Deliverable 6.6

D6.6 IT framework for the assessment of economic losses in a dynamic risk context

Deliverable information	
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Lead	ETH Zurich
Authors	Philipp Kästli
Reviewers	[Helen Crowley, EUCENTRE; Stefan Wiemer, ETH; Laura Sarson, ETH]
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Preamble

Task 6.4 has indeed two deliverables, which are described in DoA as follows:

- D6.6: Framework for the assessment of economic losses in a dynamic risk context (Feb 2020)
- D6.4: Report on the user-centric dynamic risk framework for Switzerland application (Feb 2023)

In the DoA the description for these two deliverables can be misleading, and so does the numbering (D6.6 coming before 6.4). Therefore, below we will explain our intention and present a more logical approach in delivering the aimed work and results with the two deliverables.

The first deliverable D6.6 establishes the IT framework. It presents the IT components and platforms for earthquake analysis, probabilistic & event specific ground motion prediction, risk/loss assessment and economical consequence modelling. It also deals with the second challenge of these components to be embedded into an operational and real-time context of existing seismic networks. It sets the IT framework and describes the design of this framework such that a prototype can be developed for use, in particular, for the Swiss dynamic risk test case of the upcoming Task 6.4.

All other aspects from financial (risk cost benefit analysis) to resilience enhancements (resilience enhancement for EEW, OEF, OELF, SHM) are advancing and will come together in the second reporting period:

- risk cost benefit analysis (Task 4.6)
- resilience enhancement for EEW (Task 2.5 & 4.6)
- OEF (WP3)
- OELF (Task 4.2)
- SHM (Task 4.4)

On the other hand, many of the ongoing work regarding risk cost benefit analysis, resilience enhancement for EEW, OELF and SHM is present in various other deliverables (D1.2 &D1.3 submitted). D6.4 will link these different elements on a dynamic risk framework for Switzerland application.

Task 3.5 (Guidelines for experts' judgments in OEF) that is organizing a workshop for expert’s involvement, will also contribute to the ongoing efforts of D6.4. Therefore, all of the above mentioned elements that D6.6 is lacking, will be part of the upcoming deliverable D6.4.

Summary

For its proof-of-concept framework for operational dynamic risk and loss assessment, RISE can and should rely largely on existing components and platforms for earthquake analysis, probabilistic & event specific ground motion prediction, risk/loss assessment and economical consequence modelling. A modular, distributed and somewhat heterogenous framework is required and sensible, given the availability resources and timeline, the inherent quality of and experience with the existing modules and sustainability considerations. The first challenge we need to tackled is hence to make the various existing components interoperable. The second challenge then is to embed them into an operational and real-time context of existing seismic networks. Finally, Operational Earthquake Forecasting (OEF) and Operational Earthquake Loss Forecasting (OELF) models need regular recalibration with observed seismicity (i.e., history matching), and hazard and risk components used are time-dynamic only in the sense that they provide different results for time intervals, if they are invoked with different input data (event rates, logic tree weights, exposure, vulnerability). So, a major new component required is a kind of an orchestrator, taking care of scheduling, workflow/task management, and data management. This deliverable describes the design of this framework such that a prototype can be developed for use, in particular, for the Swiss dynamic risk test case of Task 6.4.

1. Overview

Dynamic Risk & Loss assessment in the RISE context can be subdivided into two major work streams:

1. **Event specific:** The near-real time calculation of the expected losses during/after a specific, strong earthquake, potentially taking into account previous earthquakes' impact on exposure and vulnerability: starting from a given earthquake (with potential parameter uncertainties), extrapolating (and punctually interpolating from recorded) shaking, and estimating the impact of a given exposure (building stock, lifelines, socioeconomic processes, including recordings within buildings) with given or modelled vulnerability (fig. 1, upper part)
2. **Probabilistic**: The dynamic calculation of the time dependent hazard and risk metrics, given the current development of general seismicity: by extrapolating the future development of seismicity, derive probabilistic earthquake hazard, and economic / structural risk for a range of forecast horizons (fig. 1, lower part)

Both work streams result in information directly relevant for a range of stakeholders and processes including society (see Figure 1) and information can be provided both as push, and pull information, for example:

- Rapid damage estimates, during/after an event, allowing to trigger and adequately shape response operations while ground-truth is still scarce.

- Information from scenario events may help to challenge existing response blueprints for validity.
- Time-dependent probabilistic risk estimates or alerts may trigger authorities to take pre-emptive measures like temporary vulnerability reduction, response preparation, and in case of human-induced seismicity, avoidance measures.
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In order to produce a meaningful societal impact, RISE is invested in:

- validating and improving existing analysis algorithms (in realityonly a few of them will be developed from scratch within the project) – this is the scientific part addressed primarily in WP2, 3 and 7.
- standardizing data models, formats, and interfaces to allow operationalization of the algorithms (WP 8.2)
- interlink existing, and new (built as required) frameworks to chain different analysis steps into a full end-to-end workflow (WP 8.3)
- Developing test application (WP6)

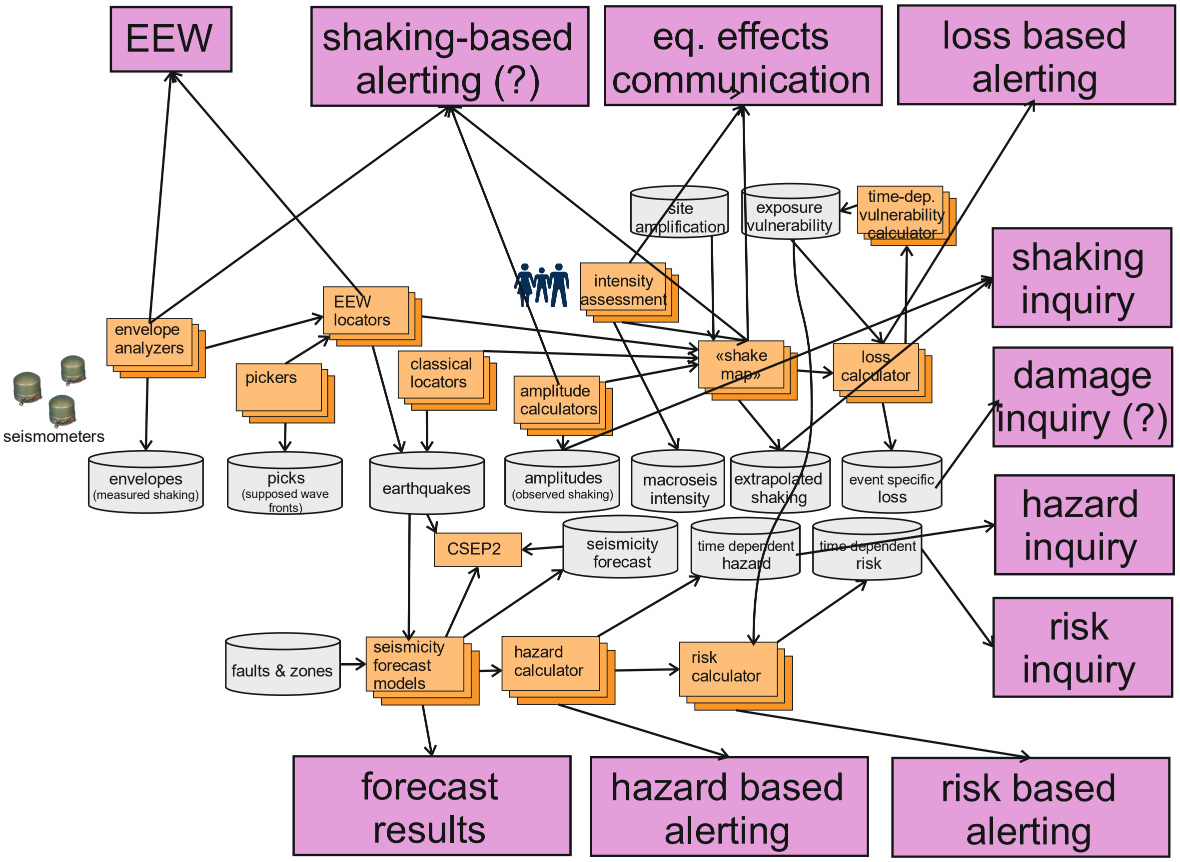

Fig. 1: Data types (grey), algorithms (orange), and societal interfaces (pink) subject of the RISE project. Event-related components are in the upper half of the chart, fully probabilistic ones in the lower half.

2. Proposed software architecture and data standards

The RISE time dependent risk modelling platform does not re-invent wheels, but builds on top of a series of well known, state-of-the art domain codes and frameworks (fig. 2). Their role is quickly presented in the following paragraphs.

2.1 Seismic event and rupture parameters

For seismic event processing and earthquake source parameter determination, many standalone codes exist, as well as several open source frameworks, such as SeisComP3 (www.seiscomp3.org) or Earthworm (www.earthwormcentral.org). For the development of new components (new location algorithms, faster magnitude extrapolations etc.), SeisComP3 is a good operative target platform, as it has a clear architecture with a generic messaging system, and centralized data repository. This typically allows the implementation and deployment of a single algorithm (e.g. for picking, pick association, event location, magnitude estimation, rupture analysis etc.), while the other features of SeisComp3 can be fully reused: an event detection mechanism based on pick association will subscribe to messages of type "pick" (potentially produced by different codes) and emit messages of type "origin", while a cross correlation detector will listen to waveforms and emit "origins". A subsequent module, e.g. for magnitude estimation, will listen to messages of type "origin" as one of its inputs, without any need to be aware of the technical internals of the location algorithm. RISE will therefore prioritise to develop modules with the SeiComp3 context.

Mainly in the field of early warning, standalone software still have their justification, as they may be invested in a tighter, and less generic integration of tasks, as well as in vendor-specific data communication in the attempt to save some fractions of seconds. Presto (www.prestoews.org) is an example of such a code. However, EEW capability has also been embedded into the SeisComp3 system (the Virtual Seismologist and SCfinder approach).

The common data interface for all subsequent users of earthquake parameter data (single events or entire catalogs) is an FDSN-specified event web service (http://www.fdsn.org/webservices/fdsnws-event-1.2.pdf) providing data in QuakeML Format. (http://quake.ethz.ch/quakeml). An update of QuakeML is under development at ETH, and RISE specific needs, if any, can be integrated in the next release of QuakeML.

2.2 Ground motion mapping

For event-specific ground motion mapping, USGS's ShakeMap package (https://earthquake.usgs.gov/data/shakemap/background.php) has emerged as a quasi-standard. ShakeMap estimates ground motions from earthquake source parameters, attenuation, instrumental peak motion measurements, observed macroseismic intensities, and site-specific (static) attenuation. However, for attenuation and ground motion parameter conversion, ShakeMap itself relies on the open source OpenQuake engine (https://github.com/gem/oq-engine, developed and maintained by the Global Earthquake Model, GEM) and its library of tested implementations of ground motion

models. In the framework of RISE, ShakeMap is extended to accommodate for logic trees of attenuation relationships, in order to provide a more complete view on the epistemic uncertainty contribution of ground motion assessment also in real time and scenario loss estimations.
ShakeMap has an input data format which is generally accepted as a standard and is offered e.g by the ORFEUS Rapid Raw Strong-motion Database (http://www.orfeus-eu.org/opencms/rrsm/). ShakeMap output data formats are relatively heterogeneous (hdf5, xml-represented grids, csv for gridded or non-gridded data). Due to different requirements (mapping vs. subsequent, portfolio-based risk/loss assessment) there is probably no unique solution for this.

2.3 Intensity assessment

Intensity data is heterogeneous not only due to different scales, but also due to different observational data collection methods:

- There is no known full software implementation of intensity assessment according to a macroseismic scale (and most macroseismic scales are not well-defined enough to allow for one).
- Most existing intensity assessment software strictly refer to a data collection scheme (typically a questionnaire) approximating one macroseismic scale, thus their results imply a kind of meta-scale.

An issue is mainly the representation of uncertainty: some researchers stick to the nature of intensity as a classification and represent uncertainty by probability distributions over different classes, whilst others use floating point values as representation of ambiguity between classes. As this introduces a continuous rather than ordinal data type, it is basically also a derived intensity scale.
While no well-defined exchange formats are established (though attempts do exist in the framework of QuakeML 2.0), the limited compatibility of data is generally considered a larger problem than its technical representation.

2.4 Calculating hazard and risk

Due to its open-source, test-covered, and versatile hazard kernel with support for arbitrarily complex seismic source models, and logic trees, GEM’s OpenQuake-engine (https://www.globalquakemodel.org/openquake) has become a quasi-standard for probabilistic seismic hazard computation, allowing the scientific community to off-load operational questions and concentrate on research issues such as seismic source characterization, scaling, and attenuation issues.

For risk assessment the situation is similar, loss calculators allow applying arbitrary fragility curves to building inventories in arbitrary classifications, and convert the resulting damage stages to losses using loss curves – the scientific challenge (of this project as well as of previous ones) is to develop models to approximate the European building stock, and to parametrize the curves. OpenQuake does not cover in the physical loss modelling based on mechanical building models (finite element models) – for this purpose, OpenSees (https://opensees.berkeley.edu/) is a framework widely used in the community. Structural modelling is carried out in RISE WP4 to calibrate the fragility/vulnerability functions used for the time-dependent risk models. However, the RISE proof-of-concept platform will not go as far as automating time-dependent structural modelling, mainly because we are still far from having adequate structural building models for a relevant share of the building stock.

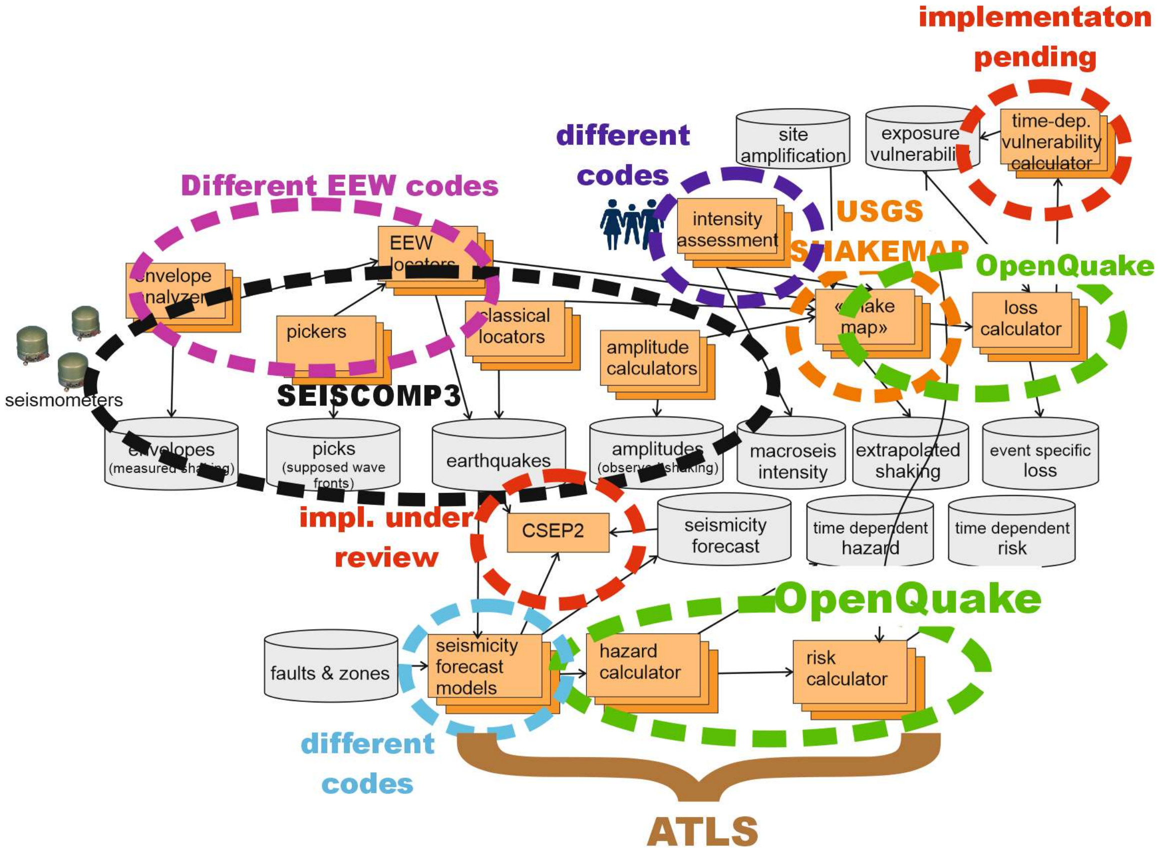

Fig. 2: Typical software packages used for RISE tasks, and intended to be operationalized for the proof-of-concept operational European dynamic risk platform.

3. Making probabilistic risk dynamic

In classical probabilistic seismic hazard assessment (PSHA) and risk assessment (PSRA), seismicity models are static, and thus the hazard and risk calculations are a once-in-a-project action with a result of time-unrestricted validity. On the contrary, in dynamic risk, at least the source (seismicity) is time-dependent, and the state of the target (asset inventory = exposure) is time-dependent as well. In order to use the tool-set available from static risk assessment, we need to describe (forecast) seismicity in time slices, calculate hazard & risk for these time slices, and (optionally) integrate results over time. This is basically not a scientific task, but a technical one of scheduling, workflow/task management, and data management.

For this, RISE plans to adapt, extend and use an orchestrator: a software framework which was started in the domain of induced seismicity monitoring and thus comes with the working title ATLS ("advanced traffic light system", to be changed, see Fig.3). We will also link to the CSEP2.0 developments which cover related tests. The framework needs to fulfil the following tasks:

1. Retrieve the time history of observed seismicity (an earthquake FDSNWS/event interface)
   (1b. Retrieve a time history of variables driving seismicity, if any [e.g., well operations, in the case of induced seismicity)
   (1c, Optionally, define an action plan for these independent variables, if they are actionable, and for the exposure model, if it allows for this feature)
2. Invoke n seismicity forecast models for a) self-calibration based on past observables from step 1, and b) seismicity prediction (a and b values for areas, volumes or faults) for one or several future time intervals
3. In case of ensemble models: Assess the performance of specific models against the observations until now, and determine model weights.
4. Use the results of n models, n weights and and t time intervals, to parametrize a hazard logic tree with an earthquake rupture forecast branches for each of the t time intervals
   (3b optional feedback loop: look at the performance of the seismicity forecast models in the past, to re-assess logic tree branch weighting for the hazard computations)
5. Invoke t hazard computations, and collect the results
6. Use hazard results to invoke probabilistic risk computations for each time interval
   (5b, optionally, modify the fragility and asset value of the exposure model based on results of the probabilistic risk results of all previous timesteps, and on the action plan defined in 1b)
7. Collect risk results, check against alerting thresholds, issue alerts if required (traffic light component)
8. Sleep, start over

Most domain software components, especially the OpenQuake-engine, have file-based data interfaces. In order to scale for an operational, real-time environment with accumulating data and use cases for automated and ad-hoc tracking, comparison, aggregation and visualization, the orchestrator also takes the role of archiving the input and output data of each processing step in parametric databases.

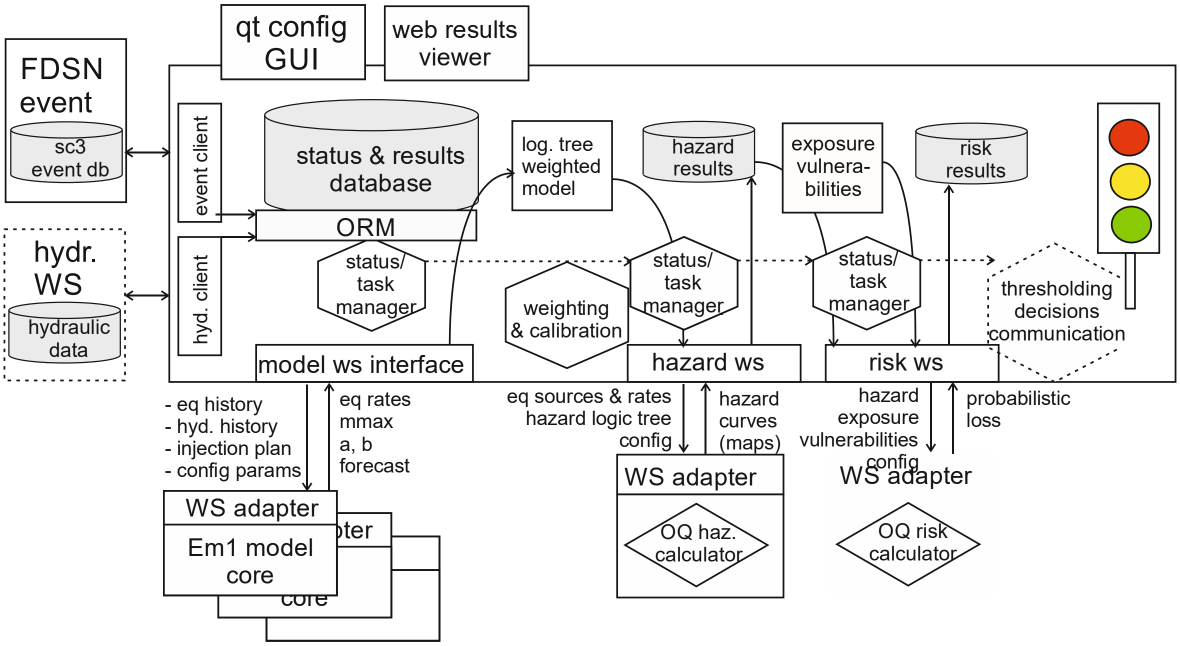

Fig. 3: Component model of the ATLS workbench for time dependent probabilistic hazard & risk computation.

4. Future development needs

Following this overall framework definition, there is in the next 6 months the need to specify in more details selected elements embedded in the overall framework. Specifically:

a) Seismicity forecast models: While ATLS has a web service that allows to invoke a seismicity forecast remotely, on basically any infrastructure, no adequate forecast models for regional, national or Europe-wide scale application implementing the client interface are available, and the project level decision on which model(s) is/are to be adapted for this operational level is pending, but will be an output of the efforts of WP3 and 7.

b) The interface to the model for time-dependent vulnerability of the exposure is not defined yet. Besides the fact that the implementation work is still to be done, it is currently not clear whether the ATLS framework can provide the information required for the assessment of the current vulnerability. Close interaction with WP4 (and more specifically Tasks 4.1 and 4.2) is thus required going forward.

c) Interface to CSEP2 and role of model calibration vs. model weighting: The CSEP2 work package of RISE shall provide a long-term assessment of the performance of seismicity forecast models. In the best case, this could provide the input for performance-based model weighting (step 3b). However, from a technical point of view it is not clear whether test cases, and timelines of CSEP2 vs. the ATLS proof-of-concept setup can match, and the technical interface between CSEP2 and ATLS is not specified yet. Scientifically, the issue may still need some attention, that the self-calibration of a model at time x may invalidate the performance assessment based on results up to time x-1, thus leading to potential instability if both feedback loops are active.

d) Second order economic effects: RISE plans to undertake extensive research in economic risks which go beyond building damage (e.g.: impact of lifelines on the productivity of business infrastructures, societal effects – this list is still open). Currently, the OpenQuake-engine calculators may be too simplistic to operationalize these effects, and thus bring them to the proof of concept platform. However, the use of OpenQuake-engine for these purposes is currently being investigated in WP4, and more specifically in Task 4.3.