# D2.12
# HEIMDALL System Architecture

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# Table of Contents


List of Figures ... iv
List of Tables ... v
List of Acronyms ... vi
Executive Summary ... 9
1 Introduction ... 10
2 Local Unit ... 12
2.1 Service Platform ... 13
2.2 User and Role Management ... 14
2.3 Scenario Management ... 15
2.4 Modelling and Simulation ... 18
2.4.1 Flood Simulation ... 18
2.4.2 Forest fire Simulation ... 22
2.4.3 Landslides ... 27
2.5 Risk and Vulnerability Assessment ... 29
2.6 Situation Assessment and Decision Support ... 30
2.7 Communication to Remote Areas ... 33
2.7.1 Information Gateway ... 33
2.7.2 Smartphone Application ... 34
2.8 Data Sources ... 35
2.8.1 Space-Based Data ... 35
2.8.2 Ground-Based Data ... 36
2.8.3 Aerial Sensors ... 37
2.9 External Systems ... 38
2.10 Graphical User Interface ... 41
3 HEIMDALL Connected ... 44
3.1 Catalogue ... 44
3.2 Interfaces to other Local Units ... 45
4 Conclusion ... 46
5 References ... 47

# List of Figures

Figure 1-1: Local Unit service architecture....................................................................10
Figure 1-2: Federated architecture ..............................................................................10
Figure 2-1: Local unit architecure ................................................................................12
Figure 3-1: Federated architecture example ...............................................................44

# List of Tables

Table 2-1: Service Platform storage services inputs and outputs........................................13
Table 2-2: Service platform additional services inputs and outputs......................................14
Table 2-3: User and role management services inputs and outputs.....................................14
Table 2-4: Administrator services inputs and outputs ..........................................................15
Table 2-5: Scenario Management and Scenario Matching products.....................................16
Table 2-6: Flood simulation inputs and outputs ....................................................................19
Table 2-7: Forest Fire Simulation products, related inputs and relation with other system components...............................................................................................................22
Table 2-8: Pyro-geomorphometry products, related inputs and relation with other system components...............................................................................................................27
Table 2-9: Landslide simulator services inputs and outputs.................................................28
Table 2-10: Risk and Vulnerability Assessment Products.....................................................29
Table 2-11: Impact Summary (ISA) information products .....................................................31
Table 2-12: Decision support (DES) information products ....................................................32
Table 2-13 - Communication to Remote Areas inputs and outputs.......................................33
Table 2-14: Information gateway inputs/outputs ...................................................................33
Table 2-15: Smartphone application products .....................................................................34
Table 2-16: Space-based Data products ..............................................................................35
Table 2-17: Ground-based data inputs and outputs..............................................................37
Table 2-18: Aerial sensors services inputs and outputs........................................................38
Table 2-19: External systems inputs and outputs .................................................................39
Table 2-20: GUI products .....................................................................................................41
Table 2-21: GUI detailed products.........................................................................................42
Table 3-1: Catalogue inputs/outputs......................................................................................45

# List of Acronyms

| | |
|---|---|
| ADA | Active Deformation Areas |
| AoS | Area of Simulation |
| API | Application Programming Interface |
| C&C | Command & Control Centre |
| CAMS | Copernicus Atmosphere Monitoring Service |
| CAP | Common Alerting Protocol |
| CMEMS | Copernicus Marine and Environment Monitoring Service |
| CMU | Crisis Management Unit |
| DataEo | Earth Observation Data Source |
| DataEx | External Data Source |
| DataSitu | In Situ Data Source |
| DB | Database |
| DEM | Digital Elevation Model |
| DS | Decision Support |
| ESB | Enterprise Service Bus |
| ETA | Estimated Time of Arrival |
| DES | Decision Support Information |
| FFS | Forest Fire Simulator |
| FR | First Responder |
| FTP | File Transfer Protocol |
| GB | Ground Based |
| GDACS | Global Disaster Alert and Coordination System |
| GIS | geographic information system |
| GOI | Geographical Locations of Interest |
| GPS | Global Positioning System |
| GUI | Graphical User Interface |
| IA | Impact Assessment |
| IG | Information Gateway |
| ISA | Impact Summary |
| ISAS | Impact Summary Service |
| LU | Local Unit |

| | |
|---|---|
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| P2P | Peer to Peer |
| POI | Points of Interest |
| RVA | Risk and Vulnerability Assessment |
| SA | Situation Assessment |
| SAR | Synthetic Aperture Radar |
| SatCom | Satellite Communication |
| Scen | Scenario |
| SP | Service Platform |
| SM | Scenario Management |
| SMAC | Scenario Matching |
| UeRM | User Role Management |
| UI | User Interface |
| VEAM | Vulnerable Elements Activity Maps |
| WCS | Web Coverage Service |
| WFS | Web Feature Service |
| WMS | Web Map Service |

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# Executive Summary

This document provides the HEIMDALL system architecture. It is the companion deliverable to D2.11 – Service Concept Specification [1] and defines the system architecture that is necessary to provide the services and products of HEIMDALL. The system elements are identified based on the requirements defined in Task 2.3 and provided as a first version in D2.6 [2]. The interfaces between system elements and with external agents are identified and presented where service requirements, rules input data and data exchange formats to other connected systems are considered. The system modules presented here will be further specified during the project and presented in dedicated deliverables for milestone 2 (M18) and 4 (M42).

# 1 Introduction

HEIMDALL will provide services and products scenario planning and scenario building for first responders (FR), command and control centres (C&C) and incident managers of different actors involved in natural and man-made hazard responding. Several services and products have been identified and presented in D2.11. We here present the corresponding system architecture that is able to offer the identified services. The setup is divided in a local unit that provides all necessary features to single authority. A high level illustration is shown in Figure 1-1 which uses different data sources, space, ground and aerial based as inputs. External systems and data sources can be integrated, too. A local unit provides services for scenario management, modelling and simulation features to forecast the behaviour of hazard, risk and vulnerability assessment, situation assessment and decision support. Data sharing and communication has two aspects in HEIMDALL, first considering the local unit, communication within the organisation is addressed, and data can be shared with the FR and C&C. Furthermore, the population can be informed to increase public awareness. Second, the information can be shared with other authorities, for instance with organisation of different disciples or neighbouring countries or municipalities.

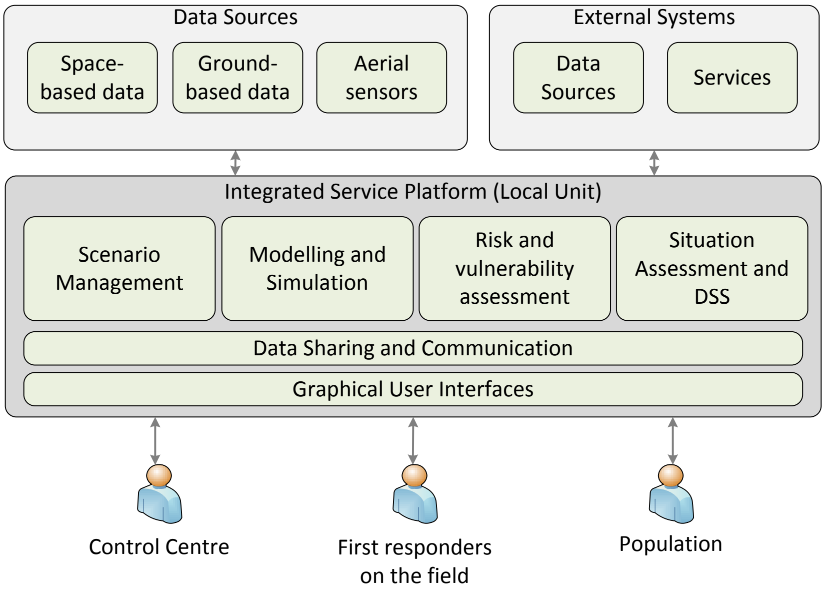


Figure 1-1: Local Unit service architecture

For this, it is possible to interconnect different local units in a federated architecture as presented in Figure 1-2. A global catalogue is used for information discovery and initiating the connections. The connection itself is established in a peer 2 peer (P2P) way and content orient based.

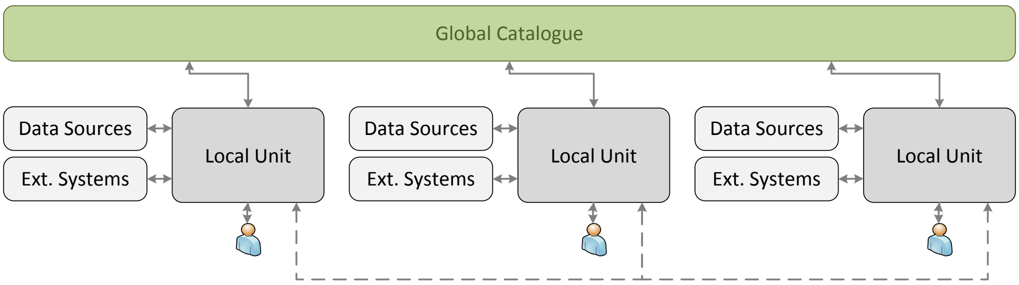


Figure 1-2: Federated architecture

HEIMDALL follows an agile approach for the development. Consequently, we consider the general architecture and core products as fixed since it is based on core user requirements, however, for some fields and modifications are expected because of an iterative approach having multiple validation and development cycles with end-user involvement.

The following sections are organized as follows:

- Section 2 specifies the system elements of the local unit and shows the provided by them as well as the interfaces.
- Section 3 describes the federated architecture and the specific modules required to establish a connection among multiple actors of different organisations.
- Finally, section 4 summarizes and concludes the document.

# 2 Local Unit

In Figure 1-1 the architecture of a local unit (LU) is presented including the interfaces (ESB, I1 – I10). On the left hand side the system inputs are presented which are further detailed in section 2.8 and 2.9. The simulators (Simu) shown in the centre upper part include simulators for fire, flood and landslide as presented in section 2.4. Modules that are using the simulation results as input are shown below and are namely the risk assessment (RVA), the impact summary (IA) generation and decision support (DS). On the right hand side everything needed for communication is shown. An information gateway (IG) connects the system via satellite communication (SatCom) or the commercial internet with a receiver application for smartphones for the FRs or the general public. For the federated architecture, the system can connect to a catalogue and provides the dedicated interface to other system instances. In the lower central part of the figure, the user role management module (UeRM) (further explained in section 2.2) the graphical user interface (GUI – see section 0) and the scenario management (SM) (section 2.3) are illustrated. The overall interconnecting middleware the service platform that orchestrates the whole system is defined in section 2.1.

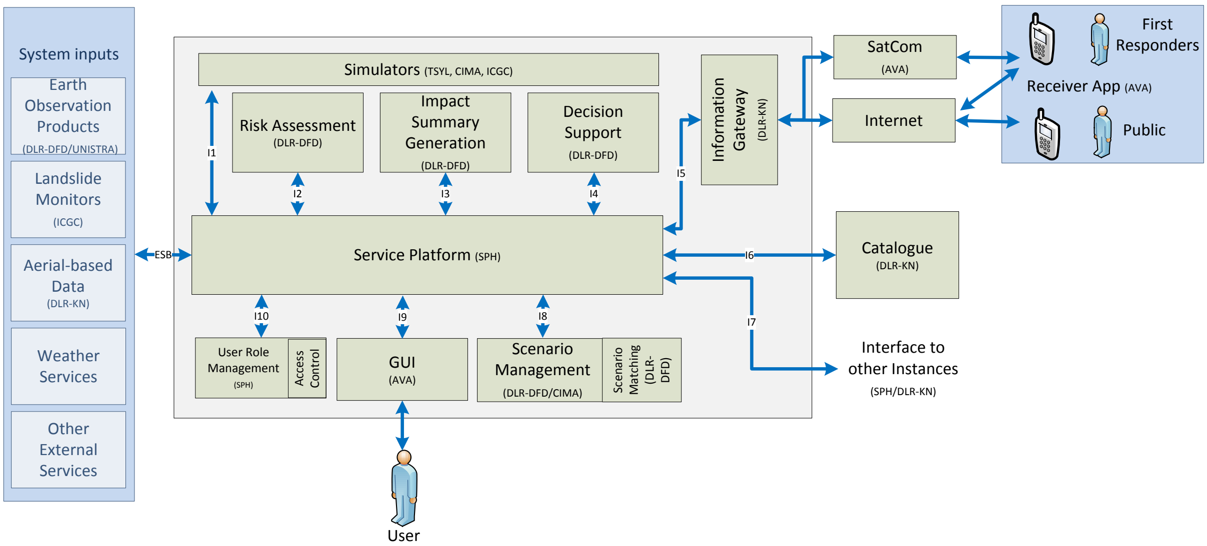


Figure 2-1: Local unit architecure

In each sub-section below, the modules are considered as a “black box” which provides the services described in D2.11 and the inputs and outputs to the “black box” and the consumer or provider are defined. For the sake of clarity, the interfaces (ESB, I1 – I10) in Figure 2-1 are combined. One interface per module shown that actually represents a bundle of interfaces to other modules. However, all the communication will be done via the service platform (SP) so indeed the interface can be represented by a single connection to the SP. The actual interfaces to other modules are indicated by the tables in the following sections, since here the inputs and the provider as well as the consumer are shown. To each of them an interface must be developed which will be done in the dedicated deliverables of each module. For the simulators the first version of I1 will be in D5.12 at M2, for the risk assessment I2 in D6.4 at M18, for the impact summary I3 in generation D6.7 at M18, for the decision support I4 in D6.10 at M18, for the SP the ESB in D4.1 at M18, for the user and role management module I10 in D4.4 at M20. The interface I9 of the GUI will be described in D4.7 at M18, I8 for the scenario management in D6.15 at M18, I5 for the IG and the SatCom in D4.16 at M22. The catalogue interface I6 and I7 the interfaces to other instances will be presented in D4.13 at M18. The Landslide monitors and aerial based data interface will be defined in D5.4 at M18, the ones for EO in D5.1 and the ones for external services in D5.9 in M22, respectively.

## 2.1 Service Platform

The core element of the HEIMDALL architecture is the service platform (SP), as presented in Figure 2-1, offered to each individual authority for response planning and scenario building. The SP accommodates and interconnects various internal services and modules (such as workflow orchestration service, the SP monitoring module, as well as interfaces with the rest of the HEIMDALL modules) for multi-hazard management. Hence, the SP implements a repository for geospatial and plain data as well as a GIS engine for data representation and transformation. Moreover, the SP offers interfaces for internal and external data sources as well as interfaces for the horizontal, peer-to-peer communication with other Local Units (see Section 3). A graphical user interface (see section 0) will facilitate interaction with the end users in an intuitive and user-friendly manner. Overall, the SP and its user interface will offer to end users a complete integrated environment for response planning and scenario building, also facilitating the exchange of data with other authorities.

With the help of the following services, the user shall be able to:

- Retrieve cartographic data from a web map service (WMS)
- Retrieve map features from a web feature service (WFS)
- Retrieve coverage information from a web coverage service (WCS)
- Submit coverages and features to the georeferenced data repository
- Submit events and observations to the georeferenced data repository
- Retrieve/submit data to a general purpose (non-georeferenced) data repository

Table 2-1 describes the outputs provided by the SP with regard to data storage, the inputs needed to generate each output, the modules or external elements providing each of the inputs and the modules consuming the corresponding outputs.

Table 2-1: Service Platform storage services inputs and outputs

| **Products and/or Services** | **Inputs needed**<br>*inputs to generate each output* | **Provided by**<br>*module or external system providing the input* | **Used by**<br>*module consuming the product/service* |
|---|---|---|---|
| Georeferenced data storage service | The invocation of the OGC compliant API provided by the SP requesting to store/retrieve/edit/etc. data. | External services | GUI |
| GIS database | Georeferenced data | Georeferenced data storage service | SP<br>GUI |
| “Plain” data storage service | The invocation of the API provided by the SP requesting to store/retrieve/edit/etc. data. | External services | SP<br>GUI |
| “Plain” database | A database that allows the storage and retrieval of plain data information. | “Plain” data storage service | SP<br>GUI |
| Historic data service | Provide access to historic data (past incidents) | SP | GUI<br>SM |

Additionally, the services in Table 2-2 shall be used to:

- Acquire data (either raw or processed) not provided by the currently installed data sources or tools.
- Communicate sensor data, events and simulation results and retrieve decisions/ recommendations.

Table 2-2: Service platform additional services inputs and outputs

| Products and/or Services | Inputs needed | Provided by | Used by |
|---|---|---|---|
| Workflow invocation service | The workflow description (sequence of services invoked and products manipulated) provided by the LU of a remote Unit (remote invocation of process). | SP (local or remote) | All other HEIMDALL services |
| SP Monitoring | Basic monitoring metrics regarding SP operation, regarding resource utilisation and generated products, through log files. | SP | SP |
| Interfaces with various services | Valid user credentials | GUI | All other HEIMDALL services |
| | Access rights | UeRM | |
| | Products and services | SP<br>Catalogue | |

## 2.2 User and Role Management

With regard to user and role management (see Table 2-3), the authentication module shall allow a user or an application/service to access the system based on the credentials provided (specifying access rights/privileges to resources). Only users/applications/services with valid credentials will be allowed to access the system.

The access control module shall apply selective restriction to HEIMDALL resources (services/products and actions on them). Valid users will have access to the resources based on their role and access rights.

Table 2-3: User and role management services inputs and outputs

| Products and/or Services | Inputs needed | Provided by | Used by |
|---|---|---|---|
| Authentication | Username and password of the user | GUI | GUI<br>Smartphone application |
| | A valid token, in the case a token-based method is used | UeRM | |

| | | | |
|---|---|---|---|
| Access control | Valid login credentials (successful authentication) | GUI | SP<br>UeRM |
| | Active role of the user | UeRM | |

Through the admin console (see Table 2-4), the SP administrators can centrally manage all aspects of the user management server, whereas through the account management console, users can manage their own accounts. In addition, the user profile shall hold their preferences, as shown in D2.11, facilitating a smoother operation from the user perspective.

Table 2-4: Administrator services inputs and outputs

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Admin console | Valid admin credentials | GUI | GUI<br>UeRM |
| Account management console | Valid user credentials | GUI | GUI<br>UeRM |
| User profile | The user preferences as shown in D2.11. | UeRM | Access control |

## *2.3 Scenario Management*

The HEIMDALL project aims at supporting decision makers in building, storing and reviewing realistic, multidisciplinary scenarios. A scenario should consist of a real or hypothetical hazard and current conditions in the local area, information on where physical impacts are likely to occur, and how they will interact with people and buildings, what measures, resources and forms of organization are needed in order to reduce the consequences. During a disaster situation, scenario objects provided by the system act as a recording of actual events and actions as the situation evolves as well as a means for tracking lessons learnt in the aftermath of a disaster.

As a matter of fact, users can define scenarios which represent both – real situations and fictive simulated scenarios. Hypothetical or simulated scenarios may be based on` real disaster situations and conditions. Emergency services need them for different planning and training purposes. For example, trainers need to simulate hazardous situations and conditions during trainings and exercises. For pre-planning of a large-scale response hypothetical worst-case scenarios need to be created. In a disaster situation different alternative prevention and mitigation measures need to be simulated. Scenario management provides means for users of the system to define the credibility of a scenario and, in the future, whether a scenario shall be used for the comparison of a situation with similar situations. For example, it makes sense for the user to be able to compare a situation with a corresponding worst-case scenario. A comprehensive methodology to separate real and hypothetical scenarios will be elaborated incrementally in close collaboration with the end users and experts in ethical, legal, and social issues.

Scenario management is comprised of three major components:

- Scenario Management (SM) component
- Scenario Repository
- Scenario Matching (SMAC) component

The SM component enables clients (e.g. the GUI) to create, store, retrieve, edit and delete scenarios and response plans. In addition, a scenario shall be able to be copied, e.g. in order to derive a fictive scenario from a real situation. Furthermore, it provides functionality to connect to a scenario all related incident information provided by the different internal and external data sources, simulation results, risk and impact assessment information, decisions made, measures taken and lessons learnt. In that sense, a scenario object (JSON object) acts as a pool of information and knowledge for effective situation assessment and plan formulation. The association of information to a scenario is assumed to be performed by the user over the UI. Some automatically acquired information such as weather conditions are assigned by the HEIMDALL system. Users shall be able to access all information associated to a scenario in order to explore them in detail. At any time during a scenario lifecycle a snapshot of the current sensor data and available information can be generated for analysis, situation reporting and archiving purposes. Based on a sequence of scenario snapshots end users are able to retrace the scenario evolution. Scenarios, scenario snapshots and response plans are stored in a Scenario Repository. The situation reporting functionality is outlined in Section 2.6.

The SMAC component matches for a given situation a list of similar historic or fictive scenarios. With the scenario matching functionality, users can find similar situations in a database and look for the taken response measures and their outcomes. They can use this information to evaluate suitable strategies for the situation at hand or to simulate different options of what could happen and what effects prevention or mitigation measures would have if applied, for instance, by simulating the effect of fire breaks on the situation evolution (i.e. what-if analysis). The SMAC can provide the different parameters for the definition of the simulated options in the form of incident behaviour observed in historic scenarios, measures taken, evaluations made, etc. Table 2-5 shows the products SM and SMAC generate.

As a basis for multi-criteria pattern matching, analysis, and comparison of scenarios suitable multi-hazard and risk-based comparison metrics will be identified and formalized. These metrics will build upon the determination of suitable distance factors and relations between scenarios in terms of time and space, rule-based algorithms, geospatial analysis, and emergency response knowledge. Matching criteria and metrics are configurable and visible to the end users in order to foster matching-process customization and optimization.

For details on scenarios, scenario management system design, functionalities and methodologies please refer to the corresponding technical specification D6.14 [3].

Table 2-5: Scenario Management and Scenario Matching products

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Scenario | Scenario information:<br>• Type (real/simulated),<br>• Name, identifier<br>• Hazard type<br>• Hazard time<br>• Hazard location<br>• Hazard behaviour<br>• Impact scale<br>• Risk level<br>• Casualties and injured<br>• Weather conditions (wind speed, wind direction, temperature, relative humidity) | GUI (user input: scenario information + association of products below)<br>Associated information from:<br>Internal and external data sources, SP, Simu, RVA, SA, DS<br>Internal: SM (for associating response plans, decisions, countermeasures, lessons learnt, similar scenarios and simulated options) | Simu, RVA, SA, DS, GUI |

| | | | |
|---|---|---|---|
| | • Credibility<br>Associated information:<br>• Internal and external data (i.e. EO-based products, Aerial-based products, landslide monitoring products, crowdsourced and first responder data)<br>• Simulation results<br>• Risk and vulnerability products<br>• Impact summary information (impact, potential interacting hazards, situation evolution)<br>• Decision support information<br>• Related scenarios<br>• Response plans<br>• Decisions<br>• Lessons learnt<br>• Countermeasures | | |
| Scenario snapshot | Scenario identifier<br>Date/time<br>Instance of a scenario at a specific point in time including all associated information | GUI (user input: description/notes) | GUI (for analysis)<br>SA, DS (for response plan/situation report generation) |
| Response plan | Inputs should allow the system the compilation of response plans.<br>Detailed inputs will be defined in the corresponding technical specification D6.14. | GUI (user input)<br>SM (scenario/incident information and similar scenarios)<br>Simu (results)<br>SA, DS, ISA information, DES information | GUI<br>SM (for association to scenario) |
| Decision | Inputs should allow the system the compilation of decisions.<br>Detailed inputs will be defined in the corresponding technical specification D6.14. | GUI (user input) | GUI<br>SM (for association to scenario) |
| Measure | Inputs should allow the system the compilation of measures. Each | GUI (user input) | Simu<br>SM (for association to |

| | | | |
|---|---|---|---|
| | measure must refer to the scenario it applies, to the response plan and decision if measure is taken in order to achieve goals set in the plan and decision.<br><br>Evaluation (text) or rating (positive/negative)<br><br>Detailed inputs will be defined in the corresponding technical specification D6.14. | | scenario)<br><br>GUI |
| Lesson learnt | Inputs should allow the system the compilation of lessons learnt.<br><br>Detailed inputs will be defined in the corresponding technical specification D6.14. | GUI (user input) | SM (for association to scenario)<br><br>GUI |
| List of similar scenarios | Expert criteria for matching<br><br>Input parameters or input scenario snapshot | Configuration (expert criteria)<br><br>GUI (input parameters or snapshot ID) | GUI<br><br>SM (for association to scenario snapshot) |

## *2.4 Modelling and Simulation*

The modelling and simulation module is the HEIMDALL's modelling component, simulating the behaviour and extension of multiple hazards. With this in mind, the module integrates several simulation tools, each of them addressing a specific hazard. The hazards that are addressed within the project are forest fires, landslides and floods, but thanks to the modularity of the system other simulation tools can be easily integrated within the system in the future. Each of these simulation tools needs to receive inputs from other internal HEIMDALL components and/or external systems for processing the outputs related to the estimations of the hazard extent and behaviour. In addition, some of the created outputs will be used as input to other system elements. Table 2-6, Table 2-7 and Table 2-9 list the relevant products of the simulation tools for each hazard and define the necessary inputs that are needed to generate the corresponding product, the module or external system providing the input, as well as the consumer modules that use the created simulation products. The specified products will be mainly used by the risk and vulnerability assessment module, the situation assessment and decision support modules to generate their products.

### 2.4.1 **Flood Simulation**

The Flood simulator will provide two simulation modes depending on the flood simulator used which depends essentially on the type of results and the computational time requested.

The flood simulator has two different mode of use:

- Real-time simplified model
- Complete 2D hydraulic model

The real time simplified model (FloS-realtime) will allow dynamic mapping in real-time balancing computational costs with required accuracy.

In Table 2-6 planned products of the flood simulator are shown. It furthermore, identifies the inputs, the unit of the input indicated in squared brackets and the components that shall provide this input data and the consumers of the products.

Table 2-6: Flood simulation inputs and outputs

| Products and/or Services | Inputs needed | Provided by | Used by |
|---|---|---|---|
| Real-time flood extensions (Simplified model) | Selection of AOI [polygon] | GUI | SM, RVA, SA, DS |
| | Digital Terrain Model [grid] | DataEX | |
| | Land Cover map [grid] | DataEX | |
| | Layer of the levees location [polyline] | DataEX | |
| | Number of streams (e.g. confluence case) [double]<br><br>Input discharge location(s) [single point or multiple points]<br><br>Peak discharge value(s) [double]<br><br>Peak discharge(s) timing [time]<br><br>Flood duration [double] | GUI | |
| Real-time water depth (Simplified model) | Selection of AOI [polygon] | GUI | SM, RVA, SA, DS |
| | Digital Terrain Model [grid] | DataEX | |
| | Land Cover map [grid] | DataEX | |
| | Layer of the levees location [polyline] | DataEX | |
| | Number of streams (e.g. confluence case) [double]<br><br>Input discharge location(s) [single point or multiple points]<br><br>Peak discharge value(s) [double]<br><br>Peak discharge(s) timing [time]<br><br>Flood duration [double] | GUI | |

| | | | |
|---|---|---|---|
| Flood extensions (Complete model) | Selection of AOI [polygon] | GUI | SM, RVA, SA, DS |
| | Digital Terrain Model [grid] | DataEX | |
| | Land Cover map [grid] | DataEX | |
| | Layer of the levees location [polyline] | DataEX | |
| | Number of streams (e.g. confluence case) [double]<br><br>Input discharge location(s) [single point or multiple points]<br><br>Peak discharge value(s) [double]<br><br>Peak discharge(s) timing [time]<br><br>Flood duration [double] | GUI | |
| Water depth (Complete model) | Selection of AOI [polygon] | GUI | SM, RVA, SA, DS |
| | Digital Terrain Model [grid] | DataEX | |
| | Land Cover map [grid] | DataEX | |
| | Layer of the levees location [polyline] | DataEX | |
| | Number of streams (e.g. confluence case) [double]<br><br>Input discharge location(s) [single point or multiple points]<br><br>Peak discharge value(s) [double]<br><br>Peak discharge(s) timing [time]<br><br>Flood duration [double] | GUI | |
| Water velocity (Complete model) | Selection of AOI [polygon] | GUI | SM, RVA, SA, DS |
| | Digital Terrain Model [grid] | DataEX | |
| | Land Cover map [grid] | DataEX | |
| | Layer of the levees | DataEX | |

| | | | |
|---|---|---|---|
| | location [polyline] | | |
| | Number of streams (e.g. confluence case) [double]<br><br>Input discharge location(s) [single point or multiple points]<br><br>Peak discharge value(s) [double]<br><br>Peak discharge(s) timing [time]<br><br>Flood duration [double] | GUI | |
| Dynamic mapping tool (hydrological model and simplified hydraulic) | Selection of AOI [polygon] | GUI | SM, RVA, SA, DS |
| | Digital Terrain Model [grid] | DataEX | |
| | Layer of the levees location [polyline] | DataEX | |
| | Number of streams (e.g. confluence case) [double]<br><br>Input discharge location(s) [single point or multiple points]<br><br>Peak discharge value(s) [double]<br><br>Peak discharge(s) timing [time]<br><br>Flood duration [double] | GUI | |
| | Location of mitigation measure on DTM grid [point and click]<br><br>local mitigation measure value (+/- level) | GUI | |
| | Location of mitigation measure on levees layer polyline [select and click]<br><br>local mitigation measure value (+/- level) | GUI | |

### 2.4.2 **Forest fire Simulation**

The Forest Fire Simulator APIs base ground shall be based on the well-known Wildfire Analyst® forest fire simulator [4]. The Forest Fire Simulator main operation mode is the fire spread simulation mode which allows to forecast the behaviour and advance of the fire in space and time, it shall provide a set of outputs to help the user assess how the fire is expected to propagate with the aim of taking operational or planning/mitigation decisions such as where to position resources, take preventive measures such as vegetation fuels treatments, building firebreaks and so forth.

With this aim the Forest Fire Simulator shall make use of two main propagation models, a surface fire model and a temporal evolution model. The surface fire model is the Rothermel model (1972) [5] which includes the modifications proposed by Albini (1976) [6] and the required expansion to admit Scott & Burgan (2005) [7] fuel types. This one-dimensional model provides a scalar expression of the fire front speed (Rate of Spread), the flame intensity as well as the flame length according to the local humidity, the wind, the slope and the existing vegetation fuels.

In HEIMDALL, the Farsite [8] approach applying an Anderson (1983) model [9] will be followed, where a sole ellipse is used. A single ellipse is used with a subtracting constant, reducing slightly the ratio between the length and width of the ellipse so that in condition with no wind and a flat surface the simulations shall represent the progression of the fire with a circular shape. In the case of the temporal evolution model it calculates spatially the arrival time of the forest fire. The time evolution algorithm is based on a Minimum Travel Time (MTT) algorithm. Both models are further explained and specified in section 5.2.4 of D5.12.

Table 2-7 displays the products that are planned to be provided by the forest fire simulator, the necessary inputs to generate these results, the components that shall provide the input data as well as which modules are planned to make use of the resulting products.

Table 2-7: Forest Fire Simulation products, related inputs and relation with other system components

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Time of arrival | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | SM, SA, DS, GUI |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |

| | | | |
|---|---|---|---|
| | Firebreaks | GUI and forest fire simulator (FFS) | |
| Fire perimeter | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | SM, SA, DS, GUI |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |
| Minimum Travel Time (MTT) fire paths | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | SM, SA, DS,GUI |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |

| | | | |
|---|---|---|---|
| Flame length | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | SM, SA, DS, GUI |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |
| Fire intensity | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | SM, SA, DS, GUI |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |

| | | | |
|---|---|---|---|
| Rate of Spread (ROS) | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | SM, SA, DS, GUI |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |
| Out of suppression capacity | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | SM, SA, DS, GUI |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |
| Forest fire impact relevance assessment | Census data and/or Land use economic data | Simu or DataEx | SM, SA, DS, GUI |

| | | | |
|---|---|---|---|
| | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |
| Impact oriented fire paths | Census data and/or Land use economic data | Simu or DataEx | SM, SA, DS, GUI |
| | Weather parameters:<br>• Wind speed (in the direction of wind. (Km/h)<br>• Wind direction (º)<br>• Air temperature (ºC)<br>• Relative humidity (%)<br>• Cloudiness (Yes/No) | DataEX | |
| | Hours of simulation (h) | SP and/or GUI | |
| | Selection of adjustment | GUI | |
| | One or multiple geometries with associated date and time | DataSitu or GUI | |
| | Simulation start date and time | SP or GUI | |
| | Area of simulation (AoS) | SP | |
| | Firebreaks | GUI and FFS | |

#### 2.4.2.1 Pyro-geomorphometry

The service that provides the following products shall calculate/identify for a given area the geological elements of the terrain that influence the way the fire behaves and spreads, i.e. the elements that accelerate or decelerate the progression of fire. These elements are specified in Table 2-8.

Table 2-8: Pyro-geomorphometry products, related inputs and relation with other system components

| Products and/or Services | Inputs needed | Provided by | Used by |
|---|---|---|---|
| Mountain ridges | Area of simulation (AoS) | SP and/or GUI | GUI |
| Consolidation lines | AoS | SP and/or GUI | GUI |
| Valley nodes | AoS | SP and/or GUI | GUI |
| Vertical walls | AoS | SP and/or GUI | GUI |

### 2.4.3 Landslides

Three types of landslides can be simulated with the HEIMDALL landslide simulation module:

- Rotational landslides
- Debris flows
- Rock falls

The reason why these three types of landslides have been selected can be summarized in two aspects: first, debris flows and rock falls are fast landslides with large runout and therefore simulations are useful tools to predict potentially affected areas; and second, rotational landslides are often deep, have high magnitudes and affect large areas. Therefore, it is difficult to identify the most critically stable areas.

The landslide simulation module will allow the user to model a hypothetical or real situation of instability in a certain area. The purpose of the simulator is twofold: a) the user will be able to determine which would be the affected area in case of a hypothetical landslide event, and b) the user will be able to determine the stability in the nearby areas of an area affected by a landslide. The proposal in HEIMDALL is to complement these simulations with monitoring systems in order to assess the terrain movement. While simulations are only thought for the three types of landslides that are potentially most destructive, monitoring can also be used to detect other types of terrain movements. Section 2.8.2 of this document provides details on the monitoring systems. Simulation methods are different depending on the type of landslide, although there is only one simulation module for landslides in HEIMDALL. Once the simulation module is initialized, the user must select the specific landslide type, and depending on this choice a specific simulation is run.

The landslide simulator provides three products, which are listed in Table 2-9. These products allow the user to identify areas potentially affected by landslides and also, in case that a landslide occurred, the triggering factors and the evolution of stability based on weather forecast.

The first product of the landslide simulator is the susceptibility map**.** Landslide susceptibility is the likelihood of a landslide occurring in an area on the basis of local terrain conditions [10]. Many approaches and methods for assessing landslide susceptibility have been described in the literature (e.g.: [11], [12], [13], [14] among others). Physically-based landslide modelling schemes are a type of approach used for the analysis of the stability/instability conditions of the terrain. Physically-based methods can be focused either on the potentially unstable areas to be mobilized using deterministic methods that apply classical slope stability theory and principles, or on the areas that may be covered by the moving masses using dynamic and numerical methods or GIS-based methods that predict flow paths and travel distances. On the following, details of the landslide simulator of HEIMDALL are provided.

For rotational landslides, the susceptibility analysis is based on the failure. The simulator carries out a limit equilibrium analysis that provides the probability of spatial occurrence of slope failure for each pixel of the digital elevation model (DEM) in the form of factor of safety. The limit equilibrium analysis is performed using Scoops3D, a computer program developed by the U.S. Geological Survey [15] for analysing slope stability throughout a digital landscape, as represented by a DEM. The factor of safety is automatically transformed into susceptibility by the simulator and is classified into three classes: high, medium, low. The simulator of rotational slides requires geotechnical input data, and the reliability of the simulation will strongly depend on the quality of these data. In order to facilitate the task of providing complex geotechnical input data to the user, the inputs have been parameterized according to simple geological characteristics.

For debris flows and rock falls, since they are rapid movements that can travel large distances, the analysis of the susceptibility will be to the propagation, not to the failure. Therefore, the susceptibility map will provide the area that may be affected by the propagation of the landslide, without considering the initial failure. The simulation will be done using Flow-R, a computer program developed by the University of Lausanne for analysing propagation of moving masses throughout a digital landscape, as represented by a DEM. The probability of reaching at each DEM cell is calculated based on algorithms of flow direction and persistence functions that control the spreading, and frictional laws that control the runout distance. The probability is automatically transformed into susceptibility and will be classified into three classes: high, medium and low. DEM resolution is a key point for these cases because the propagation of the moving mass will be strongly dependent of the DEM. For these cases, it is recommended to use at least a 5m DEM, but in order to have the results in a reasonable computing time (few minutes), it is necessary to define a small extension. In case that it is necessary to analyse a big extension, a lower resolution DEM can be used, but the results will be of lower precision. Model accuracy and computation time should be taken into account when selecting the DEM resolution.

The second product of the landslide simulator provides the trends of triggering conditions for terrain movements**.** Rainfall is the most common triggering factor of landslides and the analysis of the critical rainfall conditions is a fundamental research task [16]. Rainfall thresholds have been defined worldwide [17]. The simulator contains a sub-module that gathers rainfall data from the nearest weather station (including past data that triggered the landslide event, and forecasted data, in order to analyse how the stability condition will evolve in the future) and compares it with predefined rainfall thresholds.

Finally, the third product of the simulator provides the scenarios of potential landslide warning areas. This product combines the two previous products (susceptibility and trends of triggering conditions) and determines which is the situation in terms of stability at the study area and how will this evolve. All three products should be shown in the GUI, together with the inputs of all of them. At the same time, while the terrain movement susceptibility map will be used as an input by the risk assessment module, the other two products will be used only for the situation assessment, decision support and scenario management.

Table 2-9: Landslide simulator services inputs and outputs

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Terrain Movement Susceptibility map | Digital Elevation Model | DataEx | Simu, SM, RVA, SA, DS, GUI |
| | Other cartographic information (source areas, geology, etc.) | DataEx | |

| | | | |
|---|---|---|---|
| Trends of triggering conditions that can trigger terrain movements | Weather data | DataEx | Simu, SM, RVA, SA, DS, GUI |
| Scenarios of potential landslide warning areas based on triggering conditions evolution. | Trends of triggering conditions that can trigger terrain movements | Simu | SM, RVA, SA, DS, GUI |
| | Terrain Movement Susceptibility map | Simu | |
| | Sentinel-1 Information about landslides | DataEO | |
| | Near real-time terrain movement information | DataSitu | |

## *2.5 Risk and Vulnerability Assessment*

The Risk and Vulnerability Assessment module (RVA) will support the HEIMDALL platform with designated risk products. The bases for the assessment are the generated hazard information (flood, landslide or forest fire) products from the Earth observation (DataEo) or simulation modules (Simu). The hazard information is used to identify the exposed elements, i.e. elements that are affected by a certain hazard. The exposed elements are composed by the physical elements (physical exposure) and the human elements (human exposure) which serve as input for the human and physical impact assessments. In the impact assessment products the expected impact on the population and the valuable assets affected by the occurring incident are estimated. Table 2-10 lists the relevant products of the RVA module and defines the necessary inputs that are needed to generate the product, the module or external system providing the input, as well as the consumer modules that use the created RVA products. The specified products will be mainly used by the situation assessment and decision support modules (compare section 2.6) to generate their products.

Table 2-10: Risk and Vulnerability Assessment Products

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Human impact assessment | Census data | External services | SA<br>DES |
| | Critical infrastructure information | External services | |
| | Observed Crisis Information | DataEO | |
| | Simulated crisis information | Simu | |
| | Human exposure | Internal: exposure estimation | |
| Human exposure | Observed crisis information | DataEO | DES<br>SA<br>RVA |
| | Simulated crisis information | Simu | |

| | | | |
|---|---|---|---|
| | Census data | External services | |
| | Physical exposure | Internal: Exposure Estimation | |
| Physical exposure | Observed crisis information | DataEO | DES<br>SA<br>RVA |
| | Simulated crisis information | Simu | |
| | Critical infrastructure information | External services | |
| Physical impact assessment | Observed crisis confirmation | DataEo | SA<br>DES |
| | Simulated crisis information | Simu | |
| | Susceptibility information | DataEx | |
| | Physical exposure | Internal: exposure estimation | |
| Multi-hazard risk | Observed crisis information | DataEO | DES<br>SA |
| | Simulated crisis information | Simu | |
| | RVA products | Internal: hazard specific exposure and impact products | |

## *2.6 Situation Assessment and Decision Support*

HEIMDALL situation assessment and decision support services aim at providing relevant information products in the process of response planning. End users need information which supports them to understand the situation and the cascading effects, to identify the value of information for decision making and with coordination. The following situation assessment and decision support information products can be provided in different phases of the response planning process:

- Similar scenarios matched by the scenario matching service (SMAC) containing information on decisions and prevention and mitigation measures taken, their positive or negative evaluation and lessons learnt (see section 2.3 Scenario Management)
- Impact summary information (ISA Information) generated by the impact summary service (ISAS) on relevant infrastructure and people at risk, on potential cascading effects and on situation evolution which supports, together with simulation and risk and vulnerability assessment tools, the evaluation of simulated options during what-if analysis (see Table 2-11).
- Response-oriented decision support information (DES information) generated by DES on potentially save response infrastructure which supports the identification of options and contingencies (see).

- Standards-based scenario snapshot containing all information relevant for situation awareness, plan formulation, communication and information sharing, e.g. EDXL-CAP, EDXL-SitRep. During implementation this functionality will be technically separated from the other software components of situation assessment and decision support. The generation of standards-based products based on scenario snapshots is part of situation assessment and decision support just from a functional / user point of view. Technically, it is based on direct access to the database of scenario management.

For end users, an important decision making activity is a what-if analysis of the different simulated options sourcing from different foreseen hazard evolutions and potential measures of prevention and control in order to explore the consequences of impacts and measures to be performed in these options. The HEIMDALL system can assist decision makers to generate alternative scenarios (using scenario management functions) and assess their potential evolution and consequences using simulation, risk and vulnerability assessment and ISAS functions. Decision makers such as incident commanders in the field can display and explore these alternative scenarios in a GUI or browse through them when they are presented in the form of a situation report. Based on such a situation report which contains a comparison of the top best-fitting planning scenarios each with relevant information on probability and consequences, their knowledge of the context and their experience they are able to take an informed decision on the best-fitting scenario option and the appropriate working strategy.

ISA information can be generated for pre-defined geographical locations of interest (GOIs) in order to allow end users to customize significant infrastructure according to their organizational strategies and constraints. The ISAS integrates different layers of information provided by end users and other HEIMDALL modules to generate an impact summary for these GOIs. The selection of additional GOIs for impact assessment over the GUI allows end users to generate impact assessment information for dynamic objects such as response teams.

An example for DES information is a list of potentially safe (potentially not affected for a given time) alternative forward command post sites which, when included in a situation report, can help the decision maker to meet the best possible contingencies in case that a forward command post need to be moved. In order to reflect the internal diversity of end users in terms of different legal frameworks, national, regional and organizational strategies, roles and profiles, end users are able to customize infrastructure such as alternative forward command post sites which will be considered for the generation of DES information. In addition, decision makers can configure rules and thresholds and modify DES information according to their individual and organizational needs and knowledge.

Table 2-11: Impact Summary (ISA) information products

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| GOIs at risk | Pre-defined GOIs<br>Expert criteria (e.g., levels of detail, ranking of infrastructure, etc.)<br>Additional selected GOIs<br>Simulation results<br>Impact assessment and risk information<br>Incident information | Configuration (expert criteria, pre-defined GOIs)<br>GUI (selected GOIs)<br>SM (for simulation, impact/risk, incident information); requires access to:<br>Simu (results)<br>RVA (results)<br>Data Sources | GUI (show)<br>SM (connect to scenario; include in response plan)<br>DES |

| | | | |
|---|---|---|---|
| People at risk | Population numbers<br>Simulation results<br>Impact assessment and risk information | SM (for simulation, impact/risk); requires access to:<br>Simu (results)<br>Risk (results) | GUI (show)<br>SM (connect to scenario; include in response plan) |
| Potential cascading effects/related hazards | Pre-defined interacting hazards<br>Pre-defined interacting infrastructure at risk<br>Simulation results<br>Impact assessment and risk information; multi-risk information<br>Incident information | Configuration ( pre-defined hazards, infrastructure)<br>SM (for simulation, impact/risk, incident information); requires access to:<br>Simu (results)<br>RVA (results)<br>Data Sources | GUI (show)<br>SM (connect to scenario; include in response plan) |
| Hazard evolution information | Last scenario snapshot<br>Simulation results<br>Impact assessment and risk information; multi-risk information<br>Incident information | SM (last scenario snapshot); requires access to:<br>Simu (results)<br>RVA (results)<br>Data Sources | GUI (show)<br>SM (connect to scenario; include in response plan) |
| Standards-based situation report | Scenario snapshot containing scenario information including (optional):<br>Similar scenarios (scenarios resulting from scenario matching with actions/countermeasures taken and lessons learnt)<br>Simulated options (scenarios resulting from what-if-analysis with simulation, impacts, probabilities) | Scen | GUI |

Table 2-12: Decision support (DES) information products

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Information about safe, significant infrastructure | Pre-defined GOIs<br>Expert criteria (e.g., levels of detail, ranking of infrastructure, etc.)Simulation results<br>Impact assessment and risk information | Configuration (expert criteria, pre-defined GOIs)<br>Scen (for simulation, impact/risk, incident information); requires access to:<br>Simu (results) | GUI (show)<br>SM (connect to scenario; include in response plan) |

| | | | |
|---|---|---|---|
| | Incident information<br>GOIs at risk | RVA (results)<br>Data Sources<br>ISA (for GOIs at Risk) | |
| Information about safe response infrastructure | Pre-defined potentially suitable forward command post sites<br>Expert criteria (e.g. ranking of infrastructure)<br>Out of suppression information from fire simulation<br>Impact assessment from Risk | GUI<br>Simu<br>RVA | GUI (show)<br>SM (connect to scenario; include in response plan) |

## *2.7 Communication to Remote Areas*

The HEIMDALL system shall be capable to assure a continuous connection through satellite communications from the local units to end users. The satellite communications link will be provided through a rapidly deployable, lightweight and portable Ka-band satellite terminal that can be transported and installed at any necessary case on site. Apart from the antenna, installation of a modem will be required to generate a Wi-Fi network. Once the antenna and the modem are installed, any end user that is within the Wi-Fi network coverage area will be able to connect to the Internet and therefore, access the available services. Table 2-13 shows the different inputs and outputs for the satellite communications module.

Table 2-13 - Communication to Remote Areas inputs and outputs

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Ka-band Satellite Communications | Successful configuration and installation | N/A | First responders' users |

### 2.7.1 **Information Gateway**

In order to increase the awareness of the population and to interconnect the first responders in the field with the HEIMDALL system an information gateway (IG) is implemented at HEIMDALL site. In case of the population the gateway can be used to distribute alert messages based on the common alerting protocol (CAP) which is the de facto standard for warning and alerting messages used worldwide [18]. The communication to first responders will offer some more information and will allow accessing most information available in the system. For this the IG connects to the scenario management module and the situation assessment services to provide the dedicated information. The counterpart of the information gateway in HEIMDALL is a smartphone application that is able to receive the messages from the IG. Since the IG is standard based other types of receivers are also possible.

Table 2-14: Information gateway inputs/outputs

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| FR information service | SitRep<br>Scenario<br>UeRM | Situation Assessment<br>Scenario Management | Smartphone application |

| | | | |
|---|---|---|---|
| Alerting service | CAP message | GUI | Smartphone application |

## 2.7.2 **Smartphone Application**

The development of a smartphone application will provide HEIMDALL's end users with an alternative way to receive and provide relevant information from and to the system. This data will be received/send by accessing the different data and services available through the service platform. From the service point of view, two smartphone applications, one for the public and one for the FR in the field, are foreseen. However, the public one can be seen as a light version of the FR since it offers reduced functionality but the core is the same. Consequently, a single smartphone application will be developed during the project that includes all functionalities for the FR and could potentially be reduced to a version for the public, if time of the project allows for it.

Table 2-15: Smartphone application products

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Authentication | Username and password of the user | First responders users | SP |
| Alerts receiver | CAP message | Information gateway | First responders users<br>Population users |
| Information receiver | Situation reports<br>Response plans<br>Decisions | IG | First responder |
| Hazard | GPS location<br>Hazard type<br>Images<br>Extra further information related to the hazard | First responders users | SP |
| Incident | GPS location<br>Incident type<br>Images<br>Extra further information related to the incident | First responders users | SP |
| First responders' location | GPS location<br>User unique identifier | First responders users | SP<br>GUI |
| Chat | User's unique identifier<br>Text content to be transmitted | First responders users | First responders users<br>GUI |

## 2.8 Data Sources

### 2.8.1 Space-Based Data

Several processing chains are used within HEIMDALL to provide crisis information related to floods, forest fires and landslide events based on Earth observation data. An overview about the respective inputs and outputs are listed in Table 2-16.

The use of optical data is the most relevant for landslide detection and are the most commonly used. Today, optical satellites have spatial, spectral and temporal resolutions providing similar results for landslide inventories than those of aerial sensors [19].

An automatic landslide extraction tool dedicated to Sentinel-2 data will be developed which is based on a pixel-based approach. The methodology is to observe disappearance of vegetation where a large landslide occurs. A change detection between pre- and post-event images highlights this vegetation disappearance. Also, slope parameters are taken into account to focus change detection onto landslide susceptible areas (e.g. >=20°). The methodology includes reproductibility of the process and is being tested over operational rapid mapping cases [20]. The tool SlidEx provides a thematic layer of the visible landslide extent over an affected area at a certain time. Using the Sentinel-2 constellation large landslides can be observed in less than a 5 day interval with an spatiall resolution of 10m. Moreover, the combination of Sentinel-1 and Sentinel-2 data improves the revisit frequency over an area. A combination of pre-event optical and post-event radar data can highlight landslides but are not precise. Very high resolution satellite data are preferred for the precise detection of landslides and especially small slides [19].

The main goal of DInSAR, the radar technique used to process Sentinel 1 data, is to detect and quantify ground deformations [21], [22]. The data acquired needs to be processed with different procederes. Preliminary processes remove noise sources like topographic, atmospheric and wrapping artefacts from the actual differential phase. If a set of points are isolated and available for the mapping deformations, further processing tools are used for data analysis and final products provision. The ability of DInSAR to fully describe a deformation strongly depends of the number of available images, and on the revisit time of these acquisitions [23], [24], [25], [25], [26]. For this reason, with its six days revisiting time, Sentinel1 costellation provides a great opportunity for landslides characterization.

Using Sentinel-1 interferometric products, a procedure has been developed to generate active deformation areas (ADA). ADAs are the inputs for assessing landslide vulnerability applying the so called vulnerable elements activity maps (VEAM) procedure [27]. The generation of landslide activity maps relies on the definition of hotspots of active landslide motions ADAs with a 6-days temporal repeatability. This unique characteristic is available from Sentinel-1 constellation. The ADAs will provide the spatial distribution and the magnitude of ground deformation over the area under monitoring, updating the state of activity of already known phenomena or mapping new potential slope movements. The ADAs can also update the state of an active landslide. Vulnerable elements activity maps will be derived starting from the interferometric products, specifically from the ADAs. The VEAM will consist in a simplified colour scale map indicating those structures and infrastructures with a greater probability to suffer for the impact of a geo-hazard and those structures and infrastructures affected by the dynamic of an active geo-hazard. This methodology is designed to be semi-automatically applied, in order to follow the 6-days repeatability of the Sentinel-1 constellation.

Table 2-16: Space-based Data products

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Flood extent | Sentinel-1 (GRD), TerraSAR-X, and VHR optical satellite data | Satellite EO systems | GUI, RVA, Simu |
| Burn scar | Sentinel-2 (GRD) satellite data | Satellite EO systems | GUI, RVA, Simu |
| Fire hot spots | MODIS satellite data | Satellite EO systems | GUI, RVA, Simu |
| Landslide extent | Sentinel-2 (GRD) satellite data | Satellite EO systems | GUI, RVA, Simu |
| Information about landslides | Sentinel-1 (SLC) satellite data | Satellite EO systems | GUI, RVA, Simu |

### 2.8.2 **Ground-Based Data**

During a crisis triggered by a landslide, excluding unexpected rock falls, rock avalanche or extremely rapid debris flows, there is sufficient time to organize the availability of the necessary data sources to provide HEIMDALL products. For this reason, with respect to the fire or flood events, the area threatened by the landslide can usually be defined, and the installation of sensors optimized, also in case of new landslides. An idea of the landslide movement is a fundamental input to optimize the ground observations, including the ground based (GB) SAR measurements. Using these inputs elements, all the products available by HEIMDALL, summarised in Table 2-17, allow optimizing the crisis management, organizing and following the evolution of the event.

The use of monitoring techniques has been widely described by researchers and practitioners as a useful tool to gather data regarding landslides. Not only to detect and characterize landslides but monitoring systems can also be used as warning systems. Many different monitoring and remote sensing techniques developed during the last decades: from remote sensing to geotechnical or geophysical techniques. The best application of these techniques depends on the type of landslide or terrain movement, specifically on to the size of the affected area, the velocity of the movement and the triggering factors.

The HEIMDALL module for ground-based sensors includes two different types of monitoring systems:

- GB-SAR (Ground Based Synthetic Aperture Radar)
- Geotechnical and hydrological sensors

These systems have been selected based on the typology of terrain movements studied within the context of the project as will be presented in deliverable D3.2. On one hand, GB-SAR is a monitoring technique optimal for slow terrain movements that have a stable area nearby the moving area, where the device can be installed [30], [31], [32], [31], [32].This technique can be used in two different modes: (I) continuous monitoring, if the investigated area is threatened by fast movements and an early warning is demanded, or in (II) discontinuous way to provide information over slow or potential landslides [35], [34], [35]. The availability of fast measuring systems able to acquire an image every few seconds [36], [37] improved the performance of GB SAR system in the recent years. This makes them a reliable instrument to provide a 24/7 monitoring system in different cases: landslides [38], [39], urban areas [40], [41] and infrastructures [42], without any restriction caused by weather conditions. The sensors can cover areas up to a few square kilometres; the main limitation is represented by the non-vectorial measuring capability of the technique which provides only the line of sight component of the movement/deformation, although a smart location can minimize this drawback. An exhaustive description about the use of this technique to monitor landslides can be found in the EU FP7 project SAFELAND deliverables [43].

Geotechnical and hydrological sensors are used to gather either direct or indirect measurements of the terrain stability conditions. Direct measurements can be obtained using sensors that measure movements or displacements at specific spots of the study area, where cracks or failure surfaces have been identified. Indirect measurements, on the contrary, control some terrain properties that may indicate variations of stability conditions of the soil (e.g.: groundwater pressure or total stress in soil). Monitoring systems formed by geotechnical and/or hydrological sensors are versatile, and can be designed based on the type of instability (type of landslide) and type of terrain [43] and the type of monitoring that is going to be performed (detection, long-term monitoring, etc.) [44].

Table 2-17: Ground-based data inputs and outputs

| Products and/or Services | Inputs needed | Provided by | Used by |
|---|---|---|---|
| Terrestrial radar data for landslide monitoring | Landslide area coordinates. | DataSitu, GUI | SA, DataSitu |
| | Idea of the direction of the expected deformation, from field observations or measurements | DataSitu, GUI | |
| Geotechnical/hydrological sensors data for landslide monitoring | Idea of the direction of the expected deformation, from field observations or measurements | DataSitu, GUI | SA, DataSitu |
| Geodesic or topographic surveys | Idea of the direction of the expected deformation, from field observations or measurements | DataSitu, GUI | SA, DataSitu |
| | Position of the benchmarks | DataSitu | Simu |
| Near real-time terrain movement information | Terrestrial radar data for landslide monitoring | DataSitu | Simu, SM, RVA, SA, GUI |
| | UAV data | DataSitu | |
| | Incidences reported by emergency services | GUI | |
| | Geotechnical/hydrological sensors data for landslide monitoring | DataSitu | |
| | Geodesic or topographic surveys | DataSitu | |

### 2.8.3 **Aerial Sensors**

Aerial sensors have increased its popularity in recent years. In particular, most used aerial platforms for civil applications are the so-called micro aerial vehicles (MAVs). In the scientific and industrial communities, the use of a single MAV has been widely studied and exploited. In contrast, the simultaneous use of multiple MAVs, instead of one, offers clear advantages: efficiency to gather information, and in terms of robustness to robot failures. However, the use of multiple MAVs introduces additional challenges as the system's complexity increases. In HEIMDALL, we plan to develop novel algorithms to cope with such challenges, which will allow us to monitor a hazard with multiple MAVs that fly simultaneously. The task is to allow an operator to monitor a hazard. In particular, we consider hotspots that may remain after a fire in a local area. To monitor local areas, multirotor MAVs have been proven to be the most effective type of aerial sensors. Multirotor MAVs have two main advantages respect to fixed wing MAVS. First, they can hover, which is a fundamental characteristic in case an operator intends to monitor a specific location continuously from the same perspective. Second, they have better manageability than their fixed wing counterparts.

Our goal in HEIMDALL is to develop algorithms that allow multirotor MAVs to identify potential hotspots. Hotspots may have different shapes and sizes. To guarantee that even small hotspots can be identified we plan to use state-of-the-art thermal sensors. Such sensors typically have a weight of a few hundred grams. As thermal sensors need to be carried by MAVs, we decided to use a platform that admits a high weight payload. Note that in addition to the thermal sensor, another sensors and computers should be carried by the drone. In particular, we plan to use MAVs that are based on DJI S900 frame.

The monitoring process is implemented by a module that offers the products described in Table 2-18, for which we specify the inputs to the modules, the inputs provider, and the user of the module.

Table 2-18: Aerial sensors services inputs and outputs

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Geo-referenced alert signal | Area of interest to be monitored<br>Drone's flying height<br>Confirmation to start/finalize a mission | Operator | GUI |
| Pictures | Area of interest to be monitored<br>Drone's flying height<br>Confirmation to start/finalize a mission | Operator | GUI |
| Thermal pictures | Area of interest to be monitored<br>Drone's flying height<br>Confirmation to start/finalize a mission | Operator | GUI |
| On-demand video stream | Area of interest to be monitored<br>Drone's flying height<br>Confirmation to start/finalize a mission | Operator | GUI |

## *2.9 External Systems*

Apart from the data provided by the HEIMDALL modules, it is foreseen that the HEIMDALL workflows will also involve externally available information by third party providers, such as e.g. weather data. For this purpose, the SP will implement service-specific interfaces as plugins that will retrieve the information from the external service provider using the service provider's API, adapt it and feed it to the SP via the already provided open interfaces. It is also foreseen that HEIMDALL-generated information will need to be communicated to external services. Table 2-19 presents the candidate external services. More information about the APIs and how they are used within HEIMDALL will be provided in D5.9 “Interfaces for External and Existing Systems – Specifications – Draft”, released on M22 of the project.

Table 2-19: External systems inputs and outputs

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Service-specific interfaces as plug-ins | Service API | External services | SP |
| Enterprise Service bus | ESB hosts the various services and interface proxies to external systems. It enables the use of HTTP/REST, FTP and other protocols for accessing the external interface services and products. | SP | All other HEIMDALL services |
| Copernicus EO services | Information for emergency response in relation to different types of disasters | Copernicus emergency management service | SP<br>SM<br>Simu<br>SA<br>DS |
| | Seasonal forecasts and climate predictions by holding records on temperatures, rainfall and drought, sea levels and ice sheets. | Copernicus climate change service | |
| | Enhanced atmospheric environmental information available as analyses, re-analysis and forecasts | Copernicus atmosphere monitoring service | |
| | Geographical information on land cover/land use. | Copernicus land monitoring service | |
| | Near real-time products, multi-year products, in-situ observations and forecasts. | Copernicus marine and environment monitoring service | |
| GDACS information | Real-time access to web-based disaster information systems and related coordination tools. | GDACS | SP<br>SM |
| Meteorological and hydrological | Weather and hydrological parameters (wind, wind | External services | SP<br>Simu |

| | | | |
|---|---|---|---|
| information | direction, temperature, relative humidity, precipitation, etc.)<br>Forecast over 3, 6, 9, 12, 24, 36, 48h | | |
| Cartographic data | Various layers including, geography, bathymetry, administrative, transportation networks (i.e., highways, roads, railways, etc.), and other grids. | External services | SP<br>Simu |
| Census data | Population density of the areas of interest. | External services | SP<br>SA<br>DS |
| Critical infrastructure information | Assets that are essential for the functioning of a society and economy.<br>This is linked to the GOIs | External services | SP<br>Simu<br>SA<br>DS |
| Asset location | The location of the assets (vehicles and first responders) on the map. | External services | SP<br>SA<br>DS |
| Information received from drones | Data captured from the drones | External services | SP<br>Simu<br>SA<br>DS |
| Crowdsourcing information from FRs | Information received through the smartphone application | Smartphone application | SP<br>SM<br>SA<br>DS |
| Information received from social media and other services | Information received from social media<br>Information received from 112 services | External services | SP<br>SM |

The service specific interfaces can be found in the deliverables of each service, e.g., the service management technical specification D6.14 [3], whereas details about the ESB of the SP will be part of D4.1 “Service Platform Design and Specification – Draft” (on M18) and D4.2 “Service Platform Design and Specification – Final” (on M38).

Regarding the census data, a candidate external service is the one provided by Institute d’Estadistica de Catalunya (Idescat) through its API. Its online documentation is available through an API where the user would be able to search and retrieve information for counties and municipalities covered by that authority regarding:

- Population

- Homes and households
- Main aggregates and taxes
- Economic sectors
- Employment
- Culture and sport
- Elections
- Environment

The information relevant to HEIMDALL is about the population and the number of homes and households. The rest of the information such as about the economic sectors can be used by other modules (e.g., impact assessment) as additional auxiliary input to provide updated metrics.

Regarding the asset location, an additional source of data, apart from the information received thought the HEIMDALL mobile application, is through the coordination centre of participating first responder entities. For example, in the case of Catalan Fire and Rescue Service this could be achieved through the SIGB and DPX applications, i.e., interfacing with the Oracle databases that support these applications.

## *2.10 Graphical User Interface*

The graphical user interface (GUI) is the main visual tool for end users to interact with the HEIMDALL system. End users will have access to the GUI via a standard internet browser, like, Chrome. The GUI will provide access to most of the data information and services by communicating to the different modules through the Service Platform. For example, the GUI will be able to indicate to the user about the mode – preparedness or response- they are working on, based on the information available from Scenario Management module. Table 2-20 describes the inputs and outputs needed to provide the GUI services.

Table 2-20: GUI products

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Provide information to the GUI | Login credentials<br>Roles and users definition<br>Graphical data and metadata information<br>Simulation results | SP | End users |
| Provisioning of products and services to users | Administrators functionalities<br>Monitoring of mobile assets<br>Ability to run simulations<br>Incident and scenario management<br>Risk assessment<br>Response plans<br>Decision support | SP | End users |

| | | | |
|---|---|---|---|
| | capabilities | | |

The services presented in Table 2-20 are high level from service point of view. From the architecture point of view it is useful to further detail the two products. Hence, the products and services provided by the GUI to the end user have been detailed in Table 2-21, detailing the services and products that are provided by the GUI to the end-user.

Table 2-21: GUI detailed products

| **Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Login | Username and password | End users | SP |
| Roles/Users | Roles instances definition<br>Users instances creation | SP<br>Administrator | Administrator<br>End users |
| System administrators features | Roles information and accessibility<br>Users information and role | Administrator | SP |
| Data display | Earth observation products<br>Aerial based data<br>Landslide monitors<br>Crowdsourced and first responders data<br>External systems | SP | End users |
| Monitoring | Mobile assets location | SP | End users |
| Simulations | Simulation results<br>Simulation triggering capabilities | SP | End users |
| Incident management | Incident information<br>Incident timeline of events | SP | End users |
| Scenario management | Scenario information<br>Scenario snapshot generation and selection capabilities<br>Information-to-scenario association capabilities<br>Scenario matching capabilities | SP | End users |
| Risk assessment | Forecasted risk assessment information | SP | End users |
| Impact summary | Impact summary display and modification | | |

| | | | |
|---|---|---|---|
| | capabilities<br>Situation report generation capabilities | | |
| Response plans | Response plans for a scenario<br>Lessons learnt from previous scenarios<br>Decisions taken during an scenario<br>Measures taken during a scenario | SP | End users |
| Decision support | Decision support information generated by the system | SP | End users |
| Notifications | Arrival of new incidents<br>Decision support suggestions<br>Simulation results available | SP | End users |
| Catalogue for data sharing | Granted access<br>Shared information | SP | End users |
| Alert creation | Alert information | End users | IG |
| FR information service | SitRep<br>Scenario | SP | IG |

# 3 HEIMDALL Connected

HEIMDALL connected refers to the federated architecture and is part of the architecture that enables the interconnection of multiple local units (LU) for efficient data exchange to facilitate the cooperation among end-users based on content oriented concepts. Natural and man-made hazards are highly complex situations requiring effective cooperation and communication of all stakeholders, from C&Cs assessing the risk for the population and infrastructure and preparing and coordinating the response, civil protection units and medical services save lives, police and fire fighting units regulating and responding to the hazard. Here, the end-users need at any point in time information and control about who can access which data. With the federated architecture based on content-oriented design this is achieved and at the same time ensures security. A data and service catalogue helps with the information discovery and the connection to other authorities. The system takes care to tailor the data so that every user can access it in his/her preferred or mandatory format. As mentioned, HEIMDALL makes use of common data formats, mostly based on open standards for this. Figure 3-1 shows an example with two connected LUs, for user A and user B. The setup can be extended for other users however, main module for the interconnection is the catalogue.

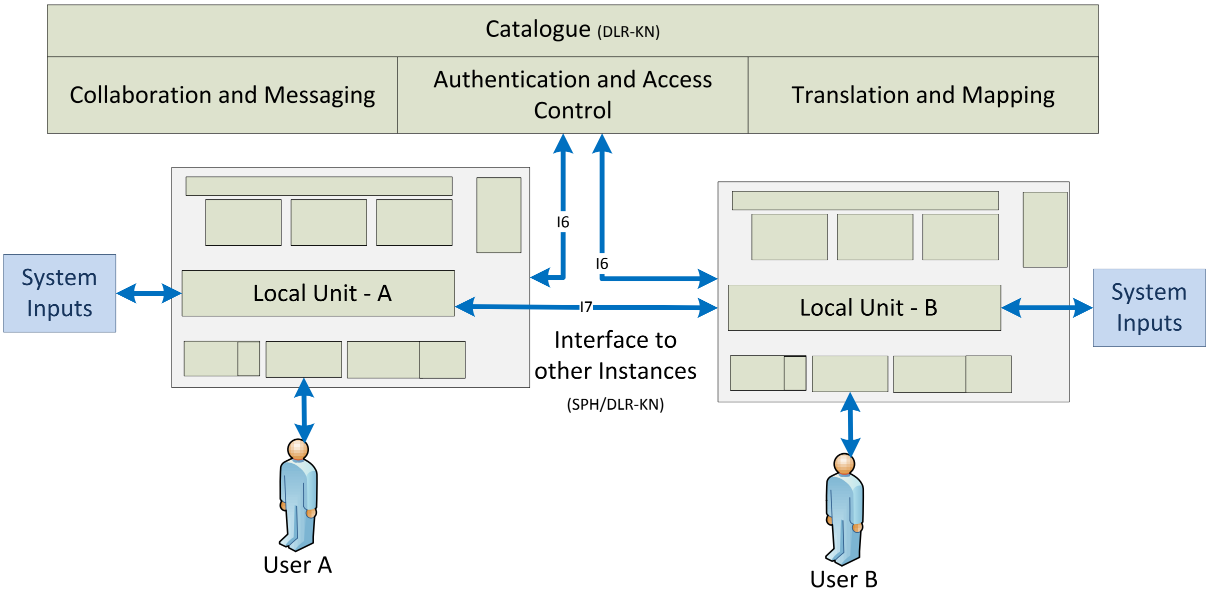


Figure 3-1: Federated architecture example

This approach provides flexibility at different levels: on one hand, different services can be available in each local unit and made accessible to users accessing other local units by means of publishing them in the catalogue. On the other hand, additional external services can be easily added to the overall architecture by publishing the corresponding services or information in the catalogue and establishing the corresponding connection, without additional integration efforts.

## *3.1 Catalogue*

The catalogue is the core unit for the interconnection of multiple LUs. It will provide several services that enable efficient communication among the end users which are:

- As basis for the interconnection the catalogue manages the addresses of the LU and provides them for P2P connection if the permission has been given.
- By the use of standards for cross-national interoperability and information exchange HEIMDALL will provide a mapping and translation of standardized formats.

- End users can publish their data to other users using the system. They grant access of specific data sets or all data. HEIMDALL offers an information discover service for this published data.
- A collaboration and messaging platform is provided for rapid sharing and exchange of text messages as well as multimedia content among end users.

Table 3-1: Catalogue inputs/outputs

| **Products and/or Services** | **Inputs needed** | **Provided by** | **Used by** |
|---|---|---|---|
| Connection to other LU | Connection Parameters | Interfaces to LU | Interface to LU |
| Information Discovery | Shared Content and metadata | GUI<br>LU | GUI<br>LU |
| Translation and mapping service | Shared Content and metadata | GUI<br>LU | GUI<br>LU |
| Collaboration and messaging | Data input by the user | GUI | GUI |

## *3.2 Interfaces to other Local Units*

The SP shall be able to communicate with other Local Units by making full usage of the HEIMDALL interoperability features.

Through the HEIMDALL Data and Service Catalogue, part or whole of the SP services and products shall be available to other Local Units within the same region, country as well as in cross-border events. Data exchange is mainly performed over HTTP directly to the Catalogue. Geospatial data can be published/retrieved via the OGC-compliant services (WFS, WCS) and can be retrieved fully rasterised via the WMS service. In addition, a REST-based interface will be available.

Furthermore, the SP shall be able to communicate with the population at risk making use of the Information Gateway, from where alarms and messages are going to reach the public. In a similar fashion, the Information Gateway shall also be used to disseminate relevant information to the first responders on the field.

# 4 Conclusion

This deliverable presented the HEIMDALL system architecture including the identified system elements and the corresponding interfaces. It showed the local unit that can be used by a single authority for response planning and scenario building during all phases of the disaster management cycle. The local units can be connected in a federated architecture in order to foster the collaboration of end users of different disciplines and countries. The presented architecture is the enabler to provide the HEIMDALL service and products defined in D2.11 [1].

# 5 References


[1] Barth et al., HEIMDALL D2.11: "Service Concept Specification", March 2018

[2] Barth et al., HEIMDALL D2.6: "HEIMDALL Requirements Report – Issue 1", September 2017

[3] Friedemann et al., HEIMDALL D6.14: "Scenario Specification, Scenario Management Specification and Scenario and Situation Metrics - Draft", April 2018

[4] J. Ramírez et al., "Wildfire Analyst: practical approach to operational wildfire simulation", *5th Wildfire Conference*, Sun City, South Africa, 2011.

[5] R. Rothermel, "A mathematical model for predicting fire spread in wildland fuels". USDA Forest Service, Intermountain Forest and Range Experiment Station Research Paper INT-115. (Ogden, UT). 1972.

[6] F. Albini, "Estimating wildfire behavior and effects". Intermountain Forest and Range Experiment Station General Technical Report INT-GTR-30. (Ogden, UT). 1976.

[7] J. Scott, R. Burgan, "Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model", 2005.

[8] M. Finney, "FARSITE: Fire Area Simulator – Model Development and Evaluation", 2004.

[9] H. Anderson, "Predicting wind-driven wildland fire size and shape". USDA For. Serv. Res. Paper, INT-305, 1983.

[10] Brabb, E. E., 1984 "Innovative Approaches to Landslide Hazard Mapping," in Proc. 4th International Symposium Landslides, Toronto, 307–24.

[11] Cascini, Leonardo. "Applicability of Landslide Susceptibility and Hazard Zoning at Different Scales." *Engineering Geology* 102, no. 3–4 (December 2008): 164–77. https://doi.org/10.1016/j.enggeo.2008.03.016.

[12] Fell, Robin, Jordi Corominas, Christophe Bonnard, Leonardo Cascini, Eric Leroi, and William Z. Savage. "Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for Land-Use Planning." *Engineering Geology* 102, no. 3–4 (December 2008): 99–111. https://doi.org/10.1016/j.enggeo.2008.03.014.

[13] Pastor, M., Picarelli, L., 2010. Safeland D1.9. Recommendations for run out models for use in landslide hazard and risk mapping (Deliverable No. 1.9). FUNAB & AMRA.

[14] Reichenbach, Paola, Mauro Rossi, Bruce D. Malamud, Monika Mihir, and Fausto Guzzetti. "A Review of Statistically-Based Landslide Susceptibility Models." *Earth-Science Reviews* 180 (May 2018): 60–91. https://doi.org/10.1016/j.earscirev.2018.03.001.

[15] U.S. Geological Survey. "Scoops3D- Software to Analyze Three-Dimensional Slope Stability Throughouth a Digital Landscape." In *Landslide and Debris-Flow Assessment*, 326. Virginia: USGS, 2015.

[16] Abancó, Clàudia, Marcel Hürlimann, José Moya, and Marc Berenguer. "Critical Rainfall Conditions for the Initiation of Torrential Flows. Results from the Rebaixader Catchment (Central Pyrenees)." *Journal of Hydrology* 541 (October 2016): 218–29. https://doi.org/10.1016/j.jhydrol.2016.01.019.

[17] Fiorucci, F., Cardinali, M., Carlà, R., Rossi, M., Mondini, A.C., Santurri, L., Ardizzone, F., Guzetti, F., 2011: Seasonal landslide mapping and estimation of landslide mobilization rates using aerial and satellite images. Geomorphology, 129, 59-70.

[18] OASIS Standard, Common Alerting Protocol Version 1.2, 01 July 2010, available at: http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.html [last accessed: 03/04/18]

[19] Plank, S., Twele, A., and Martinis, S.: Landslide Mapping in Vegetated Areas Using Change Detection Based on Optical and Polarimetric SAR Data. Remote Sens. 2016, 8, 3

[20] https://disasterscharter.org/image/journal/article.jpg?img_id=916318&t=1531466391441 [last accessed: 07/09/18]

[21] Guzzetti, F., S. Peruccacci, M. Rossi, and C. P. Stark. “Rainfall Thresholds for the Initiation of Landslides in Central and Southern Europe.” *Meteorology and Atmospheric Physics* 98, no. 3–4 (December 2007): 239–67. https://doi.org/10.1007/s00703-007-0262-7.

[22] Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N. & Crippa, B. Persistent scatterer interferometry: a review. ISPRS Journal of Photogrammetry and Remote Sensing. 115, 78–89 (2016).

[23] C. Delacourt, P. Allemand, E. Berthier, D. Raucoules, B.Casson, P. Grandjean, C. Pambrun, E. Varel, Remote-sensing techniques for analysing landslide kinematics: a review, Bulletin de la Société Géologique de France (2007) 178 (2): 89100. https://doi.org/10.2113/gssgfbull.178.2.89

[24] Colesanti, C., Ferretti, A., Prati, C. & Rocca, F. Monitoring landslides and tectonic motions with the Permanent Scatterers Technique. Engineering Geology. 68(1), 3–14 (2003).

[25] Ferretti, A., Prati, C. & Rocca, F. Permanent scatterers in SAR interferometry. Ieee Transactions on Geoscience and Remote Sensing. 39(1), 8–20 (2001).

[26] Ferretti, A. et al. A new algorithm for processing interferometric data-stacks: SqueeSAR. IEEE Transactions on Geoscience and Remote Sensing. 49(9), 3460–3470 (2011)

[27] Description of the procedure to generate the ADA and VEAM , Deliverable D2.4: Geohaz 783169U project http://www.icgc.cat/en/Innovation/R-D-i-projects/U-Geohaz

[28] Michoud, Clément, Antonio Abellán, Marc-Henri Derron, and V. Jaboyedoff. “Safeland D4.1. Review of Techniques for Landslide Detection, Fast Characterization, Rapid Mapping and Long-Term Monitoring.” Deliverable. Unil, 2012.

[29] Tarchi, D., Casagli, N., Fanti, R., Leva, D., Luzi, G., Pasuto, A., Pieraccini, M., Silvano, S., 2003. Landslide monitoring by using ground-based SAR interferometry: an example of application. Engineering Geology 68 (1–2), 15–30.

[30] Tarchi, D., Antonello, G., Casagli, N., Farina, P., Fortuny-Guasch, J., Guerri, L., Leva, D., 2005. On the Use of Ground-Based SAR Interferometry for Slope Failure Early Warning: the Cortenova Rock Slide (Italy). Landslides: Risk Analysis and Sustainable Disaster Management, Proc. of the 1st General Assembly of the Int. Consortium on Landslides, Sassa, K., Fukuoka, H., Wang, F., Wang, G. (Eds.), Springer-Verlag, Berlin, Heidelberg.

[31] Luzi G., “Ground-based SAR Interferometry: a novel tool for Geoscience”, pp. 01-026, in Geoscience and Remote Sensing, New Achievements, P. Imperatore & D. Riccio editors, In-the Vukopvar, Croatia, February 2010 (book chapter).

[32] Caduff, R., Schlunegger, F., Kos, A., Wiesmann, A., 2015. A review of terrestrial radar interferometry for measuring surface change in the geosciences. Earth Surf. Process. Land. 40, 208–228. DOI: 10.1002/esp.3656

[33] Monserrat, O., M. Crosetto, and G. Luzi. 2014. “A Review of Ground-Based SAR Interferometry for Deformation Measurement.” ISPRS Journal of Photogrammetry and Remote Sensing 93: 40–48.

[34] Barla G., Antolini F., Barla M., Mensi E., Piovano G., 2010. Monitoring of the Beauregard landslide (Aosta Valley, Italy) using advanced and conventional techniques. Eng. Geol., 116, 218-235 (2010).

[35] Casagli N, Catani F., Del Ventisette C., Luzi G.; “Monitoring, prediction, and early warning using ground-based radar interferometry”, Landslides(2010) 7: pp. 291–301 DOI 10.1007/s10346-010-0215-y Springer-Verlag 2010. landslides

[36] Corsini, A., Berti, M., Monni, A., Pizziolo, M., Bonacini, F., Cervi, F., Truffelli, G., 2013. Rapid Assessment of Landslide Activity in Emilia Romagna Using GB-InSAR Short Surveys. In Landslide Science and Practice (pp. 391-399). Springer Berlin Heidelberg.

[37] Meta A., Trampuz C., 2010. MetaSensing compact, high resolution interferometric SAR sensor for commercial and scientific applications. Proceedings of the 7th Radar Conference, EURAD2009. Rome (I), pp. 21–24.

[38] Werner, C., Strozzi, T., Wiesmann, A., Wegmuller, U., 2008. A Real-Aperture Radar for Ground-Based Differential Interferometry. Proc. of Int. Geoscience and Remote Sensing Symposium, IGARSS 2008, 7-11 July 2008, Boston (USA), Vol.3, pp. 210-213.

[39] Leva, D., Nico, G., Tarchi, D., Fortuny, J., Sieber, A.J., 2003. Temporal analysis of a landslide by means of a ground-based SAR interferometer. IEEE TGRS 41, 745–752.

[40] Herrera, G., Fernandez-Merodo, J.A., Mulas, J., Pastor, M., Luzi G., Monserrat, O., 2009. A landslide forecasting model using grou2nd based SAR data: the Portalet case study. Engineering Geology 105 (3-4), 220-230.

[41] Tapete, D., Casagli, N., Luzi, G., Fanti, R., Gigli, G., Leva, D., 2013. “Integrating radar and laser-based remote sensing techniques for monitoring structural deformation of archaeological monuments”, Journal of Archaeological Science, Volume 40, Issue 1, January 2013, Pages 176-189, ISSN 0305-4403, http://dx.doi.org/10.1016/j.jas.2012.07.024.

[42] Takahashi, K.; Matsumoto, M.; Sato, M., "Continuous Observation of Natural-Disaster-Affected Areas Using Ground-Based SAR Interferometry," Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of , vol.6, no.3, pp.1286,1294, June 2013

[43] Del Ventisette, C., Intrieri, E., Luzi, G., Casagli, N., Fanti, R., Leva, D., 2011. Using ground based radar interferometry during emergency: the case of the A3 motorway (Calabria Region, Italy) threatened by a landslide”, Nat. Hazards Earth Syst. Sci. 11, 2483–2495.

[44] SAFELAND Project https://blogs.agu.org/landslideblog/2016/12/27/safeland-project-reports-2/

[45] John Dunnicliff. *Geotechnical Instrumentation for Monitoring Field Performance*, 1993.

[46] Stumpf, A., Kerle, N., and Malet, J-P. “Safeland D4.4: Guidelines for the Selection of Appropriate Remote Sensing Technologies for Monitoring Different Types of Landslides.” Deliverable. Safeland, 2011