

JRC TECHNICAL REPORTS

GRRASP version 3.1 User Manual

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Dock

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OpenStreetMaps

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+	imported_network_1473779565	<input type="checkbox"/>	<input type="checkbox"/>
grrasp_dmci			
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	network_links1473840176		
+	eu	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	network_nodes1473840184		

4

Submit



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Abstract

This report is a comprehensive manual for GRRASP including also a detailed description of the installation procedure. The user manual describes the main functionalities of GRRASP as well as how the end user can apply the models included in GRRASP. This software platform is evolving so this manual is a living document which will be updated on the basis of new functionalities.

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Abstract

Critical Infrastructure Protection (CIP) is getting increased attention as a result of the number of man-made threats (terrorism, malicious attacks, cyber events) and natural disasters. In addition to that, critical infrastructure systems are becoming more and more interconnected with the introduction of ICT technologies and thus isolated events may lead to large-scale or even continent wide disruptions. Interdependencies between critical systems are a key factor that needs to be considered in the framework of their analysis and simulation with the objective to improve their resilience.

This is not simply an EU approach but also in the US, the National Infrastructure Simulation and Analysis Centre (NISAC) has developed a number of tools for the analysis of critical infrastructure systems, supply chains, etc. which obviously are tailored to the US reality. In Europe, most tools are developed responding to national efforts and focus on the specific issues that need to be addressed at national scale. Obviously this approach shows its limitations in case large-scale infrastructures that expand across borders and jurisdictions need to be assessed.

Data sharing concerns are a major issue in the field of critical infrastructures analysis and this is a factor that somehow hinders the development of shared tools and methodologies for the analysis and simulation. Collaboration among CI stakeholders is indeed an open issue in the framework of CI analysis and simulation. In order to foster collaborative analysis, it is important to make sure that all stakeholders agree on a common terminology and to provide tools that enable collaboration while ensuring data security and privacy through the whole analysis cycle.

Critical infrastructure owners and operators have agreed on several occasions the importance of developing tools and methodologies for modelling and simulation. It is true that in the recent years, several tools have been developed and these can be used for the assessment of a wide number of disruptive scenarios. It seems though that most of such tools lack the features to be used at a European scale and therefore fail to become a standard. In principle, they represent ad-hoc efforts tailored to the needs of a particular region/state/sector. Consequently, often they lack the capability to scale up to international level.

In response to the above-mentioned issues, JRC developed the Geospatial Risk and Resilience Assessment Platform (GRRASP). GRRASP is a World Wide Web oriented architecture bringing together geospatial technologies and computational tools for the analysis and simulation of critical infrastructures. It allows information sharing and constitutes a basis for future developments in the direction of collaborative analysis and federated simulation. It takes on board security concerns in the information sharing process, thanks to its ability to manage users and roles consistently. Based entirely on open source technologies, the system can also be deployed in separate servers and used by EU Member States as a means to facilitate the analysis of risk and resilience in critical infrastructures.

The current version of the GRRASP architecture represents an important improvement over the previous versions. The technical infrastructure of the project has benefited from the integration with the Drupal Content Management Systems (CMS), which streamlines the development and update process of the platform and allows the integration with a number of third-part modules, fostering interoperability and bringing collaboration capabilities to a new level. Thanks to these features, the platform seems to properly meet the objective to provide an analysis

framework that can be used by member states competent authorities and operators in order to improve risk and resilience assessment at local, regional, national and international scale. In addition, it can represent a tool to support the development and testing process of new models, as well as CIP-related training activities.

CHAPTER 1

Installation and setup

This section describes step-by-step the installation procedure for all third party software solutions that have been used in order to develop GRRASP. We consider that the installation can take place by an expert user or a system administrator. Figure 1.1 shows a schematic overview of the technologies that have been used in order to develop GRRASP and enable it with the features briefly mentioned above.

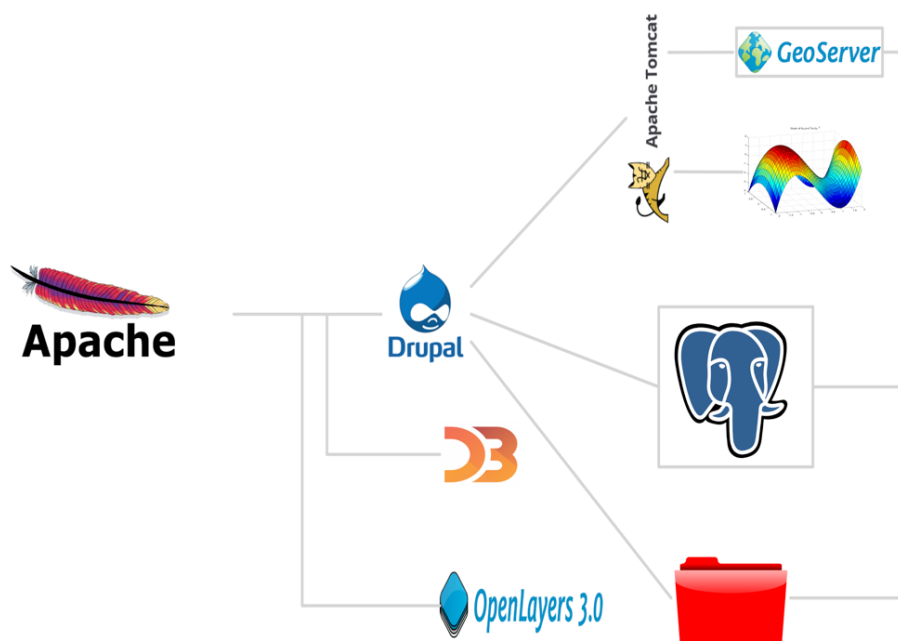


Figure 1.1: GRRASP architecture and technologies

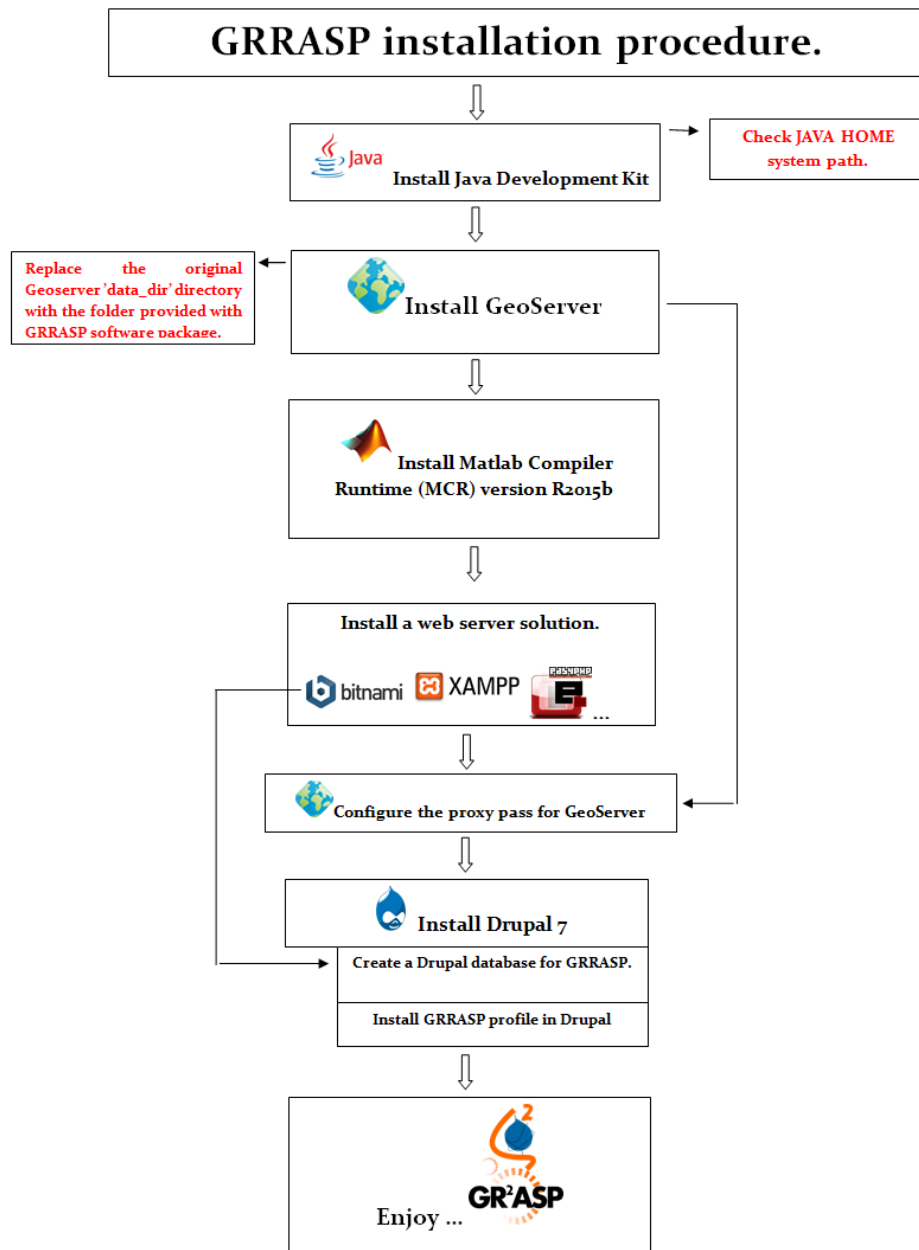


Figure 1.2: Overview of GRRASP installation procedure

Since GRRASP is a web-based tool, it is important to mention that the installation process leads to the establishment of a GRRASP server to which the remote users can connect through web. The remote users do not need to install any software tools. Connecting to the GRRASP server through an up-to-date web browser such as Internet Explorer, Firefox, Safari, Google Chrome, etc. is enough for using GRRASP. In order to establish the GRRASP server, a system administrator needs to follow the following steps:

1. **JDK Installation or updated Java Runtime Environment:** This is the first step for the installation of GRRASP. The end user or system administrator needs to verify if Java Development Kit (JDK) is already installed. If not it is necessary to download and install the latest version. This can be found in this [link](#). Download the software and run it following step by step the installation procedure. The windows sequence for the Java Development Kit installation procedure is shown in Figure 1.3.

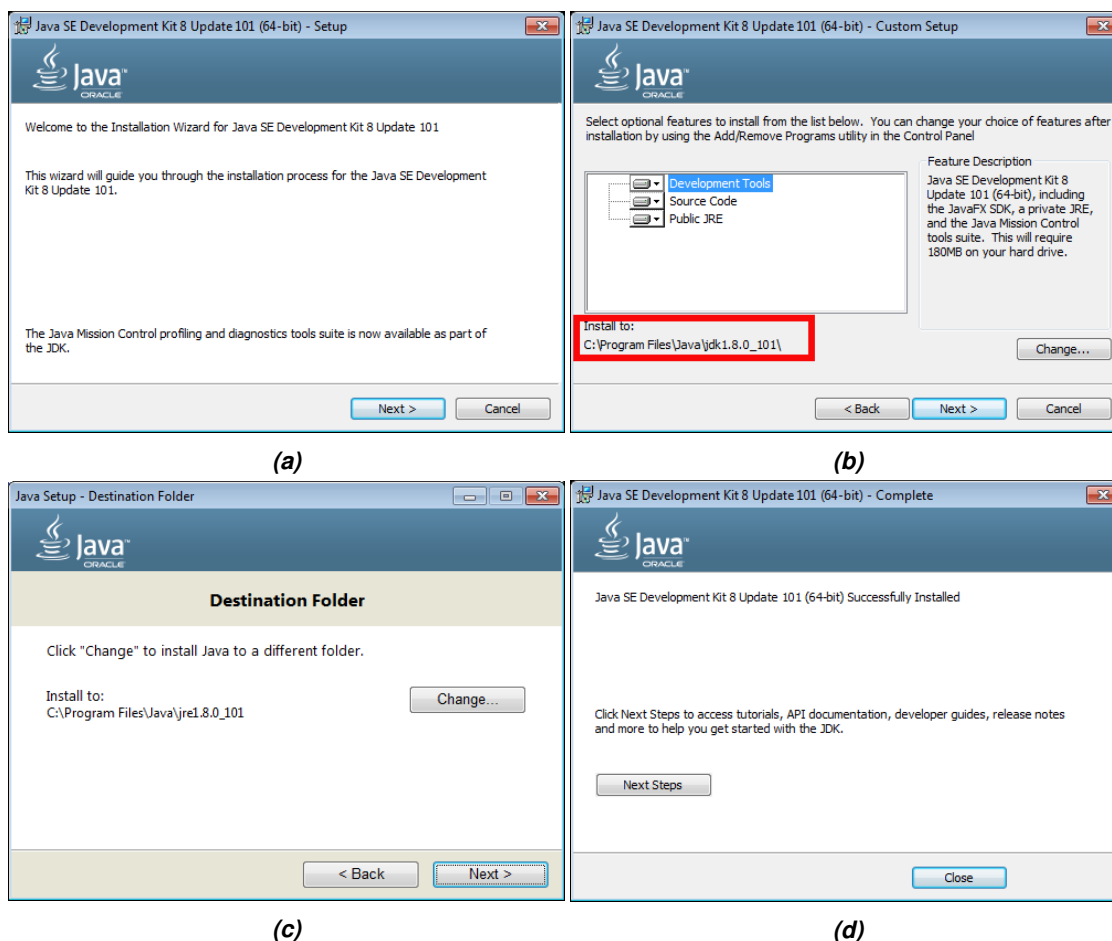


Figure 1.3: JDK installation process

2. **Verification of JAVA_HOME variable:** After the installation of JDK check if the JAVA_HOME variable (see red box in Figure 1.4d) is the same as the folder set in red box in Figure 1.3b. To check this in Windows operation system go to (follow the blue square indications) "Control Panel" > "System" > "Advanced system settings"> "System properties advanced tab"> "Environment Variables" JAVA_HOME = java-installation-root\jdk-XX. If they don't match please contact your system administrator (in case it is the installation process takes place by a non system administrator).

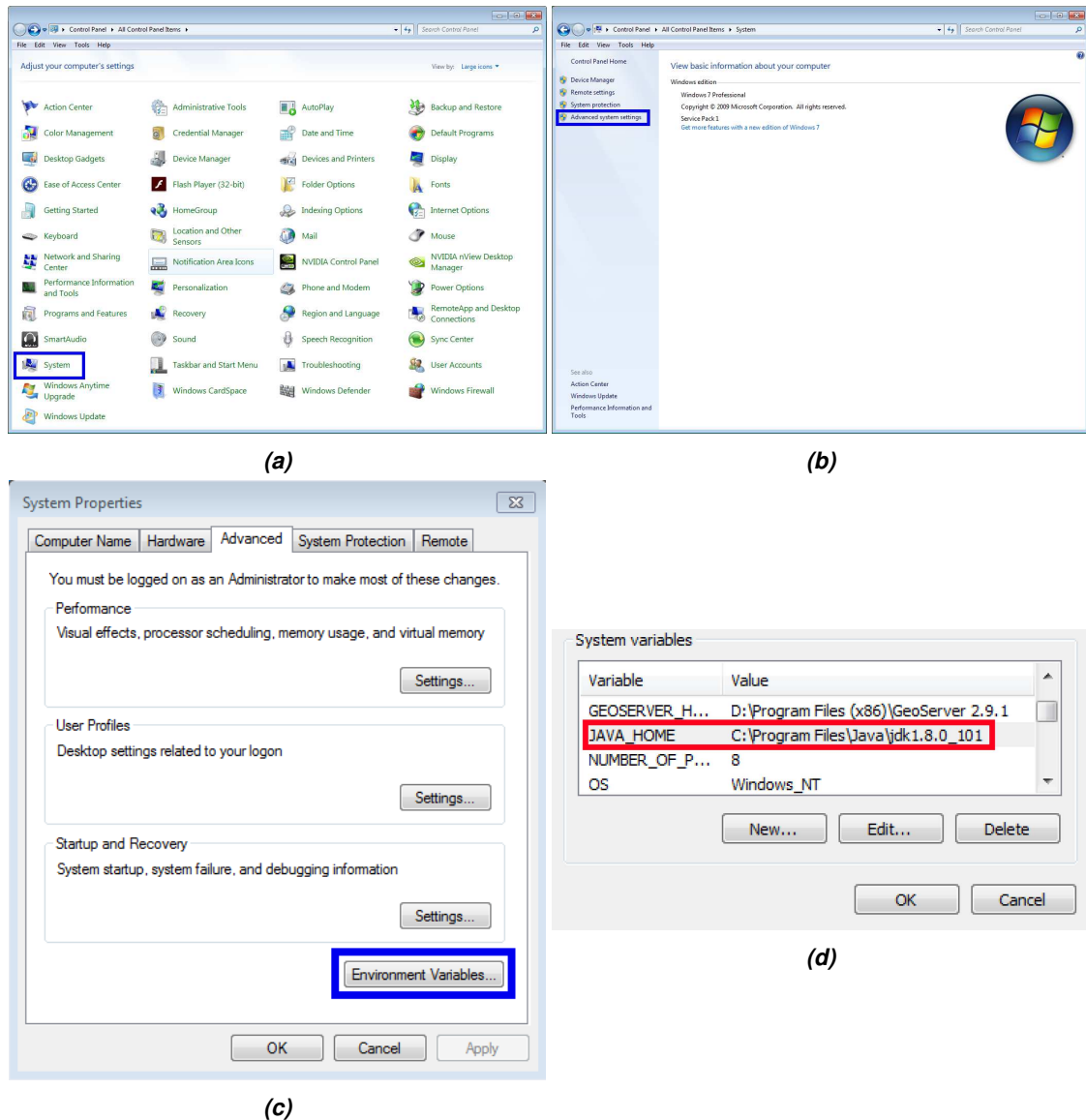


Figure 1.4: Windows operating system properties and variables

- GeoServer Installation:** Install the latest version of GeoServer (currently the latest version is GeoServer 2.9, but backwards compatibility is reassured): download it using this [link](#) and follow the steps listed below.¹

- **Choose installation location:** Set the directory for Geoserver (Figure 1.5a).

¹ GEOSERVER module is a server of maps (WMS,WFS,WPS). GeoServer is an open-source server written in Java that allows users to share, process and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. GeoServer functions as the reference implementation of the Open Geospatial Consortium Web Feature Service standard, and also implements the Web Map Service, Web Coverage Service and Web Processing Service specifications. Latest version is 2.9 as of 10/10/2016

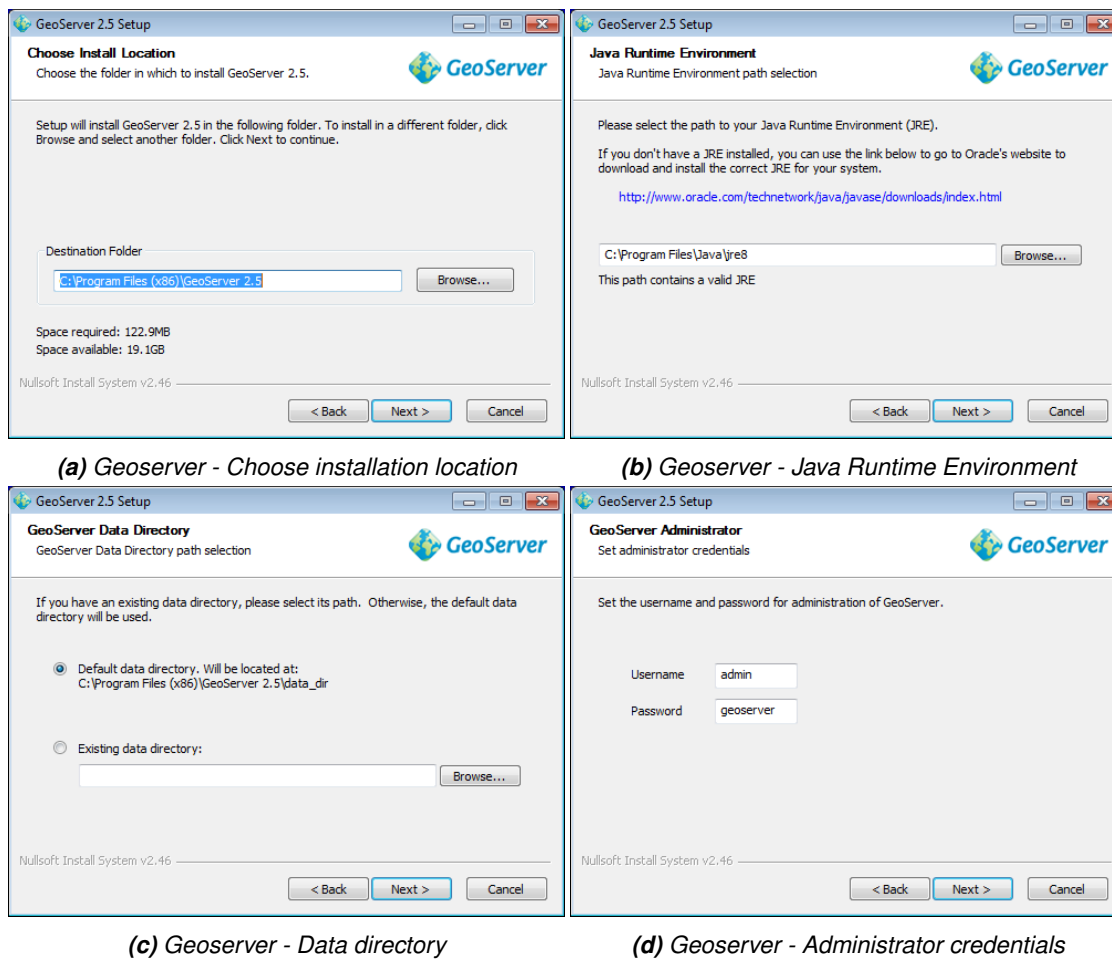


Figure 1.5: Geoserver installation process

- **Java Runtime Enviroment:** Java needs the correct path, it is usually recognized by the installation software (Figure 1.5b). It is advisable that the administrator uses the path proposed by the installation procedure.
- **GeoServer Data Directory:** "data_dir". The GeoServer data directory (data_dir) is the location in the file system where GeoServer stores its configuration information. The configuration defines what data are provided by GeoServer, where these are stored, and how services interact with and provide the data. The data directory also contains a number of support files used by GeoServer for various purposes. The user can create a default new "data_dir" or link the current Geoserver installation to an existing "data_dir" (Figure 1.5c). It is advisable to use the default data directory.
- **GeoServer Administrator:** Sets Users and Password for the Geoserver administrator ² (Figure 1.5d).
- **GeoServer Web Server Port.** Port must be the default 8080 (Figure 1.6a).

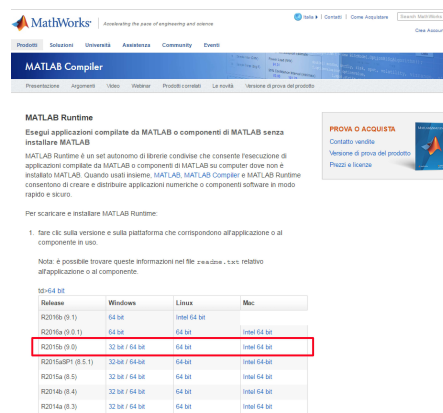
²The defaults would be the best choice, nevertheless if you want to change the default value for username and password you must remember to update them in ...drupal\htdocs\profiles\grrasp.profile\files\conf\geoserver.conf.php.



(a) Geoserver - Web server port

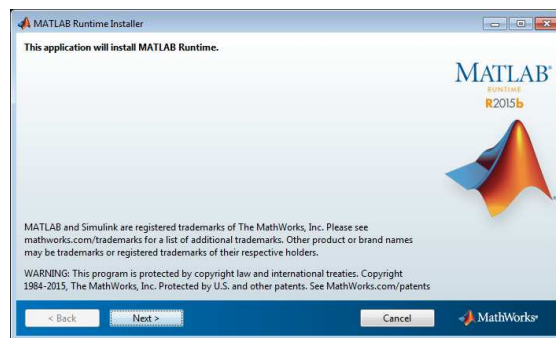


(b) Geoserver - Type of installation

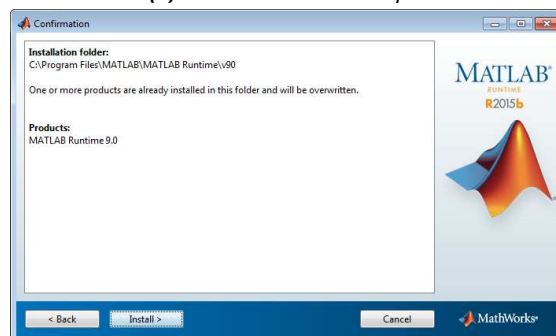
Figure 1.6: GEOSERVER configuration**Figure 1.7: Matlab MCR download page**

- **Type of Installation.** The administrator may opt for two different types of installation as shown in Figure 1.6b.
- **data_dir replacement:** After the GeoServer installation, it is mandatory to replace the “data_dir” directory set above, with the folder provided with the GRRASP software package. The “data_dir” included in GRRASP package contains data and examples of simple networks that can be used to test the models. Please note that these datasets and networks do not correspond to real networks. Please also note that if a GeoServer installation already exists, deleting this folder means that all information related to this existing GeoServer installation will be lost.
- **MCR Installation:** Install the Matlab Compiler Runtime (MCR) R2015b (9.0) 64 bit version (version released on September 2015). This is required to enable the execution of the embedded mathematical models (e.g. metrics, DMCI, CYNOPSIS, etc.). The MCR files can be found in this [link](#) (the red box in Figure 1.7 shows the correct version to download). Run the downloaded MCR package³ and follow the steps of the wizard as shown in Figure 1.8.

³Matlab is not the only software that can be used to write model in GRRASP, you can use also, for example Octave, Scilab,...or other scientific programming languages.



(a) MCR installation step 1

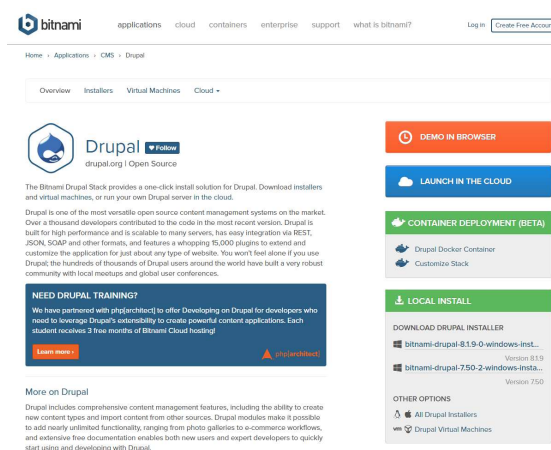


(b) MCR installation step 2

Figure 1.8: Matlab MCR installation steps

4. **Installation of Web-Server:** Download and install a web server solution (for example Bitnami, XAMPP, easyPHP, Acquia...) with Apache, PHP and MySQL.

In the following pages, we describe the installation steps for Bitnami package. If another solution is selected then please refer to the relative website. Download the Bitnami package from this [link](#)(see Figure 1.9).

**Figure 1.9: Bitnami Drupal download page**

Execute the downloaded file and follow the steps shown in Figures 1.10. The user and password requested in the red box shown in Figure 1.10d are the credentials for the Drupal site Administrator ⁴.

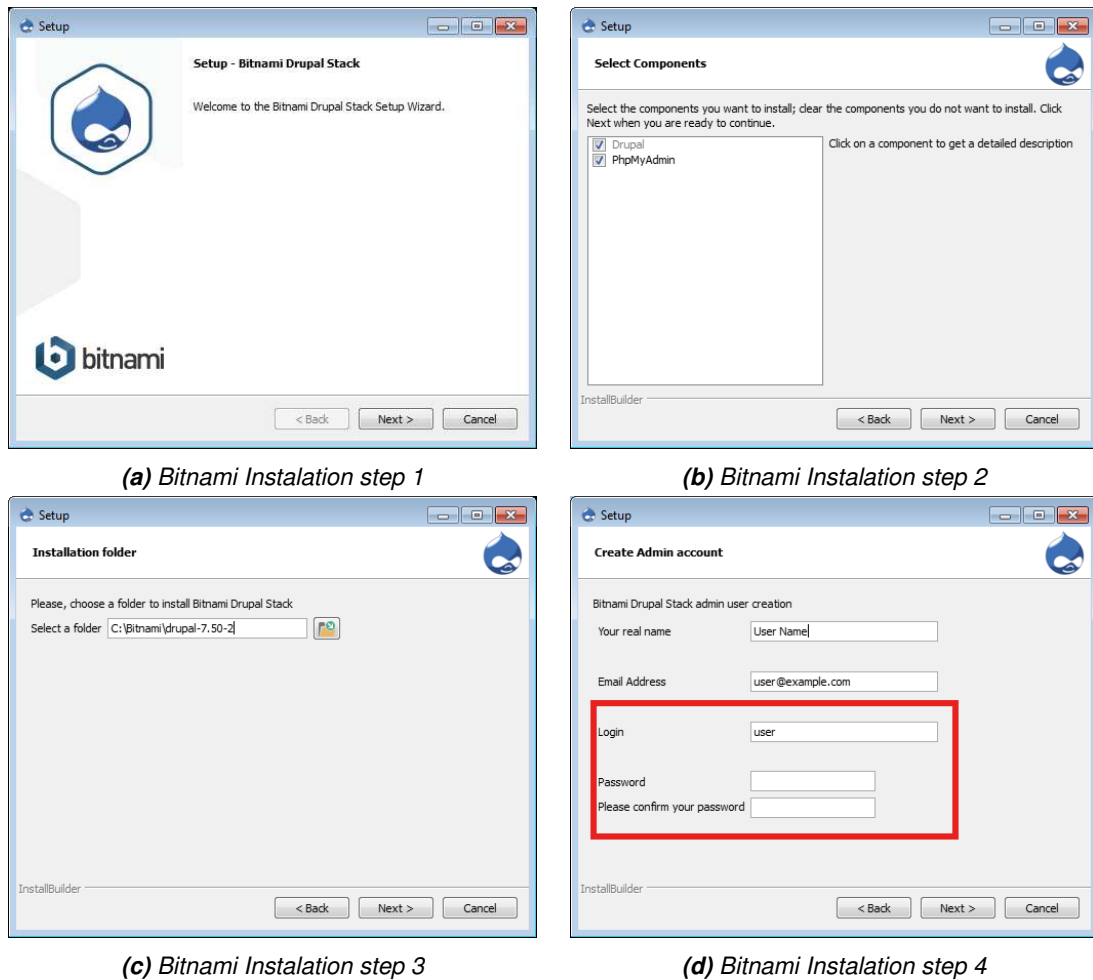


Figure 1.10: Bitnami installation process: Installing Drupal

After creating an “Admin Account” the administrator must enter the number of some ports (see [here](#)). The SSL port for a secure client-server connection is shown in Figure 1.11a. The user also needs to set the MySQL server port in order to establish the connection between Drupal site and Drupal database (Figure 1.11b).

⁴The credentials for MySQL database used by the current Drupal installation are: “root” for the username and the “Drupal site Administrator” password inserted in Figure 1.10d.

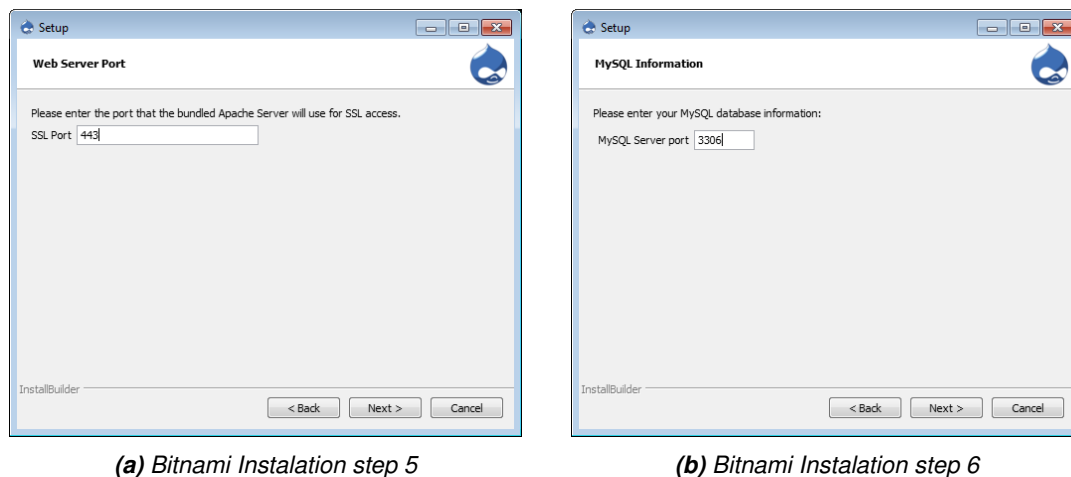


Figure 1.11: Bitnami Installation: Port configuration

Figure 1.12 shows the conclusion of the “Bitnami Stack” installation. The “Bitnami Stack” program runs automatically when Windows starts and provides access to the Drupal Web site and to the relative MySQL database.

To interact with the “Bitnami Stack” package from Windows, run Start Menu > Program > Bitnami Drupal Stack > Bitnami Drupal Stack manager tool (Figure 1.13 will appear). Once the server and the database are running the user can access the Drupal Site on local machine from a web browser with the following url `http://localhost:80/drupal` or the equivalent url such as `http://computer.name:80/drupal`, ... (Figure 1.14a or 1.14b).

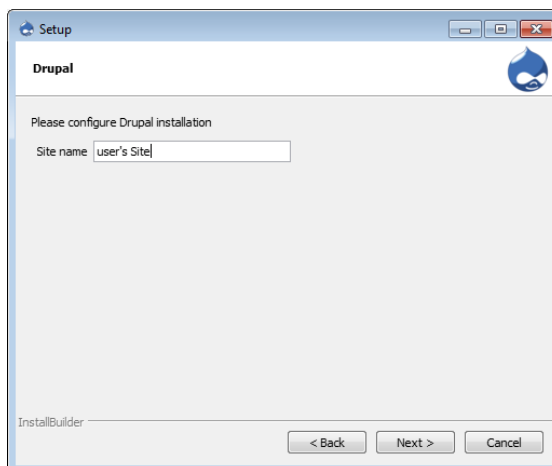
5. **GeoServer configuration:** It is mandatory to configure the proxy pass for GeoServer (to avoid same origin restriction, see [here](#)) for Apache. To do this it is necessary to modify the original Apache configuration file. This file named “httpd.conf” is a text file and is located in [Apache installation directory]\conf\. It can be edited with a simple text editor like Windows Notepad. The administrator must open the file and follow the instructions below to modify it (See also red boxes in Figure 1.15)⁵

- (a) uncomment the following lines (See the first red box in the Figure 1.15):

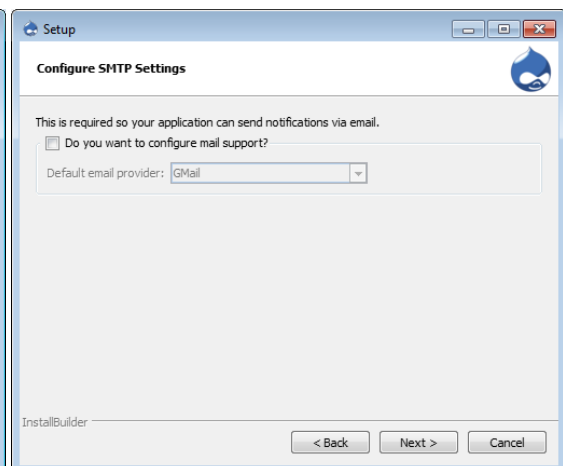

```
LoadModule proxy_module modules/mod_proxy.so
LoadModule proxy_ajp_module modules/mod_proxy_ajp.so
LoadModule proxy_connect_module modules/mod_proxy_connect.so
LoadModule proxy_express_module modules/mod_proxy_express.so
LoadModule proxy_ftp_module modules/mod_proxy_ftp.so
LoadModule proxy_html_module modules/mod_proxy_html.so
LoadModule proxy_http_module modules/mod_proxy_http.so
```
- (b) append the following lines at bottom (assuming `http://localhost:8080/geoserver` for GeoServer), see the second red box in Figure 1.15 (for more apache configuration details please see [here](#)):


```
ProxyPass /geoserver http://localhost:8080/geoserver
ProxyPassReverse /geoserver http://localhost:8080/geoserver
```

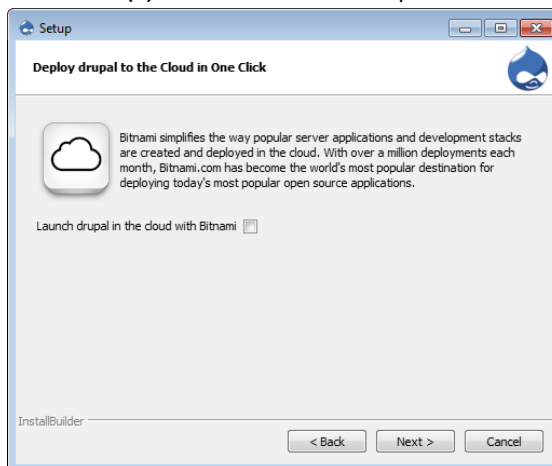
⁵In Figure 1.15 there are parts of the code that have been removed from the httpd.conf to allow a better visualization and “#” are comment lines.



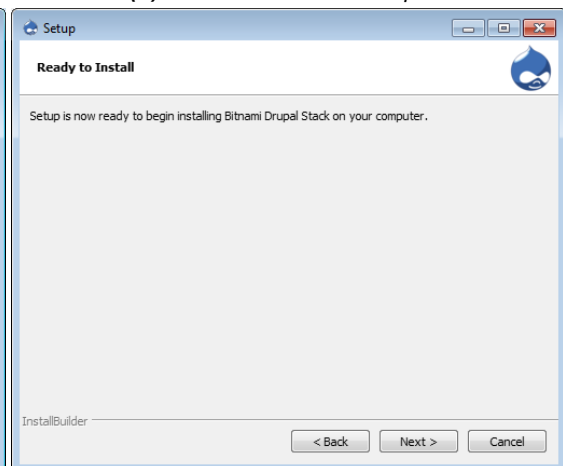
(a) Bitnami installation steps 7



(b) Bitnami installation steps 8



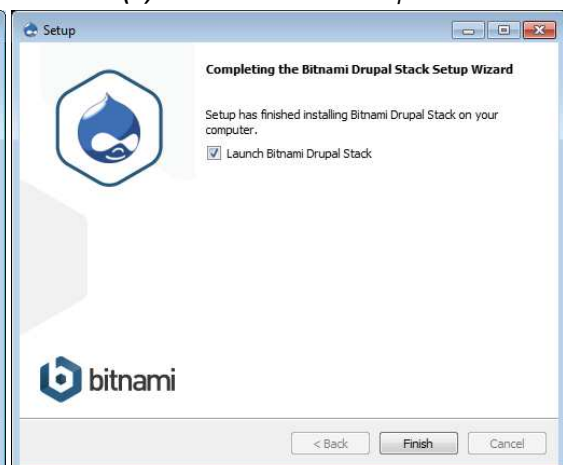
(c) Bitnami installation steps 9



(d) Bitnami installation steps 10



(e) Bitnami installation steps 11



(f) Bitnami installation steps 12

Figure 1.12: Completing installation

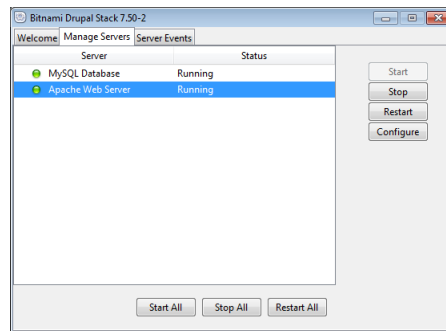
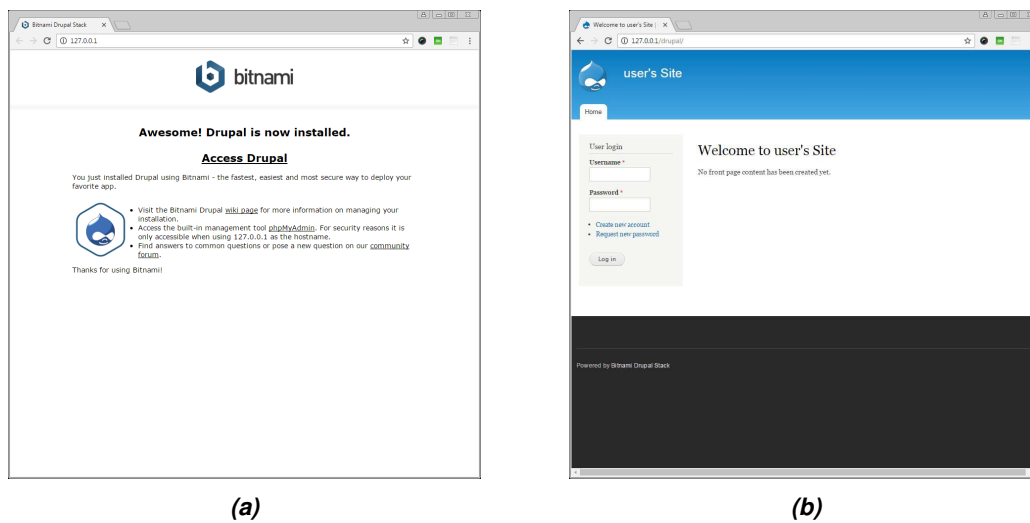


Figure 1.13: Run Bitnami



(a)

(b)

Figure 1.14: Access to Drupal site

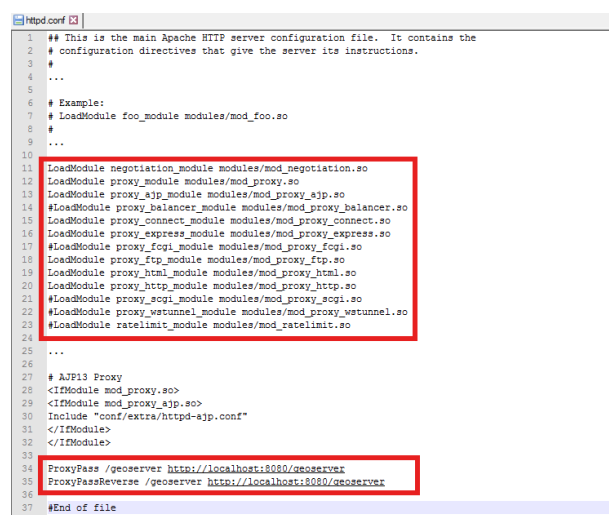


Figure 1.15: Apache configuration file example

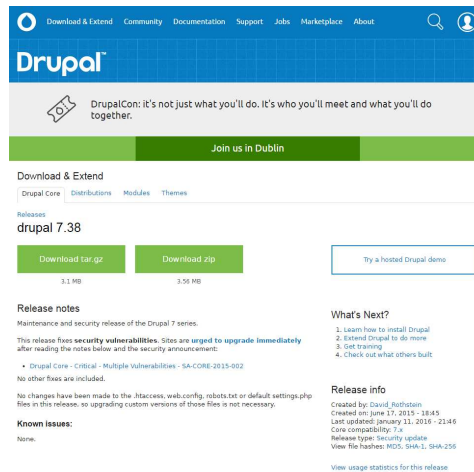


Figure 1.16: Drupal download page

6. **Drupal Installation:** If Drupal is already installed, the following step is not necessary. Otherwise proceed as follows: download Drupal 7.x version from this [link](#), see Figure 1.16). Unzip the Drupal package and copy the unzipped folder into the server root (in principle these folders are named htdocs or www but other possibilities may exist).
7. **GRRASP profile installation:** Unzip the GRRASP profile contained in gr rasp_profile.zip and copy the gr rasp_profile folder into the existing [Drupal installation directory]\htdocs \profiles folder. GRRASP software contains three default parameters to connect with GeoServer (see Figure 1.17). These parameters are located in gr rasp_profile/files/conf /geoserver_conf.php file. Check if the GeoServer connection parameters are correct. Username and Password have to be the same with the ones defined during the GeoServer installation process (see Figure 1.5d). The http_address contains the port to which the GRRASP needs to connect to GeoServer. This needs to correspond to the port provided during the GeoServer installation, see Figure 1.6a. If they are not as described above, change them accordingly.

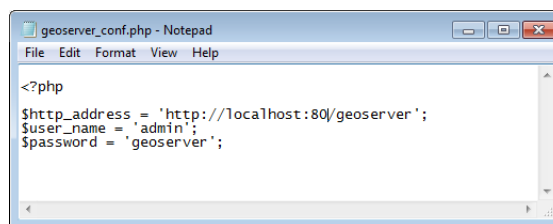


Figure 1.17: geoserver_conf.php file

8. **Drupal Settings:** If the user has followed the Bitnami installation as described in the Step number 5 it is necessary before passing to the next step to delete the [Drupal installation directory] \htdocs\sites\default\settings.php file. This allows to reset the Drupal settings and the GRRASP profile installation.
9. **GRRASP Drupal Database:** Create a new Drupal database for the GRRASP profile using

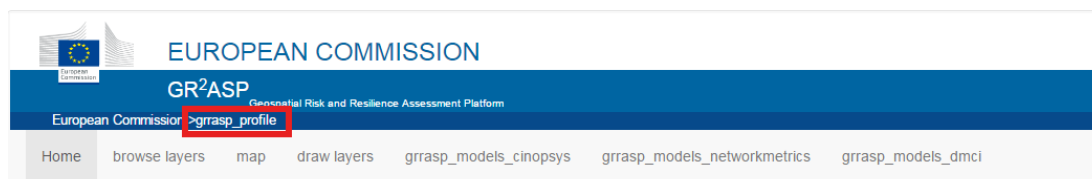


Figure 1.18: GRRASP site name

a Database Administrative Tool. In Bitnami, to do this the user can use the phpMyAdmin (for example more information in this [phpMyAdmin tutorial](#)) .

10. **Start the Apache and MySQL servers** (if they are not already running). For Bitnami follow instructions provided in Step 5 of the installation process.

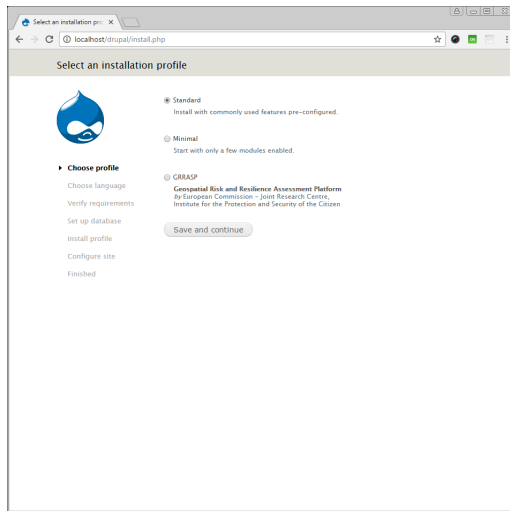
To run the Drupal Profile (in our case is GRRASP profile) installation script ([link](#)), point your web browser to the URL of your Drupal installation. This URL is the document root (directory) where you placed your Drupal files (and is defined in your web server configuration file). This URL is `http://127.0.0.1/drupal`.

If the installation process does not simply appear by entering the base URL of your site, add the file name `install.php` to the end of your site's URL.

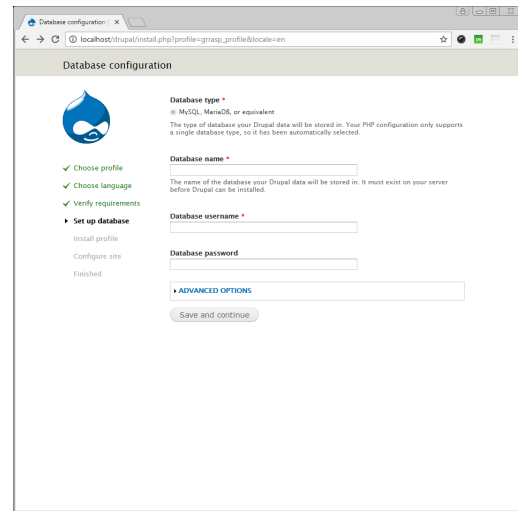
Select the GRRASP profile among the list of available profiles and follow the setup procedure as in Figure 1.19a. Follow the wizard and when the “Database configuration window” appears (see Figure 1.19b) fill in the name of the new database created in step number 10, the database username (in general “root”) and the database password (see 4). After the “Installing Drupal” window the user must provide all the necessary information for the new site configuration. Following the form in Figure 1.19d that describes the “site information”, the user must insert:

- **Site name:** The site name that will appear in the breadcrumbs above the main menu as in Figure 1.18
- **Email address:** The site e-mail address. If the user has configured an SMTP server mail as described in Figure 1.12a an automated e-mail will be sent by Drupal when it sends out notifications such as registration information.
- **Site Maintenance Account.** In the site maintenance account field, enter the Username, E-mail address, and password for the main administration account. The account you set up in the Site maintenance account section during installation is a super-user who has overall control over every aspect of the management and configuration of the site.
- **Server Settings.** In the Server settings field, select your Default country and Default time zone.
- **Update Notifications.** In the Update notifications field, leave both check boxes selected if you want your Drupal server to alert you when updates are required.

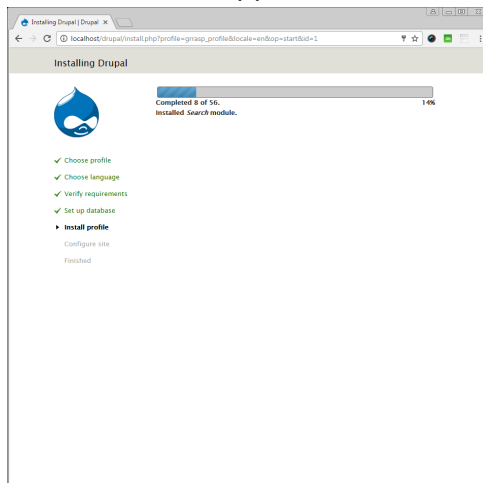
Finally the GRRASP site is ready to use (Figure 1.19e).



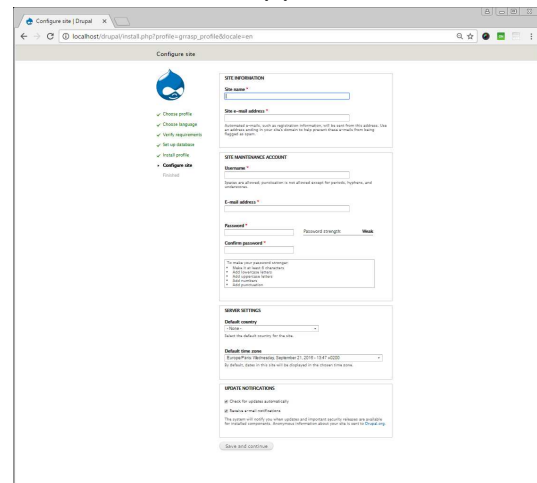
(a)



(b)



(c)



(d)



(e)

Figure 1.19: GRRASP profile installation step

CHAPTER 2

Getting started

After the successful conclusion of the installation, GRRASP server is ready for use. The access to the server can be done either through localhost or remote access. In the first case the GRRASP server is accessed from the same machine in which it is installed. In the second case, the access is done through a remote machine to the GRRASP server simply by providing the IP address of GRRASP in the address bar of the browser. More details are provided later in this text.

2.1 Accessing GRRASP through localhost

In order to access GRRASP through localhost, the server administrator needs to follow the steps below:

1. **Run the http server application.** If the user uses Bitnami please see Chapter 1 - step 4, otherwise run the specific web server.
2. **Run Geoserver.** In accordance with the Geoserver installation described in Figure 1.6b, if the user chooses the service option Geoserver is already running otherwise start Geoserver from Windows > Start button > Geoserver > Start Geoserver.

The end the user simply needs to open the web browser. In the address bar of the web browser the end user needs to type the following address: <http://localhost/drupal>. Once this has taken place, the page shown in Figure 2.1 should appear. This figure shows a standard web login page where username and password are required. To create a new account it is necessary to login in the GRRASP site with the administrator credentials. If the administrator has lost the credentials more information can be found [here](#) and [here](#) on how to tackle this issue. Once the administrator is logged in it is possible to create a new account by accessing the “People” link in the toolbar administrator on top of the page (green box in Figure 2.2a). Then from Figure 2.2b is possible to add new User account (Figure 2.2c). Finally a new user appears (see green box in Figure 2.2d). It is also possible to set in details (see Figure 2.2e) for any new added user in Roles and Permission by clicking on the Permission tab (see orange box in Figure 2.2d).

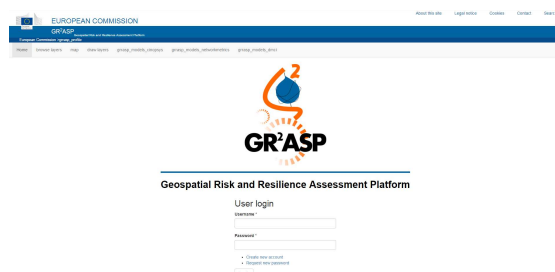
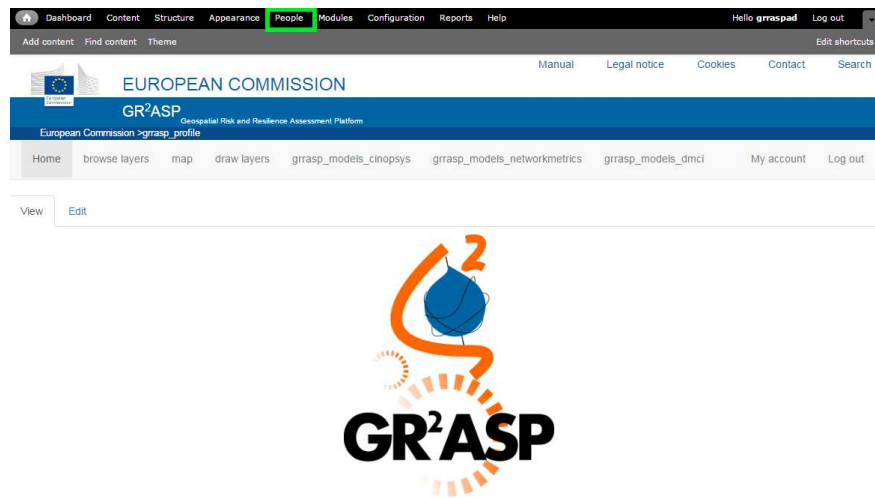
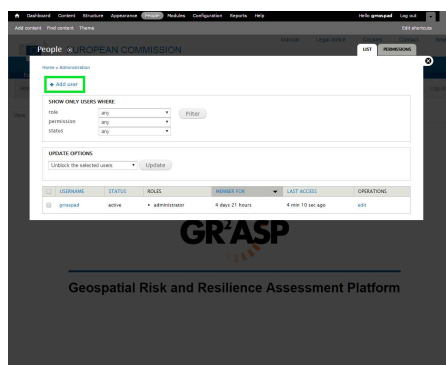


Figure 2.1: GRRASP home page

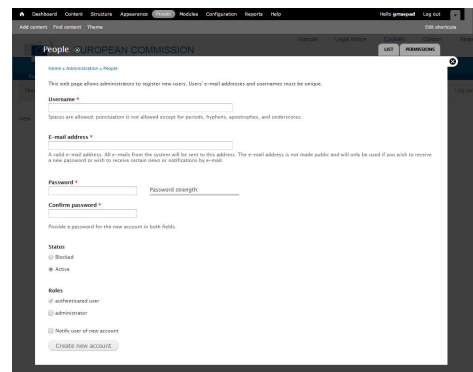


Geospatial Risk and Resilience Assessment Platform

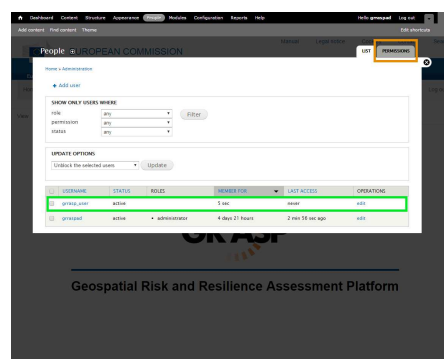
(a)



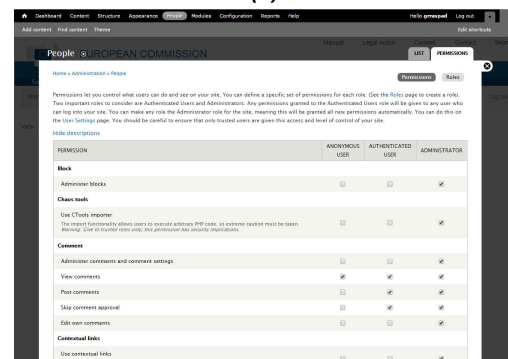
(b)



(c)



(d)



(e)

Figure 2.2: Process for creating a new account

The GRRASP main menu is shown in Figure 2.3. As one can see the various function-

alities of the tool appear as tabs under the main GRRASP page. This facilitates the use of the tool by the end user since there is no need to go through complex tree structures. This will be considered at a later stage if the number of tools and functionalities increases significantly.

2.2 Accessing GRRASP from a remote machine

In the case of remote access, the end user needs to connect to the GRRASP server. The user needs to provide the host name or IP address of the GRRASP server and the respective port number. In the Figure 2.3 the computer name is “hostname” and the “port number” is “80”. The user needs to ask to network administrator the port number in which GRRASP is accessible. If GRRASP is set up using Bitnami as described see 1 - step 4 the port number is visible in Bitnami Drupal Stack Manager tool (See red boxes in Figure 2.4).

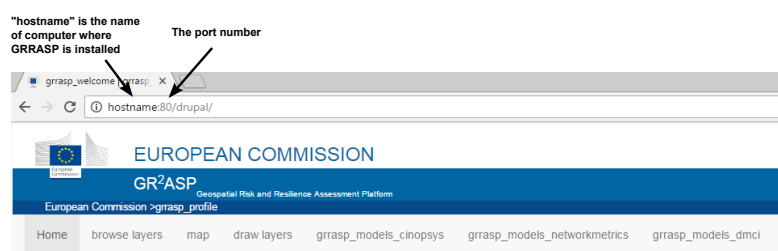


Figure 2.3: Access GRRASP from a remote machine with hostname.

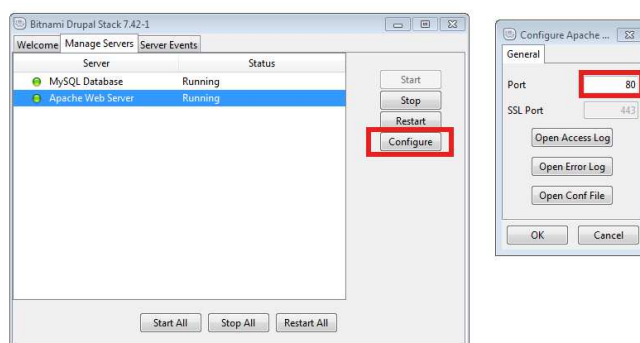


Figure 2.4: Retrieve port number in Bitnami

The user can also access the GRRASP web application using the network IP address of the host computer (See Figure 2.5).

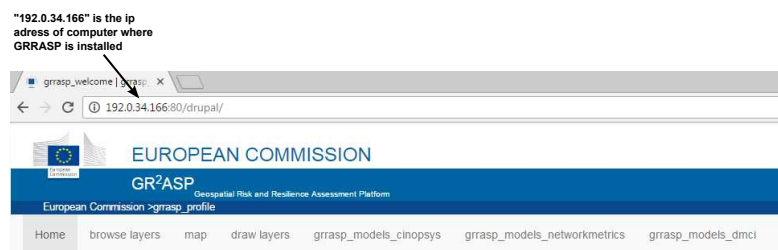


Figure 2.5: Access GRRASP from remote machine with ip address

CHAPTER 3

User manual for GRRASP Modules

In this chapter we provide a detailed description of the GRRASP functionalities and capabilities. GRRASP can be used for the visualisation of datasets related to critical infrastructures, hazards and risks and in general of any dataset that can be georeferenced and visualised on a map. Furthermore, GRRASP hosts a wide number of tools (and the list is currently expanding) that can be used for the analysis of critical infrastructures and can be applied on a range of datasets.

3.1 Browse Layers

As shown in Figure 2.3 the first menu item is “Browse Layers”. Once the user clicks on this menu item the web page depicted in Figure 3.1 appears. This page provides the main functionalities that allow users to get information (layers) from GeoServer (see [here](#)). This point is particularly important because it constitutes one of the core characteristics that allows end user to work on datasets that are stored in a remote server. Furthermore this technology allows the connection of several Geoservers allowing the establishment of a collaborative environment in which the datasets can be stored in different Geoservers. This technology provides enormous capabilities and flexibility to the end users.

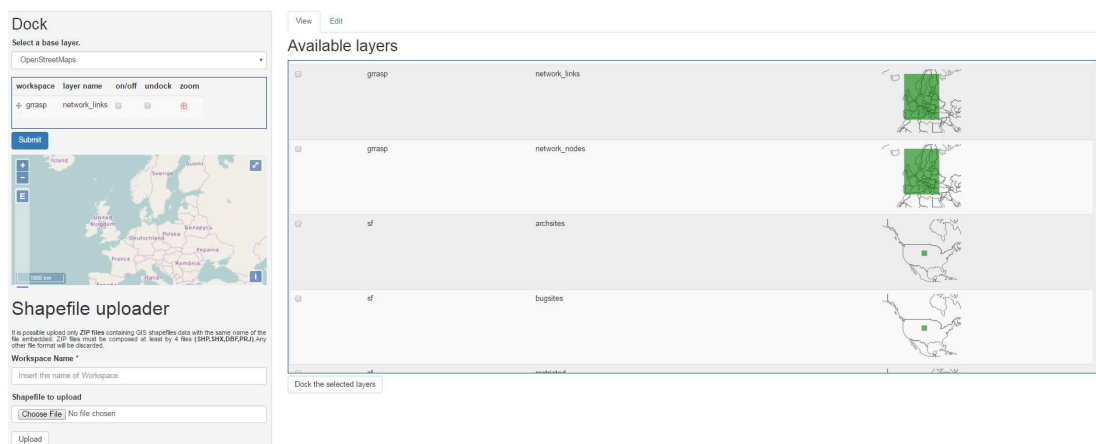


Figure 3.1: GRRASP browse layers

The implementation of the GeoServer interface is based on the geoserver-manager library. For more details please follow this [link](#). (Javadocs can be found in this [link](#)). Essentially this page is composed of three blocks: the “Available layers”, the “Dock” and the “Shapefile uploader”. The “Available layers” is an abstraction of the GeoServer content and provides an

intuitive interface that shows the list of all layers¹ that are available in the GeoServer (Vector² and Raster³ data type) with some additional information like: workspace name, layer name, description and a preview of the geographical position (Layer preview is offered through d3-based visualization, see [here](#)).

The user can load in the “Dock” one or more layers listed in the “Available layers” simply by selecting them and clicking on “Dock the selected layer” button.

The “Dock” block shows a list of the loaded layers from GeoServer and allows (clicking the on/off check box) end users to visualize them on the preview and on all GRRASP maps. To remove a layer from the “Dock” it is necessary to select the “undock” checkbox related and press the “Submit” button.

Furthermore the “Dock” block provides the possibility to change standard base layers (the default is OpenStreetMap, see [here](#) and the other is from Stamen, see [here](#)). The little map just below the list of layers in the “Dock” block depicts the preview of the layer selected in the “Dock”.

An important functionality of GRRASP that renders it compatible with several other GIS-based tools (ARCGIS, QGIS, etc.) is its capability to handle “shapefiles”⁴. These are standard GIS based files. The end user has the capability of uploading shapefiles in GeoServer using the “Shapefile uploader” Block, in order to use the information contained in these files for further numerical and geospatial analysis. In Figure 3.2b the user with the “Choose file” button in the “Shapefile to upload” section, can navigate the filesystem, identify the shapefile and upload it in GeoServer. The chosen filename will appear at the right side of the button. This Shapefile will be stored in a GeoServer layer with the same filename without the “.zip” extension plus a unique identifier (the current Unix timestamp) to avoid overwriting an existing layer. From a GeoServer point of view, layers can be grouped through some criterion of similarity. These groups of similar layers are stored in GeoServer in data type named “Workspace”. Any workspace in GeoServer is identified with a name, the user must provide this name in “Workspace name” text input. Finally the user must use the “Upload” button to save it in the specific GeoServer Workspace (with the name already provided by the end user). The Shapefile is saved as a layer in GeoServer, the layer name is equal to the filename of the shapefile (without the zip extension).

For example the end user can create a shapefile of a network using one of the commercially available tools (although even this can take place in GRRASP, it is explained later on) and upload this shapefile (i.e. the “nation_euro.zip” file in Figure 3.2c). Once the file is uploaded then it is stored in the GeoServer (in the “european.data” workspace in Figure 3.2c) and it is available for any further analysis within the GRRASP environment.

¹In Geoserver, the term layer refers to raster or vector data that contains geographic features. Vector layers are analogous to featureTypes and raster layers are analogous to coverages. Layers represent each feature that needs to be shown on a map. All layers have a source of data, known as a Store, see [here](#)

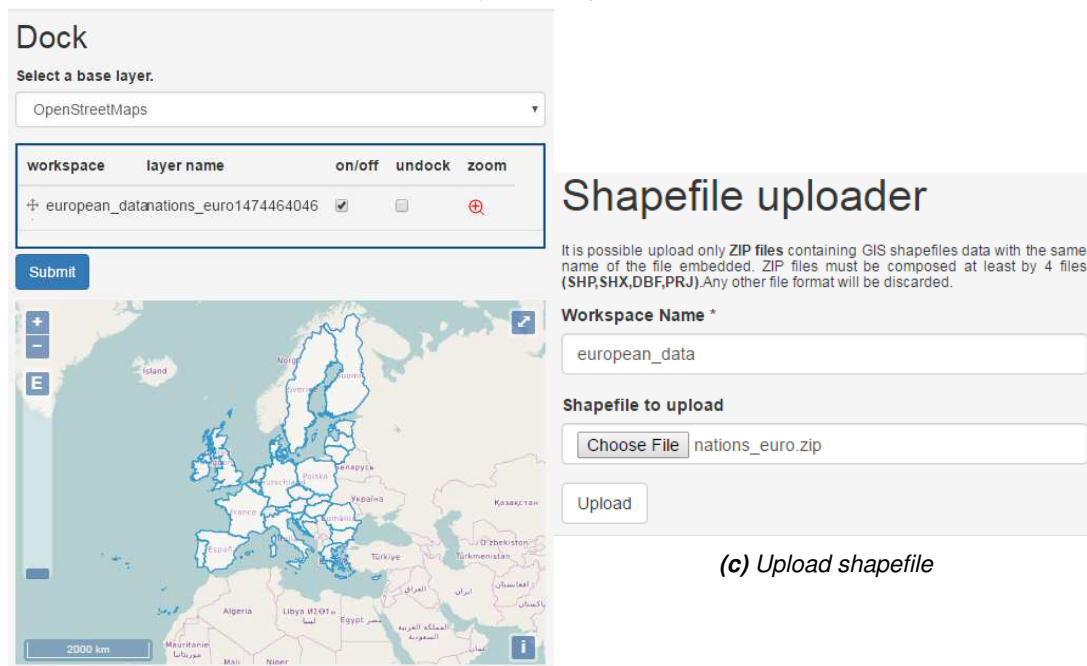
²Vector data model is a representation of the world using points, lines, and polygons. Vector models are useful for storing data that has discrete boundaries, such as country borders, land parcels, and streets.

³Raster data model is a representation of the world as a surface divided into a regular grid of cells. Raster models are useful for storing data that varies continuously, as in an aerial photograph, a satellite image, a surface of chemical concentrations, or an elevation surface.

⁴The shapefile is the most popular format of geospatial vector data type for geographic information system (GIS) software. In general a shapefile is packaged as .zip file containing four mandatory files (a zip file of the four mandatory files : .shp,.shx,.dbf,.prj).



(a) The uploaded layer is available



(c) Upload shapefile

(b) Uploaded layer appears in the dock list and on the map

Figure 3.2: Uploading and visualising a shapefile in GRRASP

3.2 Map

This page provides a full space for the “Dock” block components described above with some additional functionalities and tools. In this case the map is larger to facilitate the navigation, the selection, the visualization and the analysis of the data by the selection toolbar below the map (see Figure 3.3a).

In order to help the GRRASP users with the selection, editing and visualization of several features⁵ on the map, a specific toolbar has been developed to facilitate this process. In Figure 3.3c these features are presented.

In case of multilayer visualization the position of each layer in the ordered list of the “Dock” is equivalent with the visualization position in the map i.e. the first layer in the “Dock” is the top

⁵Features are combinations of geography and attributes. For example an electrical power station can be represented by the coordinates, called geography, plus some other relevant information like “year of construction”, “maximum power provided”, “number of employees”, and so on. This information is called attributes, i.e. the nonspatial information.

layer visualized in the map, the second layer in the “Dock” corresponds to the layer below the top in the visualization map, etc. (see Figure 3.3a). Given this policy for the link between the layers flagged in Dock and their relative position on the Map, it is possible to move layers using a drag and drop event function in the Dock (see Figure 3.3b). In order to facilitate the expert user to understand the underlying technology of this functionality it is important to mention that this feature is the implementation of the GRRASP-specific OpenLayers 3 integration (see [link](#)).

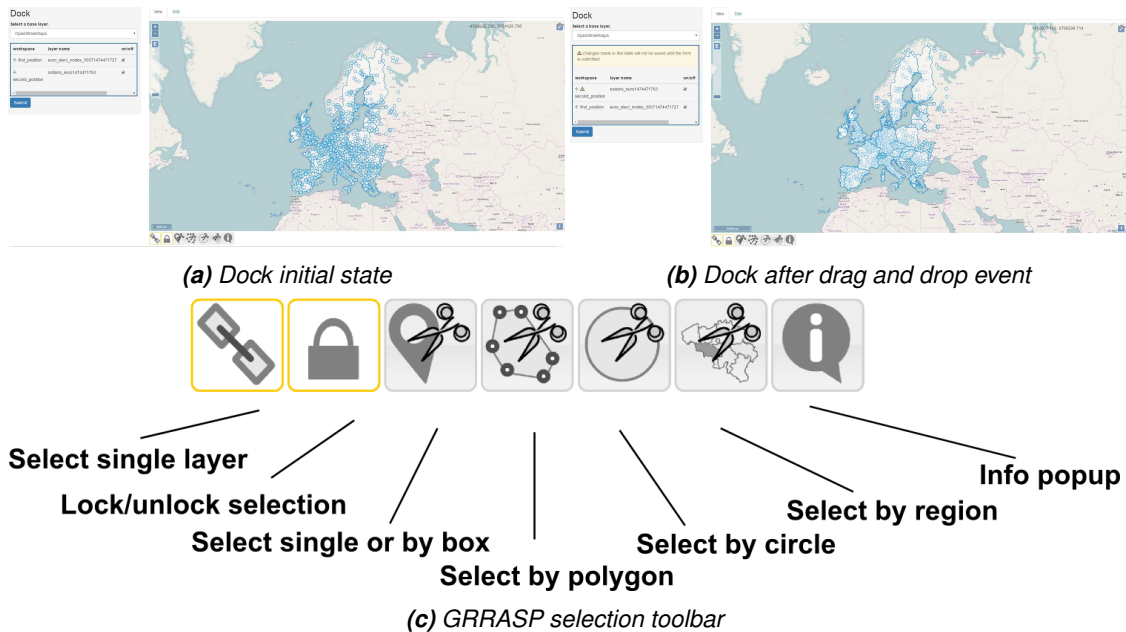


Figure 3.3: Dock features

The selection toolbar (Figure 3.3c) is composed by seven icons. These icons can activate or deactivate a specific action on the map. Once an icon in the toolbar is deactivated it is represented in grey, instead in the activated state it is represented in red. The available actions are:



Figure 3.4: Activation example

- The “Select single layer” icon allows to select only the first layer checked as a visible in the dock list if it is activated. If it is deactivated, all layers checked as visible in the dock list can be selected.
- The “Lock/unlock selection” icon permits to freeze a selection on the map.
- The “Select single or by box” icon enables the user to select a single feature with a mouse click on the feature. On the other side, this same icon allows selection of multiple features by drawing a box using the mouse with the shift button pressed (Figure 3.5).

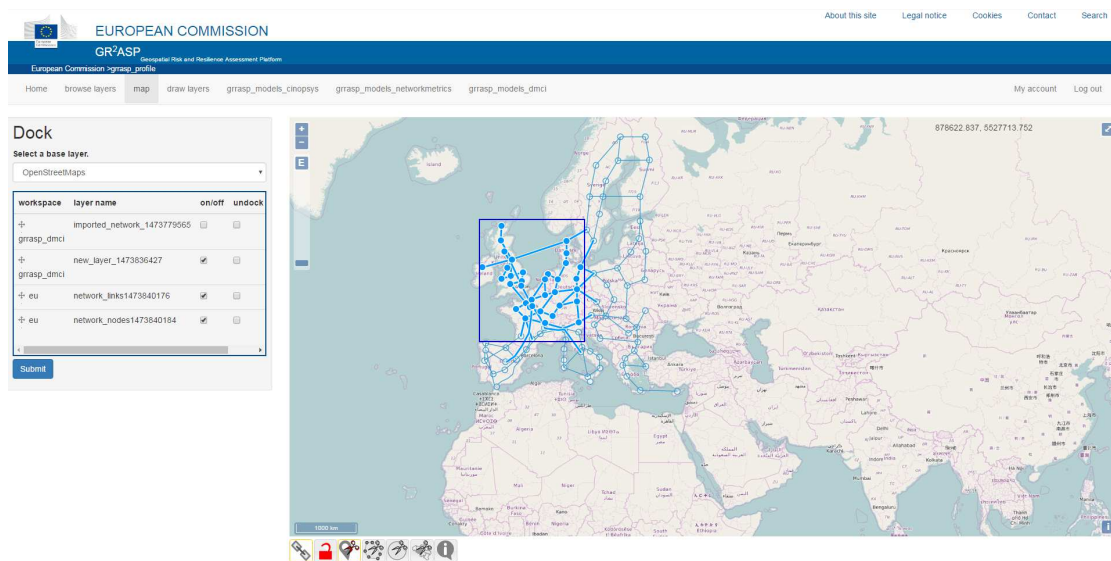


Figure 3.5: Select by box tool

- The “Select by polygon” icon allows to select features by drawing a polygon with the mouse (Figure 3.6).

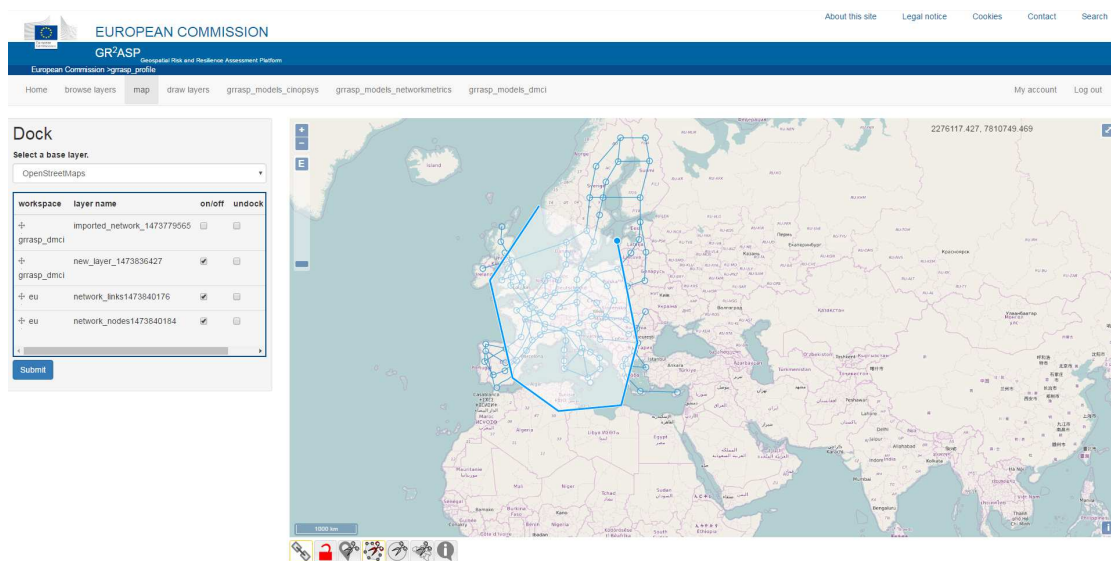


Figure 3.6: Select by polygon tool

- The “Select by circle” icon allows to select features by drawing a circle with the mouse (Figure 3.7).

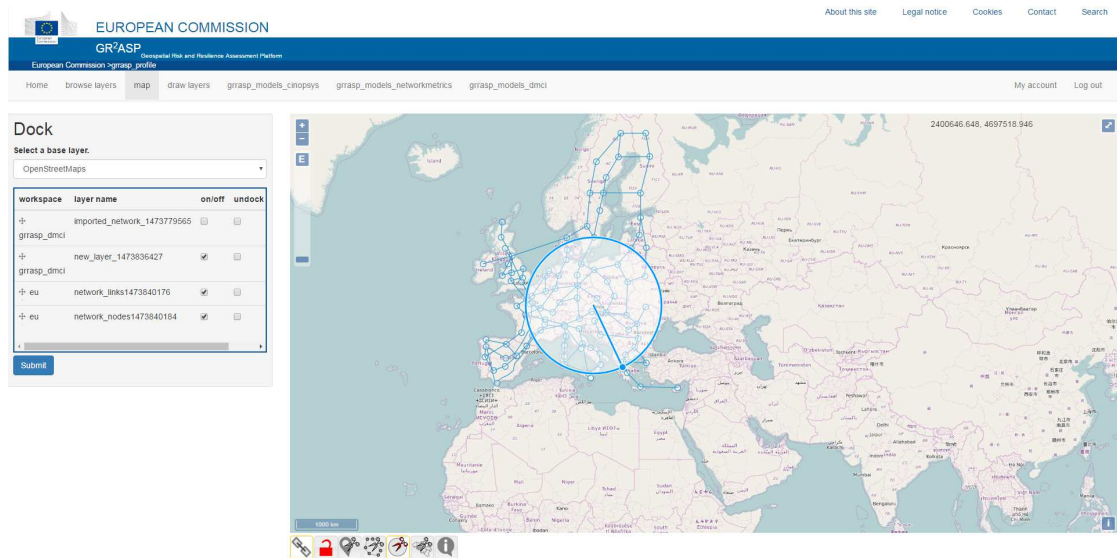


Figure 3.7: Select by circle tool

- The “Select by nation” icon allows to select features by nation with a mouse click (Figure 3.8).

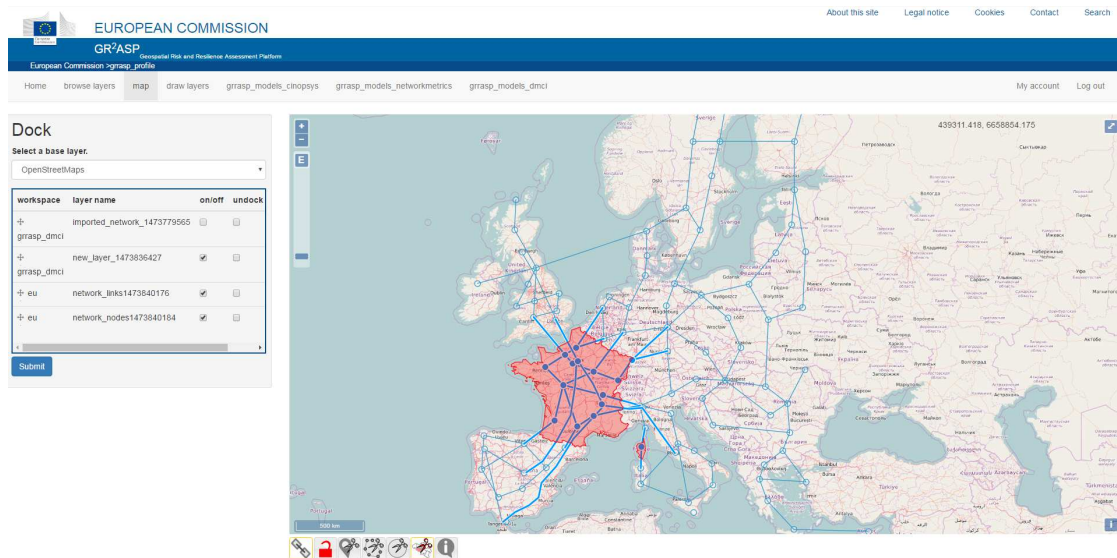


Figure 3.8: Select by nation tool

- The “Info popup” icon allows to visualize the attributes of a single feature (if of course attributes exist) (Figure 3.9).

Finally it is important to mention that in the “Map” page all the selections performed by the toolbar on the active layers are only for visualization. No manipulation of data is allowed in this page.

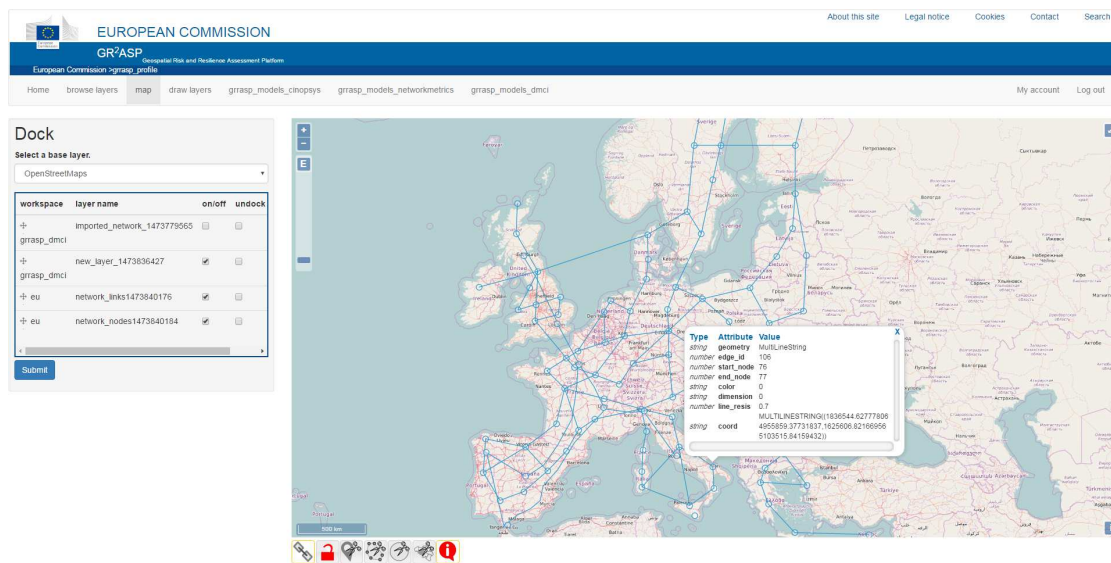


Figure 3.9: GRRASP information popup

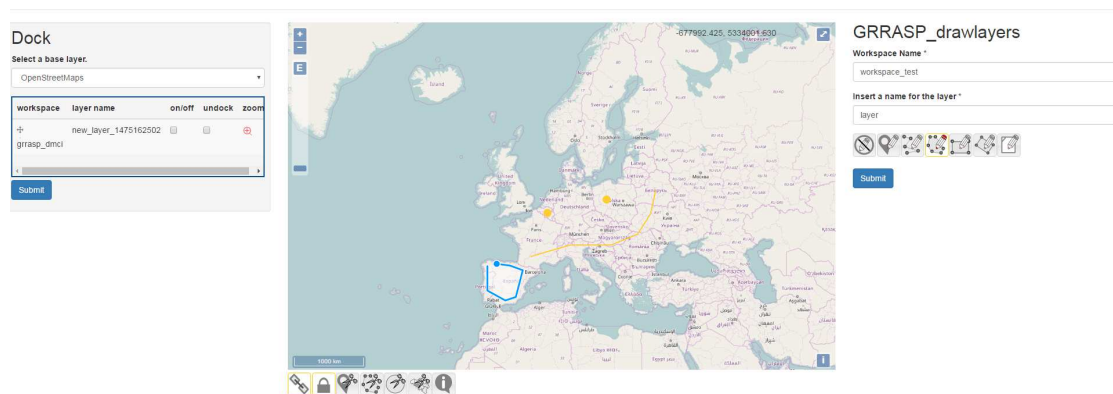
3.3 Draw layers

The “Draw layer” page is an elegant “alternative” to “Shapefile uploader” block (Figure 3.2b). The blocks shown in this page are the “Dock” and the “Map” blocks described in the previous sections. The only additional block presented in this page is the “Draw layers” block, which is shown at the right side of the page. This block enables the end user to draw and save personalized layers with various geometry elements (see Figures 3.10a) together with attributes (through drawing tools and variable-fields popup input forms) using the drawing toolbar at the right side of the map, see Figure 3.10c. During the drawing phase the geometries added by the end user are designated in yellow colour to discern them from the other layers eventually added through the “Dock” which are always designated by blue colour. The drawing toolbar operates in a way similar to the toolbar described in section 3.2. The actions provided by the drawing toolbar (Figure 3.10c) are:

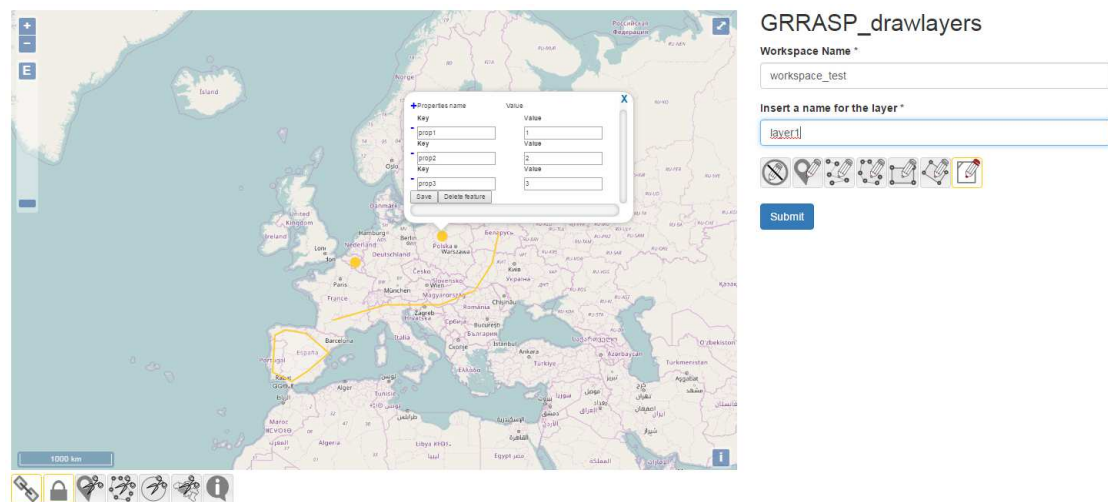
- The “Disabled map drawing” icon. When active (red colour) this button allows the user to zoom and pan the map. To disable (grey color) this icon and return to the map in order to perform some other drawing actions, the user simply has to use another icon from the toolbar.
- The “Draw points” icon.
- The icons from the second to the sixth one in the toolbar are devoted to draw the relative geometric shapes described in Figure 3.10c.
- The last icon “Edit attributes” allows to add, remove or modify attributes of a selected feature.

The input form enables the end user to insert the “Workspace name” and the name for the new layer. The “submit” button will store the new layer locally in the Drupal database⁶.

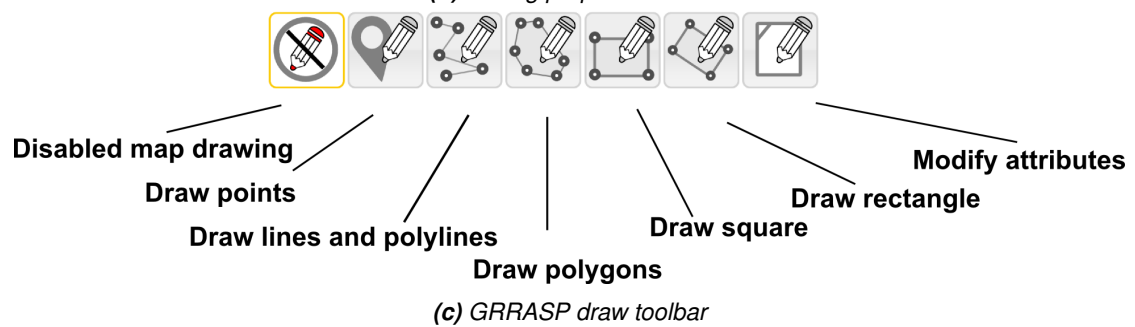
⁶Note that the new layer created by using the “Draw layer” block is not stored in GeoServer but in Drupal database. This is done intentionally in order to avoid making public available a layer created by the user



(a) Draw features tools examples



(b) Editing properties tools



(c) GRRASP draw toolbar

Figure 3.10: GRRASP draw layers

3.4 Models

3.4.1 Introduction

One of the most important features of GRRASP is the ability to incorporate and use mathematical models that can also operate and interact with geographical data. In the following sections a detailed description of the models introduced in GRRASP are described. It is important to mention that these models have been developed by the JRC but also by third party organisations.

3.4.2 Cinopsys

This page (Figure 3.11) allows the end user to access the dynamic input output model with inventory as described in [2] and in [4].

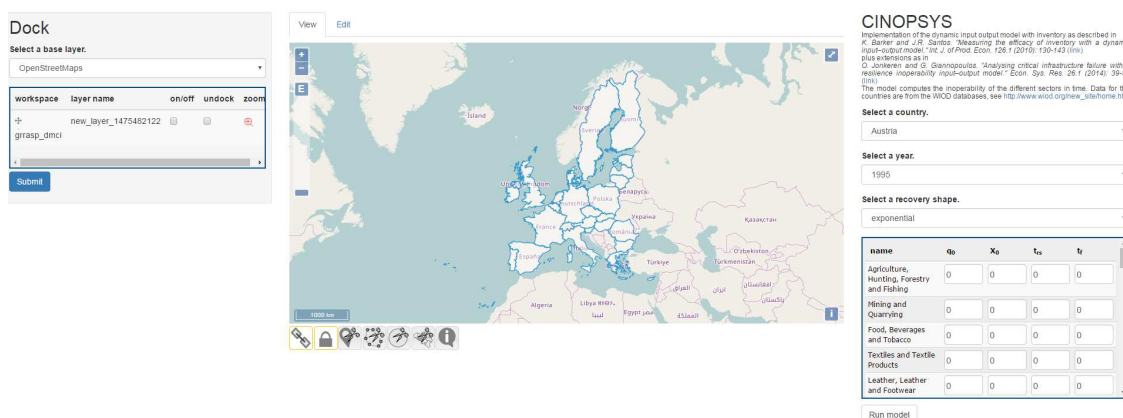


Figure 3.11: GRRASP cinopsys model

The Cinopsys model can be used to estimate the inoperability of different economic sectors as a function of the time. The disruptive event may hit directly one or more economic sectors. Due to the monetary exchanges between the various economic sectors, the inoperability propagates to other sectors which further increases the economic impact of the primary disruptive event. An important parameter for the functioning of the model is the economic data that describe the interdependencies between the various economic sectors. This work takes place by the statistics office of the various countries and these data are available on-line and can be found [here](#).

These databases constitute the cornerstone for the analysis of the economic impact of a disruptive event. These databases are already introduced in the GRRASP environment so that the effort that is required by the end user is minimum. An additional parameter of this model is the one of inventory. This term actually refers to the option that some economic sectors may have stocks of products available (this is obviously not the case for the services sectors) in order to be able to cover the request for products from other sectors during periods of disruptions. This would delay the propagation of the inoperability from the directly impacted sectors to the depended ones which would lead to a reduction of the overall economic cost due to the business disruption. However, the data-sets for this parameter are not always available.

In a similar manner to the other pages/models presented so far in this report, the user can find the "Dock" and the "Map" blocks with a default view of the European countries as a layer painted in blue border.

In order to run the model, the user needs to simply select the country of interest and start

providing the information for the disruptive scenario. Then the user simply needs to run the model by clicking on the calculate button at the bottom of the input data block.

The input data in order to run the model are the following:

- The country that can be also selected through the map
- The reference year for which the WIOD are available (some times past years have to be used since the update of this database with current data requires a lot of time)
- The recovery shape method. There are two options for this parameter: The accelerated recovery in the aftermath of the event and the accelerated recovery towards the end of the recovery process. In fact in both cases an exponential equation is used. For each economic sector i at time t , we have:

$$p_i(t) = e^{-\tilde{k}_{ii}} p_i(0) \quad (3.1)$$

$$p_i(t) = p_i(0)(1 + e^{\tilde{k}_{ii}f_i} - e^{\tilde{k}_{ii}(t-f_i)}) \quad (3.2)$$

In Equations (3.1) and (3.2) \tilde{k}_{ii} is the resilience coefficient for sector i . This value describes the ability of the sector i to recover the production capability from an initial disruptive event. This parameter is sector specific and it does not take into account the interdependencies. A higher value of \tilde{k}_{ii} results in faster recovery of production capability. This parameter is subject of a long debate in the scientific community. In GRRASP the K matrix is assumed to be the identity matrix. In the same way f represents the duration of the analysis for the sector i expressed in days.

In order to facilitate the data input and analysis by the non-expert user of the model, the data required for this model can be introduced through a very intuitive and user friendly interface that requires the following information for each of the economic sectors:

- (1) initial inoperability (in [0,1]) (actually it represents the amount of initial inoperability in one or more economic sectors due to a disruptive event that hits directly one or more sectors)
- (2) initial inventory (≥ 0) in Euros (€).
- (3) recovery start time (≥ 0). This shows after how many days the recovery process starts for the directly affected sectors. No interdependencies need to be taken into account. This is done by the algorithm.
- (4) recovery end time (\geq recovery start time). This shows when the recovery process is considered to be finalized. The default value for the minimum time is 1 day.

The input data form handles all wrong values inserted by the user outside the correct range defined above. If the user inserts a wrong value an error message will appear. For example if the user enters a wrong value for initial operability, an error message like in Figure 3.12a. In the same way for the other input values (see Figures 3.12b, 3.12c, 3.12d).

If all values inserted in the Cinopsys input form by the user are correct (note that zero values in all sectors is acceptable input), the model can be executed. An example for the output of the model, depicted in Figure 3.13 will appear below the map. This is done using d3 libraries capabilities (more information can be found [here](#)). The output includes the inoperability profiles along the time for all sectors with info on economic losses (see figure 3.13). To simplify the visualization of the output, the legend of the first ten sectors in terms of inoperability are shown in the plot in Figure 3.13.

CINOPSYS

Implementation of the dynamic input output model with inventory as described in K. Barker and J.R. Santos, "Measuring the efficacy of inventory with a dynamic input-output model," *Int. J. of Prod. Econ.* 126.1 (2010): 130-143 (link) plus extensions as in O. Jonkeren and G. Giannopoulos, "Analysing critical infrastructure failure with a resilience inoperability input-output model," *Econ. Sys. Res.* 26.1 (2014): 39-59 (link). The model computes the inoperability of the different sectors in time. Data for the countries are from the WIOD databases, see http://www.wiod.org/new_site/home.htm

Value $q_0=2$ in sector "Mining and Quarrying" is bad! Insert a value $\in [0,1]$

Simulation output summary.

Select a country.

Austria

Select a year.

1995

Select a recovery shape.

exponential

name	q_0	x_0	t_{rs}	t_f
Agriculture, Hunting, Forestry and Fishing	0	0	0	0
Mining and Quarrying	2	0	0	0
Food, Beverages and Tobacco	0	0	0	0
Textiles and Textile Products	0	0	0	0
Leather, Leather and Footwear	0	0	0	0

Run model

(a)

CINOPSYS

Implementation of the dynamic input output model with inventory as described in K. Barker and J.R. Santos, "Measuring the efficacy of inventory with a dynamic input-output model," *Int. J. of Prod. Econ.* 126.1 (2010): 130-143 (link) plus extensions as in O. Jonkeren and G. Giannopoulos, "Analysing critical infrastructure failure with a resilience inoperability input-output model," *Econ. Sys. Res.* 26.1 (2014): 39-59 (link). The model computes the inoperability of the different sectors in time. Data for the countries are from the WIOD databases, see http://www.wiod.org/new_site/home.htm

Value $x_0=-1$ in sector "Leather, Leather and Footwear" is bad! Insert a value ≥ 0

Simulation output summary.

Select a country.

Austria

Select a year.

1995

Select a recovery shape.

exponential

name	q_0	x_0	t_{rs}	t_f
Agriculture, Hunting, Forestry and Fishing	0	0	0	0
Mining and Quarrying	0	0	0	0
Food, Beverages and Tobacco	0	0	0	0
Textiles and Textile Products	0	0	0	0
Leather, Leather and Footwear	0	-1	0	0

Run model

(b)

CINOPSYS

Implementation of the dynamic input output model with inventory as described in K. Barker and J.R. Santos, "Measuring the efficacy of inventory with a dynamic input-output model," *Int. J. of Prod. Econ.* 126.1 (2010): 130-143 (link) plus extensions as in O. Jonkeren and G. Giannopoulos, "Analysing critical infrastructure failure with a resilience inoperability input-output model," *Econ. Sys. Res.* 26.1 (2014): 39-59 (link). The model computes the inoperability of the different sectors in time. Data for the countries are from the WIOD databases, see http://www.wiod.org/new_site/home.htm

Value $t_f=-2$ in sector "Mining and Quarrying" is bad! Insert a value ≥ 0

Simulation output summary.

Select a country.

Austria

Select a year.

1995

Select a recovery shape.

exponential

name	q_0	x_0	t_{rs}	t_f
Agriculture, Hunting, Forestry and Fishing	0	0	0	0
Mining and Quarrying	0	0	0	-2
Food, Beverages and Tobacco	0	0	0	0
Textiles and Textile Products	0	0	0	0
Leather, Leather and Footwear	0	0	0	0

Run model

(c)

CINOPSYS

Implementation of the dynamic input output model with inventory as described in K. Barker and J.R. Santos, "Measuring the efficacy of inventory with a dynamic input-output model," *Int. J. of Prod. Econ.* 126.1 (2010): 130-143 (link) plus extensions as in O. Jonkeren and G. Giannopoulos, "Analysing critical infrastructure failure with a resilience inoperability input-output model," *Econ. Sys. Res.* 26.1 (2014): 39-59 (link). The model computes the inoperability of the different sectors in time. Data for the countries are from the WIOD databases, see http://www.wiod.org/new_site/home.htm

Values $t_{rs}=15$ and $t_f=5$ in sector "Food, Beverages and Tobacco" are bad! Specify $t_f \geq t_{rs}$

Simulation output summary.

Select a country.

Austria

Select a year.

1995

Select a recovery shape.

exponential

name	q_0	x_0	t_{rs}	t_f
Agriculture, Hunting, Forestry and Fishing	0	0	0	0
Mining and Quarrying	0	0	0	0
Food, Beverages and Tobacco	0	0	15	5
Textiles and Textile Products	0	0	0	0
Leather, Leather and Footwear	0	0	0	0

Run model

(d)

Figure 3.12: GRRASP cinopsys input error

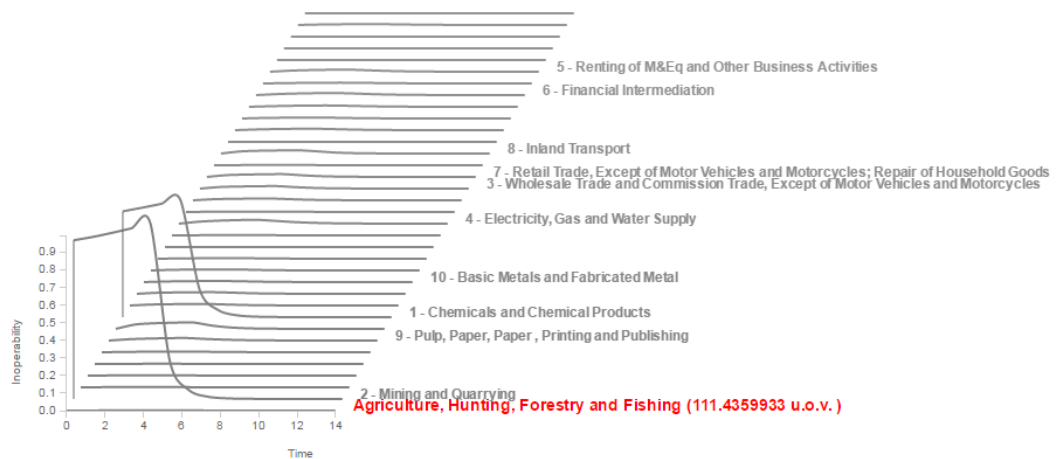


Figure 3.13: GRRASP cinopsys output

3.4.3 Network Metrics

Network metrics is a very powerful tool for analysing complex networks and reveal their intrinsic characteristics and resilience with respect to random and targeted attacks. In GRRASP several algorithms related to network metrics have been introduced (see figure 3.14). The vast majority of metrics introduced in GRRASP are described in detail in [3]. In this section we provide a thorough explanation on how the end user can take advantage of these capabilities.

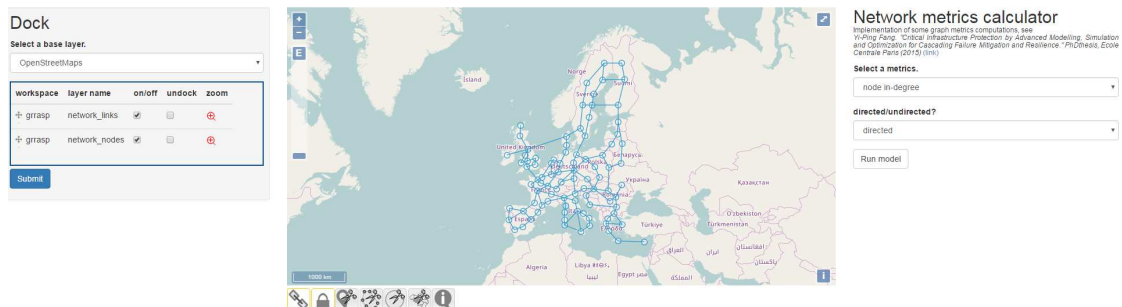


Figure 3.14: GRRASP Metrics

A graph is a pair of $G = (V, E)$, where V are the nodes and E are the edges that connect them. Networks of infrastructures can be represented by graphs which can be either directed or undirected. Directed graphs are the ones that the flow of goods or services follows a predefined direction (e.g. water networks), while in undirected graphs the flow of goods or services can change dynamically over time (e.g. power networks). All the metrics introduced in GRRASP accept as input both directed and undirected graphs.

As in the previous pages we can find the “Dock” and the “Map” section with a specific block for “Network metrics calculation” at the right side. The “Network metrics calculation” block has two selectors. The first drop-down list is devoted to select a metric and the second to choose

the kind of graph (direct/undirect). The metrics implemented in GRRASP are listed below:

1. **node in-degree**: The number of edges connected to the node i in a directed network coming to node i .
2. **node out-degree**: The number of edges coming out from the node i .
3. **minimum path**: A path starting in node i and ending in node j with the smallest possible length between i and j .
4. **local clustering coefficient**: It describes the proportion of neighbor nodes u of node i that are connected to each other.
5. **global clustering coefficient**: Describes how clustered the network is in form of the density of triangles in the network.
6. **node criticality**: It shows the number of nodes that may be affected by the disruption of a node i . It is mostly useful for directed networks.
7. **degree of centrality**: The degree of a vertex i normalized over the maximum number of neighbors this node could have.
8. **efficiency**: A measure of efficiency in the communication between nodes i and j , defined as inversely proportional to the minimum path between these nodes.
9. **characteristic path length**: The average distance of a graph, i.e the average of the shortest distance between all pairs of nodes.
10. **network (average) efficiency**: A measure of how efficiently the whole network exchanges information.
11. **network closeness centrality**: A measure of the idea of speed of communication between nodes in a way that the node that is “closest” to all others receives the higher score. The closeness of a node i is defined as the reciprocal of the average shortest path length.
12. **information centrality**: The information centrality of a node i is defined as the relative drop in the network efficiency caused by the removal from G the edges incident in u .
13. **betweenness centrality (nodes)**: A measure that tries to capture the importance of a node u in a network. It describes how many shortest paths go through a specific node.
14. **betweenness centrality (edges)**: A measure that tries to capture the importance of edge e in a network. It describes how many shortest paths go through a specific edge.

In the distribution version of GRRASP no datasets of realistic networks are included. However, in order to enable the end user to test the capabilities of the metrics module a couple of example networks are provided in the sub-folder “network_examples”. They are already linked to the GeoServer data_dir according to the standard GRRASP installation described in Chapter 1. These layers can be found listed in “Available layers” in “Browse layers” page. These layers are named network_edges and network_nodes which constitute a complete graph described by $G = (network - edges, network - nodes)$.

In order to apply the metrics operator included in GRRASP, in this case on the example graph $G = (network - edges, network - nodes)$ the end user needs to execute the following steps:

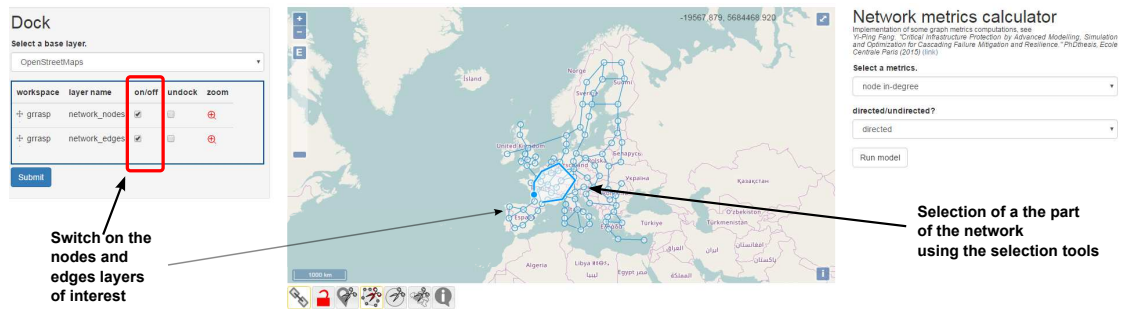


Figure 3.15: GRRASP metrics step 1 and step 2

1. Switch on the nodes and edges layers of interest (see red box in Figure 3.15) to show them on the map (see gray arrow in Figure 3.15).
2. Select the part of the network to be analyzed using the selection tools. The end user can select using a polygon, a circle with variable radius or by country (in Figure 3.15 an example of selection by polygon is shown).
3. The end user needs to define the type of the Metrics. The metrics can be split in two groups. The first group as shown in Figure 3.16 requires the input of a graph which can be either directed or undirected. The second group of metrics as shown in Figure 3.17 requires the input of a node id in addition to the graph. In this case only the nodes included within the graph selection are available. There are two options for providing the node id. The end user can provide directly the node id in the interface. If this node is included in the selected graph then it is accepted, otherwise the system proposes automatically the closest node (in terms of id number) to the one introduced by the user. The second option is to use the drop down menu and select one of the proposed nodes.
4. Press “Run model” in order to run the algorithm that corresponds to the selected metric.

The output will be shown on the map as a layer with different colours and different sizes depending on results. Three different types of output are available.

1. Numerical output. The green box in Figure 3.18, shows an example for this kind of results
2. Output related to the network nodes. The green box in Figure 3.19a, shows an example for this kind of results
3. Output related to the network edges. The green box in Figure 3.19b shows an example for this kind of results.

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

node in-degree

directed/undirected?

directed

Run model

(a)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

node in-degree

directed/undirected?

undirected

Run model

(b)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

node out-degree

directed/undirected?

directed

Run model

(c)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

local clustering coefficient

directed/undirected?

directed

Run model

(d)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

global clustering coefficient

directed/undirected?

directed

Run model

(e)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

degree of centrality

directed/undirected?

directed

Run model

(f)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

characteristic path length

directed/undirected?

directed

Run model

(g)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

network (average) efficiency

directed/undirected?

directed

Run model

(h)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

network closeness centrality

directed/undirected?

directed

Run model

(i)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

information centrality

directed/undirected?

directed

Run model

(j)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

betweenness centrality (nodes)

directed/undirected?

directed

Run model

(k)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

betweenness centrality (lines)

directed/undirected?

directed

Run model

(l)

Figure 3.16: GRRASP metrics that require only graph selection input

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

minimum path

directed/undirected?

directed

start node

8

end node

22

Run model

(a)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

node criticability

directed/undirected?

directed

Compute the criticability for the node:

22

Run model

(b)

Network metrics calculator

Implementation of some graph metrics computations, see
Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
and Optimization for Cascading Failure Mitigation and Resilience." PhDthesis, Ecole
Centrale Paris (2015) ([link](#))

Select a metrics.

efficiency

directed/undirected?

directed

node 1

8

node 2

22

Run model

(c)

Figure 3.17: GRRASP metrics that require id node input in addition to the graph selection

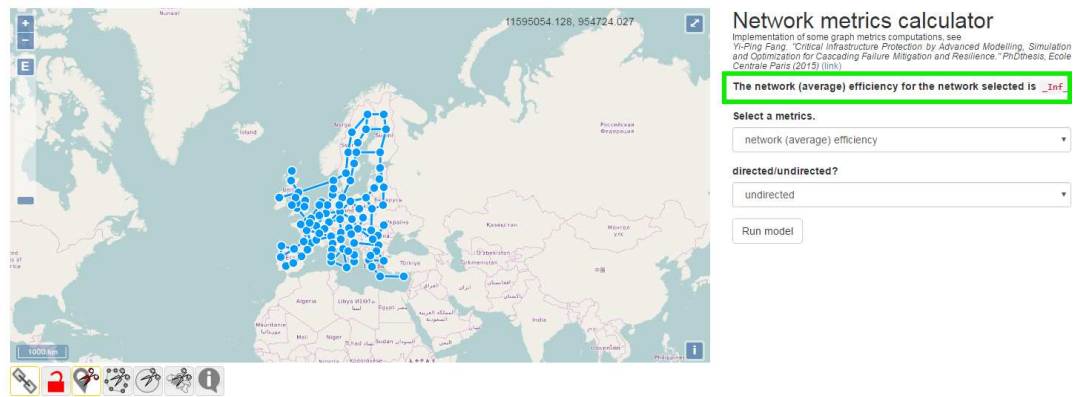
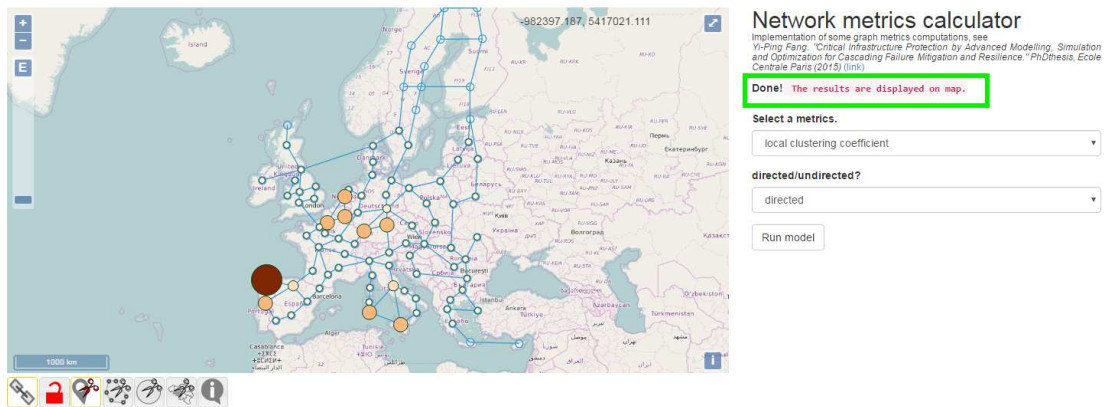
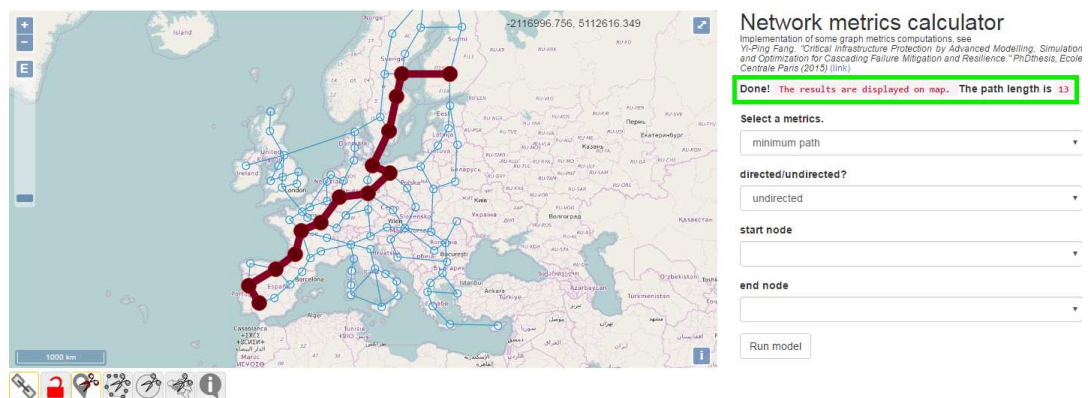


Figure 3.18: GRRASP numerical output



(a) GRRASP nodes result



(b) GRRASP edges output

Figure 3.19: Plots of GRRASP metrics

Network metrics calculator

Implementation of some graph metrics computations, see
 Yi-Ping Fang, "Critical Infrastructure Protection by Advanced Modelling, Simulation
 and Optimization for Cascading Failure Mitigation and Resilience," PhDthesis, Ecole
 Centrale Paris (2015) ([link](#))

NO SELECTION ACTIVE ON THE MAP!

Select a metrics.

node in-degree

directed/undirected?

directed

Run model

Figure 3.20: GRRASP Metrics error management

Finally, an error management mechanism is introduced in GRRASP in order to reassure that in case of wrong data input, the end user gets an error message. An example of such an error is shown in Figure 3.20 where the user tried to launch an analysis without selecting an input graph.

3.4.4 DMCI

3.4.4.1 Overview

The **Dynamic Functional Modeling of Vulnerability and Interoperability of Critical Infrastructures** module (DMCI) is a service based model which assesses the propagation of impacts in terms of disservice due to disruptive events occurring to an infrastructure. The model formulation is thoroughly described in [5]. One of the main advantages of this model is that describes interdependencies on the basis of the services that infrastructures exchange. In addition, the level of functional integrity and operability of an infrastructure is represented at a higher level and it is not required by the end user to enter into the technical details but rather provide generic information such as the amount of time that is needed for an infrastructure to recover after a disruptive event, how much time an infrastructure can continue to operate without exhibiting inoperability if it is not receiving services or products from the infrastructures upon which it depends, etc.

A disruptive event may propagate within the same infrastructure and/or to other CIs by means of cross-sectoral interdependencies. These interdependencies may represent physical, cybernetic, geographic as well as logical interdependencies and also the shift of the demand between two infrastructures that can provide the same or fully/partially replaceable service. The model is dynamic, since both the impact of the specific threat on a infrastructure node and the inoperability functions are time-dependent. The DMCI formalism is characterized by some distinctive features:

- The concept of vulnerable node is the foundation of the model. A vulnerable node defined as "a large functional part of a CI that assures the satisfaction of a considerable part of service demand at regional or local level (e.g. part of a pipeline network, a railway station, a portion of a highway, an underground line) and that does not need further disaggregation for the sake of the analysis." A vulnerable node has to be homogeneous (i.e. uniform in structure and function with respect to service demand), service self-providing (i.e. a system able to supply a value-added service through own means), and vulnerable (i.e. susceptible to threats that could decrease its functional integrity). Vulnerable nodes

are mutually connected to create intra-and inter-infrastructure interdependencies;

- specification of threat nodes, characterized by time-variant intensity and specific potential impact on different vulnerable nodes;
- quantification of both functional and logic interdependencies thanks to the use of both service demand and service capacity for each node of the considered CI;
- time dependent specification of the main parameters of the model: node functional integrity, interoperability, service demand and loss, etc.;
- propagation of both inoperability and demand variations throughout the nodes of the same infrastructure and between interdependent CI.

The model, firstly implemented using [Matlab](#), is able to assess the propagation of impacts on one node to the whole network of interconnected infrastructures independently from the type of threat that affects a node. Therefore, the disservice can be propagated within the same infrastructure or to other CI exploiting the model capability to represent functional, cybernetic, geographical, physical as well as logical interdependencies. The service level can be reduced either by a threat impact on node or through interdependencies. Functional integrity quantifies the direct impact of threats on the node service capability, i.e. the reduction of its maximum service capacity over time (the direct effect). Inoperability quantifies how disturbances coming from the CIs network through interdependencies (physical, cyber, geographical, logical) reduce the maximum service level of a node starting from its actual service capacity. As a consequence, service disruption, globally, is due to combined effects of loss of functional integrity on some nodes and propagation of inoperability between nodes. The mathematical foundation of the model are described in [5] and [1], the extensions, the testing and the applications of this model is reported in [5].

3.4.4.2 Editing and creating new datasets for the DMCI model

The DMCI initial page (see figure 3.22) contains the “Dock” and the “Map” blocks like the previous pages as well as two specific blocks for the DMCI module, “DMCI uploader” and “DMCI model”.

The “DMCI uploader” enables the end user to import a network from a .mat file. A template file (NetworkExampleWith5Nodes.mat) that can be used in MatLab or Octave to build the network can be found in the DMCI module directory ([Drupal installation directory] \htdocs \grrasp_profile\ modules\ custom\ grrasp_dmci\network_example\). The input network for DMCI model is represented in Matlab like a structure with main fields: data and textdata, with many different sub fields (Figure 3.21). These fields are described in detail below. A new method to upload data for the DMCI model is under development including the possibility to upload .txt files that can be edited by the end user using any commercial text editor. This functionality will be part of the next version of GRRASP.

Regarding the DMCI model environment the terms “Layer” will be used like a “Network” synonymous because each single network from a “Geoserver” point of view corresponds to a specific layer. On the other side on the map it is possible to visualize several layers and many networks that may be independent (see Section 3.2). Nevertheless, any operation or modification on a single Layer/Network name is done on the layer shown in “Create or modify layer” drop down menu, shown in Figure 3.22. The end user must always make sure that the Dock selection and name under “Create or modify layer” should always be the same. If this is not the case then the end user will not be able to save any modifications done on the layer. On the other hand the “DMCI model” block allows to create a new network or modify a existing network with the same drawing tools described in the “Draw layers” page.

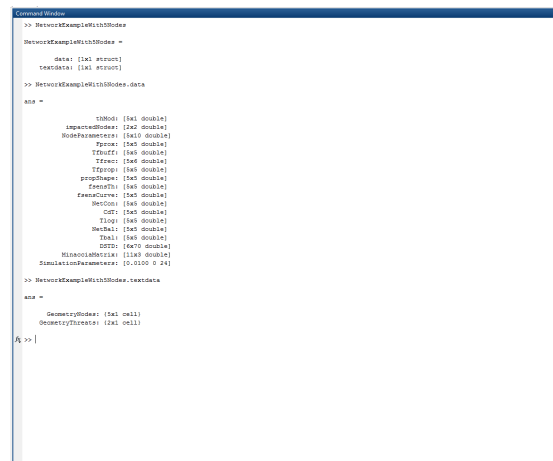


Figure 3.21

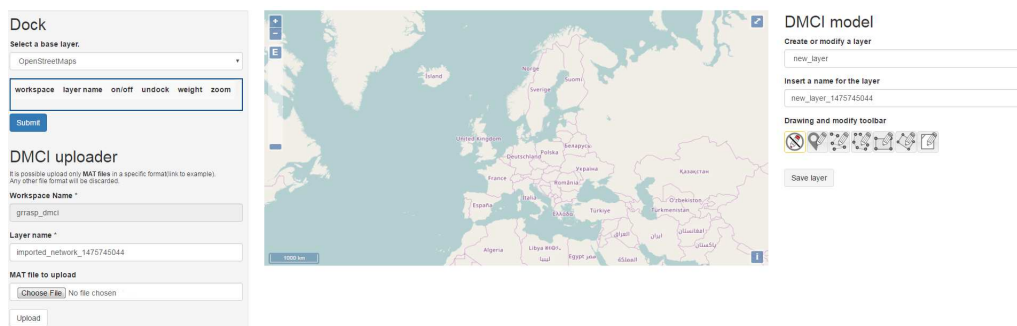


Figure 3.22: GRRASP DMCI initial page

In the drawing phase the geometries added in a “new_layer” will assume a yellow colour to discern it from the other layers eventually added through the “Dock” that are always shown using the default colour (blue). Any additional element that is added on an existing network is always coloured in blue.

If the “Create or modify a layer” drop down menu is set to “new_layer”, a new layer with a default name is created and can be saved using the “Save layer” button. In all other cases the end user can modify an existing layer which is active in the “Dock” block.

Using the “Drawing and modify toolbar” it is possible to create the graph representing the network of infrastructures. The building block of the DMCI model are the functional elements that provide services. These functional elements can be represented in terms of geographical features by nodes, lines or areas. That is done in order to facilitate the visualization and description of parts of network with specific geometric features such as motorways. In addition the definition of functional areas can be helpful in order to develop analyses at low level of granularity.

From a theoretical point of view each node of the network can be characterized using a specific dataset:

- The information that defines the node internal characteristics are listed in the window popup when a new geometry feature (node, line, area) is introduced on the map. This is

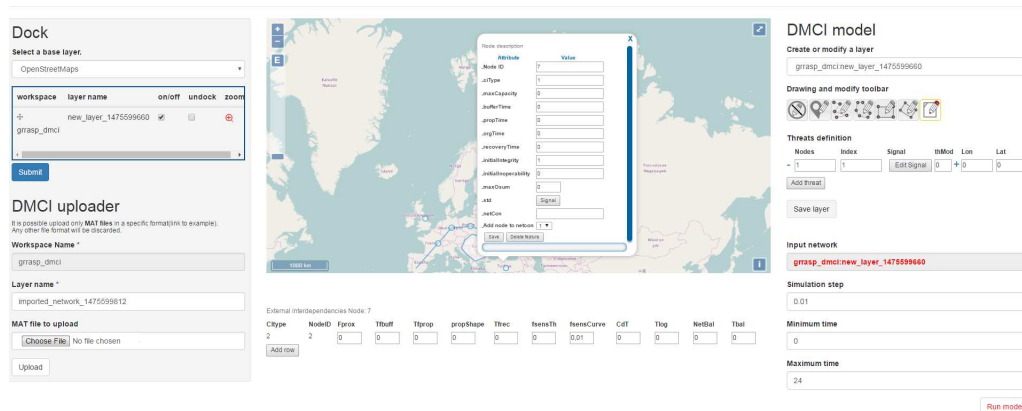
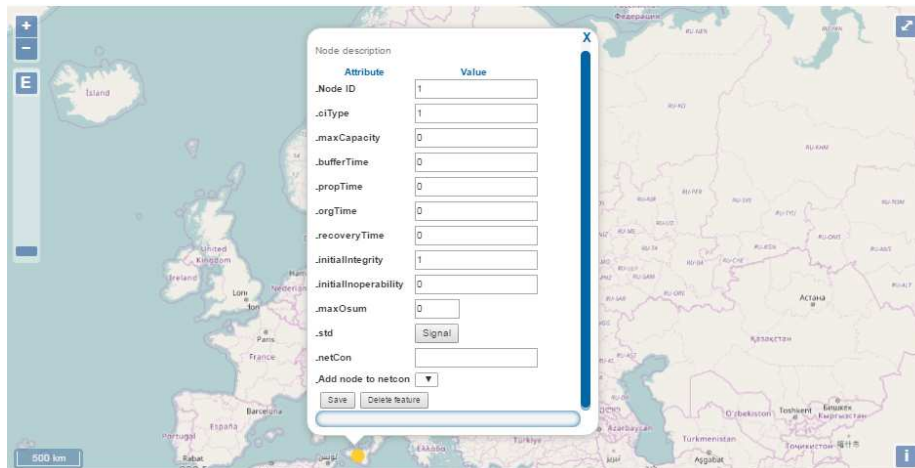


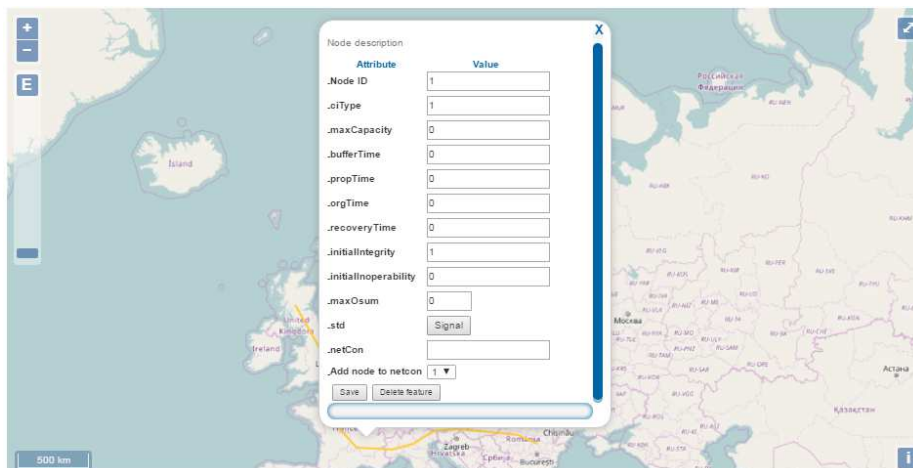
Figure 3.23: GRRASP DMCI main page

shown in Figure 3.24. The information listed in the popup is described in detail below:

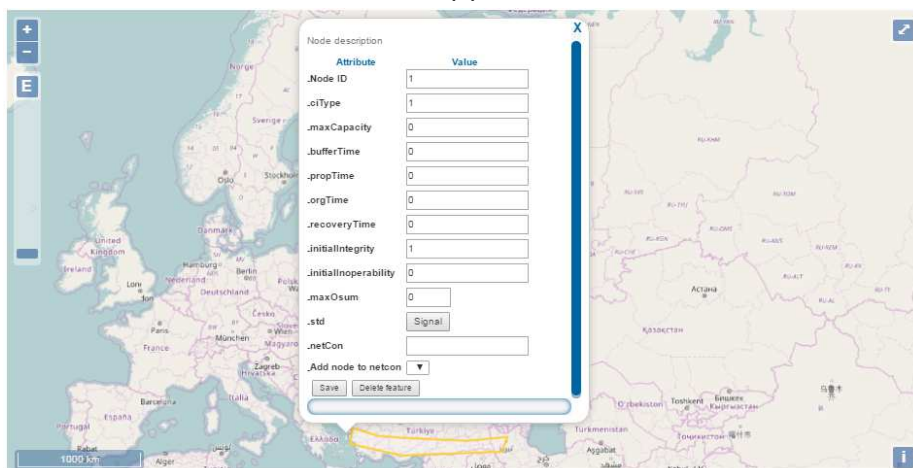
- **Node ID:** unique identifier number of the current node. This is an incremental internal counter, it can only take integer values.
- **CI Type:** Indicates the node's critical infrastructure type: Transport sector node, Gas grid node or electricity network node, or any other node. Value 1 is "Transport", 2 "Electricity", 3 "Gas", etc.
- **Maximum capacity:** This is the maximum service level that a node can provide under the condition that everything in the node works properly and that no inoperability is received by the nodes this node depends upon. The measuring units depend on the infrastructure type. The default value is 0.
- **Integrity modulation:** These four parameters define the dynamic response of the node's functional integrity after the impact of a threat. This part of the model is not related to interdependencies. These variables are measured in hours, as are all times used by the simulator, and could be 0 by default. These variables are:
 - * **buffer time:** This variable defines the amount of time that it takes for the functional integrity of the node to take place when a disruptive event impacts this node.
 - * **propagation time** This parameter shows how quickly the functional integrity of the node is reduced when a disruptive event impacts this node. In order to simplify the data collection process this variable is considered constant over time and equal to the average propagation time.
 - * **organizational time** This is the time that is needed to start the recovery process after the full development of the disruptive event.
 - * **recovery time** The time is needed for full recovery to the functional integrity status before the disruptive event. This time is counted from the moment that the recovery actions have finished and the node starts to return to its previous status.
- **Initial Integrity:** Integrity of the node before any impact takes place. By default is 1 and can take any value in the space [0 1]. Integrity means the capability of a node to offer the services for which it has been designed. This should not be mixed-up



(a)



(b)



(c)

Figure 3.24: DMCI node information popup

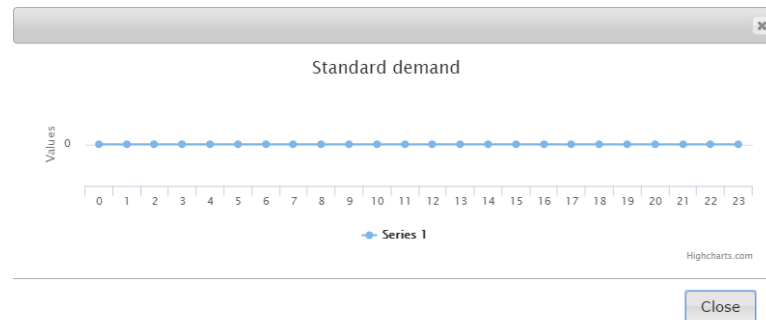


Figure 3.25: DMCI Standard demand default

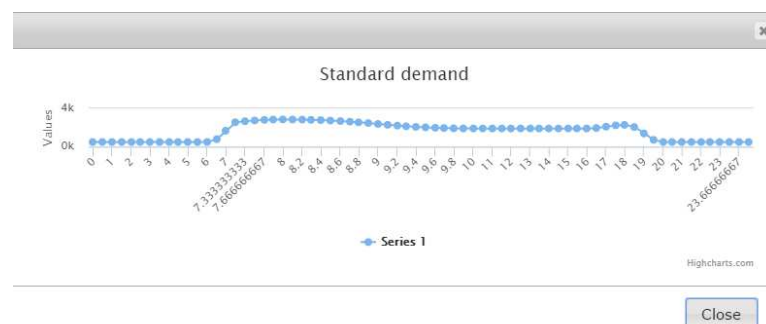


Figure 3.26: DMCI Standard demand

with inoperability. The later may depend on the inoperability received by other nodes upon which a node depends. Even if this node has 100% functional integrity it may be inoperable because it does not receive the services/goods it needs in order to provide services or products.

- **Initial Inoperability:** Node's internal inoperability. By default is 0 and can take any value in the space. [0 1].
- **Node's total inoperability:** Indicates whether to sum up all individual inoperability contributions from nodes upon which a node depends (father nodes) or to only consider the largest individual contribution to determine the node's inoperability (bottleneck approach). It is a binary variable, use 0 to sum or 1 to only take the maximum. By default 1 is used.
- **Standard Demand:** It is a function that represents the node demand under nominal conditions. To help the user to correctly insert the standard demand profile a specific tool shown in Figure 3.26 was developed. With this interactive window the user can modify the values of the function along the simulation time moving up and down the points. The default function is shown in Figure 3.25. The point in this function can have any value in $[0, +\infty)$ depending on the time of infrastructure (in power for example demand is in kWh, in transport persons/hour, etc.)

In the last field located in the feature popup the end user needs to provide the connectivity of the node with other nodes that belong to the same type of infrastructure.

Attribute	Value
Node ID	6
.ciType	1
.maxCapacity	0
.bufferTime	0
.propTime	0
.orgTime	0
.recoveryTime	0
.initialIntegrity	1
.initialInoperability	0
.maxOsum	0
.std	Signal
.netCon	2,3
Add node to netcon	2

Figure 3.27: DMCI Netcon detail

- **Netcon:** Is the (internal) adjacency matrix ⁷ for the nodes in a network belonging to the same type of infrastructure. In fact an adjacency matrix simply provides the connectivity of the nodes. For example in Figure 3.27 the node identified in the network with the “_Node ID” 6 ,in the blue box, has a network connection with the nodes 2 and 3 listed in the “_netCon” field shown in the red box. The user can add a link to the adjacency matrix by the drop down menu “_add node to netcon” that shows only the id of the nodes that belong to the same infrastructure type.

Once the user has finalised the introduction of the data with respect to the performance of a node, then the end user needs to introduce the data for the interdependencies of the node with nodes belonging to a different type of infrastructures.

- The information that relates a node with the nodes that are in different infrastructure sector and the information that relates the node with the network dynamics need to be introduced. This information is shown when a feature is selected (the _Node ID 2 in 3.28). For example in Figure 3.28, the node with id 2 (the father node) belongs to an infrastructure of type 1 (for example electrical network), is connected to the nodes with id 3,4,5 (the son nodes) that belong to an infrastructure of type 2 (for example gas network). The information that relates a node with the nodes that are in different infrastructure types are called “External Functional Interdependencies” and are used to model the inoperability resulting from disservice of nodes of different infrastructures (from the variable “Fprox” to the variable “fsensCurve” in 3.28). In the same way the information that relates the node with the network dynamics are of two different types: “Logical interdependencies” and “Network Balancing”. Logical interdependencies (the variable “CdT” and “Tlog” in 3.28) deal with demand variations due to users’ shifting from one vulnerable node to another in order to get a better service. Network balancing functions (the variable “NetBal” and “Tbal” in 3.28) de-

⁷In graph theory, an adjacency matrix is a square matrix used to represent a finite graph. An element $\neq 0$ of the matrix indicate whether pairs of vertices are adjacent or not in the graph.

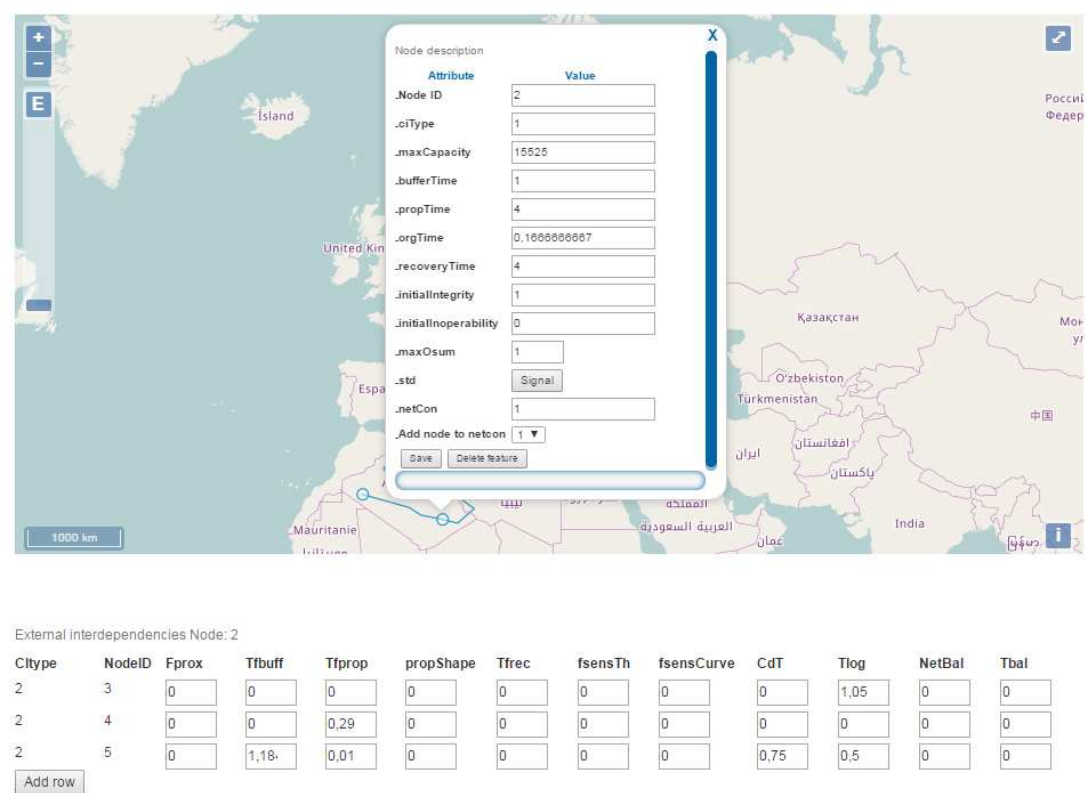


Figure 3.28: DMCI external information



Figure 3.29: DMCI external interdependencies list with default values

fine how operators may rebalance their network to satisfy users needs and minimize overall disservice.

To help the end user to insert an external connection with the relative network dynamic variables, the “add Row” button allows to insert only the nodes with different “_ciTpe” with respect to the selected node. In the external interdependencies and network dynamic list, only the nodes that have at least one no zero value are shown. This is done to simplify the visualization in case of complex networks.

When the “add Row” button is pressed to insert a new external interdependency and network dynamic list, the fields in Figure 3.29 are all set to zero (the default values). The data input is listed and described below when a geometry is edited (see Figure 3.29).

External Functional Interdependencies:

1. **Functional proximity (Fprox):** measures the functional relation between nodes, it is a real value in a set [0 1].

Threats definition

Nodes	Index	Signal	thMod	Lon	Lat
- 3	1	Edit Signal	1	+ -0.231835	25.431221
- 1	2	Edit Signal	1	+ -0.131835	24.431221

[Add threat](#)

Figure 3.30: DMCI threats table

2. **Functional buffer time (Tfbuff)**: Father's node disservice time before the son's node service capacity is affected [h].
3. **Full propagation time (Tfprop)**: Time it takes for the disruptive event in the Father node to propagate and affect the son node [h]. It is considered constant and equal to the average propagation time of the disruptive event.
4. **Propagation shape (propShape)**: Single number that indicates the shape of the propagation transient, can be a real value in the set [0 3]. It represents different types of propagation function, a linear, exponential or step one
5. **Full recovery time (Tfrec)**: Minimum time it takes for the son node to recover from a fully developed perturbation [h].
6. **Functional sensitivity threshold (fsenTh)**: Minimum father's disservice that triggers a propagation to the son node [0 1].
7. **Functional sensitivity curve (fsenseCurve)**: Single number that defines the intensity modulation curve's shape, can be a value in a set [0.01 100].

Logical interdependencies:

1. **Demand transfer coefficient (CdT)**: Indicates the proportion of unsatisfied demand that is transferred to a different vulnerable node, it is a value in the range of [0 1].
2. **Logical time (Tlog)**: Buffer time before users begin shifting to other possible nodes to provide them with service [h].

Network Balancing:

1. **Network balancing (netBal)**: Binary value that simply indicates if the nodes cover the selected node [0 1].
2. **Balancing time (Tbal)**: Time it takes for the new node, group or line to take over the overloaded ones [h].
 - The information regarding eventually node failure, shown in the "Threats definition" table (an example of real network threats list is shown in Figure 3.30 and an empty threat with default values is shown in Figure 3.31).

From a theoretical point of view, a threat is a generic entity with the potential to be the source of a disturbance or disruption for the considered vulnerable node of a generic CI and it is described by (see Figure 3.31):

Threats definition

Nodes Index	Signal	thMod	Lon	Lat		
-	1	Add Signal	0	+	0	0

Add threat

Figure 3.31: DMCI threats table initialization

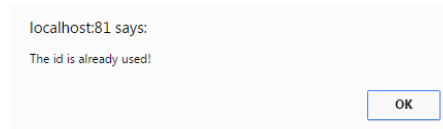


Figure 3.32: DMCI Threat table alert example

- **Impacted node.** The user can insert only the id of the node existed in the network considered for the analysis. Furthermore it is not possible to use the same node id for two different threats. This means that the model allows only a single signal threat for each node in the network. If the user tries to use an id already used for a threat an error message stops the data input process (see Figure 3.32).
- **Index :** The specific threat signal associated with the impacted node. Note that this index can be used in other threats, this mean that the same threat signal may impact on two or more different nodes.
 - * **Threat signal:** like “Standard demand”, to help the user to correctly insert the threat signal, a specific window was developed. An example of real threat signal is shown in Figure 3.33. When the user wants to add a new threat in the network the default threat signal appears like in Figure 3.34. Like in Standard Demand the user can move points up or down to fix the exact function value for the simulation time. In this case, the threat signal values must be between 0 and 1, and the end user is impossible move the point function over the these limits.
 - **Threat modulation (thMod):** indicates whether a threat's signal should be modulated in its impacted nodes or if, on the other hand, their functional integrity must simply mirror the threat signal. It is a binary variable where 1 indicates the signal should be modulated and 0 indicates otherwise.

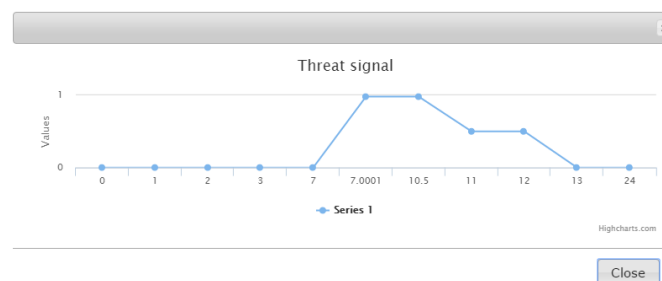


Figure 3.33: DMCI threat signal example

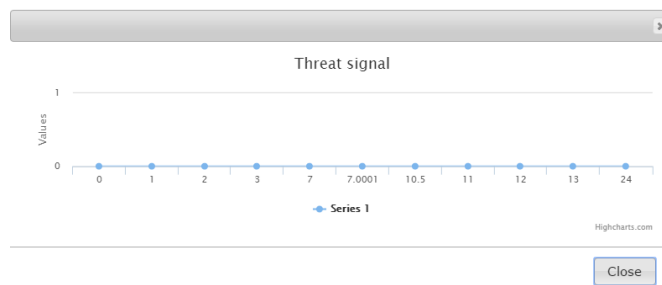


Figure 3.34: DMCI threat signal default

DMCI model

Create or modify a layer

grrasp_dmci:example_network

Drawing and modify toolbar

Threats definition

Nodes	Index	Signal	thMod	Lon	Lat
- 3	1	Edit Signal	1	+ -0.231835	25.431222
- 1	2	Edit Signal	1	+ -0.131835	24.431222

Add threat

Save layer

Figure 3.35: DMCI save network

- **Geographical coordinates:** Longitude and Latitude of the threat. These values can be extracted from a simple click on the map after the activation of the event by the “+” link just before. These two values are not involved in the model simulation.

It is important to mention that when the user adds (or modifies) any kind of information as described in detail in the points above, the user must save this information using the “Save layer” button. A very important issue is related to the “Save layer” which is related to the dropdown menu selection “Create or modify a layer”. If this selection is changed, the last data inserted by the user will be lost. In other words during the editing session it is not possible to change the name of the layer in the “Create or modify a layer” drop down menu without losing all the information added before the last save.

3.4.4.3 Model execution

Once all the information required by the model is filled in for a specific network it is necessary to save all the components required using the “Save layer” button below the threat definition (see Figure 3.35). This submission will save the layer within the Drupal database in JSON format.

In order to run the model on a specific input network the user has to select the network name in the drop down menu on the top of the “DMCI” model block and set the simulation parameters:

Input network
grrasp_dmci:example_network

Simulation step
0.01

Minimum time
0

Maximum time
24

Run model

Figure 3.36: DMCI simulation parameters

- The “input network” shows the name of the network input for the model and is not editable.
- the simulation start time (Minimum time)
- the simulation stop time (Maximum time)
- Simulation step: is measured in hours or fractions of hours. A nominal value of 0.01 h is used by default.

The (maximum time - minimum time), represent the time interval for the model simulation. The $1/(\text{simulation step})$ is the time slice considered in the time interval. The “Run model button” below these three items launches the execution of the model.

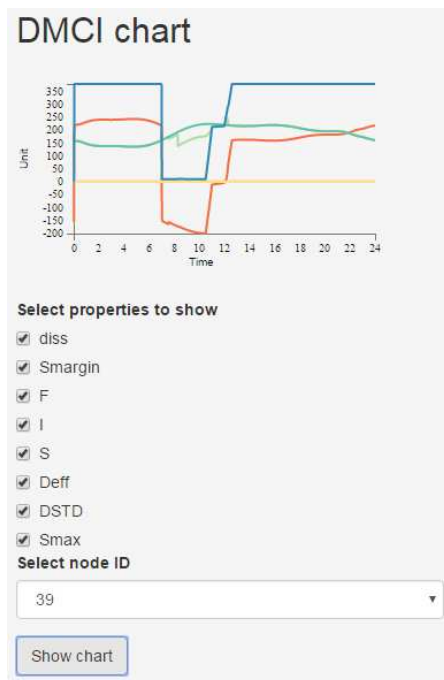
3.4.4.4 Output visualization

After the finalisation of the analysis, three different blocks showing the output are displayed. The first output block is related to a set of variables that characterize the network nodes. The second are statistical analyses regarding the network input and the last shows an animation along the simulation time for a subset of node variables.

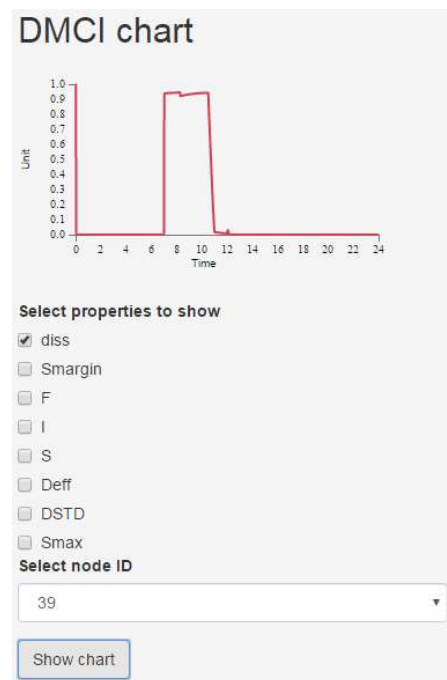
- **The “DMCI chart”:** For each node it is possible to show in a graph, the following output variables along the simulation time (see fig. 3.37):
 - **diss:** Disservice level of each node.
 - **Smargin:** Service margin of each node.
 - **F:** Functional integrity of each node.
 - **I:** Inoperability of each node.
 - **S:** Service finally performed by each node.
 - **Deff:** Effective demand that each node finally satisfies at a fixed time.
 - **DSTD:** Standard Demand.
 - **Smax:** Maximum service that each node can perform after all restrictions have been taken into account.

These variables can be shown all together like in Figure 3.37a, individually (see Figure 3.37b) or a subset (see Figure 3.37c). To show the chart, after the checkbox selection change, the user must press the button “Show chart”.

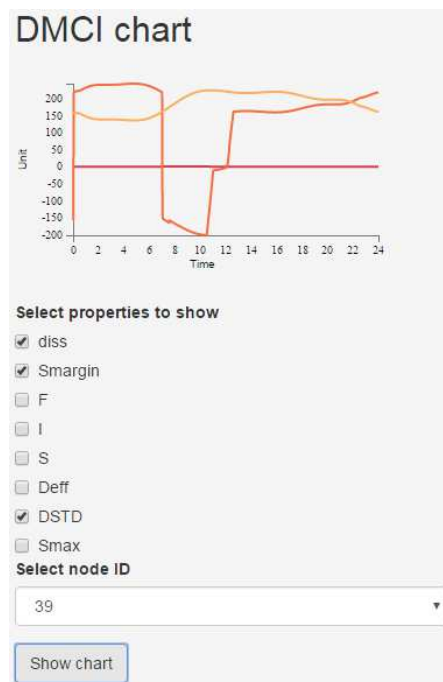
- The “DMCI stat”: In these two tables we are collecting statistical output for each nodes (see fig. 3.38).



(a)



(b)



(c)

Figure 3.37: GRRASP DMCI chart

DMCI stat

Impacted nodes statistics				
NODE ID	CI TYPE	PEAK VALUE	TOTAL DISS	DISS TIME
1	1	1	1.385817713	4
2	1	1	1.412970535	4
3	1	1	3.816105965	9
4	1	1	3.816105965	9
5	1	1	1.446655519	4
6	1	1	1.36634465	4
7	1	1	1.446655519	4
8	1	1	1.36634465	4
9	1	1	1.1375	2
10	1	1	1.212208795	3
11	1	1	2.703227254	10
12	1	1	3.332800508	8
13	1	1	1.414014438	5
14	1	1	1.389152644	4
15	1	1	1.248317713	3
16	1	1	1.460059775	5
17	1	1	1	1
18	1	1	1.075444251	2

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Disservice assessment				
CI TYPE	Average/Abso	Average/pero	Cumulative/Al	Cumulative/p
1	0.0702039684	0.0351019842	296.6117666	0.6474745691
2	0.1538037107	0.0769018553	161.4938962	0.3525254309

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Figure 3.38: GRRASP DMCI statistics

The “Impacted nodes statistics” table shows a ranking of the nodes by Diss peak, Total disservice and longest impact (Diss time in the table). The Disservice assessment table shows statistics grouped by infrastructure type.

- **The “DMCI animation”:** Provides an animation scenario for the values of I, F and Diss, mentioned before in the “DMCI chart” section, along the simulation time. When the value of these variables in a node changes, this corresponds to a color change on the map according to the legend, see Figure 3.39.

3.4.4.5 DMCI use cases

Import a network from file As described above it is possible to import a network directly from an existing “.mat” file. To do this follow the steps shown in Figure 3.40 which demonstrate how to import, visualize and run the network which is provided as an example together with the installation and which can be found in ([Drupal installation directory] \htdocs \grrasp_profile\ modules\ custom\ grrasp_dmc\ network_example\ NetworkExampleWith5Nodes.mat) :

- **Step 1** - Press the “Choose file” button in the DMCI uploader block to navigate file system and select the “NetworkExampleWith5Nodes.mat”.
- **Step 2** - Press the “Upload” button to import the network in the Drupal database. If the network is correctly uploaded in the database then it will appear in the “Dock” block.
- **Step 3** - Flag the “on/off” checkbox in the “Dock” block to visualize the network on the map.
- **Step 4** - Select the network from the drop down menu “Create or modify layer” to visualize the “Threats table” and “Simulation parameters”.
- **Step 5** - Finally the user can run the model with the “Run model” button. At the end of the model execution the results appear as shown in Figure 3.41.

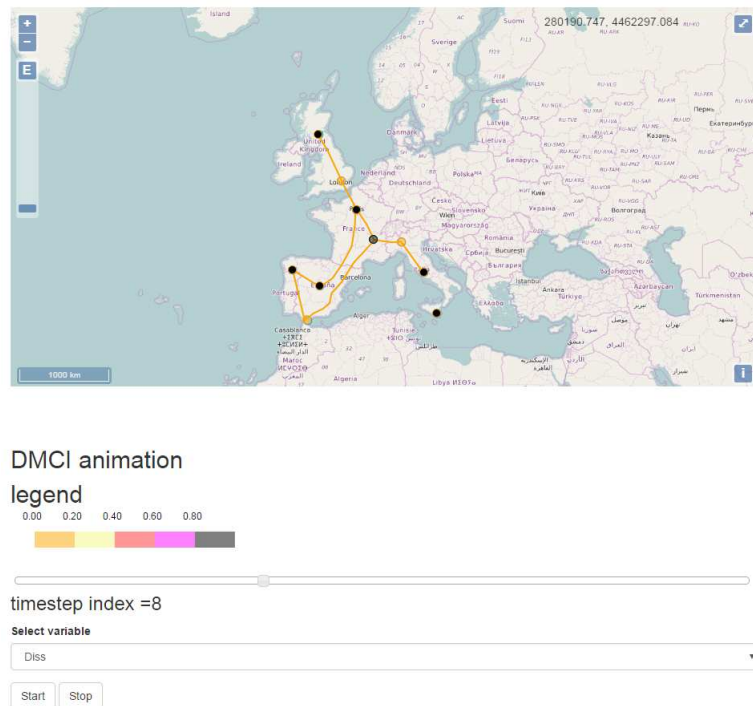


Figure 3.39: GRRASP DMCI animation

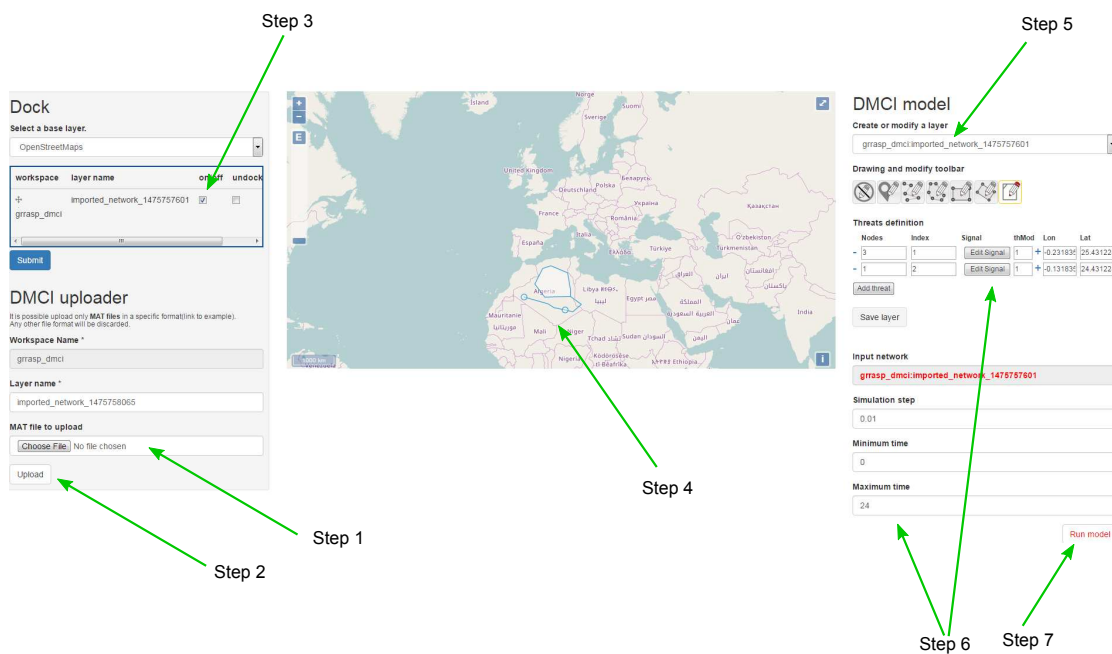


Figure 3.40: GRRASP DMCI import and run model

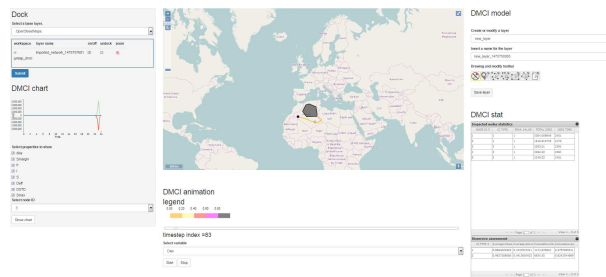


Figure 3.41: GRRASP DMCI output result

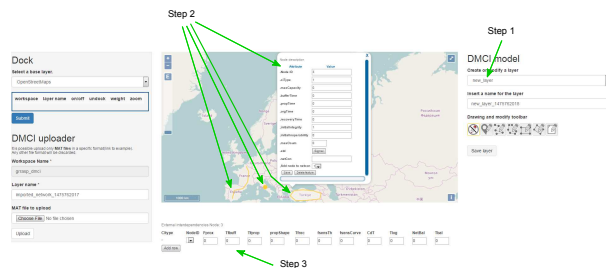


Figure 3.42: GRRASP DMCI example new network

Build a new network The user can also create an input network for the DMCI model starting from an empty network. To do this follow the steps shown in Figure 3.42 which are also listed below.

- **Step 1** - Make sure that the drop down menu is set to “new_layer”.
- **Step 2** - Insert points, lines or polygons (the network nodes) one by one according to the network topology, using the “Drawing and modify toolbar” identical to the “Drawing toolbar” described in Section 3.3. The user for each node drawn on the map can insert the information related to the internal and/or external
- **Step 3** Interdependencies.

The user can repeat Step 2 and/or 3 to add as many nodes as it is required in order to obtain the network topology (Figure 3.43). If necessary the user can also insert the threats according to the simulation scenario (see Section 3.4.4.2).

When the user finishes building the network it can then be saved with the “Save layer” button. At this point the user in order to run the model needs simply to follow the procedure from Step 3 to Step 7 as described in 3.4.4.5.

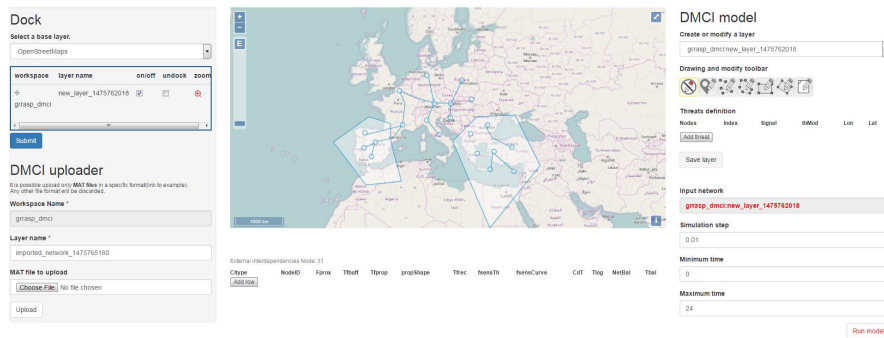
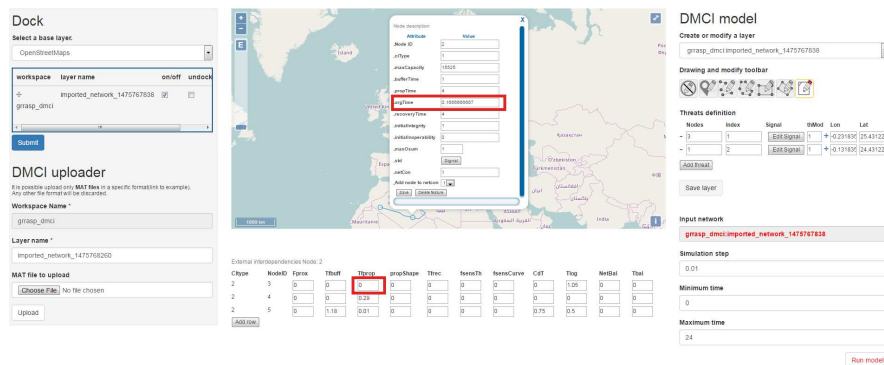
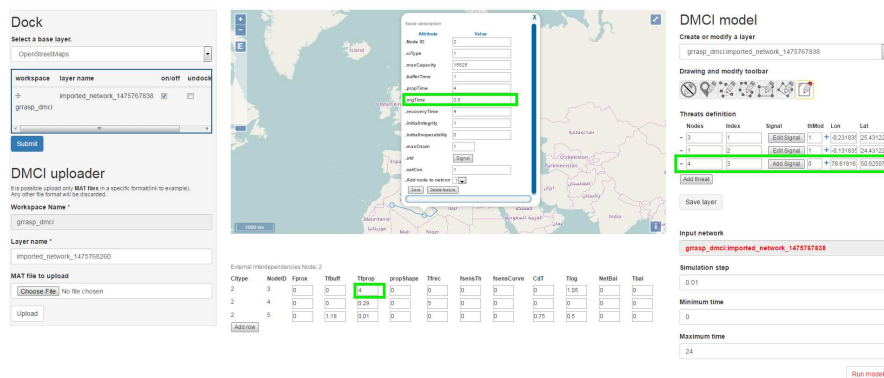


Figure 3.43: GRRASP DMCI complex network



(a)



(b)

Figure 3.44: GRRASP DMCI network modification

Dock

Select a base layer:

workspace layer name on/off undock

workspace	layer name	on/off	undock
+	Imported_network_1475767838	<input checked="" type="checkbox"/>	<input type="checkbox"/>
+	grrasp_dmci	<input type="checkbox"/>	<input type="checkbox"/>

Submit

DMCI uploader

It is possible to upload only MAT files in a specific format (link to example). Any other file format will be discarded.

Workspace Name *

grrasp_dmci

Layer name *

Imported_network_1475767838

MAT file to upload

Choose File No file chosen

Upload

DMCI model

Create or modify a layer

grrasp_dmci.Imported_network_1475767838

Drawing and modify toolbar

Threats definition

Nodes	Index	Signal	thMod	Lon	Lat
3	1	<input type="text" value="Edit Signal"/>	<input type="text" value="1"/>	-0.231835	25.431122
1	2	<input type="text" value="Edit Signal"/>	<input type="text" value="1"/>	-0.131835	24.431122

Add threat

Save layer

Input network

grrasp_dmci.Imported_network_1475767838

Simulation step

0.01

Minimum time

0

Maximum time

24

Run model

(a)

Dock

Select a base layer:

workspace layer name on/off undock

workspace	layer name	on/off	undock
+	Imported_network_1475767838	<input checked="" type="checkbox"/>	<input type="checkbox"/>
+	grrasp_dmci	<input type="checkbox"/>	<input type="checkbox"/>

Submit

DMCI uploader

It is possible to upload only MAT files in a specific format (link to example). Any other file format will be discarded.

Workspace Name *

grrasp_dmci

Layer name *

Imported_network_1475767838

MAT file to upload

Choose File No file chosen

Upload

DMCI model

Create or modify a layer

grrasp_dmci.Imported_network_1475767838

Drawing and modify toolbar

Threats definition

Nodes	Index	Signal	thMod	Lon	Lat
3	1	<input type="text" value="Edit Signal"/>	<input type="text" value="1"/>	-0.231835	25.431122
1	2	<input type="text" value="Edit Signal"/>	<input type="text" value="1"/>	-0.131835	24.431122

Add threat

Save layer

Input network

grrasp_dmci.Imported_network_1475767838

Simulation step

0.01

Minimum time

0

Maximum time

24

Run model

(b)

Figure 3.45: GRRASP DMCI network topology modification

Modify an existing network Starting from an imported network (see Section 3.4.4.5) or a new network (see Section 3.4.4.5), the user can add new nodes and modify the existing nodes.

To show how to modify an existing network the user has to visualize the network (for example the network used in 3.4.4.5). At this point the user can modify any information related to the network or add new nodes, lines or areas. The user can modify the data as shown in Figure 3.44 or the topology of the network (add/remove network node) as in Figure 3.45.

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