differences arise between how practitioners viewed the usefulness of the tools when it comes to prioritizing risk and developing risk management strategies. Similarly, practitioners found the tools less useful than academics when it comes to preparing for disasters and allocating resources.

Closing comments

We have collected recommendations on two possible areas involving the application of decision-support tools. The first is in the more narrow sense of convincing stakeholders involved in the decision-making process of the usefulness of the multi-hazard approach. The second deals with the broader view of disseminating these results to the general public, hence confronting public acceptance issues. Some stakeholders expressed the opinion that politicians could use such models as training to see what the consequences of a multi-hazard situation could be. Another general recommendation was that the decision-support tools could be used for educational purposes.

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The MATRIX framework applied to the test cases of Naples, Guadeloupe and Cologne

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Introduction

One of the objectives of the MATRIX project was the development of a conceptual framework that could be applied to multi-hazard and multi-risk environments. The developed framework (MATRIX deliverable D5.2, Nadim et al., 2013, Liu and Nadim, 2013) involves several levels of analysis of increasing sophistication, an overview of which is provided in another reference report in this document[7]. It is therefore the aim of this chapter to present some results of a simplified application of this framework to the MATRIX test cases, namely Naples, Italy, Guadeloupe, French West Indies, and Cologne, Germany. All three test cases represent multi-hazard and risk environments, although with differing degrees and complexities of hazard and risk interactions. As outlined in the overview of the framework, one of the aims was to develop a system whereby a decision-maker or end-user could identify how much effort is actually required (also dependent upon the available resources) by answering a series of questions, and then deciding whether a complete, quantitative multi-risk analysis is necessary for the case at hand.

The MATRIX test cases

In order to verify the concepts and tools developed within MATRIX, it is necessary to apply them to real world situations where conjoint and cascading events and interactions between

[7] Nadim et al., 2013 "MATRIX framework for multirisk assessment",

different hazards and risks need to be considered. It is for this reason, and matching the expertise of the consortium, that the MATRIX test cases were chosen. All three are under threat from multiple hazards (see MATRIX deliverable D3.3, Garcia-Aristizabal et al., 2013a, and Garcia-Aristizabal et al., 2013 “Identifying and structuring scenarios of cascade events in the MATRIX project”, this document). Naples (MATRIX deliverable D7.3, Garcia-Aristizabal et al., 2013b) and Guadeloupe (MATRIX deliverable D7.4, Monfort and Lecacheux, 2013) are the most threatened (and complex) examples, with both endangered by volcanic eruptions, earthquakes, as well as hurricanes (Guadeloupe), landslides (Naples and Guadeloupe) and forest fires (Naples). Each case is also susceptible to cascading events, in particular rain- and earthquake-induced landslides and volcano-earthquake interactions. Cologne (MATRIX deliverable D7.5, Fleming et al., 2014) on the other hand is not as exposed to such a range of hazards, nonetheless it must still contend with threats from earthquakes, floods and windstorms (Grünthal et al., 2006), with the possibility of earthquake-induced damage to its dyke system increasing the flood risk to the city.

The MATRIX multi-risk framework

As the framework is outlined in another chapter of this document (Nadim et al., 2014), we will only present the barest details here. In summary, it consists of four levels:

- Single hazard(s) risk assessment (Figure 1 of Nadim et al., 2014).
- Level 1 – Qualitative analysis – decides if a multi-type assessment is required (Figure 2 of Nadim et al., 2014).
- Level 2 – Semi-quantitative analysis – identifies the various interactions between hazards (Figure 3 of Nadim et al., 2014).
- Level 3 – Quantitative analysis – the interactions between hazards, time-dependent vulnerability and the accompanying uncertainties are estimated.

As commented upon earlier, by considering a series of questions, a decision maker or stakeholder can decide if it is necessary to proceed to a higher level. Considering Level 1, the answers for each test case being presented in Table 1, we note immediately that for each example, we must proceed from the initial “More than one hazard?” question to dealing with the various interactions, with the need for at least a Level 2 analysis. However, even if this were not the case, i.e., only one hazard of concern, then there is also the possibility of events of the same kind repeating during a given time period, which may be taken as the time required to carry out the necessary repairs/recovery from the original event (e.g., a series of storms separated by short periods of time). We also note that for all three cases, we would probably need to proceed to a quantitative Level 3 analysis, based on the fact that cascade events may arise. However, the fact that cascade events in Naples and Guadeloupe are more likely than in Cologne cannot, at this stage of an assessment (or comparison), be resolved. In addition, the cascade example for Cologne presented, i.e., an earthquake damaging flood defences, hence increasing flood risk, would also fit within the context of conjoint events. Therefore, it would appear that even the most "quiet" territories may be exposed to several hazards, with interactions potentially always present (for example, Na-Tech - Natural Technological - interactions are in many industrialised districts a major concern, although they are not dealt with in detail in MATRIX). Hence, one may expect the situation where only a Level 1 assessment is required would be fairly rare.

	Naples	**Guadeloupe**	**Cologne**
More than 1 hazard (YES)	Earthquakes, volcanoes, tsunamis, storms, landslides, forest fires, floods.	Earthquakes, volcanoes, tsunamis, storms (hurricanes), landslides, floods (rains, storm, surges).	Earthquakes, flooding (river), windstorms.
Hazard interactions (YES)			
Possible cascades:[8]	Volcano-earthquake interactions Earthquake – landslides Volcanoes – wildfires Heavy precipitation (flood) – landslides	Volcano-earthquake interactions Volcano/earthquake-tsunamis Earthquake – landslides Heavy precipitation (floods) – landslides	Earthquake damaging a loaded dyke, causing flooding (conjoint event).
Affects triggering with some time delay	Increased landslide risk after heavy rainfalls, e.g., an earthquake soon after heavy rains, when the soils are saturated and thus more susceptible.	Increased landslide risk after heavy rainfalls.	Increased flood risk arising from unrepaired dykes following an earthquake
Potential interactions due to mitigation measures	This has not been considered within this work. While increasing a house's height could reduce loss due to flooding, it may increase loss due to earthquake.	Not considered in this work. Some retrofitting actions against cyclones or floods may increase seismic vulnerability if proper attention is not given to earthquake design issues	Location of dykes may shift the flood risk spatially.
Time-dependent vulnerability	Earthquake-Earthquake interactions; Earthquake-Landslide interactions	Time-dependent vulnerability in buildings is considered in this work; however, landslide potential varies during the year owing to the changing levels of water saturation.	The main issue would be the vulnerability of the defences to seismic loading, depending upon the water levels.

Table 1: The answers to the questions posed as part of Step 1 of the framework (Figure 1).

[8] See Deliverable D3.3 "Scenarios of cascade events", Garcia-Aristizabal et al. (2013a)

Considering the Level 2 assessment, the aim is to describe the various relationships between the assorted hazards. This is done by following a matrix approach (modified after de Simeoni et al., 1999 and Kappes et al., 2010), the results for the three test cases being presented in Figure 1 (again, please refer to Figure 3 of Nadim et al., 2014, this document). To read these figures, consider first that along the diagonal, the hazards of concern are listed. Then, moving in a clockwise manner, the level of interaction (scored between 0 and 3 with intervals of 1, where 3 indicates a strong interaction and 0 indicates none) and the nature of such interactions between each hazard pair are identified.

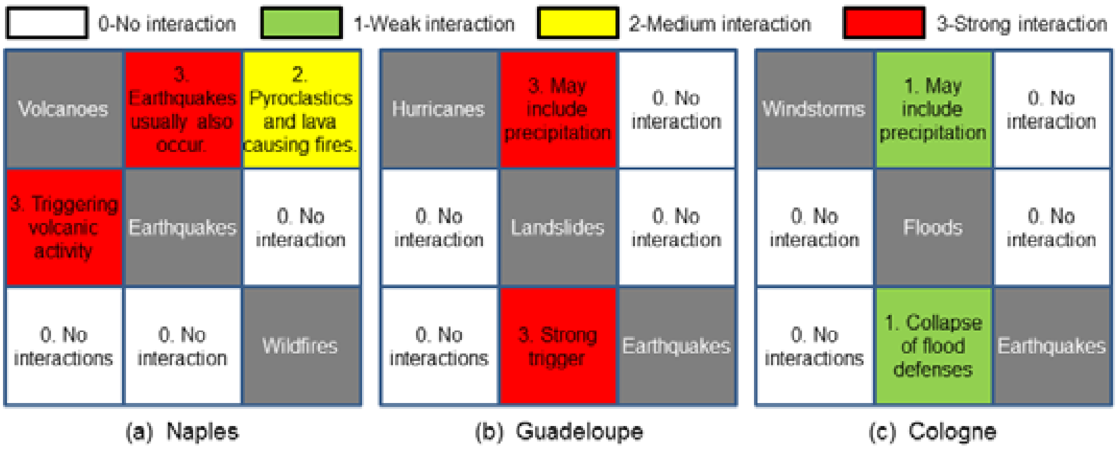

Figure 1: The hazard interaction matrix means of identifying the type and magnitude of the various interactions possible for the MATRIX test cases (0 – no interaction, 3 – strong interaction). Note, only some examples for Naples and Guadeloupe are included.

For Naples and Guadeloupe (Figure 1a and 1b), for the purpose of this work, we simply refer to three hazards, although obviously a larger matrix would be needed to be employed for a thorough study. We note the strong (3) interactions between some hazards, e.g., earthquakes and volcanoes for Naples, landslides and earthquakes for Guadeloupe, as well as hazards where no interaction would arise (e.g., hurricanes and earthquakes). Considering Cologne (Figure 1c), we identify few interactions between hazards, i.e., windstorms potentially bringing heavy rain, although for Cologne, more localised heavy precipitation causes little widespread flooding, and an earthquake damaging flood defences. However, it is also recognized that if we considered this at the risk level, then a windstorm may damage a building, increasing its susceptibility to a later earthquake, while considering the reverse (an initial earthquake followed by a windstorm) would most likely be more serious. Based on the numbers presented in each square, a so-called hazard interaction index may be inferred (found by adding all results row by row, representing causes, then column by column, representing effects), the size of which relative to some criteria (e.g., a predefined percentage of the maximum possible index for a given site) may decide whether or not to proceed to the more resource intensive Level 3 analysis. For example, Naples has a score of 16 and Guadeloupe 12, while Cologne has a value of only 4, indicating as expected the much great importance of such interactions for the first two cases.

Finally, an attempt to consider a quantitative Level 3 analysis was carried out for Naples, considering volcano-earthquake interactions at the hazard and vulnerability levels (see MATRIX deliverable D3.4, Garcia-Aristizabal et al., 2013c). For the hazard level, the contribution to seismic hazard by volcanic earthquakes during periods of volcanic unrest was assessed. Likewise, the combined effects of ash loads deposited over roofs and seismic loading were considered in order to estimate their effects on the risk quantification. It was found that because of the characteristics of the volcanic seismic swarms (shallow and generally small events), their contribution to seismic hazard is strongly localized around the epicentre zone of the events and quickly vanishes with distance. Conversely, the combined effects of seismic and volcanic ash loads increases the average risk by an order of 3% to 6% (with respect to calculations that don't take into consideration the effects of volcanic ash). Furthermore, a scenario-based analysis considering specific ash-load scenarios was also undertaken, with more specific amplification effects observed. Such scenario-based analyses can provide important information for short-term assessments.

Final comments

The multi-hazard and risk framework developed within MATRIX provides a useful and valuable scheme within which to identify the characteristics of interactions between a given area's hazard and risk environment. Although not all hazards for Naples and Guadeloupe are considered in the level 2 assessment, one can still see that this framework shows the much stronger need for the more complex analysis for Naples and Guadeloupe than for Cologne.

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Multi-risk assessment and governance: research into practice

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Introduction

In risk assessment research and policy, there is currently much debate on multi-type hazard and risk assessment and the definition and use of realistic scenarios. This debate has been evoked, not least, by several specific disasters in recent years that have resulted in extremely high numbers of fatalities and massive damage to properties and infrastructure. Recent examples are the Super Typhoon Haiyan, which hit the Philippines in November 2013, causing floods and landslides, and the Tohoku earthquake that struck Japan in March 2011, with the resulting devastating tsunami and nuclear accident.

The research undertaken in MATRIX Work package 6 “Decision support for mitigation and adaptation in a multi-hazard environment” aimed at *providing guidance on how to maximize the benefits arising from, and overcome the barriers to, the implementation of a multi-hazard and risk assessment approach within current risk management regimes.*

This reference report focuses on the synthesising the identified benefits and barriers to multi-hazard mitigation and adaption[9]. It is addressed to practitioners within the public/private sector working in communities exposed to multiple risks as well as to those active at the science-policy interface, thus including researchers, policy and decision makers in risk and emergency management.

[9] Deliverable D6.4 “Synthesis” Scolobig et al. (2013)

Research design

The research design was grounded on documentary analyses and extensive empirical work involving policy makers, private sector actors, and researchers in risk and emergency management. The work was informed by thirty-six semi-structured interviews, three workshops (Figure 1) with over seventy practitioners in total attending, feedback from questionnaires and focus groups discussions. Most of the fieldwork was conducted in two of the MATRIX test sites: Naples (Southern Italy) and Guadeloupe (French West Indies). Lessons learnt from five historical multi-hazard disasters have been also included, as well as examples reported from practitioners representing eleven countries (Italy, France, Norway, Germany, Hungary, Bulgaria, Sweden, United Kingdom, Iceland, Croatia, Austria). This lead to practical and evidence-based recommendations that are informed by a well-researched understanding of the process through which new knowledge about multi-hazard and risk assessment can be taken advantage of by practitioners.

Figure 1: A workshop with practitioners organised in Naples, Italy.

From multi-risk assessment to multi-risk governance

Within current single-risk-centred governance systems (which have evolved in parallel with the single-risk-centred risk assessment processes), practitioners hardly ever have the opportunity to discuss multi-risk issues, including triggered events, cascade effects and the rapid increase in vulnerability resulting from successive hazards. However, as revealed by the workshop results, risk and emergency managers clearly see the benefits of including a multi-risk approach in their everyday activities, especially in the urban planning sector, but also in emergency management and risk mitigation (see the chapter in this document by Komendantova et al.).

Benefits of a multi-risk viewpoint

As one example of how a multi-risk viewpoint would be of value, practitioners believe that decisions on building restrictions for urban planning would benefit greatly from the results of multi-risk assessment. A multi-risk approach is considered particularly useful also for gaining a holistic view of all of the possible risks that may affect a territory. For example, such an approach can show that focusing only on the impacts of one hazard could result in raising the vulnerability of the area to another type of hazard. For example volcanic ash can have an additive effect on seismic loads. Another example of this is in the older buildings of Kobe, Japan, which were built with relatively heavy roofs. This helped to mitigate against the frequent typhoons, but enhanced their vulnerability to rarer earthquakes.

Other benefits that are considered to be particularly crucial by practitioners include: the cost reductions and improvements in the efficiency of proposed risk mitigation actions; the development of new partnerships between agencies working on different types of risks; an awareness of the potential for expected losses being exceeded (i.e., the total risk is possibly greater than the sum of the individual parts), as well as the lives and property saved and better protected by the use of a multi- vs. single-risk approach. However, further research is still needed in order to better understand the extent of some of these benefits, as well as the need to consider aspects of the mitigation problem, such as the different time scales involved between the events themselves, response, initial recovery and ongoing mitigation. Our results also reveal that practitioners and researchers have in mind different agendas for future research on multi-risk assessment. Therefore, a transparent process to reach a compromise on the required priorities is needed.

Barriers

Barriers to an effective implementation of multi-risk assessment can be found in both the science and practice domains. For example, considering scientific contributions to risk assessment research, the process has evolved differently in the fields dealing with geological versus meteorological hazards, with the different scientific development paths representing a major barrier to understanding and communicating between different “risk communities”. Accompanying this is the lack of open access to databases and research results, which is particularly worrying for risk managers. Overarching these problems are the matters of the lack of interagency cooperation and communication, which are particularly difficult for risks that are managed by authorities acting at different levels (e.g., in Naples, national bodies are responsible for volcanic risk, while river basin authorities deal with flood risk). The lack of capacities at the local level and unsatisfactory public-private partnerships are also major barriers that need to be confronted.

Catalysts for the effective implementation of multi-risk assessment

As a result of our interactions and discussions with stakeholders, some priority actions have been identified:

- Encourage knowledge exchange and dialogue between the risk communities dealing with geological and meteorological hazards;
- Identify new options for mitigation, - e.g., multi-risk insurance schemes, new forms of public-private responsibility sharing for households exposed to multi-risks;
- Develop territorial platforms for data and knowledge exchange between researchers and practitioners;
- Create an inter-agency environment, where the different departments at the national and/or regional governmental level, can exchange information, develop complementary protocols, and serve to provide consistent information and responses to the relevant stakeholders;
- Create commissions for discussion at the local/municipal level ("local multi-risk commissions") in order to gain a common understanding of what multi-risk assessment actually is, what kind of cooperative actions can be undertaken to implement it, what are the priorities for future research etc.. Members of these commissions should be decision and policy makers, researchers and local natural hazard advisors, the latter acting as the liaising bodies between local communities and practitioners.

Additional information and references

Work package 6 of the MATRIX project produced four deliverables based upon the conceptual and empirical work of an interdisciplinary team of researchers, integrating expertise from the physical, environmental and social sciences. The interested reader is referred to them.

Komendantova, N., van Erp N., van Gelder, P. and Patt, A. (2013) Individual and cognitive barriers to effective multi-hazard and multi-risk decision-making governance, Deliverable D6.2, New methodologies for multi-hazard and multi-risk assessment methods for Europe (MATRIX project), contract No. 265138.

Scolobig, A., Vichon, C., Komendantova, N., Bengoubou-Valerius, M. and Patt, A. (2013) Social and institutional barriers to effective multi-hazard and multi-risk decision-making governance, Deliverable D6.3, New methodologies for multi-hazard and multi-risk assessment methods for Europe (MATRIX project), contract No. 265138.

Scolobig A, Komendantova N, Patt A, Gasparini P, Di Ruocco A, Garcia-Aristizabal A, Vinchon C, Bengoubou-Valerius M, Monfort-Climent D, Wenzel F (2013) Synthesis: Benefits and barriers to multi-hazard mitigation and adaptation, with policy recommendations for decision-support, Deliverable D6.4 New methodologies for multi-hazard and multi-risk assessment methods for Europe (MATRIX project), contract No. 265138 (on which this reference report is based).

Wenzel F (2012) Decision analytic frameworks for multi hazard mitigation and adaptation, Deliverable D6.1, New methodologies for multi-hazard and multi-risk assessment methods for Europe (MATRIX project), contract No. 265138.

More information is available from the MATRIX website http://matrix.gpi.kit.edu/index.php.

PART 2 - Deliverable D8.5 "MATRIX Results II and Reference Report"

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Abstract

As populations increase, especially in urban areas, the number of people affected by natural hazards is growing, as many regions of the world subject to multiple hazards. Although the volume of geophysical, sociological and economic knowledge is expanding, so are the losses from natural catastrophes. The slow transfer of appropriate knowledge from theory to practice may be due to the difficulties inherent in the communication process from science to policy-making, including perceptions by stakeholders from disaster mitigation practice regarding the usability of any developed tools. As scientific evidence shows, decision-makers are faced with the challenge of not only mitigating against single hazards and risks, but also multiple risks, which must include the consideration of their interrelations. As the multi-hazard and risk concept is a relatively young area of natural risk governance, there are only a few multi-risk models and the experience of practitioners as to how to use these models is limited. To our knowledge, scientific literature on stakeholders' perceptions of multi-risk models is lacking. In this document, we identify the perceptions of two decision-making tools, which involve multi-hazard and multi-risk. The first one is a generic, multi-risk framework based on the sequential Monte Carlo method to allow for a straightforward and flexible implementation of hazard interactions which may occur in a complex system. The second is a decision-making tool that integrates directly input from stakeholders by attributing weights to different components and constructing risk ratings. Based on the feedback from stakeholders, we found that interest in multi-risk assessment is high, but that its application remains hampered by the complexity of the processes involved.

The work presented in this document formed the basis of the publication:

Multi-hazard and multi-risk decision support tools as a part of participatory risk governance: feedback from civil protection stakeholders
by Nadejda Komendantova, Roger Mrzyglocki, Arnaud Mignan, Bijan Khazai, Friedemann Wenzel, Anthony Patt, and Kevin Fleming
International Journal of Disaster Risk Reduction, vol., pp. 50-67
doi: 10.1016/j.ijdrr.2013.12.006

Keywords: *Multi-hazard, multi-risk, decision support models, stakeholders, stakeholder's perceptions, risk governance.*

Introduction

Historical records show that economic losses from disasters have increased steadily from € 150 billion (value inflation adjusted for the year 1999) in the period 1950-1959 to about € 375 billion in the decade 1990-1999 (Munich RE, 2000). Non-economic losses, such as human lives, are much more difficult to define and they are not included in the majority of databases, but there is ample evidence in the literature that the number of people who are directly or indirectly affected in terms of daily life disruptions, losses of livelihood and deepening of poverty continues to increase (Arnald et al., 2006; Daniell et al., 2011; Hoyois and Guha-Sapir, 2003; World Bank, 2010). Many regions of the world are not simply subject to single types of hazards, but may be impacted upon by multiple hazards, which yields higher direct losses, such as damage to infrastructure, as well as higher indirect losses, such as business interruptions.

Existing risk assessment methods integrate large volumes of data and sophisticated analysis, as well as different approaches for risk quantification. However, the key question is why, if our scientific knowledge on multi-risk is increasing, are losses from natural disasters continuing to grow? (White et al., 2001). One reason might be the increasing value of assets exposed to hazards. However, there may be other reasons, and an understanding of these will play a key role in the reduction of losses in the future. As Kappes et al. (2011) state in their work, to be able to understand this question, we need to examine also the frameworks employed in the field of risk management, as well as the interactions between science and practice in terms of knowledge transfer and the applicability of results. The successful implementation of disaster risk reduction options and strategies demands not only comprehensive risk assessment schemes, but also an appropriate mechanism to communicate and transfer knowledge on risk and its underlying drivers to the various stakeholders involved in the decision-making process.

Multi-risk assessment tools have the potential to support decision-makers and provide them with information on mitigation measures. These tools influence the perceptions of stakeholders in terms of the probabilities of hazards and their impacts. But this is a double-sided communication process, as the feedback from stakeholders influences the usability of the tools and the implementation of recommendations provided by the geosciences, sociology and economics. That is why the feedback and perceptions of the usability of these models from the side of stakeholders are extremely important for the process of communication from science to policy and vice versa. So far, however, the literature on the topic of how stakeholders perceive the usability of multi-risk models is very limited.

The major aim of our research was to identify the perceptions of stakeholders to the value of two complementary decision-making tools:

(1) A generic probabilistic framework that implements hazard correlations in a comprehensive manner (Mignan, 2013), and
(2) An evaluation methodology based on the concept of the risk matrix to incorporate expert knowledge through stakeholder interactions into multi-hazard scenario development developed by B. Khazai at the Karlsruhe Institute of Technology and described in this deliverable.

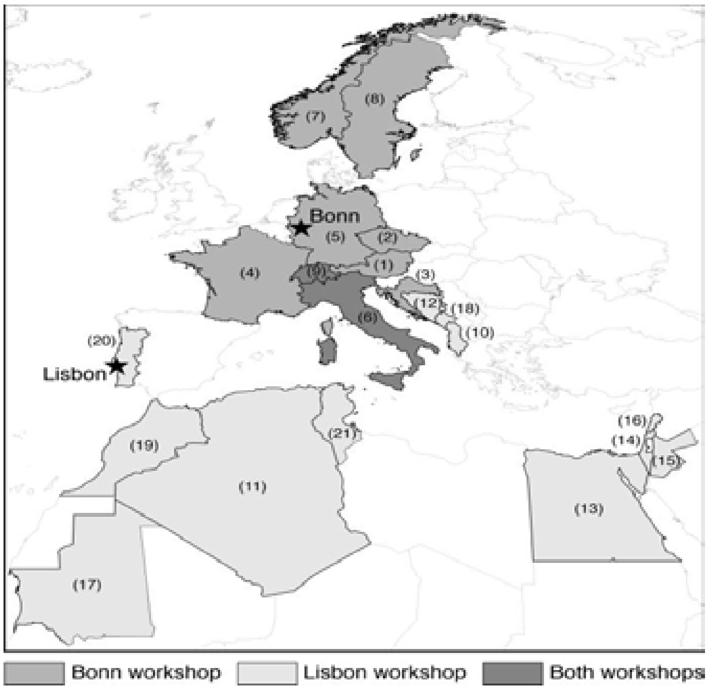
This work is a first approach to collect the perceptions of stakeholders from civil protection authorities on the decision-making tools being developed within the context of the MATRIX project. The research within this work encompasses three overarching questions:

(1) How do stakeholders perceive multi-hazard and multi-risk situations and what are their requirements for multi-risk assessment tools?
(2) How do stakeholders perceive the decision-making process for the mitigation of multi-risk and their perceptions on the usability of decision-making tools?
(3) Is there a difference in the resulting perceptions between stakeholders (based on practice) and academia (based on more theoretical considerations)?

We collected perceptions from stakeholders within framework of two workshops (figure 1). The first was held in Bonn, Germany, on the 6th and 7th of July 2012, under the auspices of the MATRIX project, while the second took place on the 17th to 19th of October 2012 in Lisbon, Portugal, sponsored by the Italian Civil Protection ("Multi-hazard risk assessment in urban environment", 12th PPRD South "prevention and preparedness" workshop for staff-level officials). The workshop in Bonn was the main source of data on stakeholder's perceptions while the one in Lisbon provided us with a secondary source of data dealing with perceptions of the tools developed after feedback from stakeholders in Bonn.

The selection of stakeholders for our study forms a representative sample, given the fact that over 50% of all national platforms in Europe were involved into our research. The stakeholders, except for Austria, represented the National Platforms. Someone might argue that the number of stakeholders involved is too small for a large-scale survey. However, here we would like to point to the fact that our aim was not to conduct a large-scale survey, but to reach targeted groups of stakeholders, such as civil protection platforms and the UN-ISDR.

As we did not apply methodologies appropriate for large-scale surveys, but instead used specialized targeted questionnaires as well as collect feedback during workshops, we regard our sample of stakeholders as being representative, as it covers most of the European countries.



Bonn Workshop

(1) Austria - Federal Ministry of Agriculture, Forestry, Environment and Water Management
(2) Czech Republic - National Committee for Natural Disaster Reduction
(3) Croatia - National Protection and Rescue Directorate
(4) France - Ministère de l'Ecologie, de l'Energie, du Développement durable et de la Mer
(5) Germany - Federal Office of Civil Protection and Disaster Assistance
(6) Italy - Civil Protection Department
(7) Norway - Directorate for Civil Protection and Emergency Planning
(8) Sweden - Center for Climate and Safety
(9) Switzerland - United Nations International Strategy for Disaster Reduction

Lisbon Workshop

(10) Italy - Civil Protection Department
(11) Switzerland - United Nations Office for Disaster Risk Reduction
(12) Albania - Civil Emergencies
(13) Algeria - General Directorate of Civil Protection
(14) Bosnia and Herzegovina - Ministry of Security
(15) Egypt - General Administration of Civil Protection
(16) Israel - Ministry of Home Front Defence
(17) Jordan - Rescue and Support Directorate
(18) Lebanon - Civil Defence
(19) Mauritania - Mayor
(20) Montenegro - Department for Civil Protection
(21) Morocco - General Directorate of Civil Protection
(22) Portugal - National Authority for Civil Protection
(23) Tunisia - Civil Protection

Figure 1: The countries that participated in the workshops held in Bonn and Lisbon, as well as in the questionnaire prior to the Bonn workshop and the survey after it.

Background

Definitions of multi-risk assessment

Risk assessment includes hazard assessment, followed by estimations of the vulnerability and values of the elements at risk (or exposure), all leading to the computation of risk as a function of hazard, vulnerability and exposure (Varnes, 1984). The term “natural hazard” refers to the “natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage” (UNISDR, 2009). Risk is defined as “expected losses of lives, persons injured, property damages and economic activities disrupted due to a particular hazard for a given area and reference period” (WMO, 1999). Another definition of risk is “the combination of the probability of an event and its negative consequences” (UNISDR, 2009). In any case, a definition of risk must also include the interaction of hazards and the vulnerability of the affected area, especially the built environment. Definitions developed by the European Commission extend the previous definitions by incorporating the terms “exposure” and “vulnerability” (COM, 2010a). This foresees that an event of the same magnitude can have a different impact, dependent upon the vulnerability and exposure of a given population and the associated elements, thus also involving the need to take into consideration preparedness and preventive measures. The definition of risk is also closely connected with the definition of uncertainty, as the term “probability” itself implies uncertainties. Risk can also be understood as “the effects of uncertainty on objectives” which appear as a “combination of the consequences of an event and the associated likelihood of occurrence” (ISO Guide 73:2009). It is therefore important to understand such uncertainties when it comes to the development of decision-making models and tools for the purposes of civil protection.

The purpose of multi-risk assessment is therefore to establish a ranking of different types of risk, taking into account possible conjoint and cascade effects. Multi-risk assessment is a relatively new field, until now developed only partially by experts with different backgrounds such as engineering, statistics or various fields of geosciences. Currently, there is no clear definition of “multi-risk”, neither in science, nor in practice (COM, 2010a; Kappes et al., 2012). The only definition that exists concerns the requirements for multi-risk, which needs to consider multiple hazards and multiple vulnerabilities (Carpignano et al.; Di Mauro et al., 2006; Marzocchi et al., 2012; Selva, 2013).

There are essentially two ways to approach multi-risk. The first considers the different types of hazards and vulnerabilities of a region and combines the results of various single risk layers into a multi-risk concept (Grünthal et al., 2006). This approach provides an overview of multiple risks, but neglects the interactions between the hazards and vulnerability. The second one considers the risk arising from multiple hazardous sources and multiple vulnerable elements coinciding in time and space (Di Mauro et al., 2006). In these cases, we speak here about conjoint and cascading events. Conjoint events are when a series of parallel adverse events are generated by different sources, for example a windstorm occurring at the same time as an earthquake (Di Mauro et al., 2006). Cascading events on the other hand are when an initial event (located inside or outside an area) triggers a subsequent event or series of events, for example an earthquake that then triggers landslides or tsunamis (Marzocchi et al., 2012).

The first approach considers more than one type of hazard, but it ignores the spatial and temporal relationships between the hazards and other elements of the risk chain. For example, in the Cities Project in Australia (Granger, 1999), a number of urban and regional areas were assessed for a wide range of geohazards, however, the various interactions that may arise between them were not part of this program. Similarly, in the German Research Network Natural Disasters Project, the city of Cologne was assessed for earthquakes, windstorms and river floods separately, and while losses in terms of monetary values arising from each hazard were plotted together against the probability of occurrence to allow a comparison, the possible interactions between them and the effect this has on the final risk were not considered, nor were the associated uncertainties (Grünthal et al., 2006). Again, neither of these studies considered the possibility of one hazard type triggering another, nor the consequences of events occurring simultaneously, or nearly-simultaneously, and how this affects an area's vulnerability. Hence, by not considering such interactions, which may lead to increased losses, such frameworks potentially grossly underestimate the final risk. Moreover, most of these studies employ the term "multi-risk" to describe what should really be referred to as "multiple single risk", which adds to the confusion.

By contrast, the second type explicitly considers spatial and temporal interactions between different hazards and their subsequent risk. An example is the EC FP6 NaRaS project for the Casalnuovo municipality in the province of Naples in Italy. This municipality is located just 13 km away from the crater of the Mount Vesuvius volcano and is exposed to several kinds of hazards, such as the Vesuvius volcano itself, active faults in the Apennine chain (the tectonic source area of the damaging 1930 and 1980 Irpinia earthquakes), as well as the presence of industrial landfills. A study supported by the local government, who was interested in the identification of the most dangerous hazards and the most effective way of financing risk mitigation measures, found that volcanic risks significantly overwhelm all others, but also that the risks associated with volcanic processes and the effects these have on industry may be underestimated if the interactions between them is not considered (Marzocchi et al., 2012).

Experience of civil protection authorities with multi-risk assessment

The reduction of risks cannot be only based on scientific knowledge about natural hazards, since risks also have social and psychological dimensions which are in turn shaped by political and cultural values (Assmuth et al., 2010). Therefore, for the successful implementation of risk mitigation measures, it is necessary to identify these different factors. The newly appearing concept of *risk governance* takes into account these ingredients and emphasizes the role of participation and communication. It is also crucial to incorporate the “insider” knowledge of stakeholders into multi-risk assessment models, and their underlying parameters and outputs, such as the consequences in case of failure. Risk governance is concerned with how information is collected, perceived and communicated and follows how management decisions are taken (IRGC, 2005). Within the context of risk governance, risk communication not only transfers information on risk or risk management decisions, but it also includes a two-way process for communicating stakeholder perceptions in shaping the outcomes of risk assessments.

Civil protection authorities have started only recently to apply multi-risk assessments for natural and technological disasters. In 2009, the European Commission issued a communication document with a set of measures to be included in the strategy of the European Commission for the mitigation of natural and man-made disasters (COM, 2009). Amongst other elements, the communication document outlines the need for multi-risk assessment. The development of multi-risk assessment methods, however, is not an easy task, given the diversity of methodological approaches in mapping risks among Member States. As an answer to this challenge, the European Commission also highlights the need for common guidelines, which will enhance the comparability of risks across Member States and will lead to a common European picture of risk.

The European Union Internal Security Strategy is another milestone towards the development of multi-risk assessment. The strategy foresees the establishment of a coherent risk management policy, which will link threats and risk assessment into decision-making (COM, 2010b). The major aim is to increase the resilience of EU member countries to crises and disasters. Among other risk mitigation measures, the strategy foresees an “all hazards approach to threat and risk assessment”.

The Risk Assessment and Mapping Guidelines for Disaster Management, published in 2011, is the third milestone (COM; 2010a). The guidelines are based on the existing national risk assessment methodologies and take into account existing EU legislation, such as the European Flood Directive. The guidelines focus on the processes and methods of national risk assessments, as well as on the mapping of risk assessment into the prevention, preparedness and planning stages. Even though it provides guidance for such steps as risk identification, risk analysis and risk evaluation, it does not deal with capacity analyses, capability planning, monitoring and review, nor with the consultation and communication of findings and results of risks assessments with stakeholders. Instead, it focuses on risk assessment not only in terms of methodologies, but also with respect to the harmonization of previous and current initiatives on risk assessment and procedures for risk assessment at the national and the European levels. However, it does not evaluate the pattern of decision-making and barriers for the implementation of risk assessments.

Existing decision-making models for multi-risk assessment

Currently, various decision models for multi-hazard and multi-risk assessment are being developed, but to be useful in disaster management, these models must respond to the requirements and expectations of the civil protection community. The principle aim of such models should be to provide stakeholders with a set of scenarios or alternatives to help them make or select the most appropriate decision or action. In risk assessment, decision models display different risks with respect to their probability and frequency, as well as to their possible outcomes. Even though the majority of decision models were developed to assess single types of risks and hazards, some models are available for multi-risk mapping of natural hazards and their impact assessment. These are the decision-making model developed within frameworks of the FP6 project ARMONIA[10] (T6, 2007) and the scenario-based approach for risk assessment used by the German Federal Office of Civil Protection and Disaster Assistance.

A decision-making model “Multi-Risk Land Use Management Support System” was developed through the ARMONIA project. The objectives of the decision-making model are to provide a basis for planning activities in areas that are prone to multiple natural hazards. The model provides assessments of both the exposure and vulnerability of a region. As a

[10] Applied Multi Risk Mapping of Natural Hazards for Impact Assessment

decision-support tool, it is intended to support planners with their decisions regarding land-use issues and the location of strategic facilities. Another objective of the tool is to develop a structure which will help ensure that planning decisions are made while being fully informed about multiple risks and the respective vulnerability of different population structures and land-use types in order to provide options for mitigating risks. The model provides different options for the mitigation of risks and the reduction of vulnerabilities through a system of Multiple Criteria Evaluations. Also, it provides a knowledge base on different approaches, which can be taken to mitigate risks through land-use management decisions.

The German Federal Office of Civil Protection and Disaster Assistance (BBK) use a scenario-based approach for risk assessment (BBK, 2010). If understood as a combination of hazardous events, multi-risk can be integrated into the concept of visualizing risks by using a risk matrix, which combines likelihood and impact. The development of such risk matrices was proposed by the risk assessment and mapping guidelines for disaster management developed by the European Commission in 2010 and is current practice in several European countries. Within the risk matrix, multi-risk events could be represented as additional scenarios (figure 2) and thus integrate this information into the knowledge base for decision-making processes.

To date and to the best of our knowledge, three principal software tools have been developed to provide multi-hazard risk assessments of a given territory. These are HAZUS[11] for the USA, RiskScape for New Zealand (Schmidt et al., 2011) and CAPRA[12] in Central America. HAZUS provides estimates of potential losses from hurricanes, earthquakes and floods, considering the physical, economic and social impacts of disasters and graphically illustrates the extent of identified high risk locations due to the three above-mentioned hazards. HAZUS is largely used by stakeholders, mainly government planners and emergency managers, to determine losses and the most beneficial approaches for their mitigation. However, it is also used by communities for the evaluation of economic loss scenarios with respect to certain hazards and to increase public awareness (FEMA, 2013). RiskScape facilitates estimations of volcanic ash falls, floods, tsunamis, landslides, storms and earthquakes. It is intended to be an “easy to use multi-hazard impact and risk assessment tool”. Its aim is to inform decision making, including land-use planning, emergency management, assets management and insurance. This tool foresees interactive cooperation with users, and has put in place a development blog on-line where users can exchange their experience with the software and suggest improvements (Reese et al., 2007). CAPRA provides analysis for hurricanes, heavy rainfall, landslides, floods, earthquakes,

[11] http://www.fema.gov/hazus
[12] http://www.ecapra.org

tsunamis and volcanic hazards. It combines hazard information with exposure and physical vulnerability data and allows users to determine conjoint and cascade risk on an inter-related multi-hazard basis (CAPRA Probabilistic Risk Assessment Initiative, 2011).

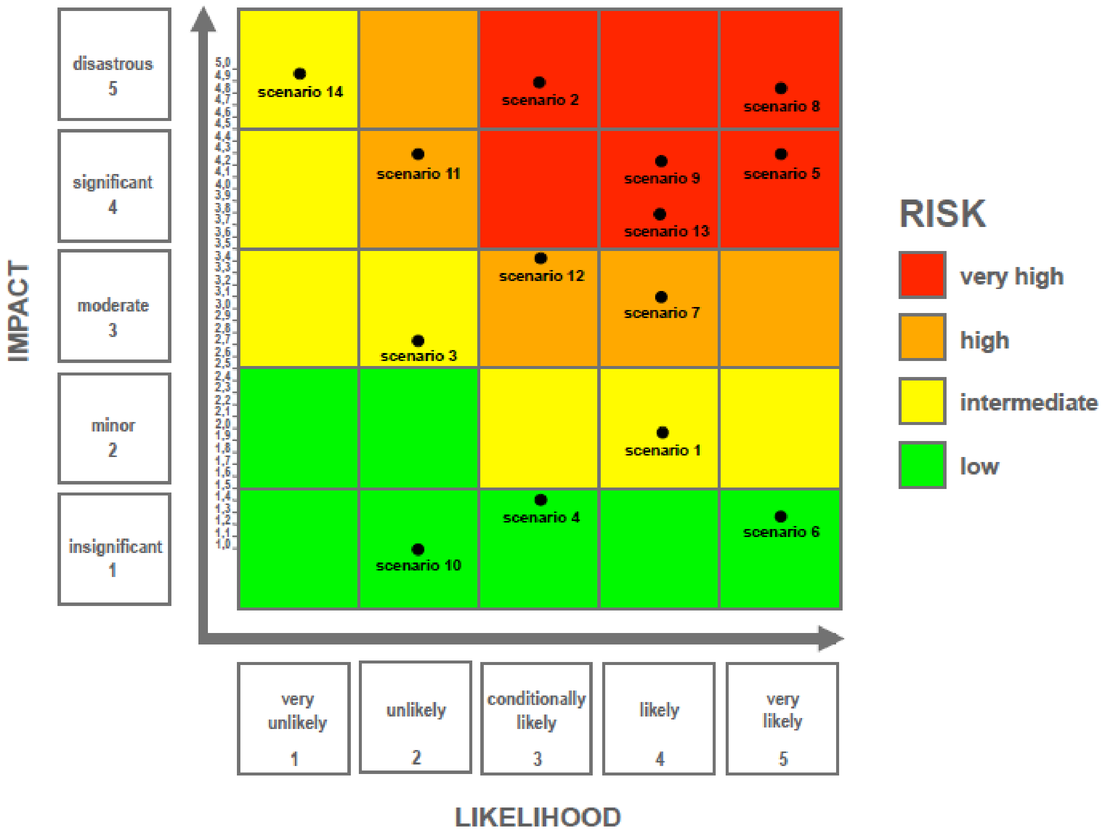


Figure 2: Example of how different scenarios fit within a risk matrix (BBK 2010).

These models focus on different geographical regions, such as the United States of America in the case of HAZUS, New Zealand for RiskScape, and Latin America and some Asian countries with CAPRA. HAZUS has been further developed as HAZTURK and HAZTAIWAN with customized functionality for Turkey and Taiwan, respectively. CAPRA is applied outside of Central America in countries such as India, Bangladesh and Nepal. RiskScape has also recently been applied in South East Asia. Even though the developers of these tools propose an interactive process with stakeholders, currently a scientific review or evaluation of the results from the use of these software and feedback from stakeholders is not available.

To our knowledge, even though some of these models have been tested by operational and practicing stakeholders, there is no evidence of stakeholder feedback. For example, the decision-making model developed by ARMONIA defines weights based on the judgments from stakeholders on different vulnerabilities within the area of their interest. Thus, it produces the risk factors for each hazard, as the risk factor is given as the vulnerability weight. Although risk factors cannot be compared across hazards, they can be compared across different scenarios. Once risk factors are included in one scenario, the stakeholder can run another scenario. By the end, the stakeholder is able to see a set of risk futures created by changes in the environment. However, there is no scientific work which analyses the perceptions of experts from civil protection in terms of usability and applicability. This deficiency is therefore one of the motivations for our research, where we have collected the perceptions of stakeholders through the methodology of stakeholders´ interactions via such means as questionnaires, decision-making experiments and workshops.

Multi-risk decision-support methods

Social science scholars argue that because production of scientific tools is a social process, it is essential to involve relevant stakeholders who will be using the tools into the process through collection and integration of their feedback (Tesh, 1990). We collected feedback from stakeholders regarding two decision support models. Both models were developed in frames of the MATRIX project. The first model "Generic multi-risk framework" was developed by the Swiss Federal Institute of Technology in Zurich (ETH Zurich). It quantifies multi-risk in a controlled environment to show the benefits of such an approach for decision-making (Mignan, 2013; Mignan et al., submitted). The second model was developed by B. Khazai at the Karlsruhe Institute of Technology (KIT). It communicates multi-hazard and multi-risk results to stakeholders, by using concepts of risk ranking and the risk matrix metric (Wenzel, 2012). While these methods were treated independently during interactions with stakeholders, we will show in our results and discussion sections that method (1) should be combined with method (2) to facilitate the communication of multi-risk assessment, as was discussed at the stakeholders' workshop in Bonn. During the workshop in Lisbon, Method (1) was combined with the visual tool developed within the framework of Method (2).

Method (1): Generic multi-risk framework

The development of a comprehensive multi-risk framework is limited by three main requirements, namely the large amount of input data required, cross-disciplinary expertise and innovative risk assessment methods. The first two points are generally solved in dedicated multi-risk projects at the national, international or private sector levels (see the previous description of the tools HAZUS, RiskScape and CAPRA). The third point remains to be solved. As indicated by Kappes et al. (2012), "despite growing awareness of relations between hazards, still neither a uniform conceptual approach nor a generally used terminology is applied".

Mignan (submitted) proposed a novel, generic, multi-risk framework based on the sequential Monte Carlo method to allow for a straightforward and flexible implementation of hazard interactions, which may occur in a complex system. Considered hazard interactions are analogue to the ones observed in recent catastrophes, such as the 2005 hurricane Katrina or the 2011 Tohoku earthquake. Validation of the framework of Mignan, which should be considered as a proof of concept, was made on a synthetic data set, based on the concept of a virtual city within a virtual hazardous region where generic data are defined heuristically (Mignan et al., 2014).

In an early version presented at the two workshops (figure 3), the role of intra-hazard earthquake interactions and of inter-hazard hurricane/storm surge interaction was presented. In the latest version of this work, additional interactions have been considered, such as an explosion at an oil refinery due to a natural event or to a cascade of natural events (figure 4). Other events considered in the latest version include asteroid impacts (AI) and technological accidents (TK).

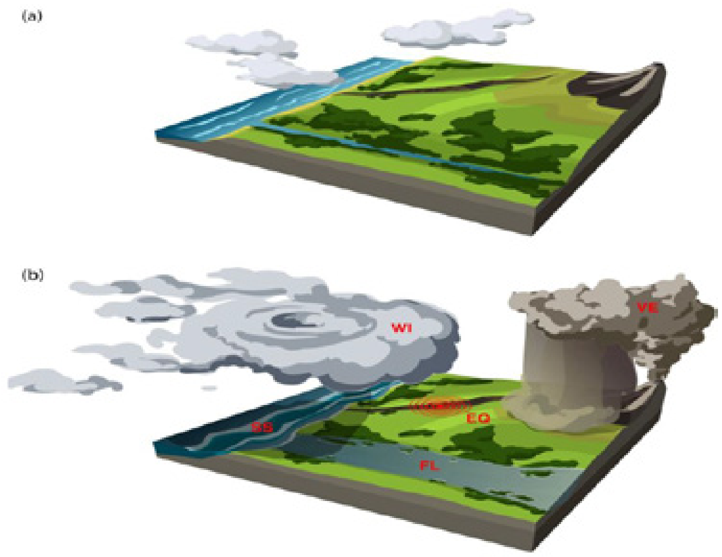


Figure 3: Artistic representation of an early version of the proposed virtual hazardous region. Top: Morphology of the 100 by 100 km region. Bottom: hazards considered are earthquakes (EQ), volcanic eruptions (VE), fluvial floods (FL), winds (WI) and sea submersions (SS). See also MATRIX deliverable D7.2. (Mignan, 2013).

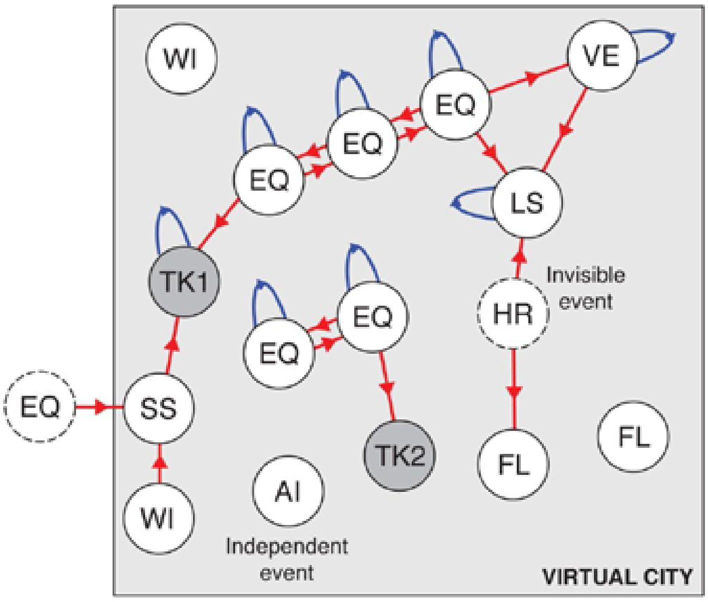


Figure 4: Network representation of the hazard interactions defined by Mignan et al. (2014) within the concept of a virtual city within a virtual region. Hazards are: earthquakes (EQ), volcanic eruptions (VE), fluvial floods (FL), winds (WI), sea submersions (SS), landslides (LS), asteroid impacts (AI), heavy rains (HR) and technological accidents (TK).

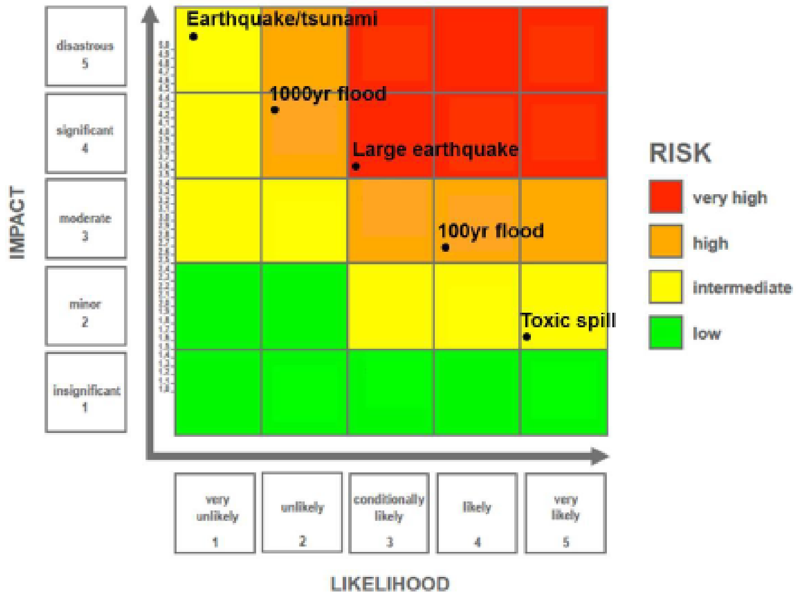
In the figure 4, positive and negative effects are represented by red and blue arrows, respectively. The spatial distribution of the different hazards roughly follows the virtual region's constraints, as defined in figure 3. The hazards considered are earthquakes (EQ), volcanic eruptions (VE), fluvial floods (FL), winds (WI), sea submersions (SS), landslides (LS), asteroid impacts (AI) and technological accidents (TK). Some events, referred to as independent events, are not influenced by the occurrence of other events (e.g., AI) but may occur simultaneously. Mignan et al. (2014) also introduced the concept of invisible events (e.g., heavy rains, HR; offshore earthquakes), which do not yield any direct damage, but interact with other damaging events. Some interactions have analogues to recent catastrophes. For example, EQ ➔ SS (tsunami) ➔ TK is reminiscent of the Tohoku earthquake / Fukushima nuclear disaster of 2011, Japan. Here TK also refers to a NaTech (Natural - Technological) event, since it (TK) is triggered by a natural hazard (SS). A negative effect represents the case when the occurrence of a second event becomes less likely or even impossible. For example, if a landslide occurs, a stable slope may be created, which hampers the occurrence of a new landslide at the same location. Again, if a technological accident occurs and the critical infrastructure is not repaired, the repeat of the same technological accident may be impossible.

The heuristic strategy, that is the use of intuitive judgment and simple rules, allows for the solving of problems that are otherwise too difficult to consider. As explained later in the results section, this approach is a very effective way to communicate the role of multi-hazard to stakeholders, regardless of their level of familiarity with the concepts of correlated chains of events and their impact on risk.

Method (2): Decision-support tool

The methodology of the decision-support tool follows the agreed definition on risk as a combination of the consequences of an event or hazard and the associated likelihood of its occurrence. Adapting the BBK (2010) framework, consequences are expressed in terms of impacts in the following categories: people (expected casualties, homeless, affected persons), economy (expected financial losses, capital stock, business disruptions), environment (threat to ecosystem, groundwater, agricultural areas stability and sustainability), infrastructure (Interruption in fresh water, gas, energy, telecommunications, transportation systems) and intangibles (public security, political consequences, psychological implications and loss to cultural values). In this way, a risk matrix relating the two dimensions of likelihood (in terms of probabilities of occurrence) and impact (in terms of an ordinal category of loss which can be expressed as “catastrophic”, “large”, “moderate”, “small” and “irrelevant”) is a graphical representation of different risks in a comparative way, and can used as a simple approach for setting priorities. Accordingly, the risk matrix presents a visual two-dimensional display of the “ranking” of risk scenarios in terms of a frequency and impact scale that is relevant to the region of interest, and will help in interpreting historical experience and translating expert opinion in a consistent manner.

The risk matrix methodology was implemented into decision-support software based on the principles of Multi-Criteria Decision Analysis (MCDA), and tested with a group of stakeholders to communicate and transfer the information contained for the different risk scenarios in the risk matrix to the various stakeholders involved. We describe our methods of interactions with stakeholders in the methodology section. The decision-support tool allows the stakeholders to display the total risk index ranking of different risk scenarios (e.g., an extremely rare offshore earthquake which can trigger a tsunami, or a release of toxic material with severe impacts on the local environment, etc.) affecting a region in terms of expected losses that are quantitatively derived in different sectors (human, environment, economy, infrastructure, intangibles) for each scenario (figure 5).

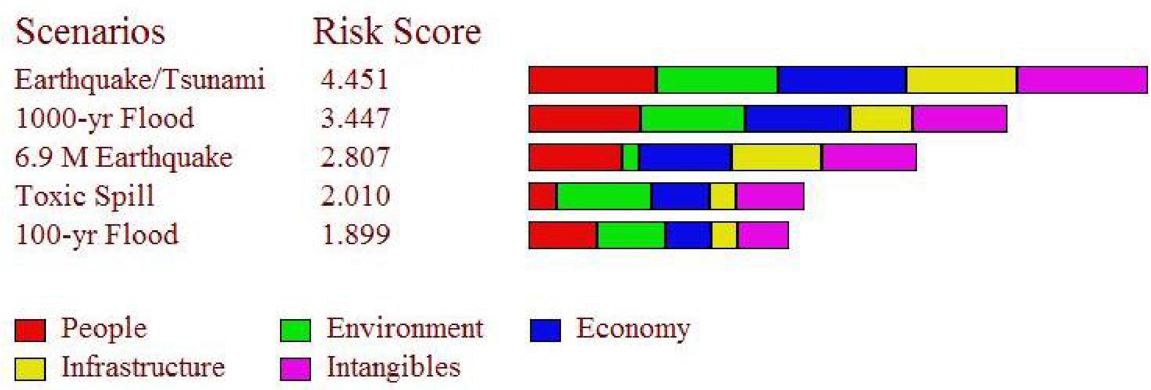


Hazard Type	Probability of Occurrence	Frequency	Impact				
			People	Economy	Environment	Infrastructure	Intagibles
Earthquake	1 in 475 years	conditionall y-likely	significant	moderate	insignificant	significant	significant
Earthquake / Tsunami	1 in 10,000 years	Very Unlikely	disastrous	disastrous	moderate	disastrous	significant
Extremely rare Flood	1 in 1000 years	Unlikely	significant	significant	disastrous	significant	significant
Regulatory Flood	1 in 100 years	Likely	minor	insignifican t	moderate	moderate	moderate
Toxic Spill	1 in 20 years	Very likely	insignifican t	insignifican t	significant	insignificant	insignificant

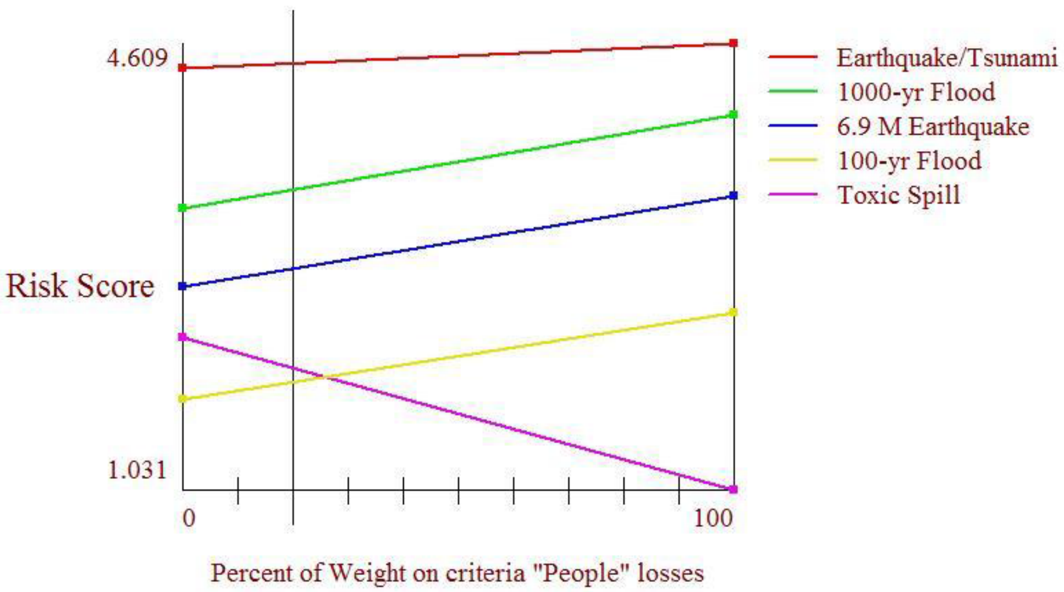
Figure 5: Methodology of the decision-support tool, where scenarios are ranked in the risk matrix (top).

According to this approach, the sectoral losses are combined together as a weighted sum into one single aggregated *loss score* for each scenario (figure 6). Together, these two steps (i.e., severity and loss scores) are combined to produce a *total risk index* for each scenario.

For example, in figure 6a, it can be seen that the offshore earthquake triggering a tsunami is deemed to have a much greater risk score than the toxic spill. As the total risk index for each scenario is determined as the aggregate weighted sum of each of the loss measures in each of the different sectors, the risk index ranking will also depend, of course, on the weights given to each sector. Through a participatory approach, the stakeholders assign the relative importance (weights) to the losses for the different sectors for each of the scenarios likely to occur in the region. Next, the decision support software is used in a group setting to discuss the weighting outcomes and interactively examine the variability of the ranking results. For example, a sensitivity graph can be used to see the effect on the rankings as the weights are changed. In figure 6b it can be seen that as more weight is given to the “People” criteria (i.e., casualties, short- and long-term mass care), the risk score for the toxic spill decreases considerably. This is due to the fact that the toxic spill scenario produces none to very few fatalities and has an insignificant impact on mass care. As a result, when all the weight is given to only one measure, in this case human losses, the risk score for this scenario is minimal. On the other hand, the risk score of all other scenarios goes up, but importantly the relative rankings between them stays the same. Using various visualization tools in the decision support software, such as sensitivity graphs, stacked bars, scatter plots, and one by one comparison between scenarios, the stakeholders are able to evaluate the total risk from different scenarios by considering many variables at once, which enables them to separate facts from value judgments, and better communicate their choice to others.



(a)



(b)

Figure 6b: (a) Total risk score and ranking shown for each of the scenarios. (b) Graph showing sensitivity of the total risk score to changes in the weights applied to the "People" losses criteria.

Methodology

In this document, we follow the MATRIX lead and consider only those hazards that are most likely to affect Europe, in particular earthquakes, landslides, volcanoes, tsunamis, wild fires, storms and fluvial and coastal flooding. However, NaTech disasters, while a critical, were outside the scope of the project and therefore are not addressed in this approach.

As mentioned in the introduction, we worked together with stakeholders from National Platforms for Disaster Risk Reduction, which are most commonly part of national Civil Protection organisations. Furthermore, the United Nations Office for Disaster Risk Reduction (UN-ISDR[13]) and the Federal Ministry of Agriculture, Forestry, Environment and Water Management, Austrian Service for Torrent and Avalanche Control[14], were involved. National Platforms are governmental organizations, for example, at the level of the Ministry of Interior - Civil Protection Department or are acting as non-governmental organizations like the German Committee for Disaster Reduction (DKKV)[15]. They are multi-stakeholder committees comprising experts and members from different sectors, enabling them to act as centres of expertise in the field of disaster risk reduction (DRR). National Platforms are advocating for DRR at all governmental and social levels and are generally responsible for coordinating DRR activities, which require a coordinated and participatory process. According to the definition from the UN-ISDR, a National Platform for Disaster Risk Reduction "should be the coordination mechanism for mainstreaming DRR into development policies, planning and programs in line with the implementation of the Hyogo Framework for Action (HFA). It should aim to contribute to the establishment and the development of a comprehensive national DRR system, as appropriate for each country".

The United Nations Office for Disaster Risk Reduction is the secretariat of the UN-ISDR, and is the successor arrangement of the secretariat of the International Decade for Natural Disaster Reduction (IDNDR). It was established in 1999 in order to ensure the implementation of the UN-ISDR and the Hyogo Framework for Action (HFA, 2005), which was adopted during the World Conference on Disaster Reduction in Kobe in 2005. Amongst the different activities the secretariat's mandate involves, one is to "provide support to countries and HFA focal points in the establishment and development of national platforms for disaster risk reduction and backstop their policy and advocacy activities; develop improved methods for predictive multi-risk assessments, including the economics of disaster

[13] http://www.unisdr.org/
[14] http://www.lebensministerium.at/en/fields/forestry/Naturalhazards/Avalanchecontrol.html
[15] http://www.dkkv.org/

risk reduction and socio-economic cost-benefit analysis of risk reduction; and integrate early warning systems into their national disaster risk reduction strategies and plans".

The research questions considered in this work are focused on stakeholders´ perceptions. This is why we use the methodology of stakeholders´ interactions. Our methodology includes several methods, among them the distribution of questionnaires to collect the perceptions of stakeholders on multi-hazard and multi-risk terminology and their views on existing multi-risk assessment tools, decision-making experiments and workshops. Importantly, we collected feedback from those stakeholders who participated in the workshops mentioned above and combined this information with that obtained from our surveys.

The Bonn workshop provided the opportunity to present and discuss current hazard and risk mapping concepts and highlight the importance of data and information for hazard and risk assessments. It allowed time for discussions on the added value of risk assessments within the context of disaster risk reduction, and to better understand current national hazard and risk assessment approaches. The part of the workshop dealing with tools for multi-risk scenarios had three aims. First, it was to capture the status of the different approaches and associated problems with regards to multi-risk assessment in Europe. The second aim was to understand the users' requirements with respect to information technology for the generation of scenarios. The third aim was to understand the range of risk components addressed in the current practice, such as losses to people's health and lives, the economy, ecological damage, impacts upon infrastructure and critical infrastructure, and intangible losses. During the workshop, we presented the results from the stakeholder survey and afterwards collected their feedback.

The general aim of this workshop was to improve the knowledge of the research community about the current status, such as availability, methods, and barriers, of hazard, risk and multi-risk assessment among the involved European countries. The focus was to understand the value of multi-hazard and multi-risk approaches and tools in real world conditions. This involved questions such as: What are the added values of hazard and risk assessments and what are their levels of integration into decision-making processes? What are the requirements for multi-risk assessment methods and tools from the perspective of disaster management? The surveys allowed us not only to gain answers to the questions set above, but also to capture the stakeholders' perceptions of the term "multi-risk".

a. Stakeholders interactions on the Method (1)

The generic multi-risk framework and its application in a virtual city were presented by A. Mignan at the workshop in Bonn. Further on, feedback from stakeholders received during the discussion of the framework was integrated and the improved generic multi-risk framework was presented and discussed with stakeholders during the Lisbon workshop. The presentation of the generic multi-risk framework in Lisbon was followed by a half-day exercise co-organized with the PPRD South team and other speakers. The exercise's aim was to provide a better understanding of the role of multi-hazard in overall risk assessment by considering two sites: Lisbon, Portugal and Istanbul, Turkey. The first part of the exercise consisted in investigating the different hazards present in the two cities based on different data, such as hazard maps, provided in the guidelines of the exercise, and to give some score to their severity and frequency, that is within the concept of the risk matrix, as described in Method (2). The second part of the exercise was to discuss potential triggering effects, based on the Virtual City results and experienced catastrophes. Participants then updated their risk matrix based on multi-hazard information and presented their new results. The final objective was to highlight the idea that new risks emerge and some others may shift to lower-probability/higher-consequence events when multi-hazard is considered in risk management.

b. Stakeholders interactions on the Method (2)

Several scenarios were developed according to this method and presented to stakeholders at the workshop in Bonn to identify the impacts arising from each type of hazard on society on the basis of multiple loss categories, such as population, economy, ecology, infrastructure, and intangible losses. However, as these losses were not exclusively expressible in monetary terms, but rather in descriptive parameters, stakeholder input was needed to identify the weights with which the impact of particular components in the overall picture of impact are specified in a participatory fashion (i.e., what is the relative importance of the different loss parameters in the risk ranking?). Thus, the primary difficulty in gathering stakeholder input involved creating a "value model" that would support stakeholders in assessing problems and expressing their views more explicitly. Using the decision-support tool in the workshop, the stakeholders ranked and compared risk scenarios to each other relative to one (or several) loss criteria by following the five steps below:

(1) Identify all the risk scenarios to be ranked.

(2) Identify loss parameters to quantify the risk score of each scenario.

(3) Quantify the loss score (5 categories, from irrelevant to catastrophic) for each of the loss parameters for each scenario.
(4) Quantify preferences (weights) for different loss categories and loss parameters.
(5) Rank the scenarios by combining information from steps (4) and (5).

Following the ranking of the scenarios, the stakeholders used the visualization tools of the decision-support software tool to conduct interactive sensitivity analyses to detect the most significant factors in the ranking of scenarios, and identify whether or not a criteria differentiates between two scenarios. Furthermore, stakeholders discussed ways to characterize uncertainties in the loss parameters and set priorities by determining how much greater risk one scenario poses over another.

Results

Perceptions of multi-hazard and multi-risk situations and the requirements of stakeholders in multi-risk assessment tools

To be useful in practice, multi-risk tools and methods need to be in-line with the requirements and expectations of the civil protection community. The results from the round table discussions at the workshops and from the returned questionnaires showed that stakeholders perceive two areas as being most problematic for multi-risk assessment tools. These are (1) the absence of clear definitions and (2) what is the added value of multi-risk assessment.

First, there is still no common understanding, nor a smooth transition between the terms "multi-risk" and "multi-hazard". These facts indicate that a common terminology does not exist and disaster management terms are used differently among different European countries. It showed the need to develop a glossary with definitions and terms relevant to multi-risk and multi-hazard, going beyond already existing basic definitions developed, for example, by the UN-ISDR. However, during the workshop discussions and as indicated in the questionnaires, almost all stakeholders agreed with the proposed definition of multi-risk, given as:

"Multi–risk represents a comprehensive risk defined from interactions between all possible hazards and vulnerabilities."

Second, the added value of multi-risk assessment in comparison to the single risk assessment and hazard assessment was not completely clear. There are also fears that multi-risk assessment will lead to more complicated and time demanding risk assessment procedures in comparison to single risk assessment. Several stakeholders spoke up that it is not possible to identify which assessment is more important, single risk or multi-risk, and spoke for the necessary combination of both of them. However, in the implementation of risk mitigation policies, stakeholders identified several advantages of the multi-risk approach relative to single risk approaches. The major advantage is in the intensified cooperation between stakeholders who are involved in the assessment and mitigation of different kinds of natural hazards, resulting in better planning and cost efficiency during the decision-making processes.

A common opinion was that the results of risk assessment are generally less needed than reliable hazard assessment products, such as hazard maps. The hazard assessment is also more frequently applied, most often for floods and landslides (Figure 7).

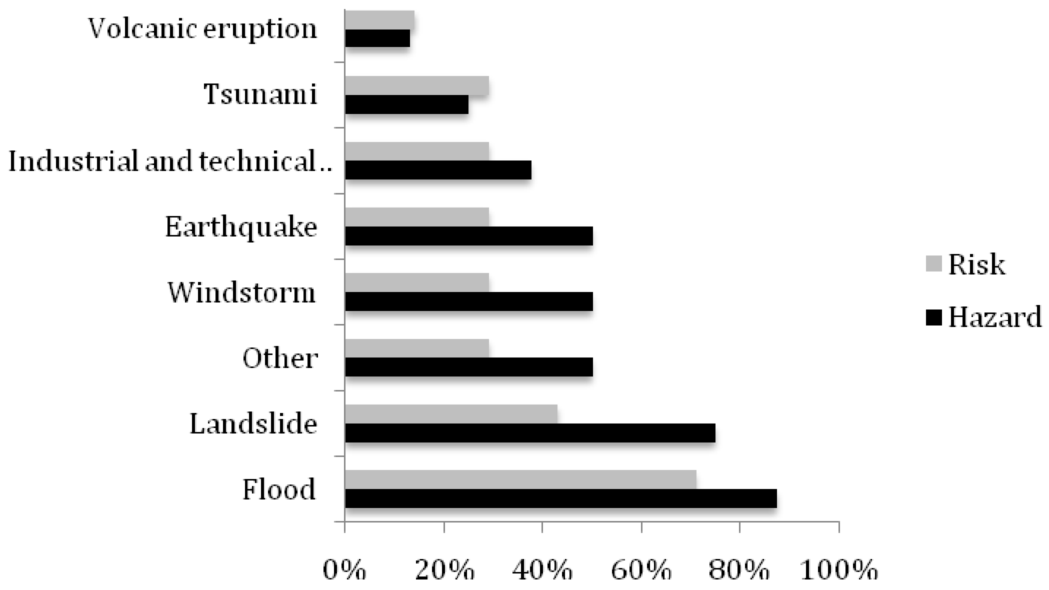


Figure 7: Distribution of the application of different types of hazard and risk assessment in the eight European countries represented in the questionnaire distributed prior to the Bonn MATRIX workshop.

Hazard maps can be used for planning and prevention, whereas risk maps are valuable for awareness raising. The stakeholders indicated five areas where hazard assessments can be used to support decision-making. These are (1) the planning of regional and local protection measures, including land-use planning, urban planning, infrastructure programs and contingency planning, (2) the prioritization and evaluation of protection measures, (3) the safety of critical infrastructure, (4) seismic zoning and building code enforcement, and (5) prevention efforts based on risk prevention plans, public awareness and information. The estimations from stakeholders of the value of hazard assessments for decision-making purposes varied between medium and high. During the workshop, stakeholders identified the advantages of the multi-hazard approach, for example, in the developed synergies in the handling of complex risks, including domino effects, as well as the potential for the instigation of complementary and systematic approaches. Furthermore, the stakeholders furthermore identified five areas for the application of risk assessments for decision-making purposes. These are (1) the formulation of national building codes, (2) scenarios and emergency planning and response, (3) the allocation of funds for risk mitigation, (4) urban management and (5) prevention efforts.

There are different ways of including risk in the mapping process, such as the French approach of overlaying exposure and hazard, or the Norwegian process of defining potential risk maps. Crossing hazard maps and asset maps is the common method used in France within the context of Risk Prevention Plans for defining land-planning zones with specific prevention requirements at the municipal level[16]. Probabilistic and scenario analyses are widespread among the European countries. In particular, scenario analysis seems to be the state-of-the-art. However, uncertainties are difficult to address because adequate methodologies and reliable data are not available.

Stakeholders identified three types of problems connected with multi-risk and multi-hazard assessments:

(1) The general standards for multi-risk assessment are still missing. The need for harmonization of multi-risk assessments across Europe was already identified five years before (T6, 2007). This includes the harmonization of methodologies for hazard and risk assessment for different types of potentially disastrous events and the different processes of risk mapping, including standardization of data collection, analysis, monitoring, output and terminology. The harmonization (again) of terms and methodologies is essential for stakeholders to understand relationships between risks.

(2) Even though cascading phenomena are of great interest, it is still easier to address them with scenarios than by probabilistic methods.

(3) Uncertainties, particularly in scenarios, are not addressed in a systematic manner.

In the next step, the stakeholders identified the following requirements for multi-hazard and multi-risk assessments:

(1) The availability of basic information as well as qualitative and quantitative data to conduct multi-hazard or multi-risk assessments, including the comparability of hazards.

(2) A clear understanding of the spatial and temporal probabilities of multiple risks, of the vulnerabilities of regions to multiple risks, and of the reliability and transparency of the cascading and conjoint probabilities calculations.

(3) A combination of consequence analysis, which considers the vulnerability of

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[16] http://www.risquesmajeurs.fr/les-plans-de-prevention-des-risques-naturels-ppr

people, property, infrastructure and goods, and risk calculation, which includes the consideration of the risk to both tangible and intangible assets.

Perceptions by stakeholders of the decision-making process on the mitigation of multi-risk and on the usability of decision-making tools

The analysis of answers to our questionnaire showed that scenario analysis is the most commonly used tool for scientific assessments, followed by probabilistic analysis, the estimation of uncertainties and socio-economic and engineering models (figure 8).

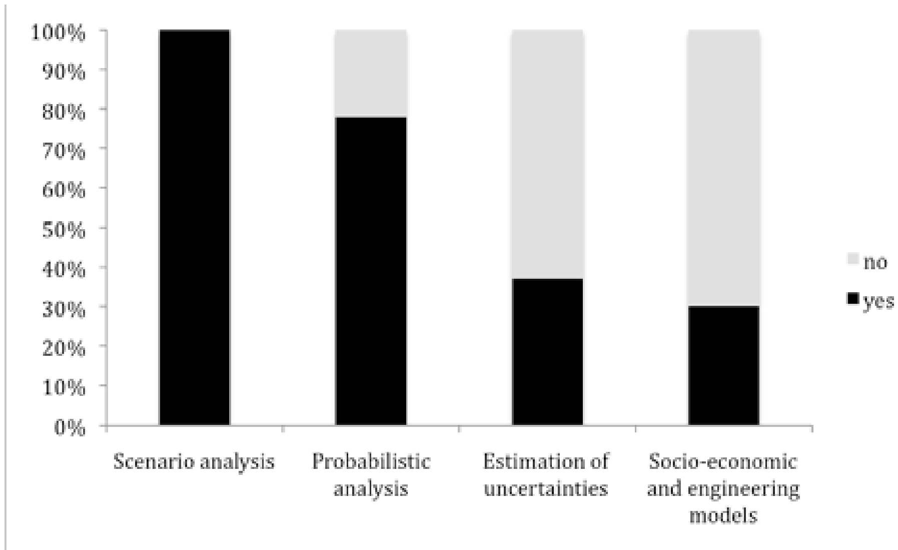

Figure 8: Application of scientific assessment tools for decision-making processes in the eight European countries that responded to the questionnaires.

The stakeholders perceive that probabilistic and scenario analysis has become widespread and has become some kind of state-of-the-art. In addition, the estimation of uncertainties is lacking, believed due to drawbacks in adequate methodologies and reliable data. However, socio-economic and engineering models are at a promising development level, although again these are dependent upon the availability of data.

Stakeholders also expressed their interest in probabilistic information, like joint probabilities for conjoint and cascading events. It was stated that for planning purposes, probabilities of adverse events are of importance. Such information is used in the field of spatial planning and disaster prevention. In Norway, for instance, probabilities of occurrence are used within risk maps to restrict different developments of certain risk-prone areas. Similarly, the Flood Directive 2007/60/EG foresees the development of hazard and risk maps for areas with significant risk of flood and the development of Flood Risk Management plans in order to avoid, protect from, and prevent floods.

Multi-risk is not systematically addressed among the EU countries for all hazards, and is only singularly integrated into risk assessment approaches. Some examples include the superposition of existing single-hazard risk prevention plans for all hazards, for example, combining flood and landslide hazards and flood risks with wind effects, the application of which is in the context for risk assessment of critical infrastructure, in particular the combination of meteorological and technological risks.

The results of the analysis of perceptions from questionnaires showed that generally, multi-risk analysis is barely or not at all integrated into decision-making processes, and only 50% of the responders were aware of methodologies and tools available to assess multi-risk. Nonetheless, all stakeholders are convinced of the usefulness of complex multi-risk scenarios and the majority of them would consider the application of them within their disaster management strategies.

Stakeholders identified several barriers to the implementation of multi-risk and multi-hazard approaches, such as financial, political, conceptual, methodological and operational. In particular, they perceive three barriers as being most problematic.

(1) The absence of common methodologies and data for different types of hazards and risks is perceived to be the most problematic barrier. Also, the level of data availability for different types of hazards and risks is very different. The data on costs estimations are also not fully comprehensive. Currently, in the majority of countries, cost assessments come only from insurance companies. Stakeholders perceive this situation as being problematic because insurance companies might be biased and therefore their assessments are not fully comprehensive or independent, as well as there being issues of the transparency of these assessments.

(2) Another barrier is that multi-risk assessment often does not match political priorities and public perceptions, and it is not always easy to communicate to the broader public what a multi- risk assessment really is.

(3) A significant barrier involves the lack of cooperation between involved institutions, organizations and departments, leading to information about risk and hazard assessments not flowing freely between the different decision-making levels (this issue was of particular concern to Croatia). This is also explained by the fact that the results of assessments are not always available to other stakeholders outside the institution which was responsible for the assessment.

Nonetheless, the reaction of stakeholders to the multi-risk assessment and decision-making tools presented at the Bonn workshop was optimistic. Several stakeholders invited the developers of these tools to give presentations and to conduct training on the tools at their home institutions. The majority of stakeholders would consider the use of the generic multi-risk framework (method 1) and the decision-making tool (method 2) after their testing phase.

They also understood the high potential of the Virtual City concept for educational purposes (Figures 3 and 4). However, stakeholders also identified two areas, which they perceived as hindering for the moment the implementation of multi-risk assessment tools like the Virtual City. These involve the input parameters and its possible application.

However, stakeholders also identified two areas of difficulty at this time for the implementation of multi-risk assessment tools like method (1). These are (i) cumbersome data gathering to consider multiple hazards and risks in a given region and (ii) the high-level of expertise required to assess the dynamic multi-hazard and multi-risk processes. The data requirements (stochastic event set, individual hazard footprints, correlation matrix that provides event conditional probabilities of occurrence, etc.) raise questions as to how user-friendly the model is, as the user (for now) needs to be an expert him or herself to be able to apply the model and to provide the necessary input parameters. Taking into account the complexity of the model and the required parameters, stakeholders believe that it is questionable that the model was applicable in practice for the land-use planning. Another question was if the model could be used to give priority to different kinds of hazards at the European level. It was finally remarked that the application of the multi-risk framework (method 1) might be very useful at a later stage when databases with the required input parameters are developed by national and international stakeholders. This shows that multi-risk assessment cannot be resolved rapidly, but will require a long-term commitment from risk modellers as well as officials, and a “brick-by-brick” approach is necessary to progressively add together all of the complexities of the risk process.

Based on the feedback from the Bonn workshop, A. Mignan improved the communication interface of his multi-risk approach and tested it successfully at the Lisbon workshop. The main criticism, being linked to the complexity of the modelling, has been partly resolved by the use of the risk matrix (see method 2, as well as Cox, 1998; Kraussmann et al., 2012) instead of the loss curve (e.g., Grossi et al., 2005) to show how risk migrates when hazard interactions are included (Fig. 9). General guidelines on how to quantify hazard interactions were also developed, based on an extensive literature search (Mignan et al., 2014). These guidelines should help risk modellers to include, again in a brick-by-brick approach, hazard interactions in their risk management schemes.

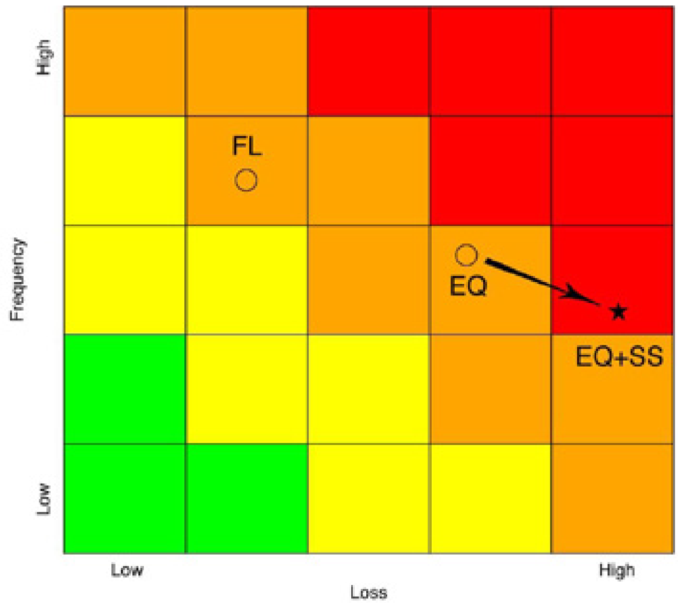

Figure 9: Example of a risk matrix determined during the multi-risk exercise organized during the October 2012 Lisbon PPRD South workshop. The level of risk increases from green, to yellow, to orange and finally to red.

Figure 9 highlights the idea that new risks emerge and some others shift to lower-probability/higher-consequence events when multi-hazard is considered in risk management. The circles represent independent events, while the star represents an event resulting from the interactions of others. In this case, floods (FL) remain independent. While not all earthquakes (EQ) will trigger a sea submersion (SS, here tsunami), the combination of both yields higher losses. The arrow represents the migration of the risk arising from an earthquake alone to lower-probability but higher-consequences when interactions are considered. While this result may appear obvious when considering this simple example, "surprise" chains of events may emerge from method (1) when numerous event and interactions are included in the system (Figure 3).

Interactions with stakeholders with regards to Method 2 allowed us to identify differences in the perceptions between stakeholders from science and practitioners. From among the 14 stakeholders that responded, 6 represented the practice community, such as civil protection, emergency management, and policy making, and 8 represented various academic organizations. In the workshop the stakeholders were asked to rank the usefulness of the decision tool in terms of four categories (highly useful, moderately useful, slightly useful and not useful) for the following three areas.

(1) Understanding the distribution of losses for different sectors and comparing risk scenarios with each other (figure 10).

(2) Preparing and planning for a multi-type risk disaster in a region, and optimizing the allocation of resources (figure 11).

(3) Communicating multi-type risk parameters to different stakeholders and for developing strategies for risk management (figure 12).

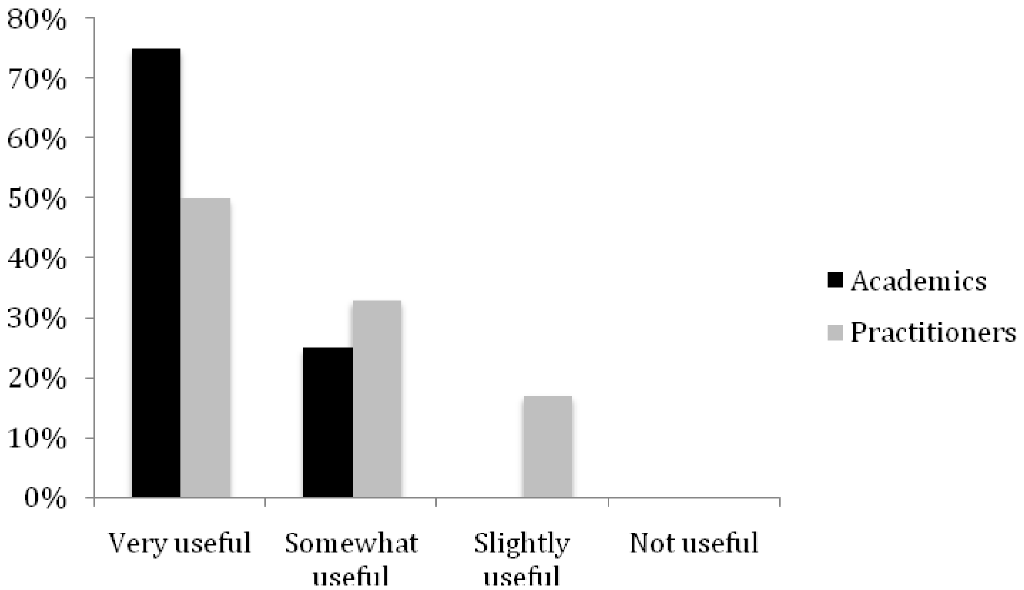

Figure 10: The results of the survey in how the Method 2 tool helps with the understanding of losses and their contribution in a risk scenario (14 answers).

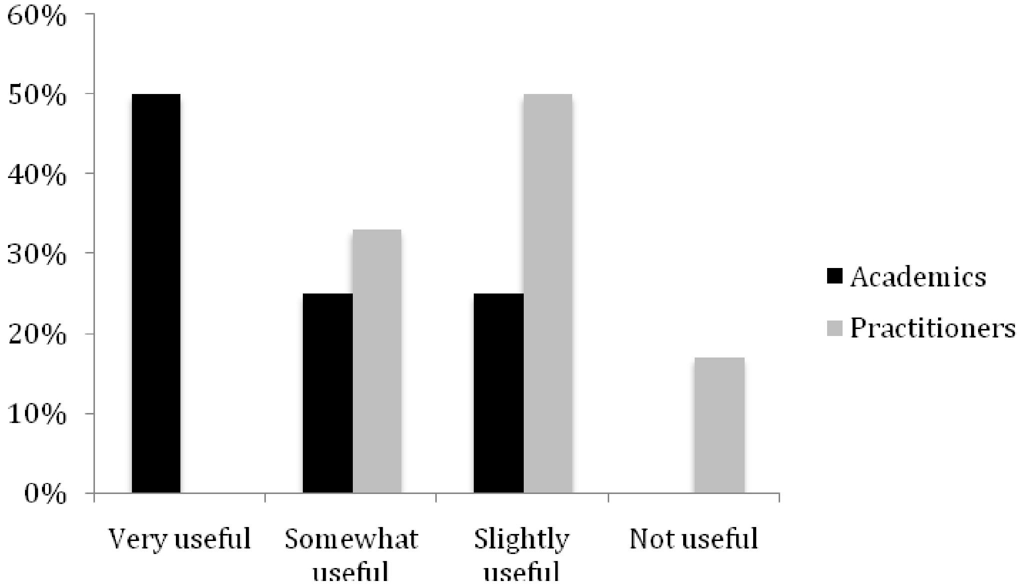

Figure 11: Same as for Figure 10, but for how the Method 2 tool helps with preparing for multi-risk disasters and optimizing allocation of resources (14 answers).

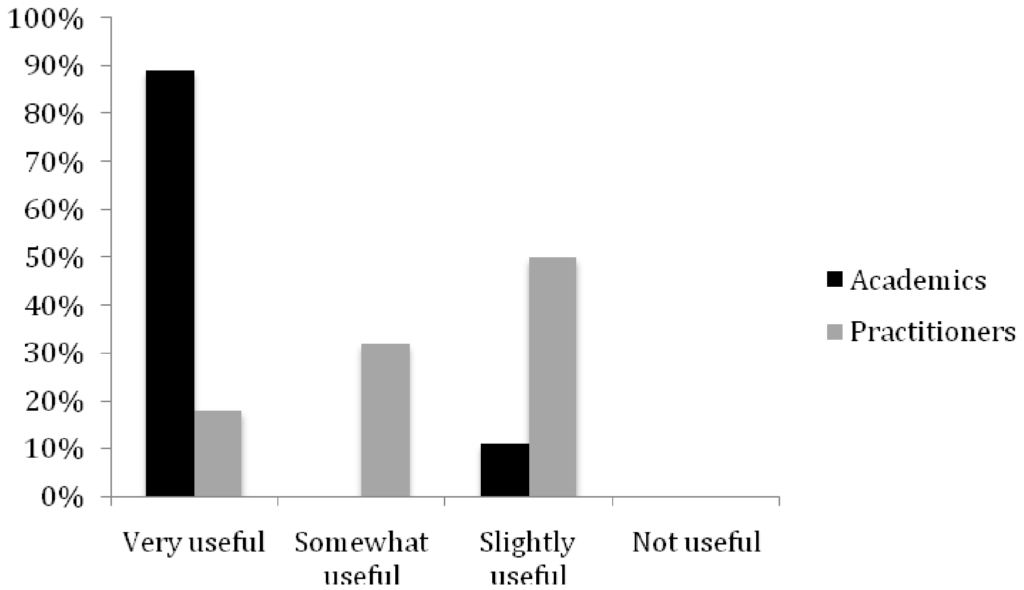

Figure 12: Same for Figure 10, but for how the Method 2 tool helps with communicating multi-type risk parameters to different stakeholders for developing risk management strategies (14 answers).

It is interesting to note the variation in the perceptions between stakeholders in academia and those in the practice community in terms of the tool's usefulness. While both academicians and practitioners agreed that the tool is useful for understanding losses and their contributions in a risk scenario (figure 10), there is a difference between how practitioners viewed the usefulness of the tool when it comes to prioritizing risk and developing risk management strategies (figure 12). In the case of the latter, most practitioners viewed the tools as being only slightly to somewhat useful, while academics believed it to be very useful for this purpose. Similarly, practitioners found the tool not to only slightly useful when it came to preparing for disasters and allocating resources as opposed to most academics, who thought it would be somewhat to very useful (figure 11). In the discussion that followed with the stakeholders, it arose that a precondition for the useful application of the tool is expert knowledge, and thus the tool is ideally to be used by risk analysis experts. In this way, the tool brings added value by providing transparency and a rational breakdown of risk against a competing set of criteria. Furthermore, the stakeholders commented that the usefulness of the tool could only be gauged following an in-depth exercise with stakeholders for a region where the expertise and context (i.e., a case study with specific problem) is available.

Discussion

The results from the discussions with and the undertaking of surveys by stakeholders on the usability and user-friendliness of decision-making models showed that stakeholders still have questions about the availability of data for input parameters, but that they did not question the usefulness of the results.

For example, the decision-making model developed by the ARMONIA project was tested in only two case studies and not by a number of stakeholders from different countries. Nevertheless, it was found that, firstly, doubts in the methodology arose, as there was the tendency to exaggerate one hazard over other ones. Second, there were concerns about methodology's output, such as the risk factor, which could be used only by decision-makers who are familiar with this method. The recommendations were to develop alternative multiple-risk mapping methods, which were not as data specific as the methods developed by the ARMONIA project. The recommendations also highlight strongly the need to appreciate participative governance and the need to conduct further research into what the end users of such risk maps actually require.

With the existing decision-making model and generic multi-risk tool, we still could not address the first recommendation. The feedback from stakeholders showed us that there is a need for a significant simplification in terms of the required input data. However, we addressed the second recommendation by collecting and addressing perceptions of stakeholders from several European countries in terms of the usability and the areas of application of the multi-risk assessment tools.

During several rounds of stakeholders´ interactions, we received the following recommendations. First, as already mentioned, there is an urgent need for more clarity with regards to the terms and definitions connected with multi-risk and multi-hazard. This will require the terminology currently being employed, for example within the MATRIX project, to be disseminated and agreed upon with all relevant stakeholders (note one of the MATRIX deliverables, D3.2 "Dictionary of terminology" is publically available via the MATRIX website[17]). Second, for input parameters, there is a need to harmonize existing methodologies on data collection and databases across the European countries. In this case, there are already on-going initiatives dealing with this, such as the INSPIRE[18] initiative of the European Union. Third, we received several recommendations regarding the area of

[17] http://matrix.gpi.kit.edu/index.php
[18] http://inspire.jrc.ec.europa.eu/

application for multi-risk assessment tools such as the decision-making model and the generic multi-risk framework. This includes the application of the multi-risk approach to enable the comparability of risks. This recommendation was included in the ongoing development of the generic multi-risk framework by comparing various risks with the use of risk as a common metric. This could be a complementary approach to single-risk assessments, where the single and multi-risk approaches relate to two different risk systems.

Our interviews with stakeholders showed that, first, the risk systems need to be defined, and only afterwards could the risk analysis and assessment be used. There are expectations on the multi-risk systems to be able to address dependencies between hazards. For politicians and decision-makers, it would be interesting to compare two sets of scenarios, one with the interdependencies between different kinds of hazards included, and the other without considering such interdependencies. This is an advantage of the generic multi-risk framework (Method 1) as it is able to provide such comparisons by including or excluding interdependencies between different risks. The developed models could also be used as a test to compare these results with previous results and data developed by insurance companies. Although insurance companies might be interested in such applications, their results would probably remain confidential. Also, the developed models could be used in training purposes in two possible ways. The first would be in a more narrow sense to convince stakeholders in the decision-making process about the usefulness of the multi-hazard approach. The second one could be with the broader view of presenting these results to the general public, hence dealing with public acceptance issues. Some stakeholders expressed the opinion that politicians should be obliged to use this model in their training regimes to see what the consequences of a multi-hazard situation could be. The general recommendation was that the model (including the concept of the Virtual City) could be used for educational purposes.

In conclusion, while the stakeholders involved in this study saw the value of the multi-risk approach, a great deal of work is required by researchers in terms of the methodological development, and in shaping these methods to meet the needs of end-users. From the other side, further efforts are required to actually understand what is required by end-users, while continuing to further disseminate the message of the value multi-hazard and risk approaches.

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Appendix: List of the deliverables resulting from the MATRIX projects

The following table lists all of the deliverables produced during the MATRIX project. These may be obtained from the MATRIX website (for the public document) or by directly contacting the project coordinator.

Regarding the dissemination level, if a document is not PU, then the consortium may need to be contacted and, at the author's discretion, the document will then be made available.

PU - Public
PP - Restricted to other programme participants (including the Commission Services)
RE - Restricted to a group specified by the consortium (including the Commission Services)
CO - Confidential, only for members of the consortium (including the Commission Services).

Number	Name	Lead partner	Dissem. level
D1.1	Kick off meeting report	GFZ	PU
D1.2	1st period intermediate reports	BRGM	PP
D1.3	2nd period intermediate and final reports	GFZ	PP
D1.4	1st period scientific audit	AMRA	RE
D1.5	2nd period and final scientific audit	GFZ	RE
D2.1	Single-type risk analysis procedures: Report on single-type risk analysis procedures in the framework of synoptical risk comparisons	GFZ	RE
D2.2	Uncertainty quantification: Report on uncertainty quantification and comparison for single-type risk analyses	BGRM	RE
D2.3	Harmonization strategy: Report on the optimal harmonization of single-type assessment methodologies for achieving risk comparability.	GFZ	RE
D3.1	Review of existing procedures: Review of the existing procedures for multi-hazard assessment	AMRA	PP
D3.2	Dictionary of terminology: Dictionary of terminology adopted.	AMRA	PP
D3.3	Scenarios of cascade events: Report on the description of the possible scenarios of cascade events.	AMRA	PP
D3.4	Probabilistic framework: Report describing the proposed probabilistic framework for multi-risk assessment.	AMRA	RE

Number	Name	Lead partner	Dissem. level
D3.5	Software for multi-hazard assessment: Software for multi-risk assessment.	BRGM	RE
D4.1	Fragility functions: Impact of repeated events with various intensities on the fragility functions for a given building typology at local scale.	BRGM	CO
D4.2	Fragility of pre-damaged elements: Realisation of fragility functions of elements pre-damaged by other past events and demonstration on a scenario.	BRGM	CO
D4.3	Functional vulnerability: Report on the functional vulnerability assessment of a system prone to multiple hazards.	BRGM	PP
D4.4	Social and economic vulnerability: Report on the social and economic vulnerability to multiple hazards.	IIASA	PP
D5.1	State-of-the-art in multi-risk assessment: Review of the state-of-the-art in multi-risk assessment.	AMRA	PP
D5.2	Framework for multi-risk assessment: Framework for consistent multi-risk assessment.	NGI	RE
D5.3	Tangible and intangible losses: Quantification of tangible and intangible losses in multi-risk assessment.	IIASA	RE
D5.4	Fault trees and event trees: Development of fault trees and event trees for environmental risks.	TU-Delft	CO
D5.5	Uncertainties in multi-risk assessment: Treatment of uncertainties in multi-risk assessment.	NGI	CO
D6.1	Decision-analytic frameworks for multi-hazard mitigation and adaption: Review of the literature on decision analytic methods, and identify those best suited to multi-hazard cases through the application in a virtual city context.	KIT	PU
D6.2	Individual barriers to multi-hazard analysis: Identify the cognitive and cultural barriers to effective decision-making for individuals, and present experimental results used to test their application to multi-hazard cases.	IIASA	RE
D6.3	Social and institutional barriers to effective multi-hazard decision-making: Report on case study analysis, including empirical work with stakeholders, to identify the social and institutional constraints and opportunities to effective multi-hazard mitigation and adaptation.	IIASA	RE
D6.4	Synthesis: Synthesis: Benefits and barriers to multi-hazard mitigation and adaptation, with policy recommendations for decision-support.	IIASA	PP
D7.1	MATRIX common IT platform: Report on the MATRIX common IT platform	ETHZ	CO
D7.2	Implementation of the Virtual City: Implementation and analysis of the Virtual City	ETHZ	RE
D7.3	Naples test case: Report on Naples test case.	AMRA	RE
D7.4	French West Indies test case: case: Report on French West Indies test case	BRGM	RE
D7.5	Cologne test case: Report on Cologne test case.	GFZ	RE

Number	Name	Lead partner	Dissem. level
D8.1	Project web portal: Project web portal and data repository system online.	KIT	PU
D8.2	Communication strategy: Communication strategy and promotional material, brochures.	KIT	PU
D8.3	Guidelines for reference reports: Guidelines for MATRIX reference reports	KIT	RE
D8.4	MATRIX results I and reference reports	KIT	PU
D8.5	MATRIX results II and reference reports	KIT	PU
D8.6	Design of semantic MediaWiki	KIT	RE
D8.7	MATRIX SMW platform: MATRIX SMW platform up and running with ontology-based content.	KIT	PU
D8.8	Contacts to National Platforms I: Contacts with National Platforms and HFA Focal Points including disaster management communities, EC Civil Protection, CoE Major Hazards Agreement, Preventionweb established.	DKKV	PU
D8.9	Contacts to National Platforms II	DKKV	PU
D8.10	Contacts to National Platforms III	DKKV	PU
D8.11	Contacts to National Platforms IV	DKKV	PU
D8.12	Contacts to National Platforms V	DKKV	PU
D8.13	DRM profiles: DRM profiles of selected EU states available	DKKV	PU
D8.14	MATRIX results to DMC	DKKV	PU
D8.15	Platforms and MATRIX community: Performance evaluation of interaction between platforms and MATRIX community.	DKKV	RE
D8.16	Materials to the public: Communication materials to the public.	AMRA	PU
D8.17	Course design and material: Course design and training course material.	AMRA	PU
D8.18	Virtual laboratory: Concept and materials for virtual laboratory.	AMRA	PU
D8.19	Vision paper: Vision paper on multi-risk assessment strategies and its implementation in national and EU-wide mitigation strategies.	KIT	PU