PREPARING FOR THE DOMINO EFFECT IN CRISIS SITUATION

D2.2 SECURITY METRICS FOR THREATS, FOR SYSTEMS’ RESILIENCE MS&A ACTIVITIES
(In the original contract named as “Scenario(s) definition of crisis situation with cascading effects”)

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### Security Assessment

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EXECUTIVE SUMMARY

PREDICT is an EU FP7 co-funded project – within the Security Research Call 6 of the 7th Framework Program, related to section 4.1-2 “Better understanding of the cascade effect in crisis situations in order to improve future response and preparedness and contribute to lower damages and other unfortunate consequences”. PREDICT project aims at providing a comprehensive solution for the modelling, simulation and analysis (MS&A) of cascade effects in Critical Infrastructures (CIs) during multi-sectorial crisis situations. Amongst its nine working packages (WPs), WP2, task T2.2, defines criteria for the security metrics for measuring threats, resilience (CI dependencies and cascading of failures) and consequences. T2.2 also gives recommendations on the security metrics to be used in the integrated PREDICT DSS Tool (iPDT). That will allow providing stakeholders with rational measurements for making the right decision at the right time based on a clear metrics (identifying and ranking potential cascading scenarios, assessing impacts and supporting decisions regarding barriers, prognostic schemes and precursor signs).

The starting point for the security metrics identification and assessment is a comprehensive state-of-the-art analysis of different types of security metrics used or can be used in the Critical Infrastructure Protection (CIP) field. This state-of-the-art analysis is based on the following data sources:

- MS&A literature of threats.
- Available reports on real past crisis situations
- Relevant databases (DBs); threat DBs, CI operators DBs, accidents analysis DBs, crisis DB and insurance companies DB (e.g. extreme wind, wildfire).

The resilience metrics (dependency and failures cascading) have been assessed and reported in PREDICT D2.1 [1] while the scenario’s aspects are reported in PREDICT D2.3 [2]. The security metrics for the characterisation of threats and consequences are assessed in the present document PREDICT D2.2.

In the first phase of the work, data on security metrics were collected, reviewed and categorised. Two categories of security metrics were firstly distinguished: those metrics used in crises initiated by nature and those initiated by man-activities. Data collection, review and categorisation are common activities between PREDICT tasks T2.1 and T2.2.

In the second phase of the work, we scanned the metrics that are used in measuring some selected natural phenomena and industrial accidents. The selection has been carried out based on the potential of those phenomena and accidents to initiate crises, specifically, cross-border crises in EU. The selected natural phenomena are: earthquake, volcanic eruption, flood, extreme wind and wild forest fire. The selected industrial accidents are: chemical process industry accidents and oil spill in deep water accidents. The data on the security metrics used in crises initiated by the previously selected natural phenomena and industrial accidents are scanned and comprehensively analysed (Chapter 2).

In the third phase of the work, a conceptual analysis of the security metrics is performed considering the metrics usage in practical crises situations and in MS&A activities in CIP field, (Chapter 3). The
conceptual analysis deepened our understanding of the security metrics and has led to the classification of the security metrics in three classes:

- **Magnitude metrics**: to measure the intrinsic properties of threats resultant either from nature phenomena or from industrial accidents.
- **Intensity metrics**: to measure the impact of the hazards resultant from threats
- **Likelihood metrics**: to measure the statistical characteristics of threats and impacts dependant on robust models and/or operational feedback experience.

A metric is also proposed to classify time intervals, depending on the threat nature, into: short, midterm and long-term. This conceptual frame for the classification of security metrics and time-intervals should lead to a better assessment of threats, cascading effects and impacts for decision making in crisis management (Chapter 3).

Finally, recommendations on security metrics are issued for the other WPs involved in the development and the integrating activities relative to the iPDT. The recommendations cover: the magnitude metrics for the threat, the likelihood metrics for the threat, the intensity metrics for the impact, the duration of the inoperability (or derivatives) for the CI resilience and successive failures likelihood to characterise the cascading failures, (Chapter 4).
1. Introduction

PREDICT aims at providing a comprehensive solution for the modelling, simulation and analysis (MS&A) of cascade effects in CIs during multi-sectorial crisis situations. The PREDICT solution will cover the following three domains: methodologies, models, and software tools. This will be called the integrated PREDICT DSS Tool (iPDT). This tool with its multiple integrated functionalities should increase the awareness; enhance the understanding and assess the cascade effects in crisis situations. Subsequently, it should improve the Critical Infrastructures (CI) resilience and preparedness.

The WP2 is divided into 3 tasks; each has its own global objective as following:

- T2.1; to assess the “state-of-the-art of the R&D in cascade effect & resilience and global modelling”,
- T2.2; to assess the “security metrics for threats, for systems’ resilience MS&A activities”, and
- T2.3 to assess the “DSS and predictive tools feature specifications”.

The realisation of WP2 assessments (T2.1, T2.2, and T2.3) followed the same working methodology as described in detail in D2.1. The three assessments share a common bibliographical core that has been collected and preliminary analysed as an integrated part of T2.1 activities [1].

This deliverable D2.2 reports on the assessment carried out in task T2.2 “Security metrics”, which is described in the DoW as: “The approaches to define criteria for security metrics will be identified and analysed. The starting point for the metrics is a comprehensive state-of-art analysis of different existing metrics in different countries and disciplines. It will address those criteria and indicators which could be used as the precursor signs for emerging danger. By new threat methodologies assessment, the WP will improve understanding on cause, consequence and sequences, in order to provide stakeholders with rationales necessary for making the right decision at the right time, by: identifying and ranking potential scenarios, defining barriers and proposing prognostic schemes to detect the precursor signs released by the relevant barriers at the right time.”

As mentioned in D2.1, within the scope of “better understanding of cascading effects”, the cascading MS&A activities covers three wide domains: threat, CI resilience and consequences.

- **Threat** identification and characterisation is a first act in any cascading effect and resilience MS&A process. In D2.1 (chapter IV), the most used methods of threat identification & specification are assessed, with no detailed mention of the used metrics. An identification and characterisation of threats would necessarily be based on the use of the most appropriate **security metrics**.
- The second act is the **CI resilience** MS&A (CI dependency/interdependency and cascading of failures/sequences/scenarios). That should allow assessing the potential scenarios of CIs failure cascading activated by a given well-defined threat. The models, the methods and the tools that allow the MS&A of cascades are covered in D2.1. The issue of resilience metrics is assessed in D2.1 (Section 5.5). The resilience metric issue is strongly connected to the inherent dynamic nature of both threats and cascading failures. The issue is discussed in-
depth in section 5.5 of D2.1, [1]. This present deliverable, D2.2, will report on the major findings on resilience metrics for CI resilience.

- The third act concerns **consequences**. Similar to “threat” above, the topic “consequences” was mentioned in in D2.1 where Decision Support Systems (DSS) and crisis management tools are treated, but the consequence metrics is specially treated here in this deliverable, D2.2.

Deliverable D2.2 aims at assessing the state-of-the-art in security metrics and developing guide lines and recommendations for PREDICT Tool design.

This chapter 1 is structured in 4 sections and we explained in this chapter why the resilience metric has been treated in the deliverable D2.1 rather than in D2.2

- Section 1.1: about the used methodology
- Section 1.2: is a short introduction to the concept of “metrics”
- Section 1.3: is a short introduction to the concept of “security metrics”
- Section 1.4: is a short overview of the existing challenges in identifying and developing “security metrics” for the proper use of CIP and crisis management

Chapter 2 “Security metrics used in measuring threats & consequences” contains a non-exhaustive count on some selected natural phenomena and industrial accidents that can be sources of threats. It gives useful information about metrics used in the characterisation of these phenomena and accidents. The rationales behind the selection of these phenomena and accidents are also given. Chapter 2 lays down the concrete elements of knowledge about security metrics in preparation to the conceptualisation analysis that will follow in the following chapter.

In Chapter 3 “Security Metrics”, the concept of the security metrics is treated. Based on the output from the preceding Chapter 2, a conceptual analysis of the security metrics was carried out. Then, a conceptual frame is developed that proposes a classification of the security metrics in three classes: magnitude, intensity and likelihood. Besides, it proposes a metric to assess time intervals such as: short, mi-term and long-term, depending on the threat dynamic.

Chapter 4 “Conclusions & Recommendations to WPs” presents a synthesis and recommendations on the security metrics to be used in the iPDT. The conclusions cover the security metrics for: threat (identification & specification), resilience (interdependencies & cascading of failures) and consequences (impact & outcomes).

### 1.1. Methodology

The approach taken consisted in screening both the current knowledge and the practices in CIP fields. The knowledge and practices that we are interested in concern **security metrics**. While, the interesting practice in CIP for the PREDICT project is when CI systems are exposed to crises situations initiated by the action of a given threat. The focus is on the security metrics used in crisis management situation. Feedbacks from past experiences in crisis management and from MS&A knowledge are both required to complete our vision regarding security metrics. Task T2.2 is based on the following three types of actions: data collection, data assessment and data synthesis & recommendations. The
methodology is identical to the one used in T2.1 and it is fully described in D2.1 [1]. Subsequently, the
data collection, the acceptance/rejection criteria and the data assessment process are the same as in
D2.1.

The used methodology can be summarised in the following phase:

- Topic identification (security metrics)
- Data sources identification (academy publishing papers, research institutions reports, databases, EU similar projects reports, PREDICT consortium expertise and assets)
- Data collection & selection
- Input data analysis (PREDICT consortium collective effort)
- Data processing, synthesis and reporting per sub-topic (collective effort)
- Deliverable compilation, harmonisation and reviewing (collective effort)

It is worth mentioning that although the major bibliographical core was collected and analysed in task
T2.1 and reported in the corresponding deliverable D2.1, some additional references haven been
collected, treated and reported in this present deliverable D2.2.

1.2. Metric definition

In hard science, metrics are used to quantitatively measure: mass, weight, velocity, acceleration, temperature, etc. However, in human science (psychology, sociology, etc.), metrics are rather qualitative: high, medium low or similar. Metrics can then be either quantitative or qualitative. If quantitative, it could be continuous or discontinuous. All phenomenological concepts (time, mass, weight, energy, force, toxicity, criticality, risk, robustness, resilience, frequency, etc.) are measurable and measured using appropriate metrics. One phenomenological concept can be measured using many different metrics. As a general rule, metrics should be: comprehensive, consistent, hierarchical, expandable, exclusive and scalable, [2],[4].

1.3. Security metric definition

The concept of “security metrics” emerged principally from the area of information system security. It receives growing interest since a decade. However, only a limited amount of literature studies can be reported on security metrics [4][5]. The concept and definition of metrics in physical sciences for measuring time, distance, speed, force, energy, power and radiation exposure doses are very well-defined. Additionally, all these metrics are quantitative.

What could then be a security metric for CIP?

The first immediate answer is: a “security metric” should be a set of metrics that allows measuring concepts relevant to the field of CIP. A complete CIP security metrics should then cover the following domains:
- Domain of threat; Metrics for threats is treated in the present deliverable, D2.2.
• Domain of CI; Metrics for the resilience of a given CI, the dependency and interdependency between CIs (cascading of failures). This is treated in D2.1, [1], and major findings will be reported in this deliverable D2.2.
• Domain of consequences; Metrics for direct short-term consequences (impact) and the indirect and long-term consequences (outcome). The impact is treated in the present deliverable D2.2.

In conclusion, two domains in security metrics will be treated in the present deliverable: Threat and consequence. Regarding resilience metrics the major findings in D2.1 will be summarized, in section 3.8.

1.4. Challenges in developing security metrics

In crisis situations, some aspects of security can be measured on sectorial bases such as: the resilience of an electrical grid, the resilience of a communication system and the resilience of a railway network. In these three cases, one can individually measure the resilience of each CI in terms of “total time” to recover (e.g.), after a disruption caused by a given threat. But what could be the resilience of a global complex system that includes the three mentioned above systems considering their interdependencies. In short, the difficulty can be referred to as an “integration” issue. This integration issue has two parts:

• Given the resilience of many individual critical systems belonging to one global system, how can the global system resilience be determined facing a single threat?
• Given the resilience of a single system facing many threats separately, how can its overall resilience be determined facing simultaneously a set of multi-threats?

This integration problem, multi-system and multi-threat, is highly complex and the absence of complete security metrics deepens this complexity.

Developing new security metrics is out of the scope of PREDICT project. However, identifying the existing security metrics and assessing their use in practice is necessary for the development of the iPDT. This is the major focus of Chapter 0 where the use of security metrics both in real crisis management situations and in MS&A of threats and impacts are assessed.

1.5. Types of threats

Only threats that do not show any self-adaptability feature are considered. They are non-reactive threats. A threat with a self-adaptability feature can intentionally modify its nature, structure or operational mode during the crisis hot-phase in order to counterbalance the actions taken by the crisis manager, see the red dashed line in Figure 1.

Subsequently, the iPDT will not consider the threats with self-adaptability features. This is the case of war, terrorism or malevolence-type of threats.
Figure 1: Flowchart of a generic process for Threat Risks Management
2. Security metrics used in measuring threats & consequences

As already mentioned above, Task T2.2 aims at assessing the state-of-the-art in security metrics and developing guidelines and recommendations for PREDICT Tool design. This assessment should lead to the formulation of recommendations and criteria regarding the security metrics to be used in the PREDICT Tool. The security metrics should allow measuring the basic concepts used in CIP and crisis management fields.

2.1. Introduction

The CIP and Crisis Management fields consider three interconnected domains: threats (identification & specification), resilience MS&A (dependency, cascading effect & sequences) and consequences (impacts & outcomes). The searched security metrics will be identified by looking into:

- MS&A literature of threats (e.g. earthquake, volcano).
- Real past crisis situations (e.g. flood in section and oil spill)
- Relevant databases (DBs); threat DBs, CI operators DBs, accidents analysis DBs, crisis DB and insurance companies DB (e.g. extreme wind, wildfire).

A sample of eight potential threat sources is selected and covers natural phenomena and industrial accidents that can initiate crisis situations. The natural threats include: Earthquake, volcanic eruption, flood, extreme wind and wildfire. While the industrial accidents include: chemical process industry accidents and deep water oil spill accidents. The selected sources of threat are relevant to the EU definition of EU-CI sectors and to cross border crisis situations. We are focusing on mono-threat crisis situations.

The eight selected sources of threat represent a wide variety regarding security metrics. In that sense one may declare that although the list of the selected threats is not exhaustive, it can be considered as representative in terms of metrics usage for measuring threats and consequences in the field of CIP.

The chapter is divided into 9 sections. It begins with an introduction in section 1 and ends by some conclusions in section 9. The selected threats (7) are representative but obviously not exhaustive and they are presented in the following order:

- Section 2.2 : Earthquake
- Section 2.3 : Volcanic eruption
- Section 2.4 : Flood
- Section 2.5 : Wind (extreme)
- Section 2.6 : Wildfire
- Section 2.7 : Chemical processing plant
- Section 2.8 : Oil spill in deep water
2.2. Earthquakes

Earthquake is one of the most studied natural threats. Corresponding literature is proliferating with significant works covering almost all subdomains in the field: physical-geological research, modelling & simulation, global data collection and treatment, standardization & normalisation, seismic risk & hazard assessments, seismic risk management and seismic engineering activities.

Seismologists assess/measure “magnitude” whereas seismic risk analysts are interested in “intensity”. Both terms are used but not to measure the same thing. In seismology “magnitude” measures the energy released at the epicentre of or deposited locally by an earthquake while “intensity” measures the local hazardous effect (injuries, fatalities, building damage, loss of communication services, etc.). In one context, one describes “how strong” is the earthquake by the amount of energy released in its epicentre which is an intrinsic property of the earthquake.

In the second context, one describes the measurable local impact of the earthquake on some given systems. Beside the “magnitude” and the “intensity”, seismologists determine also the “epicentre” of earthquakes.

2.2.1. Magnitude metrics

The American seismologist Charles F. Richter proposed in 1935 proposed a scale to measure the local magnitude of an earthquake [6]. The public often uses the term Richter scale, but technically it is known as the “local magnitude scale, $M_L$”. The Richter scale is a logarithmic one (the wave amplitude in a level 5 is 10 times greater than that in a level 4) where energy released in an earthquake is approximated by an equation that includes this magnitude and the distance between the seismograph and the earthquake’s epicentre.

Richter scale goes from 0 to 9 though neither real upper limit nor lower limit exist. Severe (or Major) quakes have magnitudes greater than 7. Quake waves travel from the epicentre in all directions, gradually losing energy, with the intensity of earth movement and ground damage generally decreasing at greater distances.

Other more recent magnitude metrics are developed such as: body wave magnitude ($M_B$), surface wave magnitude ($M_S$), and moment magnitude ($M_w$). Each of these is scaled to give values similar to those given by the local magnitude scale $M_L$. However they do not always give the same measurement of the overall released energy from the source, especially, at higher magnitudes.

Thomas Hanks and Hiroo Kanamori proposed in 1979 a new extension of those different scales mentioned above which is known as moment magnitude ($M_w$) scale [7]. All of the recent seismic magnitude measurements are effectuated using the $M_w$ scale, even if the non-specialised media continue to use abusively the term Richter scale.
Although, the local magnitude $M_L$ is dimensionless, it is calculated from mechanical moments that have the dimensions of work, N.m (Newton.meter) or dyne.cm.

The quake’s magnitude depends amongst other parameters on the quake’s focus position. Seismologists measure, then, the epicentre of all earthquakes which is the point on the Earth’s surface directly above the focus of an earthquake. These measurements are generally based on the propagation speed differences between surface primary (P) waves and secondary (S) waves. An S-wave runs, approximately, 200km in 50 seconds, while a P-wave runs 400km in 50 seconds. Once the S-P delay time is calculated, the distance to the epicentre is directly calculated. One needs then to determine this distance using three different seismograms at three different stations in order to localise the epicentre by triangulation.

2.2.2. Intensity metrics

In order to measure the consequences of a quake in a particular place, the modified Mercalli scale, based on a scale developed by the Italian geologist-seismologist Giuseppe Mercalli (1850-1914), is often used. It measures the quake’s intensity in order to assess the resultant (local) damage. An elementary objective of any seismic risk assessment regarding given systems is the estimation of the potential damages as functions of the level of the seismic hazard intensity. In general, these response functions could be deterministic, statistical, probabilistic or qualitative. The biggest quake in modern records struck Chile (Valdivia earthquake) in 1960 at a level 9.5 ($M_w$), [8]. It killed 1,900 people and caused about $4 billion in damage in 2010 US dollars. Hazardous consequences would certainly be significantly different whether it was in Japan or in Anatolia.

However, the modified Mercalli scale is not defined in terms of rigorous, objectively quantifiable measurements such as shake amplitude, shake frequency, peak velocity, or peak acceleration. The modified Mercalli scale describes qualitatively human-perceived shaking and building damages correlated to peak acceleration for lower-intensity events, and with peak velocity for higher-intensity events.

It is obvious then that a universal correspondence can’t be established between “Magnitude” and “Intensity”. It is evident that “Intensity” depends on many factors, “Magnitude” is just one of them. Intensity depends on the place topology and its geologic structure (how does the quake wave propagate in the ground? Are the buildings quake proof?). It depends even on the local culture regarding quakes. A description of the modified Mercalli Modified Intensity (MMS) scale is given in Table 1.
Table 1: Modified Mercalli Intensities scale typically observed at locations near the epi-centre

<table>
<thead>
<tr>
<th>I</th>
<th>Micro</th>
<th>Not felt</th>
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<tr>
<td>II</td>
<td>Minor</td>
<td>Felt by few persons at rest, especially on upper floors of buildings.</td>
</tr>
<tr>
<td>III</td>
<td>Weak</td>
<td>Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.</td>
</tr>
<tr>
<td>IV</td>
<td>Light</td>
<td>Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.</td>
</tr>
<tr>
<td>V</td>
<td>Moderate</td>
<td>Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.</td>
</tr>
<tr>
<td>VI</td>
<td>Strong</td>
<td>Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.</td>
</tr>
<tr>
<td>VII</td>
<td>Major</td>
<td>Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.</td>
</tr>
<tr>
<td>VIII</td>
<td>Severe</td>
<td>Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.</td>
</tr>
<tr>
<td>IX</td>
<td>Violent</td>
<td>Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.</td>
</tr>
<tr>
<td>X</td>
<td>Extreme</td>
<td>Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.</td>
</tr>
<tr>
<td>XII</td>
<td>Catastrophic</td>
<td>Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.</td>
</tr>
</tbody>
</table>

*source: United States Geological Survey

2.2.3. Likelihood metrics

The majority of quakes are less than 3 on the Richter scale and called micro-quakes. They aren’t even felt by humans but can be recorded by seismographs. Annual occurrence rate is 1.4 million quakes above scale 2.0. Only 15 quakes in average are registered annually at level 7 or above, that is the threshold for severe quakes, [8].

Some data on occurrence frequencies are given in Table 2. Seismic data on likelihood and occurrence frequencies are generally available in different databases.
2.2.4. Databases

All seismic characterising quantities (magnitude, intensity, likelihood) are increasingly well-determined because of the abundance of the collected data and its growing statistical quality. That allowed the construction of high quality seismic databases in Europe and worldwide. A detailed state-of-the-art in seismic EU databases is given in [9].

Many databases on seismology exist and provide experts and seismologist with full sets of data. Some of the often cited databases are:

- International Seismological Centre (ISC) Database – UK (http://www.isc.ac.uk)
- SHARE European Earthquake Catalogue (SHEEC) – EU (http://www.emidius.eu/SHEEC/docs/SHEEC_CET.xls)
- Seismic Equipment Infrastructure in the UK (SEIS-UK) – UK (http://seis-uk.le.ac.uk)
- The IRIS - Global Seismographic Network (GSN) – USA (https://www.iris.edu/hq/programs/gsn)
- ERI Strong Motion Observation Database – Japan (http://smsd.eri.u-tokyo.ac.jp/smad/)
- Japan University Network Earthquake Catalogue – Japan (http://www.eric.eri.u-tokyo.ac.jp/CATALOG/junec/index.html)
- Australian Seismic Brokers (ASB) – Australia (http://www.spectrumgeo.com/geological-resources/knowledge-map)

2.2.5. Conclusions about seismic metrics

For seismic crisis characterisation, there exist exceptionally well-developed universal metrics to measure: the magnitude and the likelihood of a given quake. The situation is different regarding intensity. The magnitude metrics allow measuring: the released energy in the epicentre, the deposited energy locally, the surface wave magnitude and the duration which are all intrinsic properties of the quake. The magnitude metric is intrinsic, universal and quantitative. The intensity metric allows estimating the damages that strongly depend on the magnitude of the quake but not only. The metric is extrinsic, local and qualitative. It depends on the impacted system (building, routes, air transportation, soil movement & slide…). The likelihood metric measures: occurrence frequencies, occurrence intervals between two successive events of the same class or the total number of events belonging to the same class over a well-determined interval of time. Magnitude and likelihood are both intrinsic property. Regarding the seismic threat, its likelihood metric is robust. This is due to the combination of: an ever increasing quantity of cumulated seismic data obtained and processed by high quality measurements and advanced models, respectively. An approximate correspondence between metrics of magnitude, intensity and likelihood are given in Table 2, below.
### Table 2: Approximate correlation between Magnitude and Intensity

<table>
<thead>
<tr>
<th>Typical Maximum Modified Mercalli Intensity</th>
<th>local Magnitude scale $M_L$</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Under 1.9</td>
<td>~ 8 000 /d</td>
</tr>
<tr>
<td>II – III</td>
<td>2.0 – 2.9</td>
<td>~ 1 000 /d</td>
</tr>
<tr>
<td>III – IV</td>
<td>3.0 – 3.9</td>
<td>~ 50 000 /y</td>
</tr>
<tr>
<td>IV – V</td>
<td>4.0 – 4.9</td>
<td>~ 6 000 /y</td>
</tr>
<tr>
<td>V – VI</td>
<td>5.0 – 5.9</td>
<td>~ 800 /y</td>
</tr>
<tr>
<td>VI – VII</td>
<td>6.0 – 6.9</td>
<td>~ 120 /y</td>
</tr>
<tr>
<td>VII – VIII</td>
<td>7.0 – 7.9</td>
<td>~ 18 /y</td>
</tr>
<tr>
<td>VIII - IX</td>
<td>8.0 – 8.9</td>
<td>~ 1 /y</td>
</tr>
<tr>
<td>IX or higher</td>
<td>9.0 or higher</td>
<td>~ 1 – 5 /100y</td>
</tr>
</tbody>
</table>

### 2.3. Volcanic Eruption

Volcanologists and other specialists are used to use the Volcanic Explosivity Index in order to measure and characterise volcanos. The Volcanic Explosivity Index (VEI) is a scale from 1 to 8 to measure the magnitude of volcano’s eruption. The scale was invented by Chris Newhall of the U.S. Geological Survey and Stephen Self of the University of Hawaii in 1982, [10]. The VEI measures the relative explosiveness of volcanic eruptions. It measures how much volcanic material is ejected, the height of the material thrown into the atmosphere, and how long the eruption lasts. A schematic representation of the VEI scale is given in Figure 2 below from [11]. A more detailed description of the VEI scale is given in Table 3 below from [12]. In the case of volcano threats, both magnitude of the hazard and its likelihood are measured.

#### 2.3.1. Magnitude metrics

The magnitude of the volcano hazard is directly proportional to the total ejected energy (mass, height, duration). The Volcanic Explosivity Index (VEI) classifies from 1 to 8 the ejected energy during a volcano’s eruption. However, the calculated ejected energy is associated to high uncertainty level.

The final classification of the ejected energy magnitude is qualitative and divided into 8 classes. The metric measuring the magnitude is then intrinsic but qualitative. Exact quantitative measurements for the ejected energy are not currently possible because the high level of uncertainty both in the used models and in the corresponding measurements.
2.3.2. Intensity metrics

In the case of volcanic eruption threats, no intensity measurements are performed.

There are no practices to establish systematic correspondences between magnitudes and impacts in the field of volcanic risk analysis and risk management. The impact of a given released mass/energy on the environment is not systematically measured, e.g., damage on: forests, rivers, air traffic, communication, human health, etc.

2.3.3. Likelihood metrics

The likelihood metric measures: occurrence frequency, occurrence probability, occurrence rate, average time between 2 successive eruptions belonging to the same class, total number of observed eruptions of the same class over 1000, 10,000 or one million years, eruption mean duration.

The increasing quality of the collected data over ever-longer geological periods leads to better estimation of these different probabilistic quantities.

2.3.4. Databases

One of the most recognised volcanoes databases is the “Volcanoes Database of the Smithsonian Institution”, [13]. Other frequently cited databases are:

- International Association of Volcanology and Chemistry of the Earth’s Interior (IAVCEI) database (http://www.iavcei.org)
- Volcanoes of the World (VOTW) Database Information – USA (http://volcano.si.edu/search_volcano.cfm)
- Large Magnitude Explosive Volcanic Eruptions (LaMEVE) – UK (http://www.appliedvolc.com/content/1/1/4/abstract)
- National Research Institute for Earth Science and Disaster Prevention (NIED) – Japan (http://www.bosai.go.jp/e/)

2.3.5. Conclusions about volcanic eruption metric

For volcanic eruption threat, there exist a universal metrics where one can measure: the magnitude, and the likelihood of a given eruption. While, no systematic intensity measurements are practicing to characterise volcanoes’ impact. Intensity would measure the hazardous consequences of a given volcano eruption on its surroundings.

The magnitude metrics allow measuring: the released energy (in terms of ejected mass, plume height and eruption duration), Table 3. These metrics measure the intrinsic properties of the eruption. It is worth underlying that magnitude is measured using a qualitative metric (category scale). This is mainly because the measures of the ejected masses, the plume height and eruption duration contain high uncertainty.

Only likelihood is measured using a quantitative metric that allows measuring the occurrence frequency per volcano category. We can equally measure: mean occurrence intervals between two
successive events of the same class or the total number of events belonging to the same class over a well-determined interval of time. Regarding the volcanic threat, its likelihood metric is not yet robust enough. This is mainly because of the complexity of volcanic eruption phenomena. However, the increasing quantity of cumulated volcanic eruption data, the high quality of the measurements and the development of advanced models would lead to improving the robustness of the likelihood measures.

Figure 2: Presentation of the VEI scale (a picture from Wikipedia, [11])
**Table 3**: Detailed description of the VEI scale developed by Newhall and self.

<table>
<thead>
<tr>
<th>VEI</th>
<th>Ejecta volume</th>
<th>Eruption Classification</th>
<th>identification</th>
<th>Description</th>
<th>Plume Height</th>
<th>Frequency of Eruption</th>
<th>Examples</th>
<th>Occurrences in last 10,000 years*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt; 10,000 m³</td>
<td>Hawaiian</td>
<td>Effusive</td>
<td>An outpouring of lava on the ground (as compared with eruptions of ash into the air)</td>
<td>&lt; 100 m</td>
<td>Persistent</td>
<td>Kilauea, Piton de la Fournaise</td>
<td>Many</td>
</tr>
<tr>
<td>1</td>
<td>&gt; 10,000 m³</td>
<td>Hawaiian/Strombolian</td>
<td>Gentle</td>
<td>Low-level, small to medium volume</td>
<td>100–1000 m</td>
<td>Daily</td>
<td>Nyiragongo (2002)</td>
<td>Many</td>
</tr>
<tr>
<td>2</td>
<td>&gt; 1,000,000 m³</td>
<td>Strombolian/Vulcanian</td>
<td>Explosive</td>
<td>Dense cloud of ash and gases with volcanic bombs (2-3 meters in diameter)</td>
<td>1–5 km</td>
<td>Weekly</td>
<td>Ruapehu, New Zealand (1971), Mount Sinabung (2010)</td>
<td>3,477</td>
</tr>
<tr>
<td>3</td>
<td>&gt; 10,000,000 m³</td>
<td>Vulcanian/Pelean</td>
<td>Severe / Catastrophic</td>
<td>Glowing avalanche of hot ash and pyroclastic flows</td>
<td>3–15 km</td>
<td>Few months</td>
<td>Soufriere Hills (1995), Nevado del Ruiz, Colombia (1985)</td>
<td>868</td>
</tr>
<tr>
<td>4</td>
<td>&gt; 0.1 km³</td>
<td>Pelean/Plinian</td>
<td>Cataclysmic</td>
<td>Columns of gas and ash extends to stratosphere</td>
<td>10–25 km</td>
<td>≥ 1 yr</td>
<td>Mount Pelee, West Indies (1902), Eyjafjallajokull (2010)</td>
<td>421</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 1 km³</td>
<td>Plinian</td>
<td>Paroxysmal</td>
<td></td>
<td>20–35 km</td>
<td>≥ 10 yrs</td>
<td>Mount Vesuvius, Mount St. Helens (1980)</td>
<td>166</td>
</tr>
<tr>
<td>6</td>
<td>&gt; 10 km³</td>
<td>Plinian/Ultra-Plinian</td>
<td>Colossal</td>
<td></td>
<td>&gt; 30 km</td>
<td>≥ 100 yrs</td>
<td>Krakatoa, Indonesia (1883), Mount Pinatubo, Philippines (1991)</td>
<td>51</td>
</tr>
<tr>
<td>7</td>
<td>&gt; 100 km³</td>
<td>Ultra-Plinian</td>
<td>Mega-coloossal</td>
<td></td>
<td>&gt; 40 km</td>
<td>≥ 1,000 yrs</td>
<td>Tambora (1815)</td>
<td>5 (+2 suspected)</td>
</tr>
<tr>
<td>8</td>
<td>&gt; 1,000 km³</td>
<td>Supervolcanic</td>
<td>Apocalyptic</td>
<td></td>
<td>&gt; 50 km</td>
<td>≥ 10,000 yrs</td>
<td>Yellowstone (Pleistocene)</td>
<td>0</td>
</tr>
</tbody>
</table>

Table from reference [12] with minor modifications to follow the most recent use (scale 7: Super-coloossal → Mega-coloossal and scale 8: Mega-Coloossal → Apocalyptic).
2.4. Flood

A flood threat may be caused by extreme local precipitations (e.g., torrential rain), long durations of heavy rain, rapid snowmelt, fast runoffs (e.g., alluvial fan flooding), overflowing waterways, or by failing levees and other water management infrastructure objects (e.g., dams, dunes). Examples of recent large scale floods in Europe are the UK ones in 2002 and 2007 and the extreme flooding in central Europe in 2007 and 2013. From past flood crises management, we can underline the following security metrics: magnitude, intensity and likelihood.

2.4.1. Magnitude metrics

The flood magnitude is measured using the following metrics: the total amount of water covering a given region (height in meter rather than masses), the water flow rate and the water courant, if the water source is a river. If the water source is the rain, additional magnitude metrics are added such as: rainfall rate (cm/day) and total rainfall amount (cm) over the rain period. The previous flood properties are all measured using quantitative metrics. Although crisis managers refer to water amount/quantity, they measure it in water height (cm or meter).

However, floods are often classified according to their magnitude in categories using a scale of four or three graduations, such as: extreme, medium or small. That seems more practical for flood crisis managers than the quantified magnitude measurements.

2.4.2. Intensity metrics

Different types of metrics are used in practice to measure flood threats intensity: inoperability of transportation & traffic CI, number of evacuated persons, partial damage to CIs (dams, electricity substations, highways), the regional extension of the flood, the biological and chemical contamination level, number of fatalities and/or economic losses, [36][37][38][39].

2.4.3. Likelihood metrics

The likelihood of floods per flood category can be determined combining different models such as: statistical models, water storage capacity models, meteorological forecasting models, hydrological models, flood inundation models, rivers hydraulic models and rainfall models. However, resultant figures still have high level of uncertainty. There are not yet universal metrics for flood likelihood. For instance, for the occurrence frequency measures, four cyclic periods are used: less than 1 in 1000 years, less than 1 in 100 years, less than 1 in 10 years; and at least one each year.

Several tools exist, both at national and EU levels. At the EU level, the European Flood Awareness System (EFAS) plays an important role. EFAS is an operational European system for monitoring and forecasting floods across Europe. (www.efas.eu).

Existing databases allow determining magnitudes and likelihood over short periods (~ 1-2 weeks) in terms of: occurrence probability within a given period of time or probability of a given active phase...
duration per flood category. This will certainly be improved thanks to the new M&S capabilities and remote sensing orbital climatic observation.

2.4.4. Databases

Historical floods data are of good statistical quality and allow determining magnitudes and likelihood over short periods (~ 1-2 weeks).

Different databases exist in many countries. We list the following:

- EFAS European Flood Awareness System – EC/JRC-Ispra, Italy (www.efas.eu)
- BDHI (Base de Données Historiques sur les Inondations), France (www.bdhi.fr)
- NSSL (National Severe Storms Laboratory) database of flash flood observations, USA (www.nssl.noaa.gov)

2.4.5. Conclusions about flood metrics

Large scale floods are frequent and are very often a vector of cross-border crises, in Europe. Flood magnitude and likelihood are measured using quantitative metrics. While intensity is measured using a qualitative metrics. In crisis management practices, floods are often classified according to their magnitude in categories using a scale of four or three graduations, such as: extreme, medium or small.

2.5. Extreme wind

USA has a leading role in the field of extreme winds threats as North America is more impacted than Europe. Only in recent two years (2013 and 2014) there were over 190 fatalities caused by extreme winds, [28]. The total damage costs exceeded 6 billion dollars. Hence USA and its federal agencies like National Oceanic and Atmospheric Administration, National Weather Service, National Hurricane Centre or Joint Typhoon Warning Centre and their practices are valuable starting point for the thorough consideration of metrics necessary to effectively deal with extreme winds threats. The following scales, [29][30][31][32], and methods are being used in operational environment by mentioned above Crisis Management agencies.

We will refer to the four most used scales used for extreme wind risk analysis in the USA, namely: the Beaufort Wind Force Scale (BWFS), the Enhanced Fujita Scale (EFS), the Saffir–Simpson Hurricane Wind Scale (SSHWS) and the TORRO tornado intensity scale (T-Scale). They are respectively given in Annexes 1, 2, 3 and 4. The four scales are not completely different and they use similar metrics but with different focuses.

2.5.1. Magnitude metrics

The Beaufort Wind Force Scale (BWFS, see Annex 1) is an empirical measure that relates wind speed to observed conditions at sea or on land. However, it is a measure of wind speed and not of force in the scientific sense. The Beaufort scale assesses wind speed and wave height. The highest speed level on the scale reaches 118 km/h. The wave height is measured in meters [m] and the
highest level on the scale is at 14 m. There are thirteen levels on the Beaufort scale - it starts with light air and finishes with hurricane force description. Despite the general description the scale characterizes both sea and land conditions. Although the scale is measuring wind speeds and wave heights quantitatively, it categorises wind using a qualitative scales contains thirteen level starting by “Calm” and ending at “Hurricane”, Annex 1.

Although Enhanced Fujita Scale (EFS, see Annex 2) categorises winds in 6 levels based on wind speed (EF0 to EF5), it measures wind intensity (damages) rather than wind magnitude (see the following section 2.5.2 on intensity measures).

Saffir–Simpson Hurricane Wind Scale (SSHWS, see Annex 3) categorises winds in five levels (Cat1 to Cat5). It uses three metrics: wind speed, normal central pressure and wind duration. The three metrics are magnitude measures. However, as in the case of the EFS, it ends up by a qualitative grid to measure intensities (see the following section 2.5.2). Dislike the EFS, it can be used to measure both: magnitudes and intensity. Although, the correlations between both measures are not robust because of the absence of models and the high level of uncertainties in the measured quantities: wind speed, central pressure and duration.

The TORRO tornado intensity scale (T-Scale, see Annex 4) measures tornado magnitude between T0 and T11. It differs from the EFS because it classifies tornados according to wind speed and normal central pressure measures, whereas the EFS relies on damages for classification. It differs from SSHWS in that it is does not measure durations. It remains similar to both EFS and SSHWS as:

- It includes data about magnitude.
- It uses this data partially or fully to categorise extreme wind.
- It is mainly used to measure intensities (see next section 2.5.2) while the correlations between both properties (magnitude and intensity) are not robust.

2.5.2. Intensity metrics

The EFS rates the strength of tornadoes in the United States and Canada based on the damages caused. The scale remains a damage scale although it gives wind speed figures. Those wind speed associated to the damage listed in that scale have however not undergone empirical analysis, such as detailed physical or numerical modelling. The absence of empirical analysis is owing to excessive cost and because wind speeds were obtained through a process of expert elicitation. In addition, information from damage to structures and vegetation, radar data, photogrammetry, and cycloidal marks (ground swirl patterns) may be employed when available. Currently it is based on 28 damage indicators (DI), each with different degrees of damage (DoD). The DoD is obviously a function of the wind speed and the damaged object. The scale can’t be considered as universal.

The SSHWS classifies hurricanes – Western Hemisphere tropical cyclones that exceed the conditions of tropical depressions and tropical storms – into five categories. The classifications provide indications of the potential damage caused upon landfall. Officially, the SSHWS is used only to describe hurricanes forming in the Atlantic Ocean and northern Pacific Ocean east of the International Date Line. Other areas use different scales to label these storms, which are called cyclones or typhoons, depending on the area. The SSHWS’ five categories start at the level of very dangerous...
winds will produce some damage and ends at catastrophic damage. The classification is based on three metrics: sustained wind speed, normal central pressure (with some exceptions) and duration.

The T-Scale measures tornado magnitude between T0 and T11. It was developed by Terence Meaden of the Tornado and Storm Research Organisation (TORRO), a meteorological organisation in the United Kingdom, as an extension of the Beaufort scale. The T-Scale differs from the EFS scale in that it classifies tornados according to wind speed and normal central pressure measures, whereas the EFS relies on damage for classification. In practice, damage is utilized almost exclusively in both systems to infer intensity. The scale is primarily used in the United Kingdom whereas the Fujita scale is the primary scale used in North America, continental Europe, and the rest of the world.

2.5.3. Likelihood metrics

The meteorologists try to measure the mean-time between two successive peaks of extreme wind. The objective is to come up with a provisional model. The mean time between two successive extreme wind incidents is very often expressed with the help of a Gumbel distribution. However, the model is not yet robust as precise local data for long periods are not available. Most of the extreme wind databases contain geographical global data. This is almost the only likelihood measure that could be taken in extreme wind databases.

2.5.4. Databases

Many institutes collected information on extreme wind storms over the years with different levels of access. Here are few:

- National Climatic Data Centre (NCDC) database – USA (www.ncdc.noaa.gov/data-access)
- National Climatic Data Centre-Storm Events Database – USA (https://www.ncdc.noaa.gov/stormevents/)
- Extreme Wind Storms (XWS) Catalogue – UK (http://www.europeanwindstorms.org/)
- WindData on wind characteristic – DK (http://www.winddata.com/)
- Mediterranean HIPOCAS wind database, SP (http://www.mar.ist.utl.pt/hipocas/)

2.5.5. Conclusions on extreme wind metrics

Based on the previous assessment and regarding metrics for extreme wind one may conclude the following:

- Magnitude metrics: measure wind speed, the corresponding central pressure and the duration (if possible). These measures are quantitative and universal.
- Intensity metrics: either measure a damage indicator (DI) or a degree of damage (DoD) per CI type and per wind category. This measure will be qualitative and local. It depends much on expert’s judgement.
- Likelihood metrics: use probabilistic measures (probability functions and/or probability distribution) and/or meantime intervals between successive occurrences of extreme winds
belonging to the same category. Existing database and extreme wind records will allow extracting these measures with a significant uncertainty level.

Magnitudes such as: speed, pressure and duration can be satisfactory measured with satisfying levels of uncertainty. The existing correlations between magnitudes and intensities are not robust enough to be used directly. The highest challenge with extreme wind measures is still to measure the impact (intensity).

2.6. Wild Fire

Wildfires can be ignited by lightning, volcanoes, very hot weather or accidentally by man error. Fires can generate large amounts of smoke pollution, release greenhouse gases, destroy ecosystems and threaten people, cities and critical infrastructure. One of the most significant wildfire events in recent years took place in 2007 in Greece. There were over 100 blazes, which broke out across the country in couple of days. One of them severely threatened suburbs of Athens. Relevantly electricity pylons, exploding after a record heatwave, have sparked some of the fires. Over 30 people died and emergency services from 20 countries were involved in dousing the flames.

Wildfire threat is one of the major natural hazards which receive particular interest from crisis managers, researchers and public. Modelling & Simulation of natural fire ignition, propagation and impact is well advanced and models are satisfactory robust, [33][34].

Metrics described below, derived from the domain literature, [35], seem to be the most useful in understanding fire behaviour.

2.6.1. Magnitude metrics

The focus should be laid upon the fire magnitude, but unfortunately fire fight operators use the word intensity. It describes the physical combustion process of energy release from organic matter during various phases of the fire. The common set of metrics includes mainly reaction intensity, fireline intensity, and wind. Because we are keeping the use of the work Intensity for the impact of a threat, we will rather use the following magnitude terms that better fit with the used metrics:

- Reaction Intensity: can be replaced by “Reaction Surface-Power” measured in: \( W/m^2 \), \( kcal/s/m^2 \) or \( BTU/min/ft^2 \).
- Fire-line Intensity: can be replaced by “Reaction Line-Power” measured in: \( W/m \), \( kcal/s/m \) or \( BTU/min/ft \).

This is mainly to avoid confusion between the use of the term “intensity” by fire risk management operators and our use of “intensity” to refer to the impact of a threat.

**Reaction surface-power** is defined as a measure of the time-averaged energy flux or, in other words, the energy per unit volume multiplied by the velocity at which the energy is moving \([W/m^2]\). It is expressed as heat energy/area/time, such as BTU/square foot/minute, or Kcal/square meter/second.
Reaction linear-power is the rate of heat transfer per unit length of the fire-line \([W/m]\). This measure is much broader than reaction intensity and represents the radiant or convective energy in the flaming front. Fire-line intensity is an important characteristic for propagation of a fire, and thus is critical information for fire suppression activities. Fire-line intensity is synonymous with the terms Byram's fire intensity (Byram 1959) and frontal fire intensity. It is the numerical product of a fire's rate of spread, fuel consumption, and heat yield at a given point on a fire's perimeter. Reaction intensity and total fire flux are examples of other measures of fire intensity. Fire-line intensity is the most frequently used in forested ecosystems, where dependencies between fire-line intensity, flame length, scorching height of conifer crowns and the fire itself is thoroughly proved and investigated.

Wind speed is also a measure to be considered. It is not intrinsic to fire itself, but it a vector of fire propagation.

Less frequently, other metrics are used such as in:

- smouldering combustion, which is related to temperatures at the soil surface and the duration of heating rather than to fire-line intensity. Smouldering is a slow, low-temperature, flameless form of combustion and is measure in Kelvin scale \([К]\);
- temperature (maximum temperature) is measure in Kelvin scale \([K]\);
- duration of heating (residence time) is measure in: hour \([h]\), minute \([m]\) and second \([s]\);
- radiative energy is the radiant component of total energy release form fires
- flame length is primarily applicable to fuel types with the same fuel structure characteristics, is the distance measured from the average flame tip to the middle of the flaming zone at the base of the fire.

2.6.2. Intensity metrics

No data or databases could be monitored as containing data about wild fire damages. However, fire is classified in six categories according to its potential to cause harm and damage, in the European Forest Fire Information System-EFFIS. The EFFIS identify this metric as "Fire Danger Level".

EFFIS is forecasting forest fire daily occurrence likelihood and calls this “fire danger index”. The EFFIS network has definitively adopted the Canadian Forest Fire Weather Index (FWI) System in 2007, as the method to assess the fire danger level in a harmonized way throughout Europe. Calibration of the fire danger index is still on going, thus the fire danger forecast module of EFFIS is to be considered in test or pre-operational mode. Fire danger is mapped in 6 classes (very low, low, medium, high, very high and extreme) with a spatial resolution of about 10 km (MF data) and 36 km (DWD data). The fire danger classes are the same for all countries and maps show a harmonized picture of the spatial distribution of fire danger level throughout EU, Table 4.

2.6.3. Likelihood metrics

The European Forest Fire Information System-EFFIS module generates daily maps of fire danger level projection in EU over 1 to 6 days using weather forecast data. Until 2007, the module used meteorological forecasted weather data from French (MF) and German meteorological services
In this forecasting, a qualitative probabilistic metric is used such as; very probable or probable. The information is essentially used for public awareness. Existing data records does not allow elaborating robust probabilistic measures of wildfire occurrence likelihood.

Table 4: EFFIS Fire Danger Level classified according to their danger index

<table>
<thead>
<tr>
<th>Fire Danger Level Classes</th>
<th>FWI ranges (upper bound excluded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>&lt; 5.2</td>
</tr>
<tr>
<td>Low</td>
<td>5.2 - 11.2</td>
</tr>
<tr>
<td>Moderate</td>
<td>11.2 - 21.3</td>
</tr>
<tr>
<td>High</td>
<td>21.3 - 38.0</td>
</tr>
<tr>
<td>Very high</td>
<td>38.0 - 50.0</td>
</tr>
<tr>
<td>Extreme</td>
<td>&gt;= 50.0</td>
</tr>
</tbody>
</table>

2.6.4. Databases

To supports national services and researchers many indicatives started at different location to store into databases on wildland fires. Here is a non-exhaustive list:

- Statistical Database on Forest Fire – university of Freiburg, Germany (www.fire.uni-freiburg.de/inventory/database/statistic.html)
- EFFIS (European Forest Fire Information System) Database – EC/JRC-Ispra, Italy (http://forest.jrc.ec.europa.eu/effis/)
- NFD (National Forestry Database), Canada (http://nfdp.ccfm.org/)
- CNFDB Canadian National Fire Database, Canada (http://cwfis.cfs.nrcan.gc.ca/ha/nfdb)
- FEIS (Fire Effects Information Systems) - US Department of Agriculture, USA (http://www.fs.fed.us/database/feis/ContentsFEIS.html#FireStudies)

2.6.5. Conclusions on wildfire metrics

Fire threats measures are characterized by high level of complexity. Therefore, there is no single metric which could capture all of the relevant aspects of fire threats. Metrics to measure the wildfire are available such as: reaction surface-power, reaction linear-power, fire duration, radiative energy and flame length. The intensity metric to measure damages and harm effects (impacts) are not directly available. Fire operators use a measure called “level of danger” which is a qualitative measure and gives a guess of the potential danger of a fire (if it happened). We did not monitor any existing correlation between the magnitude and the intensity measures. Existing data and records do not allow the elaboration of a probabilistic measure of wildfire likelihood.
2.7. Chemical process industry

One of the major sources of threats is chemical process industry. Some recent major accidents have affected the society at different levels: affective, economic, technological and scientific. Some of this accident had even impacted on the local governance effectiveness, [14]. Major accidents have often serious consequences, as evidenced by accidents like Seveso, Bhopal, Schweizerhalle, Enschede, Toulouse and Buncefield. Still, it is not an evidence what a “Major Accident” could be. Currently, no standard definition of major accident exists.

2.7.1. Magnitude metrics

The Seveso III Directive 2012/18/EU, [15], adopted on July 4th, 2012 and entered into force on 13th August 2012. The details of this classification are given in references reproduced from SEVESO III Directive, [15]. The threat itself is defined by an exhaustive list of all known chemical hazardous substances involved in chemical process industries, whether they are the main products or the secondary ones. The list includes 48 hazardous identified substances. Many of these have already been involved in past major accidents. Locations where dangerous substances are present are classified as either lower-tier or upper-tier establishments. A lower-tier establishment is an establishment where dangerous substances are present in quantities equal to or more than the quantities listed in Column 2 of Part 1 or in Column 2 of Part 2 of Annex 1, but less than the quantities listed in Column 3 of Part 1 or in Column 3 of Part 2 of Annex 1. An upper-tier establishment means according to the directive: an establishment where dangerous substances are present in quantities equal to or more the quantities listed in Column 3 of Part 1 or in Column 3 of Part 2 of Annex 1.

No direct magnitude measurements are used to characterise the threat of the chemical process industry. However, the metrics use masses of hazardous substances in order to build up a hierarchical classification of potential damage (intensity of the threat). This tendency may be explained by the fact that the hazard quantities can be controlled by man. The threat magnitude is under man’s control. In a given plant, one can give the total amount (kg or tonne) of the present hazardous material. But it is not evident in all situations to assess the amount of material reacting and the reaction rate during the crisis.

2.7.2. Intensity metrics

The intensity of the threat is the main metric used in order to characterise the threat impact in terms of potential damage (health, physical, environmental or others). The used metrics are fully qualitative and risk preventive-management oriented.

Metrics can be given by zones centred around the accident zone in terms of: injured and fatalities, evacuated persons, contaminating agents and concentrations, number of destroyed building (windows, cars), number of damaged assets or CI and local degree of CI loss of operability, etc.

The Seveso III Directive 2012/18/EU, [15], defines major accidents by the occurrence of “a major emission, fire or explosion resulting from uncontrolled developments in the course of the operation of any establishment covered by this directive, and leading to serious danger to human health or the
environment, immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances”.

Subsequently, an accident is major if it leads to “serious danger (in the sense of impact) to human health and environment”. SEVESO-III Directive classifies “Impacts” according to its nature in 4 classes:

- Health (3 subcategories),
- Physical (8 subcategories),
- Environmental (2 subcategories),
- Others (3 subcategories).

2.7.3. Likelihood metrics

No likelihood measurements are used in practice to characterise the threat occurrence. However, elementary data are available and could provide robust estimations of occurrence frequencies for different chemical industry needs.

2.7.4. Databases

In the field of process industry there are many available databases with records covering long periods of time and many industrial sectors. One finds principally “accident description sheets” including quantitative and qualitative factual data on industrial accidents. Very often some reports on accident analysis and lessons learned may be included. Very often, these industrial data are private access ones. We give in the following just few examples of such available databases.

- ARIA accidents database – Ministry of Durable Development, France
- MARS (Major Accident Reporting System) database is held by the EC/JRC-MAHB, Italy
- ZEMA database (Zentrale Melde- und Auswertestelle für Störfälle und Störungen in verfahrenstechnischen Anlagen) centralised informations on accidents in Germany
- ILITY database on accidents worldwide, Finland
- FACTS database on industrial accidents/incidents, the Netherlands. [http://www.factsonline.nl/](http://www.factsonline.nl/)
- PSID (Process Safety Incident Database) by the CCPS (centre for Chemical Process Safety), USA
  [http://www.aiche.org/ccps/resources/psid](http://www.aiche.org/ccps/resources/psid)
- RISCAD - Japanese database, by the National Institute of Advanced Industrial Science and Technology (AIST) and Japan Science and Technology Corporation (JST), Japan
2.7.5. Conclusions on chemical process industry security metrics

The Seveso III Directive 2012/18/EU, [14], provides guidelines that can be used to establish magnitude metrics, such: the amount of the hazardous substances in a given location and their category of hazard (48 hazardous identified substances). The amount metrics is a quantitative one (kg) while the level of hazards is a qualitative metric. This would allow measuring the maximum potential hazard.

Regarding the intensity measures, Seveso III Directive 2012/18/EU, [14] provides a qualitative metric to identify the category of hazard: health with three subcategories, physical with eight subcategories, environmental with two subcategories and others with three subcategories.

No recommendations about the likelihood can be extracted from Seveso directives. However, we will recommend the use of the occurrence probability of hazard substance release accident when it is possible.

2.8. Deep water oil spill

Oil is and will remain the single largest fuel in the primary fuel mix until, at least, year 2035. According to the World Energy Outlook (IEA, 2013) central scenario, global energy demand increases by one-third from 2011 to 2035. Demand grows for all forms of energy, but the share of fossil fuels in the world’s energy mix falls from 82% to 76% in 2035. That would mean a net increase of more than 20% in the demand of fossil fuels between 2011 and 2035. Subsequently, more drilling, oil extraction, transportation and bigger tankers should be expected. Considering major accidents in the various fossil energy chains (i.e. coal, oil and gas), 70% of the severe accidents are due to the oil chain worldwide. Tanker accidents have the largest contribution to the total volume released in oil spills from all sources and the highest likelihood. Drilling rig accidents may release higher amount of spill oil per accident than tankers, but at lower accident occurrence frequency.

Most of the data sources on oil spill risk analysis and risk management come from oil spill accident analysis and lessons learnt feedback more than academic research on the subject. In that aspect, oil spill risks are very different from volcanic eruption or seismic risks.

Two of the most important crises in recent history are presented in the following paragraphs: Macondo well (Gulf of Mexico) explosion, [16][17][18], and Gulf War (Iraq) Oil Fire, [19]. Both cases represent an oil spill disaster. For this deliverable, our interest is not in the crises itself (initiating event, failures, sequences and consequences); we are interested in the security metrics used in measuring different aspects of the crises.

Deepwater Horizon accident occurred on April 20th, 2010. It was an explosion occurred through the Deepwater Horizon drilling rig while the rig’s crew completed drilling the exploratory Macondo well deep under the waters of the Gulf of Mexico. Eleven crew members died, and others were seriously injured, as fire engulfed and ultimately destroyed the rig. Over 84 days beginning on April 20, 2010, the Deepwater Horizon oil well released over 4.9 million barrels. During the spill, oil was dispersed through the application of 1.8 million gallons of surface and subsurface chemical dispersants. By June 2, 2010, the area of federal waters closed to fishing had grown to its maximum of 88,522 square miles
or nearly 37% of federal waters in the Gulf of Mexico, [18]. The most negative environmental impact was on the regional ecosystem. Simulation of the spilled oil dispersion over 100 days and 1000 days was performed in order to assess the recuperation time of the ecosystem to original conditions (system resilience), [16][17]. The study in [16] cited that: “…integrating results from oil dispersion model (UCAR model) suggests that the maximum concentration of oil (total hydrocarbons) that would have entered Louisiana’s estuaries after 100 days of continuous spillage is likely to be in the range of 10-50 parts per billion (ppb). This is a conservative estimate, since, like similar models, UCAR model does not account for evaporation, biodegradation, or physical removal of oil. However, according to EPA guidelines for risk to aquatic and human health, these levels are not likely to impact human or marine life”. the regional economy was the most negatively affected especially the fishing industry, [16][18].

Regarding the Iraqi war oil spill of January 1991, the Iraqi army discharged around 6 million barrels of oil into the Arabian/Persian Gulf, [20]. It would be interesting to compare this number/incident with the 4.9 million barrels in the case of Deepwater Horizon, discussed in section 2.8.1. The dumping lasted from 22nd to 26th January and was caused by the deliberate discharge of oil from the Mina Al-Ahmad Sea Island terminal in Kuwait. The slick reached a maximum size of 160 km by 68 km and was 13 cm thick in some areas. According to R.C. Radolph, [20], almost half of the oil has simply evaporated (!) and more than a million barrels were confined in large pits carved out of the desert. The Environmental Assessments of IUCN (International Union for Conservation of Nature) and Collaborators,[19], concluded that: “The mean magnitude of oil pollution was significantly higher in 1991 compared with 1986, using the data set for 1986/ 1991/ 1992 /1993 (over 10 sites). However, the mean value decreased in 1992 and in 1993 to levels not significantly different from 1986. In 1992 oil pollution declined further (2.2 on scale 0-6), suggesting recovery of at surface substrata to pre-war levels (2.0)”.Almost all the reports available in the literature focused on the environmental aspect of the 1991 Gulf War oil spill disaster. Very little mention has been done regarding industrial risks relative to the water intakes of the coastal desalination plants.

Having analysed these two oil spill crisis, security metrics are derived.

2.8.1. Magnitude metrics

Magnitude measures are used in oil spill risk management and employ metrics such as: oil spilled amount (mass/volume) and spilled oil grade. In the hot phase of the crisis, a metric such as the spill rate is also required.

Besides, oil spill risk analysts and managers use the concept of “severe accident”. Some of them measure the accident “severity” through the magnitude of the threat (the spilled oil): how much oil is spilled. Some of them would measure the accident “severity” through the intensity of threat: how much hazards the spilled oil may result in.

In guidance notes to UK offshore oil & gas operators, [23], the concept of a “Dispersant Combat Rate (DCR)” is proposed and a quantitative metric to assess this combat rate is developed for three categories of offshore Oil Spill accidents; I) from 0 to 100 tonnes, II) from 100 to 500 tonnes and III) from more than 500 tonnes. The use of this concept of DCR is useful for deciding on means to employ
in collecting, dispersing and/or dissolving partially or fully the spilled oil. However, other non-intrinsic properties to the spilled oil are needed and should be considered such as: the wind speed, the sea temperature and local marine currents.

2.8.2. Intensity metrics

Intensity is equally used in assessing the deep water oil spill threat. It is not easy to measure but still it constitutes an important data element in crisis management and decision making. It allows assessing the potential hazards. It is also very useful to define a threshold beyond which an accident will be considered as “severe”. As discussed in the previous section, “severity” can’t just be measured by a magnitude metrics. “Severity” is more related to impact. So it is more appropriate to be measured using intensity metrics.

In the literature there is not any commonly accepted “severity scale” for oil spill threats. Few local classifications exist and can be applied by local states without having the power of an international standard. This is the case of the Rhode Island classification of severity, see Table 5 from reference [21]. However, very often analysts differentiate severe accidents from smaller ones, [22].

In the ENSAD (Energy-Related Severe Accidents Database) an accident is considered to be severe if at least one of the following criteria is fulfilled:

- at least 5 fatalities,
- at least 10 injured,
- at least 200 evacuees,
- extensive ban on consumption of food,
- release of hydrocarbons exceeding 10000 metric tons,
- enforced clean-up of land and water over an area of at least 25 km2,
- economic loss of at least $5 million USD (price level year 2000).

Other intensity metrics can equally be used, such as: the time for the marine wildlife to recover (fully or partially), time for the economic activities or maritime traffic in the region to recover.
Table 5: Severity Scale from State of Rhode Island - Department of Environmental Management, [22].

<table>
<thead>
<tr>
<th>category</th>
<th>severity</th>
<th>Description</th>
<th>quantity of Sp. Oil inland water (Gallons)</th>
<th>quantity of Sp. Oil coastal water (Gallons)</th>
<th>extent</th>
<th>population</th>
<th>resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>minor</td>
<td>A spill, release or potential release of a known, non-combustible variety of oil from a limited source (e.g., from a day-use recreational craft). No deaths, and, if injuries, they are minor.</td>
<td>&lt;100</td>
<td>&lt;1000</td>
<td>Limited to initial area of release and unlikely that it will spread (e.g., an area of 300 square feet or less).</td>
<td>Evacuation will be limited to the immediate area that can be secured in a short period of time and for a limited duration (usually no more than 4 hours). A limited number of the populace will be affected.</td>
<td>Normally to be handled by local emergency responders without RIOST support.</td>
</tr>
<tr>
<td>2</td>
<td>moderate</td>
<td>A spill, release or potential release of oil that poses an uncertain risk to the environment. No deaths, but injuries can be minor to severe.</td>
<td>100-1000</td>
<td>1000-10000</td>
<td>Area may be large but it is limited and not so large as to disrupt normal community functions.</td>
<td>Evacuation will be considered to a designated area that local resources can achieve. Extended sheltering is not required.</td>
<td>Local response agencies may need assistance from other agencies. The RI EMA and possibly the National Response Centre of the US Coast Guard must be notified. Incident command may request RIOST support.</td>
</tr>
</tbody>
</table>
A spill or release that has resulted in a serious fire, explosion or environmental contamination over a large area that is apt to get larger. Injuries or deaths may have already occurred.

<table>
<thead>
<tr>
<th>3</th>
<th>major</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1000</td>
<td>&gt;10000</td>
</tr>
</tbody>
</table>

Large area may be impacted, possibly disrupting essential community services. Extensive environmental contamination is possible. Presents an immediate danger to the public and response personnel. Evacuation will impact a large numbers of the populace and/or disrupt everyday life in affected communities for several days or more. Local response agencies will need assistance from several outside sources. The RIEMA and the National Response Centre of the US Coast Guard must be notified. Incident command is likely to request RIOST support.

1 barrel of oil = 42 US gallons ≈ 0.1364 tonnes
2.8.3. Likelihood metrics

The elementary data are available and well reported in different databases. A global measure of the threat occurrence frequencies is possible and generally used by insurance companies.

One of the recent studies, [21], classifies Oil Spill accidents into four categories: (i) spills occurring during exploration or production, (ii) spills from tankers transporting crude oil and refined products, (iii) spills from onshore and offshore pipelines carrying crude oil and refined products and (iv) spills from refineries and storage sites.

The authors of [21] used information contained in the ENSAD, where 1200 accidental oil spills that occurred between 1974 and 2010 have been analysed. Severe accidents are defined as that result in fatalities and correspond to more than 10,000 tons of spilled oil. This study included oil spills larger than 200 tons in order to make comparisons between incidents of varying scale. During this period (1974-2010), a total of 9.8 million tons of oil were spilled in 1213 incidents, Table 6. While exploration and production sites were responsible for far fewer spills than ships, storage and refinery and pipelines, they caused far greater quantities of released oil.

Using such data would allow assessing some likelihood measures such as:

- Mean spilled tonnage per year per accident category (ships, exploration & production, storage and refinery, pipelines) or per oil grade category.
- Mean number of accidents implying oil spill per category
- Mean number of accidents implying oil spill per year and/or per region

Table 6 : Statistical analysis of Oil Spill Accidents over the period 1974-2010, [21]

<table>
<thead>
<tr>
<th>Category</th>
<th>Spilled Oil (tonnes), Grand total</th>
<th>N° of accidents</th>
<th>tonnes /accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>ship incidents</td>
<td>6 000 000</td>
<td>888</td>
<td>6 756,8</td>
</tr>
<tr>
<td>exploration and production</td>
<td>2 200 000</td>
<td>24</td>
<td>91 666,7</td>
</tr>
<tr>
<td>storage and refinery sites</td>
<td>870 000</td>
<td>113</td>
<td>7 699,1</td>
</tr>
<tr>
<td>pipelines</td>
<td>750 000</td>
<td>188</td>
<td>3 989,4</td>
</tr>
<tr>
<td>total</td>
<td>9 820 000</td>
<td>1 213</td>
<td>8 095,6</td>
</tr>
</tbody>
</table>
2.8.4. Databases

There are many databases containing statistics about oil tankers accidents. The recorded data are of high statistical quality and allow the assessment of the probabilistic quantities required to determine the occurrence likelihood of oil spill accident as mentioned in the above section.

Some databases are mentioned in the following:

- Lloyd’s Maritime Information System (LMIS) database

2.8.5. Conclusions on deep water oil spill security metrics

Magnitude measures are largely used and the used metrics are: oil spill rate, oil spill amount/volume and spilled oil grade.

In oil spill risk analysis and risk management, experts and risk managers often use the concept of “accident severity” in order to assess the impact rather than “intensity”. In the literature, there is no commonly accepted “severity scale” for oil spill threats but local classifications exist such as the Rhode Island classification.

In our analysis we have assimilated “severity” to “intensity”. However, the metrics used in measuring the “severity” is expressed in terms of a quantified threshold. The consequences are judged as “severe” if the severity measure exceeds a threshold. The ENSAD proposes threshold values to express the severity/intensity using different metrics. The metrics are: number of fatalities, number of evacuated persons, costal affected size, economic losses, etc.

Regarding likelihood, data are available and allow measuring occurrence likelihood using metrics such as: mean spilled tonnage per year, mean number of accidents implying oil spill per year, occurrence probabilities, occurrence frequency, etc.

In Europe, the main directive that does apply to deep-sea oil spills is the Environmental Liability Directive (ELD) 2004/35/EC amended by the EC directive 2013/30/EU, [24]. This directive does not propose any metrics to measure oil spill accidents severity, [24].
2.9. Conclusion & Recommendations to the other WPs

We have screened the state of the existing security metrics in eight selected threats. The selected threats are: quakes, volcanic eruptions, floods, extreme winds, wildfires, chemical processing industry accidents and oil spill accidents. The sets of security metrics of interest are: the intensity, the magnitude and the likelihood.

The likelihood metrics have a generic probabilistic nature independent from threats. They depend only on two aspects: the statistical quality of past experience measures and the quality of the phenomenological models used in the MS&A of the events. In order to measure likelihood, one can generally use metrics such as: occurrence frequency, occurrence probability, occurrence probability distribution, meantime between two successive occurrence, the mean time of the active phase, the mean time of the cold phase, the pre-crisis management interval, the live-crisis management interval and the post-crisis management interval. Based on the metrics assessment carried out, we can conclude that occurrence frequencies, occurrence probabilities and mean-time between successive occurrences are the most used (and available) by the risk analysts and risk managers.

Some crisis situation requires management effort only during the crisis hot phase. Others require management efforts during and after the hot phase in order to manage the consequences. Some others require even a pre-crisis management: awareness effort. A synthesis is given in Table 7. If these properties should be considered, they need using a time-like metrics. At the present, only qualitative metrics are used (short-, medium-, long-term).
Table 7 : synthesis of the metrics frequently used in the threat and their impact

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquake</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
<td>short</td>
<td>short</td>
<td>medium</td>
</tr>
<tr>
<td>Volcanic eruption</td>
<td>☒</td>
<td>☐</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
<td>Short-medium</td>
<td>short</td>
<td>medium</td>
</tr>
<tr>
<td>Flood</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>short</td>
<td>short</td>
<td>Short-medium</td>
</tr>
<tr>
<td>Extreme wind</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
<td>☒</td>
<td>☐</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wild Fire</td>
<td>☒</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
<td>-</td>
<td>short</td>
<td>medium - long</td>
</tr>
<tr>
<td>Chemical processing plant</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
<td>-</td>
<td>Short-medium</td>
<td>-</td>
</tr>
<tr>
<td>Oil spill in deep water</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☐</td>
<td>☐</td>
<td>-</td>
<td>short</td>
<td>medium - long</td>
</tr>
</tbody>
</table>

* MTA-ph : mean time of active phase, ** MTC-ph : mean time of cooled phase
3. Security Metrics: Concept and Classification

In the previous chapter, we have exposed the most significant data collected on: threats and consequences (impacts and outcomes), in the view of “metrics” identification. The same has already been carried out in D2.1 [1] regarding the resilience metrics and is summarized in section 3.8 of this document. Different threats (6 nature and 2 technological initiated) have been assessed to some extent. These threats have been specifically selected considering their potential to generate EU-cross border crises. The assessment was tended to establish guidelines and recommendations, regarding the metrics to be employed in the PREDICT DSS Tool. The assessment is based on data collected from literature, mainly in D2.1, with references from different sources, such as: threat databases, available crisis reports, data published by CI operators, data published by asset owners and insurance databases.

This chapter is structured in 8 sections

- Section 3.1: Introduction
- Section 3.2: Threats versus Impact
- Section 3.3: Metrics in conventional risk analysis & risk management
- Section 3.4: Magnitude versus Intensity
- Section 3.5: Magnitude metrics to measure threats
- Section 3.6: Intensity metrics to measure Impacts
- Section 3.7: Immediate versus long-term consequences
- Section 3.8: Resilience metrics
- Section 3.9: The Ideal Security Metric System
- Section 3.10: Metrics used in DSS tools: TRIAMS Case Study
- Section 3.11: Conclusions & Recommendations to PREDICT WPs

3.1. Introduction

As presented in Chapter 1, the CI protection and Crisis Management fields consider three interconnected domains: threats (identification & specification), resilience MS&A (dependency, cascading effect & sequences) and consequences (impacts & outcomes). It is expected to measure each of the previous elements in each domain using adequate metrics. However, this task is not easy. A clear identification of the security metrics basic elements and concepts need to be developed in order to be used in the PREDICT DSS Tool for measuring: threat, resilience and impact.

A clear distinction between “magnitude” and “intensity” measures will be established in sections 3.2, 3.3 & 3.4. One should distinguish between the metrics to be used to measure the threat and those to be used for the impact. That is to say that “threats” will be characterised by their “magnitude” and impacts by their “intensity”.

The major findings on resilience metrics that are treated in PREDICT deliverable D2.1 will be recalled in section 3.8. Resilience has been separated from the threat and impact because it has a different nature. Resilience includes dynamic systemic aspects (CI failure, CI dependency/interdependency, cascading, …). In our terminology, we use indifferently “cascading failures” and “sequence failures” of CIs.

To conclude, Section 3.11 presents some conclusions & recommendations to PREDICT WPs as guidelines for the design of the iPDT.

3.2. Threats versus Impacts

Security experts, operators and managers think often about threats in the following manner:

- How frequent is the threat?
- How long would the threat last (hot phase)?
- How strong/dangerous is the threat? (something related to impact)
- How harmful/menacing is the threat? (something related to outcomes)
- How serious is the threat? (readiness, preparedness, mitigating measurements to undertake)
- When would most likely be the next time? Or
- How likely would it be within a year, 5 years, 10 years, from now?
- …

This set of questions reflects perfectly the nature of the metrics that should be implemented in all threat and crisis databases, and used by analysts, experts, crisis operators, crisis managers and other stakeholders. Which metrics can one use to measure the concepts that answer the previous questions? It may be necessary to examine “what we are measuring” before examining the metrics to be used in measuring it. As we will show in the following analysis, the questions above refer implicitly to both threat and consequences. And this is exactly what we observe in crisis management practices. We observe that the consequences of a threat are very often considered as a proper quality of the threat, and even more as one of its inherent characteristics. Certainly, consequences are functions of the threat, but not only threat. Consequences characterise the interaction between the threat, the CI and the environment (the context). This exclusive appropriation of “Consequences” by “Threats” explains why threat databases exist – including consequences - while there are not as many consequence databases. This is the situation in CIP and crisis management field. Things are different in conventional risk analysis and management.

3.3. Metrics in conventional risk analysis & risk management

In conventional risk analysis and management, the concept “threat” is similar to “initiating event”, the concept “operability” is very close to the classical “system availability” and the concept “recovery” to “reparation”. In conventional risk analysis, the concept “consequence” could be fuzzy. In classical risk analysis, any failure that may be engendered by another failure within the same system, will integrate the same event tree. An “event tree” is a chronological statement of failures that are not necessarily dependent on each other. Subsequently, it is not necessarily a cascading of failures. In classical risk
analysis, the used metrics are: occurrence probabilities, failure rates, repair rates, reliability, availability and common-mode failure factors. These are the elementary concepts. Some others are more complex such as: the distribution of number of occurrences of a given sequence of failures with a well-defined interval of time or the over-all occurrence rate of a given sequence of failures. System risk analyses are generally completed by “danger assessment” or “danger studies” which focus on the critical system failure impact on its surroundings.

In the conventional risk analysis and management, there is a clear separation between the initiating events and the system’s failure consequences. The consequence of failures is not an inherent property of the initiating event. At higher level of systems complexity, emerging concepts such as resilience and interdependency bring the analysis approaches far from the conventional risk analysis its usual metrics. And very often the threat characterisation confuses the threat and its impact, at least as far as metrics are concerned. For example, threat frequency measures an intrinsic property of the threat itself. While the question “how strong is the threat?” requires a measure of the interaction between the threat, the concerned CI and its environment. It measures an extrinsic property of the threat. This measure is often considered as “threat” measure. In most of the threats databases the measures of the consequences are considered as an integrated part of the measures of the threat.

Finally, conventional risk analysis is a single-system oriented approach, e.g.: a power plant, a gas pipeline, a water distribution network, a telecommunication network, etc. Subsequently, conventional risk MS&A practices are single-system/single-sector oriented MS&A processes. Impacted by the recent technological progress, more and more systems become smart, connected and dependent. Subsequently, classical risk MS&A process needs some conceptual updating.

It is worthwhile, to complete the specification of the basic concepts of magnitude and intensity in order to remove any potential confusion about their distinct nature.

3.4. Magnitude versus Intensity

We want to draw the attention that “Magnitude” and “Intensity” concepts are both expressing the same quantity of “energy/matter/information” released by a threat but from two different contextual standpoints:

- **Magnitude:** measures the absolute amount of released energy/matter/information... which is an “intrinsic” universal property of the threat. It will be measured by a unique metric even if the system of units is different, while
- **Intensity:** measures the same amount of energy/matter/information through its consequences on a local environment. It measures an “extrinsic” local property of the threat. It integrates the properties of the CIs, the environment as well as the intrinsic properties of the threat. For a given threats, its intensity will be measured using different metrics in the same surroundings. It will give different values in different surroundings, for the same metric.

We have seen in chapter 2 that in conventional seismic risk analysis, a quake is fully described by its magnitude/intensity, its occurrence frequency and epicentre. Magnitude measures the energy released while intensity measures the local hazardous effects (injuries, fatalities, building destruction,
loss of communication services, and loss of governance effectiveness). In this example “Magnitude” is determined using a quantitative metric while “Intensity” is determined using a qualitative one. Quake frequency is obtained from the statistical treatment of collected seismic observations and data over long time. The same remark holds for all other threats such as: floods, volcano’s eruptions or offshore oil spill.

We will explain the concepts of magnitude and intensity in more detail.

3.5. **Magnitude metrics to measure threats**

Generally, intrinsic properties are complex to measure. Very often, the metrics measuring intrinsic properties are quantitative and based on: deterministic models, statistical data, probabilistic models, field measurements or expert’s knowledge and judgement. The metrics are objective and used to characterise threats.

These metrics can, for example, be: acceleration rate or surface speed (quakes), waves’ height (tsunamis), wind speed (hurricanes), temperature (extreme weather conditions), radio-active exposure doses in contact, mass of ejected ashes and stones (volcanoes)...

In case of extreme wind speed, e.g., it would be modelled by a Gumbel probability distribution function. Likewise, other probability distributions can be proposed for volcano eruption time or tsunami wave height distribution. This is mainly because there are enough data in the corresponding databases cumulated over years and centuries and allow adjusting heuristic or numerical models.

These statistical data over long periods of times are available in most of threats databases, as we have seen in chapter 2. The statistical data allows determining occurrence probabilities and frequencies, (Ch.2, Tables 2,3,5).

3.6. **Intensity metrics to measure Impacts**

Metrics for extrinsic properties are easier to measure but contain high uncertainty and are complex to model. It is very often qualitative. The metrics are used to characterise the impact of a threat on a CI or a set of CIs. CIs can be eco-systems such as forests or rivers and can be technological or financial ones.

Intensity metrics will be used for measuring impacts (immediate, short-terms and direct consequences) and outcomes (mean, long-terms and indirect consequences). The iPDT will determine impacts, only. This is will be done using TRIAMS-like metrics.

Impact metrics measure: devastated areas (quake, fire, hurricanes, hazard materials release, spilled oil, ...), number of evacuated people, mean-time of CI inoperability, services losses down-time, temporary/permanent losses of jobs, loss in capital costs (damaged assets), loss of profit (losses of services supply), etc.

In view of the objective of T2.2, we would like to underline the following:
Impact metrics are often available in the operational database (maintained by the operators or the owners), if the concerned system is a technological one (dams, electricity grid, telecom network, etc.). Impact metrics are also available in the databases containing studies of danger and accident analysis. Impact metrics are also available in threat databases, if the concerned systems are complex and vital ones.

Although the iPDT will determine only impacts, it is worthwhile to distinguish between immediate-direct and long-term indirect consequences, i.e. between impact and outcomes. The access of such data is essential to test the iPDT in the three test-cases.

3.7. Immediate versus long-term consequences

We noticed in the state-of-use of threats metrics, D2.1, frequent confusions such as:

- Threat characterisation: use consequence identification and consequence metrics (intensity) to characterise threats, as well as using magnitude metrics.
- Consequences characterisation: use indifferently short-terms direct (impact) and long-term indirect (outcomes) metrics in characterising consequences.

The first confusion has already been already addressed above. However, the second confusion still must be briefly addressed, in the following. We noticed that the confusion comes principally from the absence of a real definition for the terms “short” and “long” that are clearly referring to time intervals within a specific crisis situation context. A time interval of ten hours could be considered long within the context of an earthquake crisis and short in the context of a flood crisis situation.

Regarding “direct” and “indirect” consequences, we will call direct consequences “first order consequences” while “indirect consequences” will be those of higher order. Subsequently, impacts are first order consequences and outcomes are higher-orders ones. Impact and outcome could also be viewed in the following terms:

- Impact (short-term direct consequences): it can be more or less fully measured within an interval of time comparable to that of the threat hot-phase. The measurements are clear enough to take decisions and prioritise actions regarding consequence mitigations.
- Outcome (long-term indirect-consequences): it can’t be fully measured within a period of time comparable to that of the threat hot-phase. Decisions and counter-actions to manage and mitigate the outcomes are not of high priority, during the crisis hot phase.

It is evident that there is no universal quantitative threshold separating the short- and long-term consequences. Instead, there is a grey zone (fuzzy zone) between “short” and “long” which one can call mid-term consequences. The assessment of the available literature has not produced a clear answer. However, it is crucial to differentiate between impacts and outcomes and use the intensity metric for decision making in crisis management correctly. Therefore, PREDICT, proposes a classification based on the use of the duration of the threat hot phase ($\Delta_{HP}$) as a referential, such as:
 Immediate: time intervals less than or equal to $\Delta_{HP}$
Short-term: time intervals longer than the preceding and less than $10\Delta_{HP}$
Mid-term: time intervals longer than the preceding and less than $100\Delta_{HP}$
Long-term: time intervals longer than $100\Delta_{HP}$

The time intervals classification does not impact the use of the metrics but have a direct and strong impact on supporting decisions making processes in terms of decision and action prioritisation, logistics management and resources allocation during the crisis hot-phase and post-crisis phase. The metrics will stay identical for measuring both types of consequences: impacts and outcomes.

### 3.8. Resilience metrics

As mentioned before, the topic of resilience metrics has been addressed in task T2.1 and reported in deliverable D2.1. In this section we recall the most significant findings after the assessment in D2.1 on this topic. The concept of “resilience” is generally not well-defined in engineering domains and more specifically in the domains of CIP & crisis management. However, we can point out a large amount of interesting work and developments in domains related to the safety and security of information & communication networks. One of the leading actors in this field is ENISA (European Network and Information Security Agency). Several specific and common needs and drivers for adopting resilience and security metrics and frameworks, have been identified by ENISA (ref.37, D2.1, [1]), in order to:

- provide assurance and evidence on the level of resilience and/or security achieved;
- validate the conformance with regulations, policies and business requirements;
- assess the effectiveness of the increasing complexity of technical logs;
- identify the trends in threats, common failure causes, cascading effects, impacts, etc.

A list of the most cited resilience models from D2.1, [1], is given in Table 8. Although these models vary in their mathematical approaches to a large extent, they all use a time-based metric to measure resilience. However, they use the time-based metric differently and do not measure all the same quantities or use the same qualitative scale.

#### Table 8: Some of the most cited resilience models [1] and the section of citing in D2.1 (section 5.5).

<table>
<thead>
<tr>
<th>#</th>
<th>Model Title</th>
<th>#</th>
<th>Model Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Input-Output Interoperability Model</td>
<td>6</td>
<td>Spatially Explicit Resilience-Vulnerability model (SERV)</td>
</tr>
<tr>
<td>2</td>
<td>Dynamic Input-Output Interoperability Model</td>
<td>7</td>
<td>Kou Model</td>
</tr>
<tr>
<td>3</td>
<td>CERT Resilience Management Model</td>
<td>8</td>
<td>Turnquist and Vugrin (T&amp;V) Model</td>
</tr>
<tr>
<td>4</td>
<td>Disaster Resilience of Place Model (DROP)</td>
<td>9</td>
<td>Ouyang and Dueñas-Osorio Model</td>
</tr>
<tr>
<td>5</td>
<td>F&amp;B Model</td>
<td>10</td>
<td>ResilUS model</td>
</tr>
</tbody>
</table>
3.8.1. Resilience Metrics in DSS

As we have already mentioned that the resilience concept has a specific nature compared to the threat and the impact. That may explain why none of the tools supporting decisions in crisis management and listed in D2.1 (Table 9) uses the notion of resilience metrics although many resilience models exist, as displayed in Table 8. The PREDICT Project has identified DSS that are interesting for the PREDICT project in D2.1 [1], including:

- RODOS – Real-time On-line Decision Support,
- SAHANA EDEN,
- ARGOS,
- Presagis STAGE & AI.implant,
- Tangible Disaster Simulation System,
- INDIGO Crisis Management Solutions

All of these tools, amongst other functionalities, model cascading dynamics and dependencies. They do also provide critical crisis scenarios (except ARGOS) and enable sharing seamless data by the end-users (except PRESAGIS…). Finally, the real-time support and the geo-localization are still the most crucial features to be implemented. All these features are necessary for determining CI resilience, even if they do not directly model resilience. They are interesting in cascading failures (interdependencies), critical scenarios (sequences) and consequences. The tools, mentioned above, are described in D2.1 (Annex 2).

3.8.2. Major outputs from D2.1 for Resilience Metric

In the absence of standard metrics to measure “resilience”, PREDICT will develop its own approach. Based on the assessment in D2.1 of models used to determine resilience of a system, we present our approach schematically, Figure 3. The resilience metric is a 2-D metric \([O(t),t]\), where “\(O(t)\)” defines the system operability and \(t\) describes the time. The operability “\(O(t)\)” represents either the “service supply level” or “the probability of having a given service supply level”. In the latter case, it will be called the probability distribution of the service supply level. D2.1 recommends the use of a simplified approach where one can assess the resilience of a complex system (/a group of CIs) using the following time-metrics:

- Damage propagation meantime (starting from the initial failure moment): this metric represents the ability (robustness) of a CI or of a group of CIs to resist disruption facing a given threat.
- Mean Recover Time: this metric represents the ability of a CI or a set of CIs to recover, if possible, after disruption caused by a given threat.

Other metrics can be derived and can be employed if statistical data and/or advanced mathematical modes allow. These derived metrics include:

- Damage propagation probability density function
- Recovery probability density function
- Given a well-defined threat, the probability of failure initiation
- Given a well-defined threat, disaster mean prevention time

![Diagram](https://example.com/diagram.png)

**Figure 3**: Schematic performance response curve of a CI facing a threat

### 3.9. The Ideal Security Metric System

The CIP and Crisis Management fields consider three interconnected domains: threats (identification & specification), resilience MS&A (dependency, cascading effect & sequences) and consequences (impacts & outcomes). By impacts, we refer to the first order direct consequences as mentioned before. Outcomes will refer to all other consequences of higher orders: the consequences of the consequences and so on. We will be considering only the first order consequences and will refer to these using the term “impacts”.

*The question remains what would theoretically be a complete security metric system?*

Because there are no normalised definitions for resilience, impact or security metrics, a complete security metric system must measure:

- The intrinsic properties of the threat (magnitude),
- The threat hot-phase period,
- The impact (intensity),
- The likelihood of the threat,
- The probability distribution of the impact,
- Threat-CI dependencies (CI vulnerability to threat),
- CI-CI dependencies (sequences/cascading/scenarios),
At present, we are far away from the complete security metric system in practice as far as CIP and crisis management are concerned. The situation regarding threats-consequences is a synthesis is given in Table 7 above.

Regarding the iPDT, a satisfactory metric system must include: a magnitude (strength) metric, a likelihood metric (occurrence rate/occurrence probability), an intensity measure (impact on a given system including its environment) and a measure for the duration of the impact (meantime to recover or similar).

3.10. Metrics used in DSS tools: TRIAMS Case Study

In practical crisis situations, most of the DSS start by establishing the context (geographical and events factual data), a shortlist of the most plausible critical scenarios and the typology of the potential serious consequences (impact and outcomes if possible), given the magnitude of the threat. Schematically, the aim is to:

- Determine the immediate impacts and decide on organisation and actions to stop potential cascades (propagation of failures) and mitigate consequences, if possible
- Follow the crisis evolution and review/correct decisions in an adaptive way.
- Assess the real operability state of different concerned CIs and impacts, proceeding from global critical systems and sub-systems (sets sectors, sectorial infrastructures, individual infrastructures, major systems in a given CI) to measurable indicators (dependent systems failures, number of deaths, financial loss, governance effectiveness, etc.).

Many organisation schemes exist in the field of crisis management. It is interesting for the sake of close-to-real use of DSS in crisis management situations, to present a relevant case-study. One such case-study, used by TRIAMS (http://www.who.int/hac/crises/international/asia_tsunami/triams/en/), is presented in the next section.

Recognised expertise with TRIAMS exists within the PREDICT consortium and this expertise will be used to guide the design and the testing of the iPDT.

3.10.1. TRIAMS case study

We propose an organization of the impacts, mostly inspired from “Tsunami Recovery Impact Assessment and Monitoring System” (TRIAMS).

TRIAMS is supported by the WHO (World Health Organization) and the IFRC (International Federation of Red Cross and Red Crescent Societies). Many risk management tools are focusing on risk reduction, relief, and recovery, this organization is also relevant in preventive phase for assessing cascading effects.
Impacts are organized in the following topics: vital needs, basic social services, infrastructure, livelihoods and cross-cutting issues.

Here is a non-exhaustive list of topics, sub-topics and metrics (*metrics are in italic*):

- **Vital needs**
  - Casualties:
    - Number of deaths,
    - Number of missing,
    - Number of injuries.
  - People evacuation:
    - Number of evacuees.
  - Water/Sanitarian infrastructure:
    - Number of people affected by lack of drinkable water.
  - Food delivered (e.g. Lack of Food):
    - Number of people affected by lack of food.
  - Housing (Lack of Accommodation):
    - Housing units destroyed or damaged,
    - Number of people affected by damaged or destroyed housing.

- **Basic social services**
  - Access to hospitals:
    - Number of health facilities damaged/destroyed,
    - Number of health personnel killed.
  - Access to school/education:
    - Number of teachers killed,
    - Number of schools damaged/destroyed,
    - Number of school children affected.

- **Infrastructure**
  - Roads & Vehicles:
    - Damages:
      - Km of road damaged/destroyed,
      - Number of bridges damaged/destroyed,
      - Number of Vehicles damaged/destroyed.
    - Traffic congestion:
      - At fine granularity: local traffic flow and occupation rates, resulting in traffic classification (fluid, dense, saturated),
      - Total number of km of congested roads,
      - Time to go from one point to another one for predefined sectors.
  - Railway / metro:
    - Punctuality (difference between the real time table and the announced time table) during or outside rush hour, at different stations or segments,
    - Number of cancelled trains,
- Regularity for the metro (mean difference between two successive trains) during or outside rush hour, at different stations or segments.
  - Aviation. Generally speaking, the goals common to all the aviation stakeholders (airlines, ground-handlers, airport operator,…) of an efficient airport can be classified under:
    - Punctuality:
      - Daily punctuality with respect to schedule for short and long haul flights,
      - Number of cancelled flights.
    - Safety:
      - Traffic congestion:
        - Number of aircrafts queuing in sequence,
        - Number of aircrafts moving simultaneously on the manoeuvring area.
    - Capacity:
      - Runway overload: Compare the actual departure and arrival rate with the departure and arrival demand.
  - Harbours/ports damaged/destroyed:
    - Number of Harbours/ports damaged/destroyed.
  - Electricity:
    - % of power loss.
  - Police department:
    - % of available police resources.
  - Fire rescue service agency:
    - % of available fire rescue resources.
- Livelihoods
  - Job losses & Personal income losses:
    - Number of Unemployment due to the crisis (direct consequence) or economic loss (indirect consequence),
    - Number of people affected by personal income loss due to the crisis (direct consequence) or economic loss (indirect consequence),
    - Average personal income loss due to the crisis (direct consequence) or economic loss (indirect consequence).
  - Cost of reconstruction,
  - Industrial loss (in the area of the crisis, but also the propagation to other areas or countries),
  - Agriculture loss:
    - Livestock perished,
    - Fishery sector damaged/destroyed,
    - Crop area damaged.
- Cross-cutting issues
  - Environmental issues:
    - Size of the contaminated area,
- Intensity of contamination in the contaminated area,
- Quantity of Contaminated food,
- Quantity of contaminated water.

- World Heritage damaged/destroyed:
  - Number of World Heritage damaged/destroyed.
- Waste management system:
  - Degree to which the Waste management system works.

The most interesting aspects of the TRIAMS case study, with respect to security metrics, are:

- It determines consequences: impact (damaged roads, fatalities, loss of operability) and outcomes (economic losses)
- It uses quantitative metrics (number of ..., km, area, ....)
- It uses qualitative metrics (fluid, dense, saturated).

3.11. Conclusions & Recommendations to PREDICT WPs

The integrated PREDICT DSS Tool should allow:

- magnitude (strength) measure for the threat,
- likelihood measure (occurrence rate/occurrence probability) for threats,
- intensity measure (impact on a given system including his environment) for the impacts,
- the duration of the impact (meantime to recover or similar) for the CI resilience and
- the meantime between two successive failures in a cascade to characterise the cascading of failures.

Metrics should comply with the International System of units.

The most important DSS tools characterise threats and impact using adequate metrics that are not always quantitative. However, almost no-one uses metrics to measure resilience or dependencies. Although many mathematical models use time-like metrics to measure resilience and binary functions to measure CIs dependencies (dependent or not), WP2 recommends that the iPDT should be able to classify a threat in terms of topics and subtopics. In addition we would also like to recommend that the iPDT specifies the threat by magnitude while intensity should be used to characterise impact.

Remarks on security metrics and some recommendations for the iPDT are given Table 9.
### Table 9: Remarks on security metrics and recommendations for the iPDT

<table>
<thead>
<tr>
<th>#</th>
<th>Metric Type</th>
<th>Metrics used / Crisis</th>
</tr>
</thead>
</table>
| 1 | The intrinsic properties of the threat (magnitude), | **Quake**: Richter scale to measure: local, wave or moment magnitudes ($M_L$, $M_w$, $M_m$), respectively and the epicentre position (latitude, longitude).  
**Volcano**: Volcano Explosivity Index (VEI)  
**Floods**: mm/s to measure rains rate, m/h and m3/h to measure river water velocity and flow rate  
**Wind**: any scale of: Beaufort scale, Enhanced Fujita Scale, Saffir–Simpson hurricane wind scale and TORRO tornado intensity scale (all measure wind speed)  
**Wild Fire**: no standards, but good practice measures are: the fire surface-power and the fire line-power ($W_m^2$, $W_m^{-1}$).  
**Chemical Process Industry**: no standard metric of magnitude is used by industry. However, SEVESO directives defines hazard source magnitude in Kg (tones) of given hazardous material category.  
**Oil Spill**: number of accidents and tankers category, amount of spilled oil (tone/barrel/M3), oil grade, position |
| 2 | The threat hot-phase period | In all crisis databases, reports exist even if they are not publically accessible. In principal, one can measure: mean time of threat hot phase. It is a time (milliseconds, seconds, minutes, hours, …). |
| 3 | The impact intensity when possible | **Quake**: Mercalli Intensities qualitative scale (I to IX)  
**Volcano**: no standard impact scale, a qualitative scale should be developed (extreme, sever, serious, moderate, low) with respect to each CI sector (transport, energy, water, navigation, communication, agriculture, food, health and life, …)  
**Floods**: a qualitative scale (extreme, sever, serious, moderate, low) should be developed in terms of: impacted region size ($km^2$), total number of habitants in the region, total CI located in the region, total economic and job-supply assets in the region, …  
**Wind**: no standard ID (indicator of damage) or DD (degree of damage). It still needs to be developed. Similar to flood above.  
**Wild Fire**: no standard metrics for impact. It should be developed to measure: total amount of released ashes and other hazardous gases (kg), ecological damage (killed or displaced species), number of fatalities, injured and displaced persons, number of damaged CI (water networks, electrical lines, communication facilities), estimated time to restore vegetation and ecological original state (years), economic losses due losses of forest industrial activities (k€, M€).  
**Chemical Process Industry**: injured and fatalities number, number of evacuated, size of contaminated zones ($km^2$), number of assets and CI in the contaminated zone, degree loss of operability per CI, degree of damage of different assets, …  
**Oil Spill**: there is no standard Severity Scale (or impact scale) as that mentions in D2.1 (State of Rohde Island - Department of Environmental Management). One should measure: the size of contaminated zone ($km^2$), the mobility of the oil slick, impact on marine life (killed or species), damage on local fishing activity and local maritime traffic, …. |
<table>
<thead>
<tr>
<th>#</th>
<th>Metric Type</th>
<th>Metrics used / Crisis</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>The likelihood of the threat</td>
<td>Similar to what mentioned in #2 in this table, in principal, one can measure likelihood in terms of: mean time between two successive threats of the same magnitude (hours, days, years) and if possible occurrence probability functions (e.g. extreme wide occurrence can be described by a Gumbel probability function)</td>
</tr>
<tr>
<td>5</td>
<td>The probability distribution of the impact</td>
<td>Unlike what is mentioned in #2 and #4 regarding the threat magnitude, impact database are often inexistent and most of the data regarding impact (consequence) are partially included in: the threat DBs, crisis reports, crisis investigations reports, CI operators DB, assets owners DB and insurance companies DB. The probability distributions of impacts are not available but can easily be determined once data are available. However, qualitative assessments are available in terms of: highly probable, probable, fairly probable or rare (or any similar scale).</td>
</tr>
<tr>
<td>6</td>
<td>Threat-CI dependencies (CI vulnerability to threats)</td>
<td>Most of the existing models describe the threat-CI dependency in terms of: CI’s loss of operability or CI’s physical damage, given the local intensity (not the magnitude) of the threat in probabilistic terms.</td>
</tr>
<tr>
<td>7</td>
<td>CI-CI dependency (sequences/cascading)</td>
<td>No quantitative metrics are available mainly because: no standard definition of vulnerability and no robust models exist to describe functional dependencies. However, binary matrix can be constructed to describe dependency between any two CIs in terms of: dependent (1) or independent (0). Some researchers develop models with a probability figures in the interval [0,1].</td>
</tr>
<tr>
<td>8</td>
<td>Threat-CI-Environment (direct and indirect consequences/impacts)</td>
<td>Most of the existing models that are implemented in DSS are using models that directly measure the “impact” as a function of the threat “magnitude”. More complex are the considered system, less considerations are given to modelling the details of CI failures (modes, mechanisms, dependencies) and higher interest in big consequences and impact (life losses, vital CI damages, economic losses, social unrest, governance effectiveness)</td>
</tr>
<tr>
<td>9</td>
<td>The identification of the impacts (short- and long-term).</td>
<td>Metrics are always the damage and the operability loss indicators as above and very often no clear distinction is done between direct consequences (impacts) and outcomes (long terms consequences)</td>
</tr>
<tr>
<td>10</td>
<td>The geo-temporal distribution if possible</td>
<td>Geo-temporal models are more and more available thanks to the extension of the use of different type of sensors and detection systems, such as: meteorological conditions (wind, rain, floods, hurricanes, volcanos, hazards materials release and dispersion. Measures gives: time, position, magnitude of threats, its local impact and exposure index*. However, that requires very big data treatment equipment and tools. Very often not practical for real-time Crisis Management Decision Making process.</td>
</tr>
</tbody>
</table>
4. Conclusions & Recommendations to WPs

In this document, the main interest was on the security metrics to be used, in view of enhancing systems’ resilience MS&A. A security metric should cover: threat (identification & specification), resilience (interdependencies & cascading of failures) and consequences (impact & outcomes). Within the scope of this document, threat is limited to natural threats and man-made technological threats, excluding threats with adaptability features. The exclusion is comprised of the cases of terrorist actions, sabotages and wars.

Some representative threats have been analysed with a focus on the used security metrics and synthesised in Table 7. The principal feature of the security metrics cover four concepts: magnitude of the threat, intensity of the consequences, likelihood and geographical positioning.

Resilience security metrics have been treated in task 2.1 and reported in D2.1. For the sake of completeness, report (D2.2) reiterates on the major findings on resilience metrics from D2.1.

Regarding threat, the magnitude is considered as an intrinsic property of threats. Intrinsic properties could be: the total amount of oil spilled or of hazardous substances spilled, the ejection rate of ashes and debris from a volcano, the energy released in a quake epicentre, the rain fall rate, the total quantity of water, the acceleration of the soil surface, the speed of the wind, the height of a sea wave or the total power offset in an electric network. The magnitude metric is always quantitative, universal and relatively the easiest to measure.

Regarding consequences, they should be measured using the “intensity” concept. Intensity is an extrinsic property of: threats, impacted CIs and consequences. It can be: the number of fatalities, the size of the contaminated area, the financial losses, the assets degradation or the length of the service disruption time. Intensity measures the impact of a threat on a given set of systems. In some manner, it combines the intrinsic properties of the threat and those of the local environment. A given threat with the same magnitude would correspond to different intensities in different locations. The intensity metric could be quantitative, qualitative or mixed. It is not universal and not easy to measure. It is not easy to combine intensities corresponding to different threats either. Qualitative metrics could satisfactorily contain four levels: extreme, high/strong, moderated, weak or highly probable, probable, less probable or rare. In some few cases a fifth level can be added to the scale of severity in order to describe the very weak or insignificant (noise/natural background) property of a given threat.

Regarding cascade of failures, the likelihood metric should be used by the iPDT. It generally uses concepts such as: occurrence probabilities, occurrence rates, time intervals between identical renewable events, cumulative occurrence of the same renewable events over well-determined time intervals, etc. Quantitative metrics are used when deterministic models, statistical data, probabilistic models or empirical models are available and validated by measurements from real world. If real data are not enough or even unavailable, one uses qualitative metrics guided by smart guess and experts’ judgement. Generally, the equivalence between the quantitative and the qualitative metrics is possible.
Regarding dependencies, we recommend the use of binary-type functions to describe the dependencies between any couple of CIs: dependent (1) or independent (0).

Regarding resilience, the dynamic probabilistic metric could be the mean-time to recover. It can also be the mean time interval between two successive occurrences of the same type of events (recoveries). Finally, it can be the mean number of occurrences of similar events (recoveries) in a well-defined interval of time (how many recovery in a given interval of time).

In all cases, it allows measuring the mean-time for a given system to recover from the hazardous impact of a well-defined threat. In a perfect world, recovering would mean to be back to state “as good as before” the threat occurrence.
5. References


[2] D2.3 “DSS and Predictive Tools Feature Specifications” EU FP7 PREDECT deliverable D2.3.


[22] State of Rhode Island, Department of Environmental Management, scale of severity (http://www.dem.ri.gov/topics/erp/1_3.pdf)

[23] Peter Burgherr and Stefan Hirschberg, “Severe Accidents in the Oil Chain with Emphasis on Oil Spills”. Strategic Insights, Volume VII, Issue 1 (February 2008), a bi-monthly electronic journal produced by the Center for Contemporary Conflict at the Naval Postgraduate School in Monterey, California.


## Annex 1 – The Beaufort Scale

### Table 1 The Beaufort Scale

<table>
<thead>
<tr>
<th>Beaufort number</th>
<th>Description</th>
<th>Wind speed</th>
<th>Wave height</th>
<th>Sea conditions</th>
<th>Land conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Calm</td>
<td>&lt; 1 km/h</td>
<td>0 m</td>
<td>Flat</td>
<td>Smoke rises vertically</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 1 mph</td>
<td>0 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 1 knot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 0.3 m/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Light air</td>
<td>1.1–5.5 km/h</td>
<td>0–0.2 m</td>
<td>Ripples without crests.</td>
<td>Smoke drift indicates wind direction. Leaves and wind vanes are stationary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1–3 mph</td>
<td>0–1 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1–3 knot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.3–1.5 m/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Light breeze</td>
<td>5.6–11 km/h</td>
<td>0.2–0.5 m</td>
<td>Small wavelets. Crests of glassy appearance, not breaking</td>
<td>Wind felt on exposed skin. Leaves rustle. Wind vanes begin to move.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4–7 mph</td>
<td>1–2 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4–6 knot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.6–3.3 m/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Gentle breeze</td>
<td>12–19 km/h</td>
<td>0.5–1 m</td>
<td>Large wavelets. Crests begin to break; scattered whitecaps</td>
<td>Leaves and small twigs constantly moving, light flags extended.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8–12 mph</td>
<td>2–3.5 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7–10 knot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.4–5.4 m/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Moderate breeze</td>
<td>20–28 km/h</td>
<td>1–2 m</td>
<td>Small waves with breaking crests. Fairly frequent whitecaps.</td>
<td>Dust and loose paper raised. Small branches begin to move.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13–17 mph</td>
<td>3.5–6 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11–16 knot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.5–7.9 m/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Scale</td>
<td>Description</td>
<td>Wind Speed (km/h)</td>
<td>Wind Speed (mph)</td>
<td>Wind Speed (knot)</td>
<td>Wind Speed (m/s)</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>------------------</td>
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<td>-----------------</td>
</tr>
<tr>
<td>5</td>
<td>Fresh breeze</td>
<td>29–38 km/h 18–24 mph 17–21 knot 8.0–10.7 m/s</td>
<td>2–3 m 6–9 ft</td>
<td>Moderate waves of some length. Many whitecaps. Small amounts of spray.</td>
<td>Branches of a moderate size move. Small trees in leaf begin to sway.</td>
</tr>
<tr>
<td>7</td>
<td>High wind, moderate gale, near gale</td>
<td>50–61 km/h 31–38 mph 28–33 knot 13.9–17.1 m/s</td>
<td>4–5.5 m 13–19 ft</td>
<td>Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.</td>
<td>Whole trees in motion. Effort needed to walk against the wind.</td>
</tr>
<tr>
<td>8</td>
<td>Gale, fresh gale</td>
<td>62–74 km/h 39–46 mph 34–40 knot 17.2–20.7 m/s</td>
<td>5.5–7.5 m 18–25 ft</td>
<td>Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.</td>
<td>Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.</td>
</tr>
<tr>
<td>9</td>
<td>Strong gale</td>
<td>75–88 km/h 47–55 mph 42–49 knot 15.9–17.9 m/s</td>
<td>7–10 m</td>
<td>High waves whose crests</td>
<td>Some branches break off trees, and some</td>
</tr>
<tr>
<td>Category</td>
<td>Speed Range</td>
<td>Height Range</td>
<td>Phenomena Description</td>
<td>Impact</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------</td>
<td>--------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>8</strong> Storm, whole gale</td>
<td>47–54 mph (41–47 knot) 20.8–24.4 m/s</td>
<td>23–32 ft</td>
<td>Sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.</td>
<td>Small trees blow over. Construction/temporary signs and barricades blow over.</td>
<td></td>
</tr>
<tr>
<td><strong>10</strong> Violent storm</td>
<td>103–117 km/h (64–73 mph) 56–63 knot 28.5–32.6 m/s</td>
<td>9–12.5 m (29–41 ft)</td>
<td>Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.</td>
<td>Trees are broken off or uprooted, structural damage likely.</td>
<td></td>
</tr>
<tr>
<td><strong>11</strong> Hurricane force</td>
<td>≥ 118 km/h (≥ 74 mph)</td>
<td>≥ 14 m (≥ 46 ft)</td>
<td>Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.</td>
<td>Widespread vegetation and structural damage likely.</td>
<td></td>
</tr>
<tr>
<td><strong>12</strong> Hurricane force</td>
<td>≥ 118 km/h (≥ 74 mph)</td>
<td>≥ 14 m (≥ 46 ft)</td>
<td>Huge waves. Sea is completely white</td>
<td>Severe widespread damage to vegetation and structures. Debris</td>
<td></td>
</tr>
<tr>
<td>$\geq 64$ knot</td>
<td>$\geq 32.7$ m</td>
<td>with foam and spray. Air is filled with driving spray, greatly reducing visibility.</td>
<td>and unsecured objects are hurled about.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Annex 2 – The Enhanced Fujita Scale

### Table 2 The Enhanced Fujita Scale

<table>
<thead>
<tr>
<th>Scale</th>
<th>Wind speed (estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mph</td>
</tr>
<tr>
<td>EF0</td>
<td>65–85</td>
</tr>
<tr>
<td>EF1</td>
<td>86–110</td>
</tr>
<tr>
<td>EF2</td>
<td>111–135</td>
</tr>
<tr>
<td>EF3</td>
<td>136–165</td>
</tr>
<tr>
<td>EF4</td>
<td>166–200</td>
</tr>
<tr>
<td>EF5</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

### Table 3 The Enhanced Fujita Scale - Damage Indicators (DI)

*DI: Damage Indicator, DoD: Degree of Damage*

<table>
<thead>
<tr>
<th>DI No.</th>
<th>Damage indicator</th>
<th>Degrees of damage (DoD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small Barns or Farm Outbuildings (SBO)</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>One- or Two-Family Residences (FR12)</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Manufactured Home – Single Wide (MHSW)</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Manufactured Home – Double Wide (MHDW)</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>Apartments, Condos, Townhouses [3 stories or less] (ACT)</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Motel (M)</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Masonry Apartment or Motel Building (MAM)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Building Type Description</td>
<td>Risk Level</td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>8</td>
<td>Small Retail Building [Fast Food Restaurants] (SRB)</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Small Professional Building [Doctor’s Office, Branch Banks] (SPB)</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>Strip Mall (SM)</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>Large Shopping Mall (LSM)</td>
<td>9</td>
</tr>
<tr>
<td>12</td>
<td>Large, Isolated Retail Building [K-Mart, Wal-Mart] (LIRB)</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>Automobile Showroom (ASR)</td>
<td>8</td>
</tr>
<tr>
<td>14</td>
<td>Automobile Service Building (ASB)</td>
<td>8</td>
</tr>
<tr>
<td>15</td>
<td>Elementary School [Single Story; Interior or Exterior Hallways] (ES)</td>
<td>10</td>
</tr>
<tr>
<td>16</td>
<td>Junior or Senior High School (JHSH)</td>
<td>11</td>
</tr>
<tr>
<td>17</td>
<td>Low-Rise Building [1–4 Stories] (LRB)</td>
<td>7</td>
</tr>
<tr>
<td>18</td>
<td>Mid-Rise Building [5–20 Stories] (MRB)</td>
<td>10</td>
</tr>
<tr>
<td>19</td>
<td>High-Rise Building [More than 20 Stories] (HRB)</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>Institutional Building [Hospital, Government or University Building] (IB)</td>
<td>11</td>
</tr>
<tr>
<td>21</td>
<td>Metal Building System (MBS)</td>
<td>8</td>
</tr>
<tr>
<td>22</td>
<td>Service Station Canopy (SSC)</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>Warehouse Building [Tilt-up Walls or Heavy-Timber Construction] (WHB)</td>
<td>7</td>
</tr>
<tr>
<td>24</td>
<td>Electrical Transmission Lines (ETL)</td>
<td>6</td>
</tr>
<tr>
<td>25</td>
<td>Free-Standing Towers (FST)</td>
<td>3</td>
</tr>
<tr>
<td>26</td>
<td>Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Trees: Hardwood (TH)</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---------------------</td>
<td>---</td>
</tr>
<tr>
<td>27</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>28</td>
<td>Trees: Softwood (TS)</td>
<td>5</td>
</tr>
</tbody>
</table>

PREparing for the Domino effect in Crisis situations.
# Annex 3 – The Saffir – Simpson hurricane wind scale

## Table 4 The Saffir - Simpson hurricane wind scale

<table>
<thead>
<tr>
<th>Category</th>
<th>Wind Damage</th>
<th>Sustained winds:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>Very dangerous winds will produce some damage</td>
<td>33–42 m/s, 64–82 kn, 119–153 km/h, 74–95 mph;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal central pressure: 980–994 mbar, 28.94 inHg</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>Extremely dangerous winds will cause extensive damage</td>
<td>43–49 m/s, 83–95 kn, 154–177 km/h, 96–110 mph;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Normal central pressure: 965–979 mbar, 28.50–28.91 inHg</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>Devastating damage will occur</td>
<td>50–58 m/s, 96–112 kn</td>
</tr>
</tbody>
</table>

Category 1 storms usually cause no significant structural damage to most well-constructed permanent structures; however, they can topple unanchored mobile homes, as well as uproot or snap numerous trees. Poorly attached roof shingles or tiles can blow off. Coastal flooding and pier damage are often associated with Category 1 storms. Power outages are typically widespread to extensive, sometimes lasting several days. Even though it is the least intense type of hurricane, the storm can still produce widespread damage and can be a life-threatening storm.

Storms of Category 2 intensity often damage roofing material (sometimes exposing the roof) and inflict damage upon poorly constructed doors and windows. Poorly constructed signs and piers can receive considerable damage and many trees are uprooted or snapped. Mobile homes, whether anchored or not, are typically damaged and sometimes destroyed, and many manufactured homes also suffer structural damage. Small craft in unprotected anchorages may break their moorings. Extensive to near-total power outages and scattered loss of potable water are likely, possibly lasting many days.

Tropical cyclones of Category 3 and higher are described as major hurricanes in the Atlantic or Eastern Pacific basins. These storms can cause some structural damage to small residences and utility.
buildings, particularly those of wood frame or manufactured materials with minor curtain wall failures. Buildings that lack a solid foundation, such as mobile homes, are usually destroyed, and gable-end roofs are peeled off. Manufactured homes usually sustain severe and irreparable damage. Flooding near the coast destroys smaller structures, while larger structures are struck by floating debris. A large number of trees are uprooted or snapped, isolating many areas. Additionally, terrain may be flooded well inland. Near-total to total power loss is likely for up to several weeks and water will likely also be lost or contaminated.

<table>
<thead>
<tr>
<th>Category</th>
<th>Damage will occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 4</td>
<td>Catastrophic damage will occur</td>
</tr>
<tr>
<td>Category 5</td>
<td>Catastrophic damage will occur</td>
</tr>
</tbody>
</table>

Category 4 hurricanes tend to produce more extensive curtain-wall failures, with some complete structural failure on small residences. Heavy, irreparable damage and near complete destruction of gas station canopies and other wide span overhang type structures are common. Mobile and manufactured homes are often flattened. Most trees, except for the heartiest, are uprooted or snapped, isolating many areas. These storms cause extensive beach erosion, while terrain may be flooded far inland. Total and long-lived electrical and water losses are to be expected, possibly for many weeks.

Category 5 is the highest category a tropical cyclone can obtain in the Saffir–Simpson scale. These storms cause complete roof failure on many residences and industrial buildings, and some complete building failures with small utility buildings blown over or away. Collapse of many wide-span roofs and walls, especially those with no interior supports, is expected.

### Sustained Winds

- **Category 4**
  - 58–70 m/s
  - 113–136 kn
  - 209–251 km/h
  - 130–156 mph

- **Category 5**
  - ≥ 70 m/s
  - ≥ 137 kn
  - ≥ 252 km/h
  - ≥ 157 mph

### Normal Central Pressure

- **Category 4**
  - 945–964 mbar
  - 27.91–28.47 inHg

- **Category 5**
  - 920–944 mbar
  - 27.17–27.88 inHg
is common. Very heavy and irreparable damage to many wood frame structures and total destruction to mobile/manufactured homes is prevalent. Only a few types of structures are capable of surviving intact, and only if located at least 3 to 5 miles (5 to 8 km) inland. They include office, condominium and apartment buildings and hotels that are of solid concrete or steel frame construction, public multi-story concrete parking garages, and residences that are made of either reinforced brick or concrete/cement block and have hipped roofs with slopes of no less than 35 degrees from horizontal and no overhangs of any kind, and if the windows are either made of hurricane-resistant safety glass or covered with shutters. Unless all of these requirements are met, the absolute destruction of a structure is certain.

The storm's flooding causes major damage to the lower floors of all structures near the shoreline, and many coastal structures can be completely flattened or washed away by the storm surge. Virtually all trees are uprooted or snapped and some may be debarked, isolating most communities impacted. Massive evacuation of residential areas may be required if the hurricane threatens populated areas. Total and extremely long-lived extensive power outages and water losses are to be expected, possibly for up to several months.

| < 920 mbar | < 27.17 inHg |
## Annex 4 – The TORRO tornado intensity scale

<table>
<thead>
<tr>
<th>Cat</th>
<th>Wind speeds</th>
<th>Description</th>
<th>Damage description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC</td>
<td>-</td>
<td>Funnel cloud aloft (Not a tornado)</td>
<td>No damage to structures, unless on tops of tallest towers, or to radiosondes, balloons, and aircraft. No damage in the country, except possibly agitation to highest tree-tops and effect on birds and smoke. Record FC when not known to have reached ground level. A whistling or rushing sound aloft may be noticed.</td>
</tr>
</tbody>
</table>
| T0  | 17 - 24 m/s  
   61 - 86 km/h  
   39 - 54 mph | Light | Loose light litter raised from ground-level in spirals. Tents, marqueses seriously disturbed; most exposed tiles, slates on roofs dislodged. Twigs snapped; trail visible through crops. |
| T1  | 25 - 32 m/s  
   87 - 115 km/h  
   55 - 72 mph | Mild | Deckchairs, small plants, heavy litter becomes airborne; minor damage to sheds. More serious dislodging of tiles, slates, chimney pots. Wooden fences flattened. Slight damage to hedges and trees. |
| T2  | 33 - 41 m/s  
   116 - 147 km/h  
   73 - 92 mph | Moderate | Heavy mobile homes displaced, light caravans blown over, garden sheds destroyed, garage roofs torn away, much damage to tiled roofs and chimney stacks. General damage to trees, some big branches twisted or snapped off, small trees uprooted. |
| T3  | 42 - 51 m/s  
   148 - 184 km/h  
   93 - 114 mph | Strong | Mobile homes overturned / badly damaged; light caravans destroyed; garages and weak outbuildings destroyed; house roof timbers considerably exposed. Some of the bigger trees snapped or uprooted. |
| T4  | 52 - 61 m/s  
   185 - 220 km/h | Severe | Motor cars levitated. Mobile homes airborne / destroyed; sheds airborne for considerable distances; entire roofs removed from some houses; roof timbers of stronger brick or stone houses completely exposed; gable ends |
<table>
<thead>
<tr>
<th>Cat</th>
<th>Wind speeds</th>
<th>Description</th>
<th>Damage description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T5</td>
<td>115 - 136 mph</td>
<td>Torn away. Numerous trees uprooted or snapped.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62 - 72 m/s 221 - 259 km/h 137 - 160 mph</td>
<td>Intense</td>
<td>Heavy motor vehicles levitated; more serious building damage than for T4, yet house walls usually remaining; the oldest, weakest buildings may collapse completely.</td>
</tr>
<tr>
<td>T6</td>
<td>73 - 83 m/s 260 - 299 km/h 161 - 186 mph</td>
<td>Moderately devastating</td>
<td>Strongly built houses lose entire roofs and perhaps also a wall; windows broken on skyscrapers, more of the less-strong buildings collapse.</td>
</tr>
<tr>
<td>T7</td>
<td>84 - 95 m/s 300 - 342 km/h 187 - 212 mph</td>
<td>Strongly devastating</td>
<td>Wooden-frame houses wholly demolished; some walls of stone or brick houses beaten down or collapse; skyscrapers twisted; steel-framed warehouse-type constructions may buckle slightly. Locomotives thrown over. Noticeable de-barking of trees by flying debris.</td>
</tr>
<tr>
<td>T8</td>
<td>96 - 107 m/s 343 - 385 km/h 213 - 240 mph</td>
<td>Severely devastating</td>
<td>Motor cars hurled great distances. Wooden-framed houses and their contents dispersed over long distances; stone or brick houses irreparably damaged; skyscrapers badly twisted and may show a visible lean to one side; shallowly anchored highrises may be toppled; other steel-framed buildings buckled. (2008 Poland tornado outbreak, for example)</td>
</tr>
<tr>
<td>T9</td>
<td>108 - 120 m/s 386 - 432 km/h 241 - 269 mph</td>
<td>Intensely devastating</td>
<td>Many steel-framed buildings badly damaged; skyscrapers toppled; locomotives or trains hurled some distances. Complete debarking of any standing tree-trunks.</td>
</tr>
<tr>
<td>Cat</td>
<td>Wind speeds</td>
<td>Description</td>
<td>Damage description</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------</td>
<td>-----------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>mph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T10/11</td>
<td>121 - 134 m/s or over</td>
<td>Super (T10),</td>
<td>Entire frame houses and similar buildings lifted bodily or completely from foundations and carried a long or large distance to disintegrate. Steel-reinforced concrete buildings may be severely damaged or almost obliterated.</td>
</tr>
<tr>
<td></td>
<td>433 - 482 km/h or over</td>
<td>Colossal (T11)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>270 - 299 mph</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PREDICT PROJECT PARTNERS

[Logos of various partners]