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1 Introduction

1.1 Acronyms

Acronym	Explanation
BS	Base Station (mobile telecommunication)
BTS	Base Transceiver Station
CBRS	CIP Benchmarking Reference Set
CD	Cyber Dependency
CI	Critical Infrastructure
CIP	Critical Infrastructure Protection
CIPRNet	Critical Infrastructure Preparedness and Resilience Research Network
EU	European Union
FP	Framework Programme
GDN	Gas distribution node
OL	Operative Level
SS	Substation
TLC	Telecommunications
UA	Urban Area
WDC	Water distribution centre

1.2 Introduction

As dramatically experienced in several situations due to natural (e.g., Kathrina hurricane, Chelyabinsk meteor crash), accidental (e.g., blackouts experienced in 2003 in USA and Italy), and intentional (e.g., 9/11 terroristic attack, STUXNET cyber attack) circumstances, Critical Infrastructures (e.g., power, telecommunications, etc.) are exposed to the threat of cascading failures. Such exposure may lead to the complete or partial halt of the services provided to society, with dramatic and often life-threatening consequences. The reliable, resilient operation of dependent critical infrastructure systems is "essential to the Nation's security, public health and safety, economic vitality, and way of life", true not just for the EU but across the globe. Risk managers preparing for disruptive events, whether by attack, disaster, accident, or common cause failure, must plan for mitigating the disruption of these infrastructures, their composing subsystems and across their dependencies.

Understanding the impact that underlying infrastructure systems may have on other infrastructure, on the overall economic system and on the society at large is vital for enabling preparedness and response planning for a (likely inevitable) disruption. The dependent nature of infrastructure systems and their services has gained considerable government (e.g, [2]) and research attention (e.g., [1], [3], [4], [5], [6], [7], [8]).

It should be noted that, since the pioneering works of Bàrabasi [9], Strogatz [10] and Holme [11] in the early 2000s, it has become paramount that attacks or disruptions affecting complex networks of highly interacting elements may have very different outcomes, depending on how such disruptions match with the topological structure of the networks. In fact, based on the topology of the network, several studies (see for instance [11] or [12]) pinpointed attack/disruption patterns that correspond to dramatic consequences for the network.

While attempting to implement a true Critical Infrastructure Protection (CIP)/ Critical Infrastructure Resilience (CIR) strategy, however, several difficulties have to be overcome.

Moreover, note that a focus on topology alone could be misleading while attempting to implement any CIP/CIR strategy. In order to tackle such an issue, a typical approach is to resort to modelling and simulation techniques.

However, setting up a detailed simulator able to capture the complexity of the dependency phenomena in place among Critical Infrastructures (CIs) and their subsystems is a hard task. Indeed, as argued in a recent survey on CIP [13], it is "*difficult to access data or lack of precise data is a key problem in the field (of Critical Infrastructure Protection, editor's note). To provide a detailed description and modeling of interdependent CIs, it requires a lot of relevant data, such as the topologies of single CI, component geographical locations, interdependency relationships, operational, emergency and other procedures used by CI owners under normal or crisis scenarios, government and corporate policies*".

It should be noted further that, to date, no "reference" data model exists which allows benchmarking different simulation approaches.

1.3 Aim of the document

This report aims at developing and describing a benchmarking reference data set, useful to perform comparative analysis of CIP models using the benchmark reference set of data.

Notice that the complexity detailing every possible aspect of the physical and functional behaviour of the different CIs in nominal condition and considering domino effects and dependencies is overwhelming. Hence, we assume a high-level perspective. Therefore, we focus on the coupling and dependencies among the different CIs and subsystems, leaving to the modeller of the particular simulation approach the task to account for the physical and functional/logical behaviour underlying the different CIs.

In this document, we consider two different spatial scales: regional-level and urban-level. Specifically, we consider a fictional region, namely *Esperantia*, enclosed in a 100* 100 km square. We model different CIs, namely: urban areas, electric power transmission and distribution grids, telecommunication network, railways and roads networks, and drinking water and gas distribution networks.

Specifically, the benchmarking reference data set encompasses several entities (urban areas, substations, etc.) and several typologies of dependency relations (e.g., cyber, functional, common cause failure). Such relations are modelled as a *multigraph*, i.e., a superposition of network topologies where each network models a specific typology of relation.

Without limiting the scope to a mere structural description, the reference scenario has the ambition to characterise the input-output behaviour of the different entities in a dynamic fashion, focusing mainly on how the operative condition of the entities degrades when they are dealt a direct damage. Moreover, it takes into account when the entities lack the essential resources provided by other entities that share some kind of dependency with them.

Moreover, we complement the benchmarking reference data set with an urban-scale reference data set, where we take into account a portion of the main city within Esperantia, namely, *Esperantia City*; the portion of the city under exam is enclosed in a 10* 10 km square. In particular, we detail the main components of the power distribution and telecommunication networks and the major hospitals.

Notice that, the initial benchmarking reference data set aims at becoming a reference for the testing and validation of impact/consequences analysis tools and methodologies, thus it is intentionally general and abstract and does not refer to any particular modelling approach for the dynamic behaviour of the different entities in place. The input-output dynamic behaviour, therefore, will be described in a highly abstract way, leaving room to the modellers.

Notice further that the data set is the result of the anonymisation and merging of different data sources. The topological information provided in some of the plots are, therefore, in no mean descriptive of a real topology and should be considered just a convenient way to display the different types of infrastructural information on a map.

1.4 CIP Benchmarking reference set in a nutshell

The CIPRNET CIP benchmark reference set describes the fictional region of Esperantia, a region enclosed in a 100* 100 km square and a detailed 10* 10 km urban-type of area.

The region features two main urban areas and 28 minor urban areas, seven substations, 35 telecommunication base stations, six water distribution stations and 20 gas distribution stations.

The urban areas are connected via a network of different transport routes: highways and local roads, as well as railways.

The electric substations are connected via a mesh representing the power transmission backbone; moreover, the different urban areas and telecommunication base stations (BS) are connected to primary electric cabins via a radial power distribution network. Such radial network represents also the physical dependencies between the power distribution infrastructure and the other entities encompassed in Esperantia.

Similarly, the telecommunication base stations are connected via a redundant network mesh that represents the backbone of the telecommunication infrastructure, while residential areas and substations each use one or more telecommunication base stations in their neighbourhood. In this case, the links connecting the telecommunication backbone to the other entities partly represent cyber dependencies, as they model the fact that one entity relies on the services provided by the telecommunication infrastructure for its correct operation.

For the drinking water and gas infrastructures, we consider for each of them a network representing the transport system of such commodities as well as a distribution network.

Moreover, we provide data to model common cause failures with respect to catastrophic events such as an avalanche, flooding or a tsunami, and we show the cyber dependencies in place between the different entities.

As for the urban-level reference set, we take into account a 10 * 10 km wide portion of Esperantia City, the main city within the Esperantia reference set. Specifically, we consider three Base Transceiver Stations (BTSs), eight hospitals, and a power distribution network involving five primary electric substations and 101 secondary electric substations, of which three are automated and telecontrolled by a BTS, 50 are telecontrolled via BTS, and 48 are not telecontrolled.

Notice that, in the following figures, we will use fictional cartographies to represent Esperantia; such cartographies are used only to improve the visual rendering of the different networks or entities, but they have no concrete relation with the Esperantia region.

2 CIP Benchmarking reference set

2.1 A Guide to Using the Data Set

This document represents a description and explanation of the data set which is offered publicly via the web portal as a benchmarking reference set.

2.1.1 Regional-Scale Data Set

The regional-scale data set is composed of three spreadsheets, each containing several sheets.

The spreadsheet **ESPERANTIA_Elements** contains general information on the different entities that constitute the benchmark reference set. Specifically, each sheet within such a spreadsheet contains information on a given typology of entity (the typology of an entity is specified in the sheet name).

Notice that each row corresponds to an entity, and that each row is associated to a unique identifier of the entity.

The identifiers are as follows:

- UAi stands for the i-th urban area;
- SSi stands for the i-th substation;
- BSi stands for the i-th telecommunication base station;
- WDCi stands for the i-th water distribution station;
- GDNi stands for the i-th gas distribution station.

For all entities, we provide the abscissa and the ordinate (in km) representing their (relative) position in Esperantia. For the urban areas (UAi), we provide also the population size.

The spreadsheet **ESPERANTIA_Networks** contains general information on the different graphs and topologies featured by the benchmark reference set (we will explain the topologies in detail later in this chapter). Specifically, each sheet within such a spreadsheet contains information on a given topology (the typology of an entity is specified in the sheet name).

Specifically, the networks considered are:

- Road Transport Network (TRSPN);
- Railway Network (RLWN);
- Power Transmission Network (PTN);
- Power Distribution Network (PDN);
- Telecommunication Backbone (TLCBKBN);
- Telecommunication “Distribution” Network (TDN);
- Drinking Water Transport system (WTBKN);
- Drinking Water Distribution Network (WDN);
- Gas Transport Backbone (GBKN);
- Gas Distribution Network (GDNWK);
- Common Cause Failure of Networks in the case of an Avalanche (CCFA);
- Common Cause Failure of Networks in the case of a Tsunami (CCFT);
- Common Cause Failure of Networks in the case of a Flooding (CCFF);
- Cyber Dependencies (CD).

Notice that each row corresponds to a link within the topology specified by the sheet name, and such link is associated to a unique identifier. For each link, we specify the identifier of the two endpoints (FROM and TO columns within each table in the spreadsheet).

Specifically, the identifiers are as follows:

- TRSPNi stands for the i-th edge in the Road Transport Network;
- RLWNi stands for the i-th edge in the Railway Network;

- PTNi stands for the i-th edge in the Power Transmission Network;
- PDNi stands for the i-th edge in the Power Distribution Network;
- TLCBKBNi stands for the i-th edge in the Telecommunication Backbone;
- TDNi stands for the i-th edge in the Telecommunication "Distribution" Network;
- WTBKNi stands for the i-th edge in the Water Transport System;
- WDNi stands for the i-th edge in the Water Distribution Network;
- GBKNi stands for the i-th edge in the Gas Transport Backbone;
- GDNWKi stands for the i-th edge in the Gas Distribution Network;
- CCFAi stands for the i-th edge in the set of Common Cause Failure of Networks in the case of Avalanches;
- CCFTi stands for the i-th edge in the Common Cause Failure of Networks in the case of a tsunami;
- CCFFi stands for the i-th edge in the Common Cause Failure of Networks in the case of a flooding;
- CDi stands for the i-th edge in the set of Cyber Dependencies.

The last spreadsheet, namely **ESPERANTIA_Dependencies** contains information on the dependencies for each entity. Each sheet within the spreadsheet contains a table summarizing the kind of dependency. For each row we report the identifier of the element experiencing a dependency phenomenon. A set of parameters is used to describe its dynamic dependency behaviour from a high level perspective: time t_{half} representing the time in which the element's degradation has reached an intermediate condition, the slope k representing the steepness of the descent of the overall condition of the element, and the minimum achievable degree of functioning $\sigma_{A,B,min}$ (such parameters and their meaning will be discussed in section 2.2.4).

Notice that the parameter $\sigma_{A,B,min}$ is shown as sigma(A,B,min) in the spreadsheet.

Each sheet represents a particular type of dependency; we adopt the formalism

Dependency X-> Y

for the name of the sheet, to represent that Y depends on X; in this view X can be an entity or a good/service provided by an entity, and the dependency models the effect of the disruption of X on Y or the lack of service X provided to Y.

Specifically, the spreadsheet encompasses:

- **Dependency UA->UA** models the dependency of UAs on other UAs;
- **Dependency Power->UA** models the dependency of UAs on power;
- **Dependency TLC Service -> UA** models the dependency on Telecommunication (TLC) services;
- **Dependency Water-> UA** models the dependency of UAs on drinking water;
- **Dependency Gas->UA** models the dependency of UAs on gas;
- **Dependency Railway ->UA** models the dependency of UAs on the correct functioning of railways;
- **Dependency Cyber ->UA** models the cyber dependency of UAs on other entities;
- **Dependency Power->SS** models the dependency of SSs on power provided by other power substations;
- **Dependency TLC Services ->SS** models the dependency of SSs on telecommunication services;
- **Dependency Cyber -> SS** models the cyber dependency of SSs on other entities;
- **Dependency BS->BS** models the dependency of BSs on other BSs;
- **Dependency Power->BS** models the dependency of BSs on power;
- **Dependency Cyber -> BS** models the cyber dependency of BSs on other entities.

2.1.2 Urban-Scale Data Set

The urban-scale dataset is composed of one spreadsheet, namely **ESPERANTIACITY,** describing the position and the relations among several entities.

The spreadsheet **ESPERANTIACITY** contains general information on the different entities that constitute the benchmark reference data set, as well as information on the dependency phenomena among such entities.

The proposed urban-scale reference set features several different entities, distributed as shown in Figure 24. In the Figure, each entity is associated to a unique identifier, which is lowercase in order to distinguish it from the regional scale identifiers.

The next table details the position of the entities within a 10 * 10 km square portion of the main city within Esperantia, Esperantia City.

In order to univocally define the entities within such a reference set, we use the following conventions:

- *hi* stands for the i-th hospital;
- *ssi* stands for the i-th secondary substation;
- *pi* stands for the i-th primary substation;
- *btsi* stands for the i-th BTS.

The spreadsheet contains four tables:

1. The details of the different entities considered, with their identifier, description and position;
2. A table describing the dependencies of secondary substations on the BTSs: each row is a dependency relation involving a substation and a BTS;
3. A table describing the dependencies of BTSs on the secondary substations: each row is a dependency relation involving a substation and a BTS;
4. A table describing the dependencies of hospitals on the secondary substations: each row is a dependency relation involving a substation and a hospital.

2.2 Regional Scale Reference Set

2.2.1 Entities

In this section, the position and details of the main entities considered in the Esperantia benchmarking reference set are discussed.

2.2.1.1 Urban areas

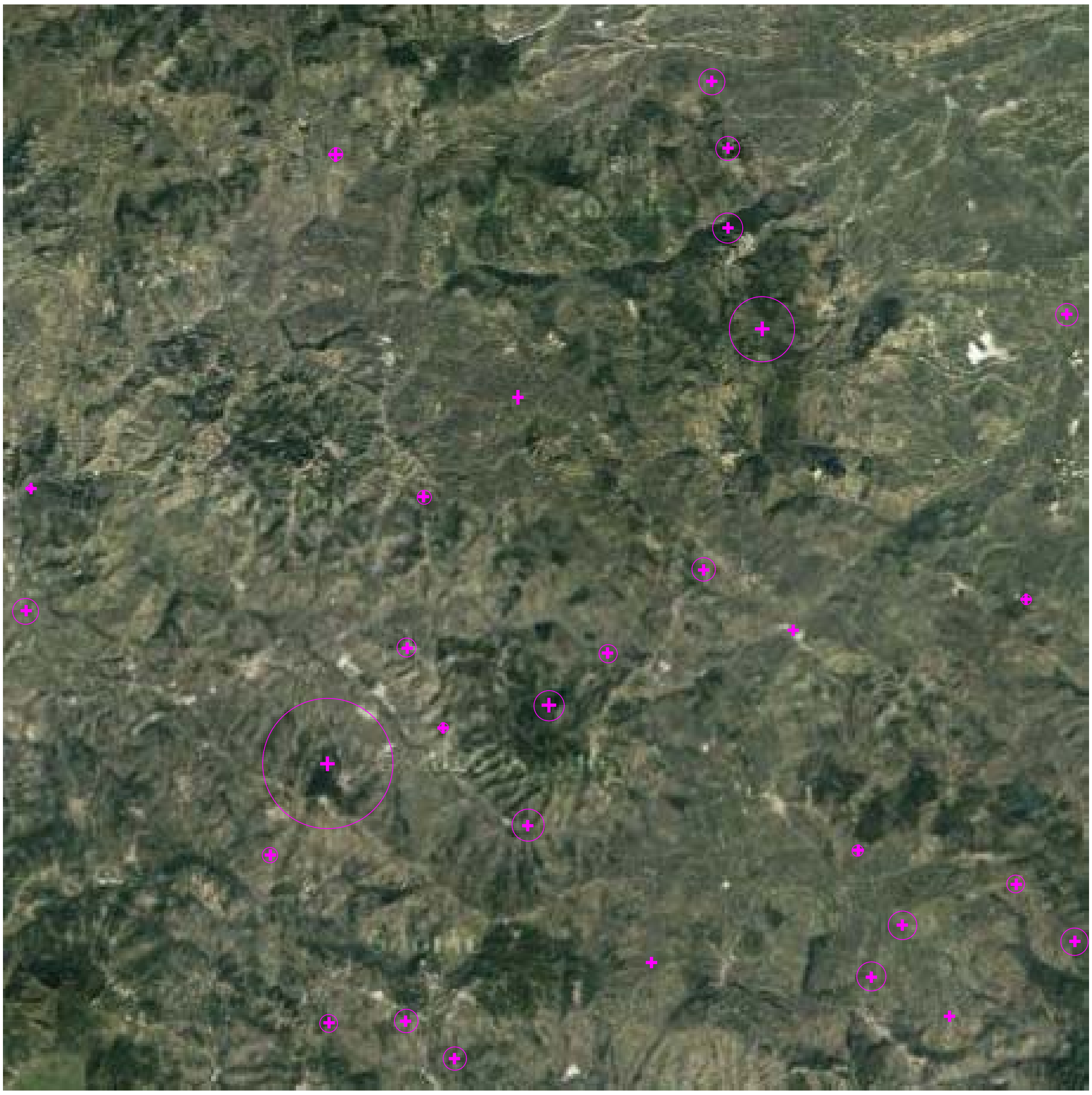

Figure 1: 30 Urban areas considered in Esperantia, each with a circle whose radius is proportional to population size[1].

Esperantia encompasses 30 urban areas: two main urban areas with 4 and 2 million inhabitants each, and 28 minor urban areas between 2 and 984 thousand inhabitants. Figure 1 shows with purple crosses the points associated to the urban areas, while magenta circles centred in the purple crosses have a radius which is proportional to the population size of each urban area.

The next table summarises the relative vertical and horizontal position of the urban areas in km with respect to the upper left corner and the population of the urban areas.

[1] The underlying image is fiction and it has no meaning. It has been added just to give a more understandable view with respect to white background.

Table 1: Urban areas

ID	Ordinate (km)	Abscissa (km)	Population
UA1	30,00	70,00	4000000
UA2	70,00	30,00	2000000
UA3	50,38	64,68	930040
UA4	30,77	13,87	399019
UA5	47,55	36,24	47401
UA6	78,81	78,03	342373
UA7	66,85	13,35	735966
UA8	2,15	55,98	794682
UA9	30,08	93,94	544905
UA10	98,09	28,66	686223
UA11	80,08	89,61	893632
UA12	59,75	88,40	54791
UA13	94,37	54,91	303661
UA14	72,83	57,67	2191
UA15	2,58	44,65	195476
UA16	64,63	52,12	720165
UA17	37,23	93,71	721753
UA18	82,95	84,90	877799
UA19	37,25	59,31	582432
UA20	87,25	93,35	70684
UA21	66,84	20,67	922744
UA22	65,38	7,20	800372
UA23	40,67	66,69	285946
UA24	93,37	81,09	543663
UA25	48,45	75,67	984776
UA26	41,70	97,17	715678
UA27	98,79	86,41	838969
UA28	38,88	45,47	433260
UA29	24,66	78,44	470624
UA30	55,82	59,88	560713

2.2.1.2 Electric Substations

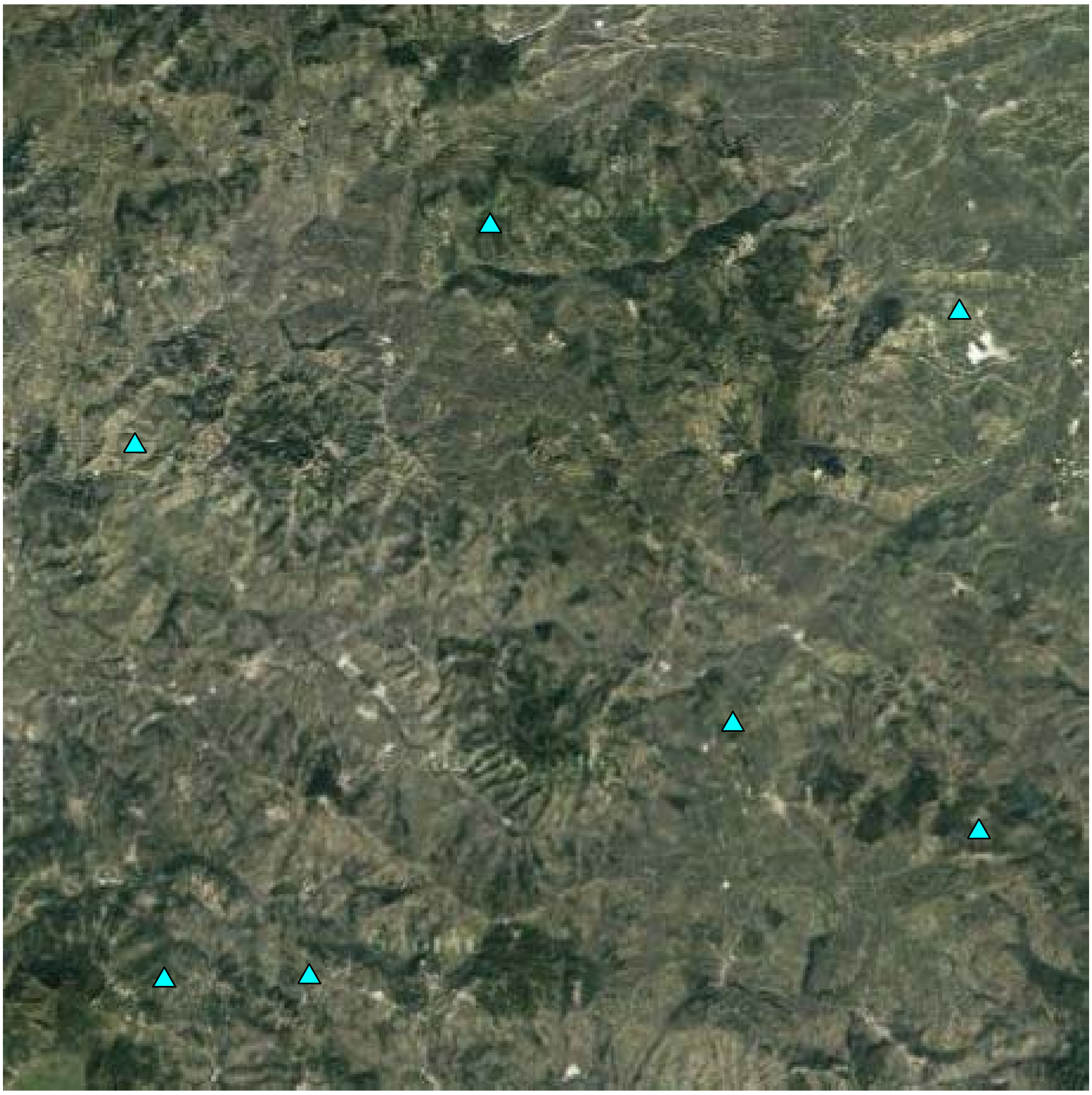

Figure 2: 7 Electric substations within Esperantia.

Esperantia encompasses seven electric substations, represented by cyan triangles in the figure above. The next table summarises the position of the electric substations.

Table 2: Electric Substations

ID	Ordinate (km)	Abscissa (km)
SS1	14,88	89,97
SS2	45,03	20,56
SS3	89,96	76,25
SS4	88,24	28,49
SS5	67,32	66,42
SS6	12,28	40,73
SS7	28,33	89,62

2.2.1.3 Telecommunication Base Stations

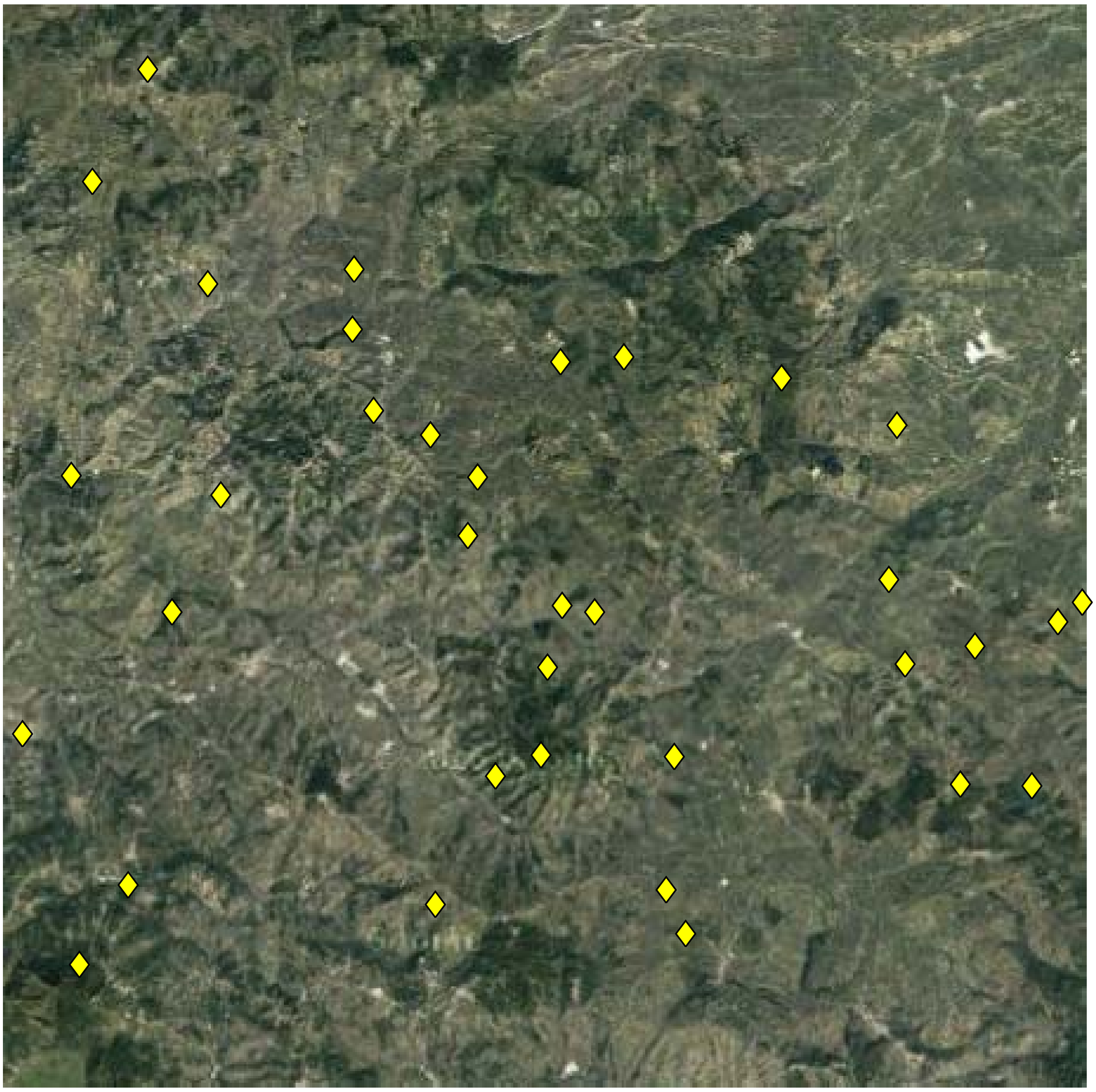

Figure 3: 35 Telecommunication Base Stations within Esperantia.

Esperantia features 35 telecommunication base stations represented by the yellow diamonds in the figure above. The next table summarises the position of the telecommunication base stations.

Table 3: Telecommunication base stations

ID	Ordinate (km)	Abscissa (km)
BS1	82,65	39,00
BS2	49,79	69,48
BS3	83,43	60,96
BS4	57,47	32,60
BS5	45,64	71,38
BS6	88,44	72,08
BS7	1,86	67,47
BS8	43,85	43,78
BS9	11,70	81,46
BS10	32,48	24,62
BS11	34,27	37,56
BS12	54,65	56,19
BS13	39,58	39,81
BS14	95,09	72,23
BS15	40,00	83,18
BS16	13,43	6,04
BS17	8,42	16,39
BS18	32,42	30,17
BS19	63,11	85,93
BS20	97,42	57,08
BS21	99,68	55,35
BS22	51,54	33,06
BS23	43,00	49,18
BS24	7,10	88,77
BS25	6,46	43,61
BS26	61,34	81,86
BS27	19,07	25,85
BS28	89,78	59,33
BS29	50,38	61,28
BS30	81,94	53,18
BS31	20,20	45,38
BS32	62,00	69,53
BS33	72,01	34,69
BS34	51,69	55,66
BS35	15,65	56,20

2.2.1.4 Drinking Water Stations

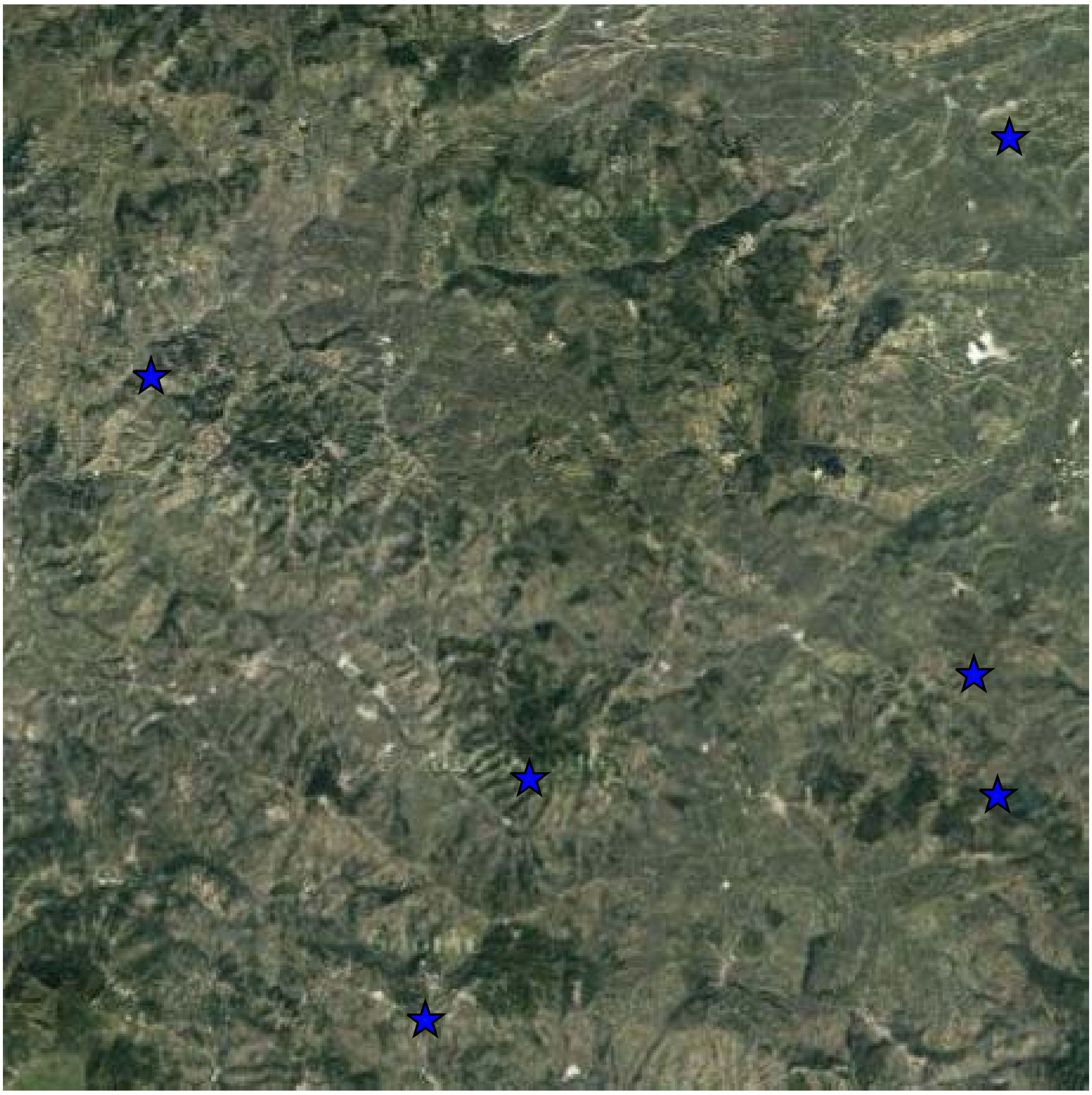

Figure 4: 6 Drinking water stations within Esperantia.

Esperantia encompasses six drinking water stations, represented by blue stars in the figure above. The next table summarises the position of the stations.

Table 4: Drinking water stations.

ID	Ordinate (km)	Abscissa (km)
WDC1	48,56	71,35
WDC2	89,44	61,83
WDC3	13,75	34,32
WDC4	39,00	93,60
WDC5	92,73	12,47
WDC6	91,74	73,05

2.2.1.5 Gas Distribution Stations

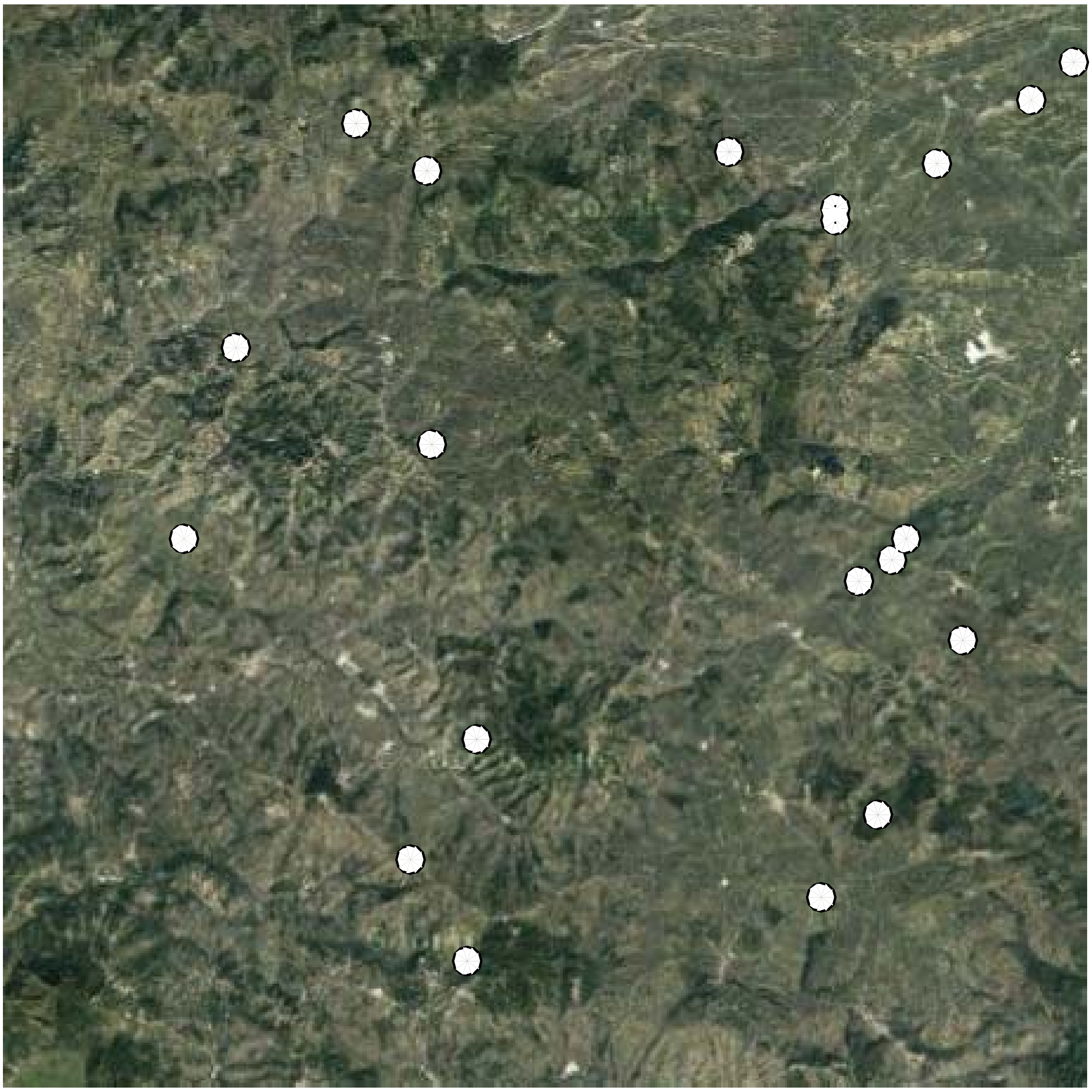

Figure 5: twenty gas distribution stations within Esperantia.

Esperantia encompasses twenty gas distribution stations, represented by white circles in the figure above. The next table summarises the position of the stations.

Table 5: Gas distribution stations.

ID	Ordinate (km)	Abscissa (km)
GDN1	82,17	51,44
GDN2	42,99	88,42
GDN3	88,77	58,80
GDN4	39,11	15,47
GDN5	76,91	19,98
GDN6	39,67	40,69
GDN7	80,85	74,87
GDN8	75,50	82,55
GDN9	37,73	78,99
GDN10	21,60	31,85
GDN11	79,04	53,40
GDN12	94,93	8,99
GDN13	32,75	11,17
GDN14	67,12	13,62
GDN15	43,86	67,86
GDN16	83,35	49,51
GDN17	76,88	18,97
GDN18	16,72	49,50
GDN19	86,19	14,76
GDN20	98,98	5,49

2.2.2 Esperantia as a Multigraph

In this section, we provide a data set that encompasses the different networks that constitute the Esperantia multigraph.

2.2.2.1 Road Transport Network

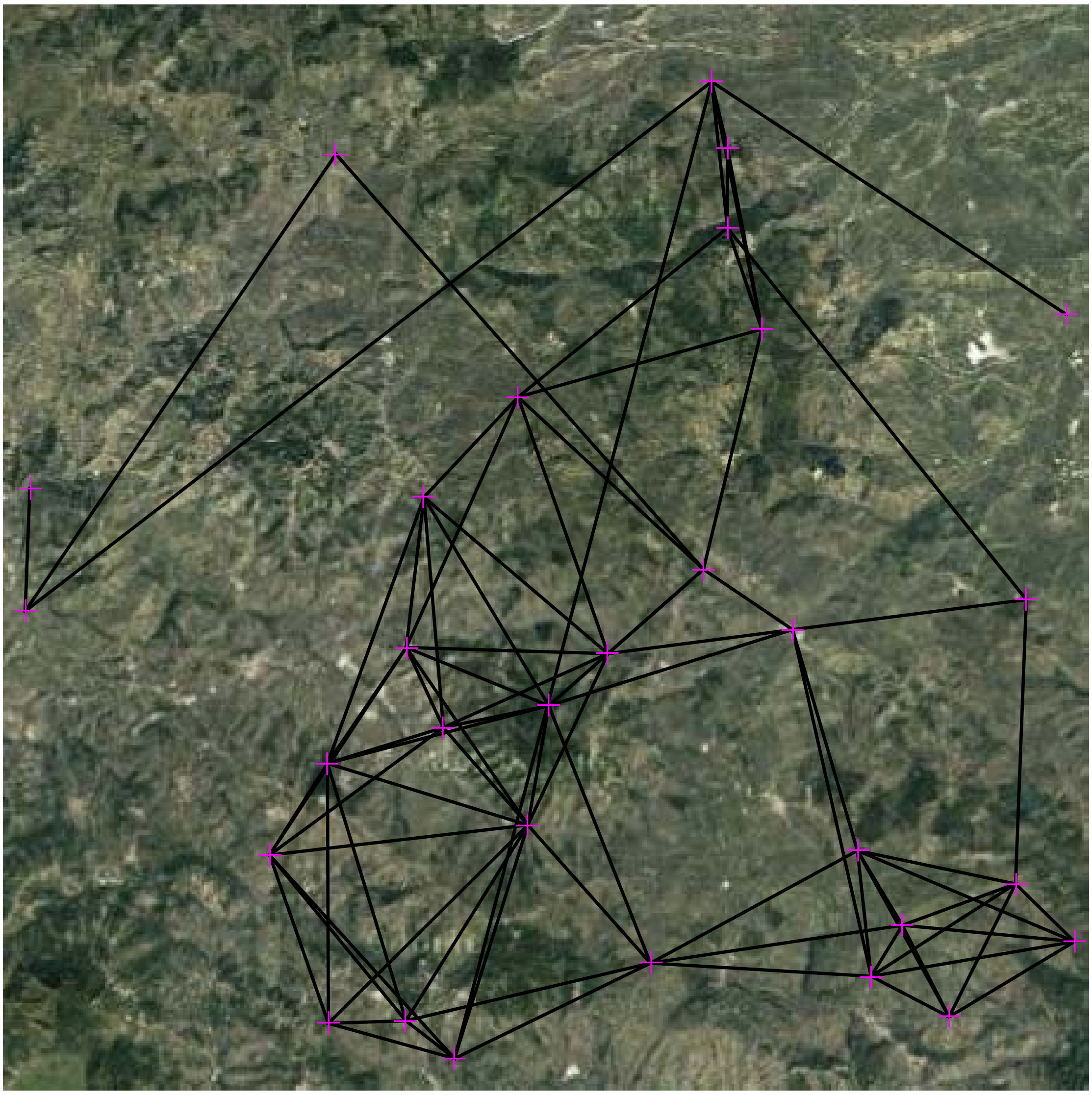

Figure 6: Esperantia road transport network: each link represents a highway or local road connecting two urban areas. The network has 33 links.

The different urban areas are interconnected by a network of local roads and highways. In particular, we chose to focus just on the main highways, and we show in the above figure the network via black lines. We provide in the next table the details of the road grid; for each link, we detail the two endpoint urban areas (from and to) and the type (1 for local road and 2 for highway; the capacity is maximum 1.000 vehicles/hour for local roads and maximum 2.500 vehicles/hour for highways). Starting and endpoints in the same UA are considered to be connected to each other.

Table 6: Links in the road transport network.

ID	From	To	Type (1 local, 2 highway)
TRSPN1	UA1	UA3	1
TRSPN2	UA2	UA5	1
TRSPN3	UA2	UA7	1
TRSPN4	UA4	UA8	2
TRSPN5	UA1	UA9	1
TRSPN6	UA6	UA11	1
TRSPN7	UA3	UA12	1
TRSPN8	UA6	UA12	1
TRSPN9	UA11	UA12	1
TRSPN10	UA3	UA14	1
TRSPN11	UA6	UA14	1
TRSPN12	UA11	UA14	2
TRSPN13	UA13	UA14	1
TRSPN14	UA8	UA15	1
TRSPN15	UA2	UA16	1
TRSPN16	UA3	UA16	1
TRSPN17	UA4	UA16	2
TRSPN18	UA5	UA16	1
TRSPN19	UA14	UA16	1
TRSPN20	UA1	UA17	1
TRSPN21	UA9	UA17	1
TRSPN22	UA12	UA17	1
TRSPN23	UA6	UA18	1
TRSPN24	UA11	UA18	1
TRSPN25	UA12	UA18	1
TRSPN26	UA1	UA19	1
TRSPN27	UA3	UA19	1
TRSPN28	UA5	UA19	1

TRSPN29	UA6	UA20	1
TRSPN30	UA11	UA20	1
TRSPN31	UA18	UA20	1
TRSPN32	UA2	UA21	1
TRSPN33	UA5	UA21	1

2.2.2.2 Railway Network

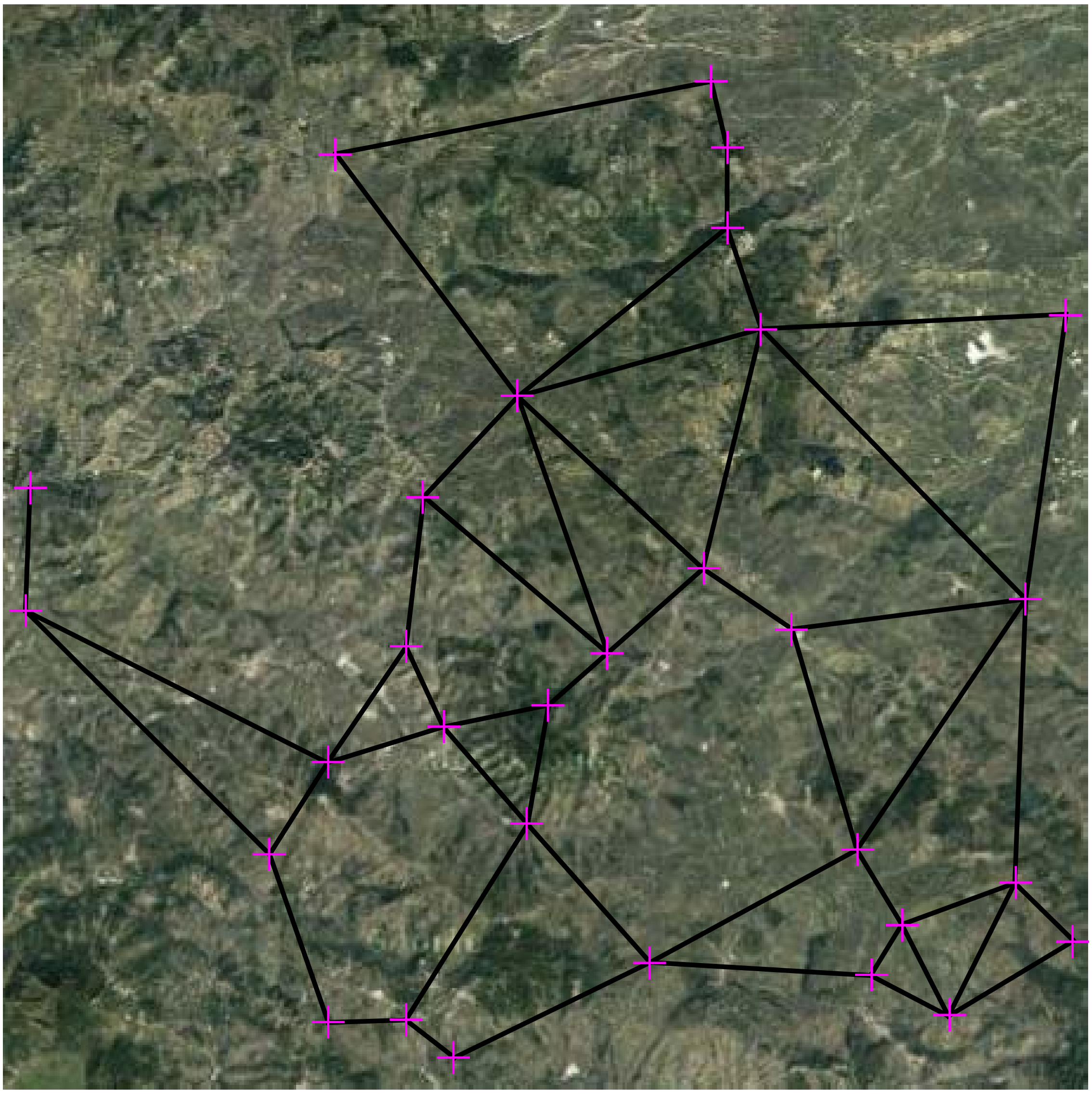

Figure 7: Esperantia railway network: each link represents a railway line connecting two urban areas. The network has 49 links.

The different urban areas are interconnected by a railway network; we provide in the next table for each link the two endpoint urban areas (from and to). Starting and endpoints in the same UA are considered to connect to the same "central station".

Table 7: Links in the railway network.

ID	From	To
RLWN1	UA2	UA5
RLWN2	UA4	UA5
RLWN3	UA1	UA8
RLWN4	UA2	UA10
RLWN5	UA6	UA12
RLWN6	UA11	UA12
RLWN7	UA2	UA13
RLWN8	UA6	UA13
RLWN9	UA10	UA13
RLWN10	UA6	UA14
RLWN11	UA13	UA14
RLWN12	UA8	UA15
RLWN13	UA2	UA16
RLWN14	UA5	UA16
RLWN15	UA14	UA16
RLWN16	UA9	UA17
RLWN17	UA6	UA18
RLWN18	UA11	UA18
RLWN19	UA1	UA19
RLWN20	UA11	UA20
RLWN21	UA18	UA20
RLWN22	UA2	UA21
RLWN23	UA5	UA21
RLWN24	UA7	UA21
RLWN25	UA4	UA22
RLWN26	UA7	UA22
RLWN27	UA1	UA23
RLWN28	UA3	UA23

RLWN29	UA19	UA23
RLWN30	UA13	UA24
RLWN31	UA18	UA24
RLWN32	UA20	UA24
RLWN33	UA3	UA25
RLWN34	UA12	UA25
RLWN35	UA17	UA25
RLWN36	UA23	UA25
RLWN37	UA12	UA26
RLWN38	UA17	UA26
RLWN39	UA20	UA27
RLWN40	UA24	UA27
RLWN41	UA5	UA28
RLWN42	UA19	UA28
RLWN43	UA1	UA29
RLWN44	UA8	UA29
RLWN45	UA9	UA29
RLWN46	UA3	UA30
RLWN47	UA5	UA30
RLWN48	UA16	UA30
RLWN49	UA28	UA30

2.2.2.3 Power Transmission Network

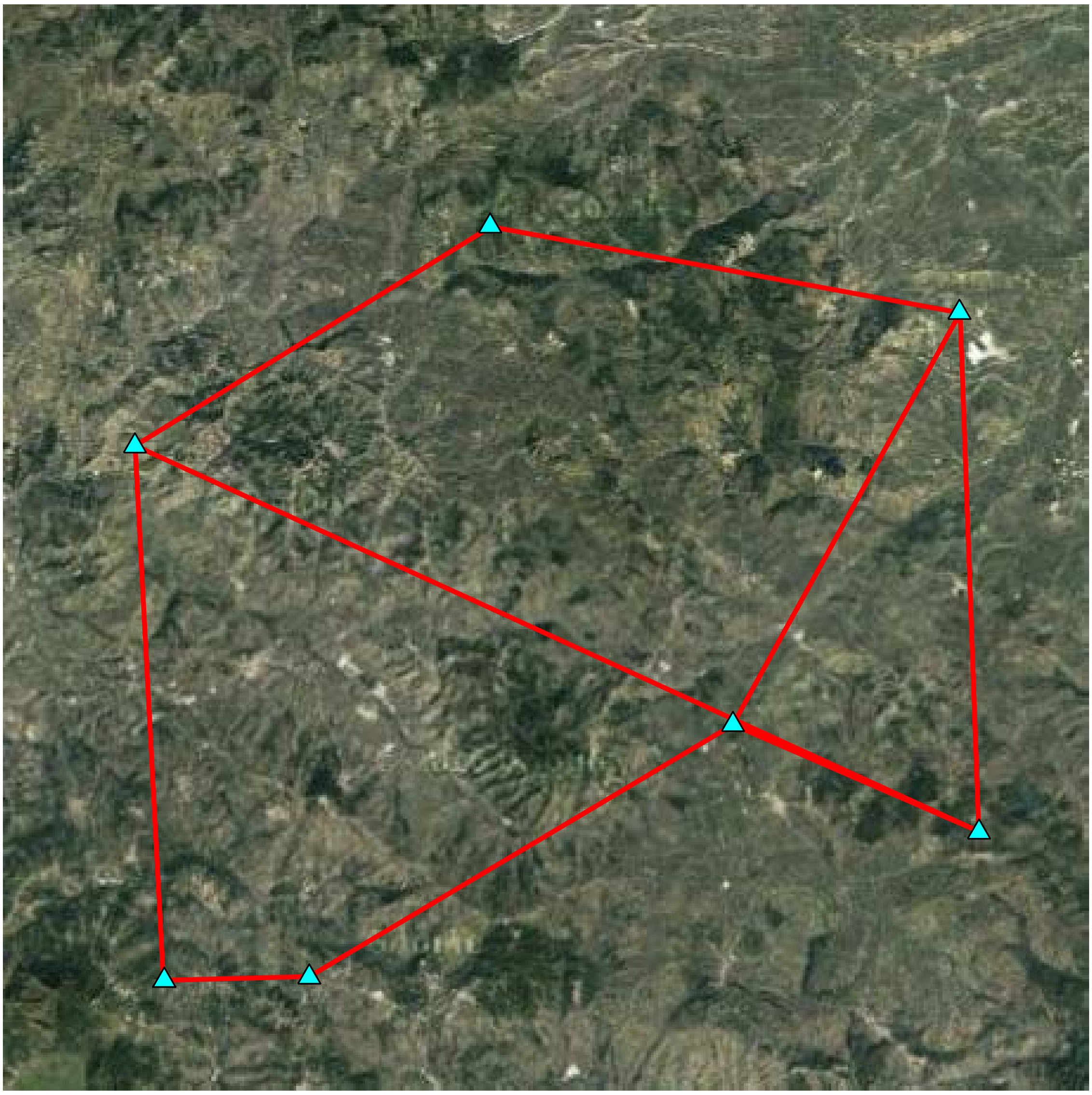

Figure 8: Power Transmission Backbone connecting the electric substations within Esperantia. The network is composed of nine links.

The different electric substations are interconnected by a power transmission network that constitutes the power transmission grid. We provide in the next table the details of the network; for each link, we detail the two endpoint urban areas (from and to).

Table 8: Links in the Power Transmission Network.

ID	From	To
PTN1	SS2	SS4
PTN2	SS3	SS4
PTN3	SS3	SS5
PTN4	SS4	SS5
PTN5	SS1	SS6
PTN6	SS2	SS6
PTN7	SS3	SS6
PTN8	SS1	SS7
PTN9	SS5	SS7

2.2.2.4 Telecommunication Backbone

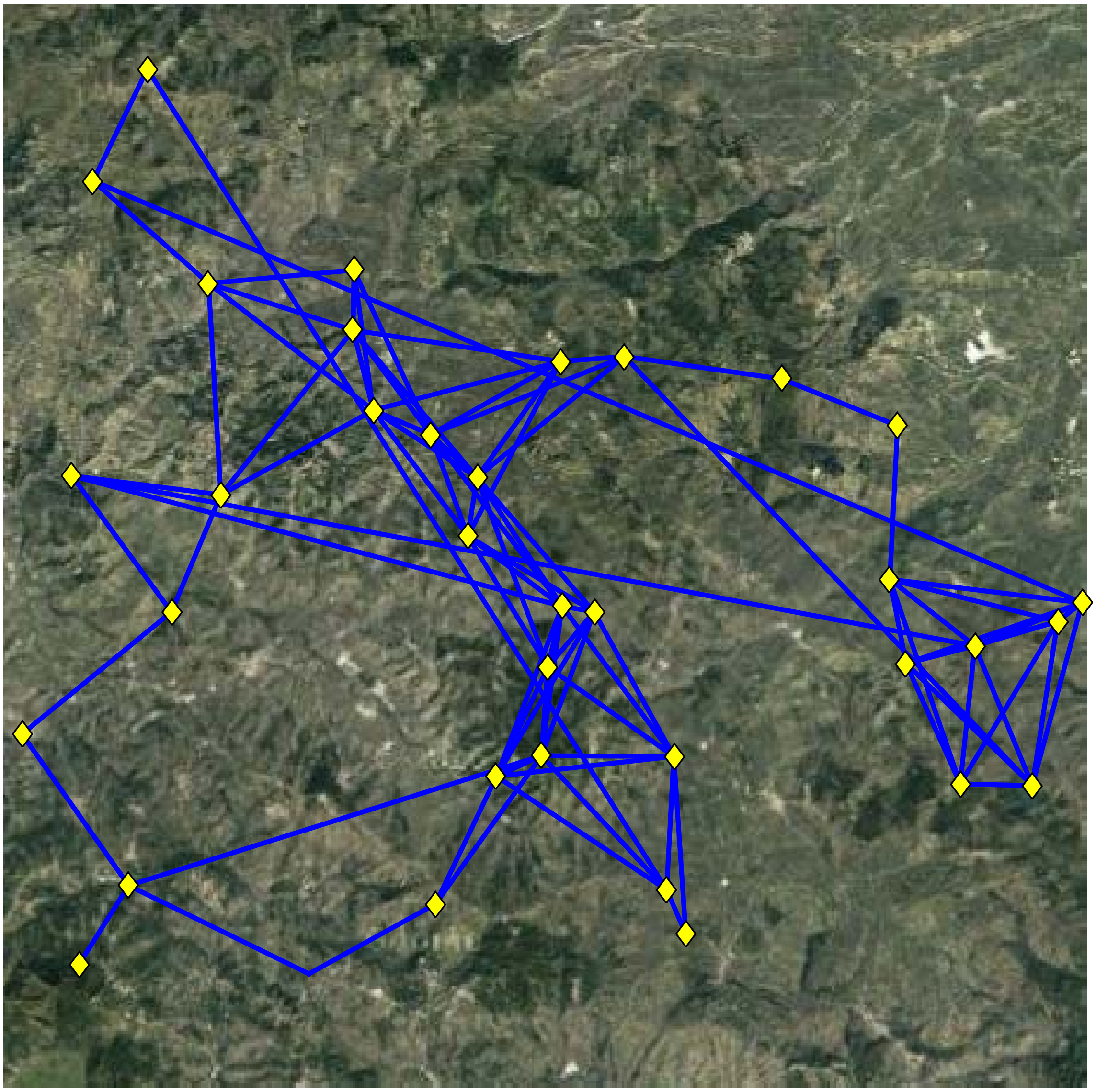

Figure 9: telecommunication backbone connecting the base stations within Esperantia. The network is composed of 91 links.

The different telecommunication base stations are interconnected by a network that constitutes the telecommunication backbone. We provide in the next table the details of the network. For each link, we detail the two endpoint urban areas (from and to).

Table 9: Links in the telecommunication backbone.

ID	From	To
TLCBKBN1	BS2	BS5
TLCBKBN2	BS3	BS6
TLCBKBN3	BS4	BS8
TLCBKBN4	BS2	BS9
TLCBKBN5	BS7	BS9
TLCBKBN6	BS8	BS11
TLCBKBN7	BS10	BS11
TLCBKBN8	BS2	BS12
TLCBKBN9	BS5	BS12
TLCBKBN10	BS8	BS12
TLCBKBN11	BS4	BS13
TLCBKBN12	BS8	BS13
TLCBKBN13	BS10	BS13
TLCBKBN14	BS11	BS13
TLCBKBN15	BS3	BS14
TLCBKBN16	BS4	BS14
TLCBKBN17	BS6	BS14
TLCBKBN18	BS2	BS15
TLCBKBN19	BS5	BS15
TLCBKBN20	BS16	BS17
TLCBKBN21	BS8	BS18
TLCBKBN22	BS10	BS18
TLCBKBN23	BS11	BS18
TLCBKBN24	BS13	BS18
TLCBKBN25	BS3	BS20
TLCBKBN26	BS6	BS20
TLCBKBN27	BS14	BS20
TLCBKBN28	BS3	BS21
TLCBKBN29	BS14	BS21

TLCBKBN30	BS17	BS21
TLCBKBN31	BS20	BS21
TLCBKBN32	BS4	BS22
TLCBKBN33	BS8	BS22
TLCBKBN34	BS11	BS22
TLCBKBN35	BS13	BS22
TLCBKBN36	BS18	BS22
TLCBKBN37	BS8	BS23
TLCBKBN38	BS11	BS23
TLCBKBN39	BS12	BS23
TLCBKBN40	BS13	BS23
TLCBKBN41	BS22	BS23
TLCBKBN42	BS9	BS24
TLCBKBN43	BS2	BS26
TLCBKBN44	BS5	BS26
TLCBKBN45	BS16	BS26
TLCBKBN46	BS19	BS26
TLCBKBN47	BS10	BS27
TLCBKBN48	BS11	BS27
TLCBKBN49	BS17	BS27
TLCBKBN50	BS18	BS27
TLCBKBN51	BS3	BS28
TLCBKBN52	BS6	BS28
TLCBKBN53	BS14	BS28
TLCBKBN54	BS20	BS28
TLCBKBN55	BS21	BS28
TLCBKBN56	BS25	BS28
TLCBKBN57	BS2	BS29
TLCBKBN58	BS5	BS29
TLCBKBN59	BS8	BS29
TLCBKBN60	BS12	BS29

TLCBKBN61	BS23	BS29
TLCBKBN62	BS1	BS30
TLCBKBN63	BS3	BS30
TLCBKBN64	BS6	BS30
TLCBKBN65	BS20	BS30
TLCBKBN66	BS21	BS30
TLCBKBN67	BS28	BS30
TLCBKBN68	BS11	BS31
TLCBKBN69	BS18	BS31
TLCBKBN70	BS25	BS31
TLCBKBN71	BS27	BS31
TLCBKBN72	BS2	BS32
TLCBKBN73	BS5	BS32
TLCBKBN74	BS12	BS32
TLCBKBN75	BS19	BS32
TLCBKBN76	BS26	BS32
TLCBKBN77	BS29	BS32
TLCBKBN78	BS1	BS33
TLCBKBN79	BS4	BS33
TLCBKBN80	BS2	BS34
TLCBKBN81	BS5	BS34
TLCBKBN82	BS8	BS34
TLCBKBN83	BS12	BS34
TLCBKBN84	BS13	BS34
TLCBKBN85	BS23	BS34
TLCBKBN86	BS25	BS34
TLCBKBN87	BS29	BS34
TLCBKBN88	BS32	BS34
TLCBKBN89	BS7	BS35
TLCBKBN90	BS25	BS35
TLCBKBN91	BS31	BS35

2.2.2.5 Power Distribution Network

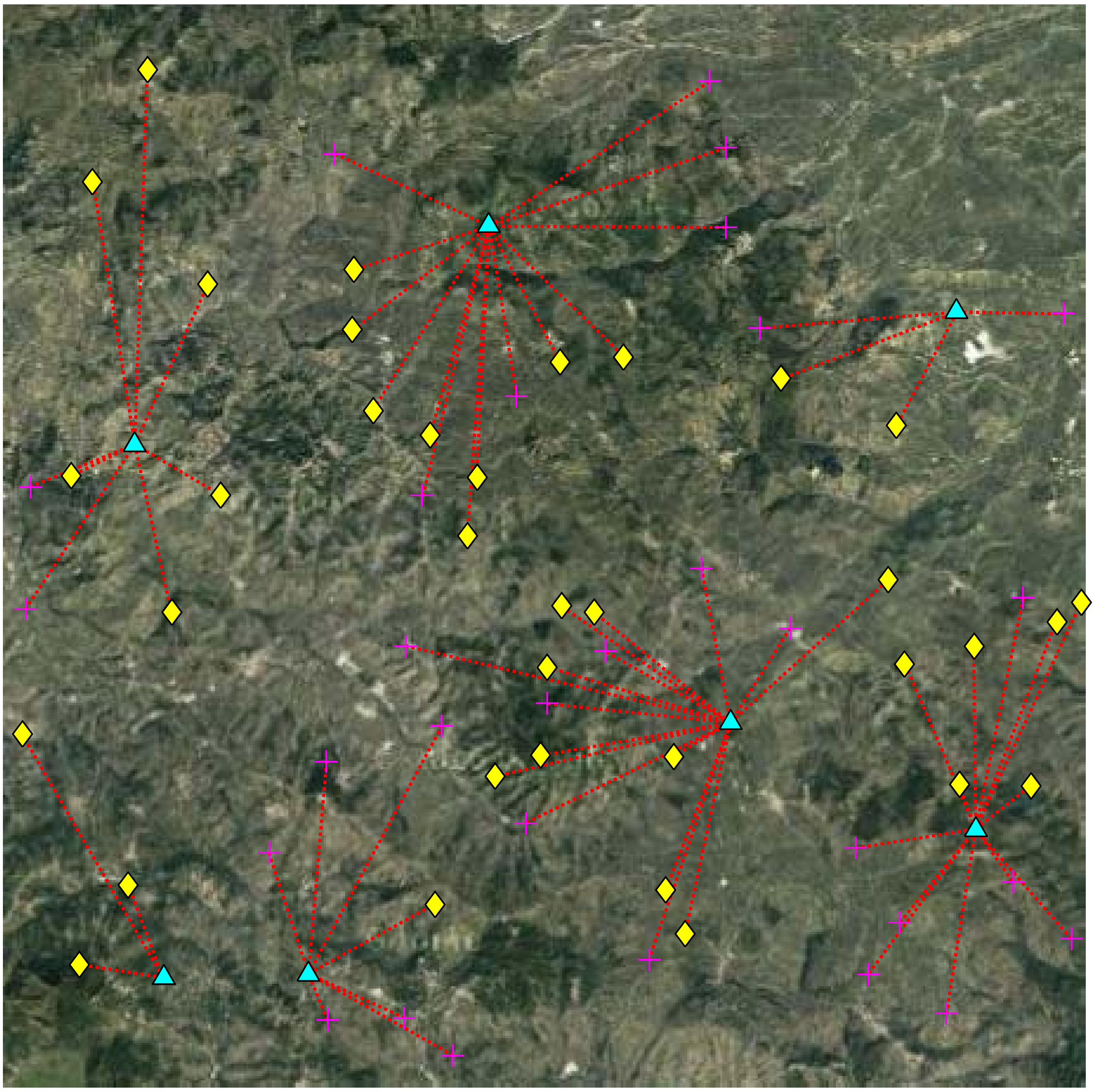

Figure 10: Radial power distribution network connecting the different entities to the primary cabins within Esperantia. The network is composed of 63 links.

The different urban areas and base stations within Esperantia are connected to the electric substations by a network that constitutes the power distribution network. We show in the above figure the power distribution network that summarises such interactions, and we provide in the next table the details of the network. For each link, we detail the two endpoints (from and to).

Table 10: Links in the Power Distribution Network.

ID	From	To
PDN1	SS2	UA7
PDN2	SS2	UA21
PDN3	SS2	UA22
PDN4	SS2	UA28
PDN5	SS3	UA6
PDN6	SS3	UA11
PDN7	SS3	UA13
PDN8	SS3	UA18
PDN9	SS3	UA20
PDN10	SS3	UA24
PDN11	SS3	UA27
PDN12	SS4	UA2
PDN13	SS4	UA10
PDN14	SS5	UA3
PDN15	SS5	UA12
PDN16	SS5	UA14
PDN17	SS5	UA16
PDN18	SS5	UA19
PDN19	SS5	UA25
PDN20	SS5	UA30
PDN21	SS6	UA8
PDN22	SS6	UA15
PDN23	SS7	UA1
PDN24	SS7	UA9
PDN25	SS7	UA17
PDN26	SS7	UA23
PDN27	SS7	UA26
PDN28	SS7	UA29
PDN29	SS4	BS1

PDN30	SS5	BS2
PDN31	SS3	BS3
PDN32	SS2	BS4
PDN33	SS5	BS5
PDN34	SS3	BS6
PDN35	SS1	BS7
PDN36	SS2	BS8
PDN37	SS1	BS9
PDN38	SS2	BS10
PDN39	SS2	BS11
PDN40	SS5	BS12
PDN41	SS2	BS13
PDN42	SS3	BS14
PDN43	SS7	BS15
PDN44	SS6	BS16
PDN45	SS6	BS17
PDN46	SS2	BS18
PDN47	SS5	BS19
PDN48	SS3	BS20
PDN49	SS3	BS21
PDN50	SS2	BS22
PDN51	SS2	BS23
PDN52	SS1	BS24
PDN53	SS6	BS25
PDN54	SS5	BS26
PDN55	SS6	BS27
PDN56	SS3	BS28
PDN57	SS5	BS29
PDN58	SS5	BS30
PDN59	SS6	BS31
PDN60	SS5	BS32

PDN61	SS4	BS33
PDN62	SS5	BS34
PDN63	SS6	BS35

2.2.2.6 Telecommunication "Distribution" Network

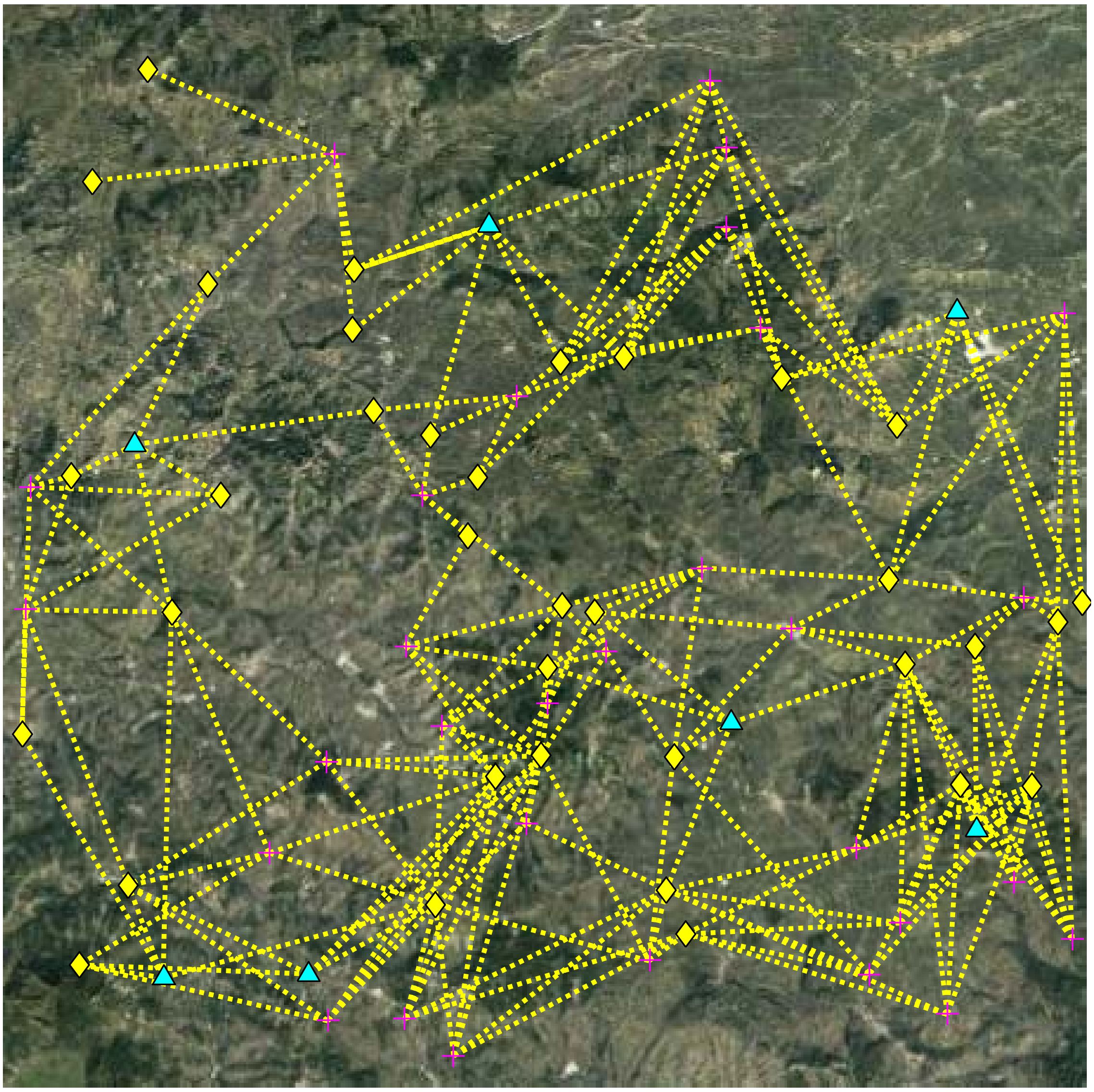

Figure 11: Telecommunication "distribution" network connecting the different urban areas or substations to the telecommunication base stations. The network is composed of 185 links.

The different urban areas and substations within Esperantia are connected the base stations via a "distribution" network that represents the functional dependency on the elements in the telecommunication backbone. We show in the above figure the network that summarises such interactions. We provide in the next table the details of the network; for each link, we detail the two endpoints (from and to).

Table 11: Links in the TLC "distribution" Network.

ID	From	To
TDN1	BS1	UA2
TDN2	BS1	UA7
TDN3	BS1	UA10
TDN4	BS1	UA21
TDN5	BS1	UA22
TDN6	BS1	SS4
TDN7	BS2	UA1
TDN8	BS2	UA3
TDN9	BS2	UA9
TDN10	BS2	UA12
TDN11	BS2	UA17
TDN12	BS2	UA19
TDN13	BS2	UA23
TDN14	BS2	UA25
TDN15	BS2	UA26
TDN16	BS2	UA30
TDN17	BS2	SS7
TDN18	BS3	UA6
TDN19	BS3	UA13
TDN20	BS3	UA14
TDN21	BS3	UA18
TDN22	BS3	UA20
TDN23	BS3	UA24
TDN24	BS3	UA27
TDN25	BS3	SS3
TDN26	BS3	SS5
TDN27	BS4	UA2
TDN28	BS4	UA5
TDN29	BS4	UA7

TDN30	BS4	UA21
TDN31	BS4	UA22
TDN32	BS4	SS2
TDN33	BS5	UA1
TDN34	BS5	UA3
TDN35	BS5	UA9
TDN36	BS5	UA17
TDN37	BS5	UA19
TDN38	BS5	UA23
TDN39	BS5	UA25
TDN40	BS5	UA26
TDN41	BS5	UA29
TDN42	BS5	SS7
TDN43	BS6	UA6
TDN44	BS6	UA11
TDN45	BS6	UA18
TDN46	BS6	UA20
TDN47	BS6	UA24
TDN48	BS6	UA27
TDN49	BS6	SS3
TDN50	BS7	UA8
TDN51	BS7	UA15
TDN52	BS7	SS1
TDN53	BS8	UA5
TDN54	BS8	UA21
TDN55	BS8	UA28
TDN56	BS9	UA1
TDN57	BS9	UA8
TDN58	BS9	UA9
TDN59	BS9	UA29
TDN60	BS9	SS1

TDN61	BS9	SS7
TDN62	BS10	UA4
TDN63	BS10	UA7
TDN64	BS10	UA22
TDN65	BS10	SS2
TDN66	BS11	UA5
TDN67	BS11	UA28
TDN68	BS11	SS6
TDN69	BS12	UA3
TDN70	BS12	UA14
TDN71	BS12	UA16
TDN72	BS12	UA30
TDN73	BS12	SS5
TDN74	BS13	UA5
TDN75	BS13	UA28
TDN76	BS13	SS2
TDN77	BS14	UA6
TDN78	BS14	UA11
TDN79	BS14	UA18
TDN80	BS14	UA20
TDN81	BS14	UA24
TDN82	BS14	UA27
TDN83	BS14	SS3
TDN84	BS15	UA1
TDN85	BS15	UA9
TDN86	BS15	UA12
TDN87	BS15	UA17
TDN88	BS15	UA23
TDN89	BS15	UA25
TDN90	BS15	UA26
TDN91	BS15	UA29

TDN92	BS15	SS1
TDN93	BS15	SS7
TDN94	BS16	UA4
TDN95	BS17	UA4
TDN96	BS18	UA4
TDN97	BS18	SS2
TDN98	BS19	UA6
TDN99	BS19	UA11
TDN100	BS19	UA12
TDN101	BS19	UA17
TDN102	BS19	UA18
TDN103	BS19	UA20
TDN104	BS19	UA26
TDN105	BS20	UA10
TDN106	BS20	UA13
TDN107	BS20	UA24
TDN108	BS20	UA27
TDN109	BS20	SS3
TDN110	BS20	SS4
TDN111	BS21	UA10
TDN112	BS21	UA13
TDN113	BS21	SS4
TDN114	BS22	UA2
TDN115	BS22	UA5
TDN116	BS22	UA7
TDN117	BS22	UA21
TDN118	BS22	UA22
TDN119	BS22	SS2
TDN120	BS23	UA19
TDN121	BS23	UA28
TDN122	BS24	UA9

TDN123	BS24	UA29
TDN124	BS24	SS1
TDN125	BS24	SS7
TDN126	BS25	UA8
TDN127	BS25	UA15
TDN128	BS25	SS6
TDN129	BS26	UA6
TDN130	BS26	UA11
TDN131	BS26	UA12
TDN132	BS26	UA17
TDN133	BS26	UA18
TDN134	BS26	UA20
TDN135	BS26	UA25
TDN136	BS26	UA26
TDN137	BS26	SS5
TDN138	BS27	UA4
TDN139	BS27	UA15
TDN140	BS27	SS6
TDN141	BS28	UA13
TDN142	BS28	UA14
TDN143	BS28	UA24
TDN144	BS28	UA27
TDN145	BS28	SS3
TDN146	BS29	UA3
TDN147	BS29	UA16
TDN148	BS29	UA19
TDN149	BS29	UA23
TDN150	BS29	UA25
TDN151	BS29	UA30
TDN152	BS29	UA35
TDN153	BS30	UA2

TDN154	BS30	UA10
TDN155	BS30	UA13
TDN156	BS30	UA14
TDN157	BS30	UA16
TDN158	BS30	SS4
TDN159	BS31	UA8
TDN160	BS31	UA15
TDN161	BS31	SS6
TDN162	BS32	UA11
TDN163	BS32	UA12
TDN164	BS32	UA14
TDN165	BS32	UA16
TDN166	BS32	UA30
TDN167	BS32	SS5
TDN168	BS33	UA2
TDN169	BS33	UA7
TDN170	BS33	UA10
TDN171	BS33	UA21
TDN172	BS33	UA22
TDN173	BS33	SS4
TDN174	BS34	UA3
TDN175	BS34	UA16
TDN176	BS34	UA19
TDN177	BS34	UA23
TDN178	BS34	UA28
TDN179	BS34	UA30
TDN180	BS35	UA1
TDN181	BS35	UA8
TDN182	BS35	UA15
TDN183	BS35	UA29
TDN184	BS35	SS1

TDN185	BS35	SS6

2.2.2.7 Drinking Water Transport Backbone

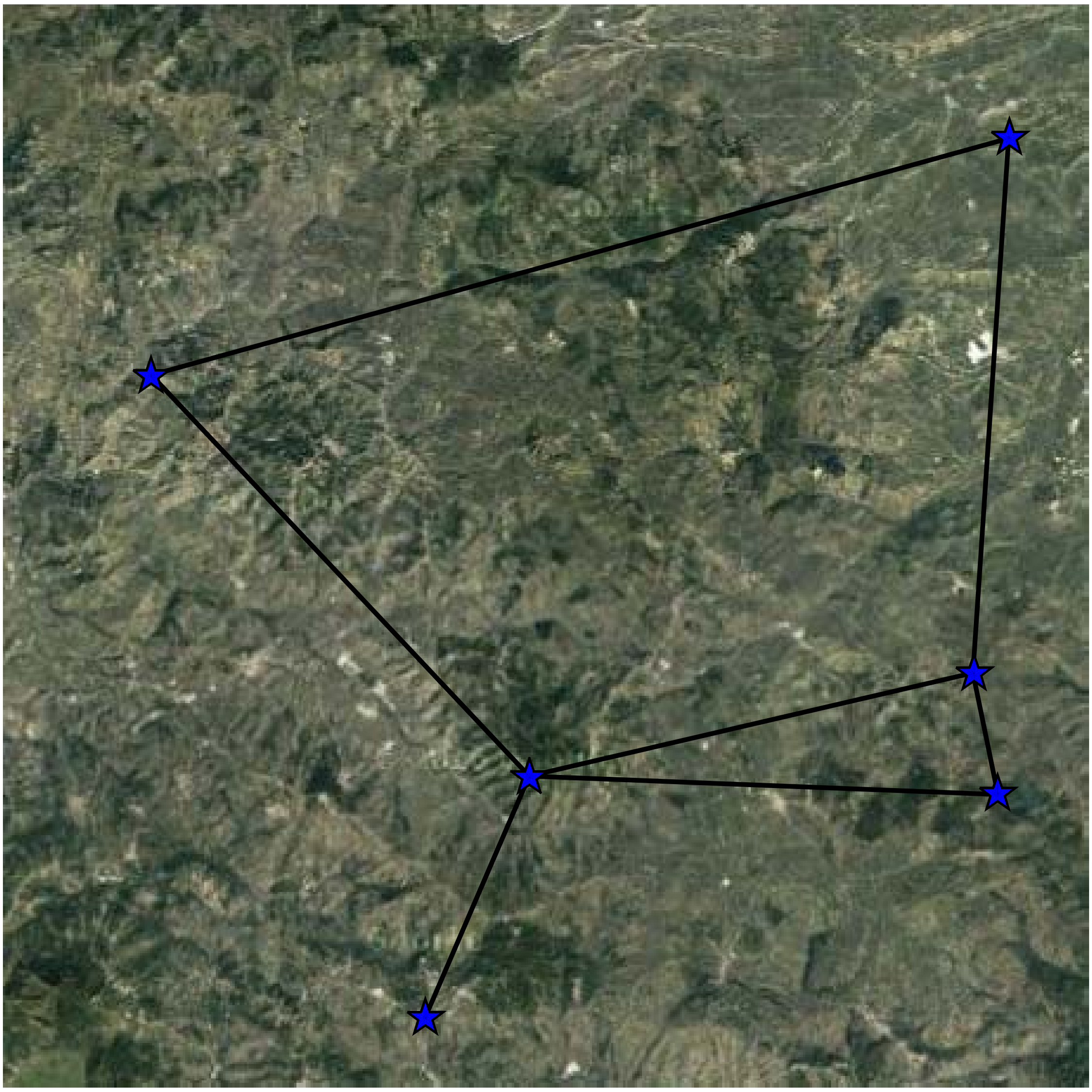

Figure 12: Water Transport Backbone within Esperantia. The network is composed of seven links.

The different drinking water distribution stations are interconnected by a network that constitutes the drinking water transport backbone. We provide in the next table the details of the network; for each link, we detail the two endpoints (from and to).

Table 12: Links in the Drinking Water Transport Backbone.

ID	From	To
WTBKN1	WDC1	WDC2
WTBKN2	WDC1	WDC3
WTBKN3	WDC1	WDC4
WTBKN4	WDC2	WDC5
WTBKN5	WDC3	WDC5
WTBKN6	WDC1	WDC6
WTBKN7	WDC2	WDC6

2.2.2.8 Water Distribution Network

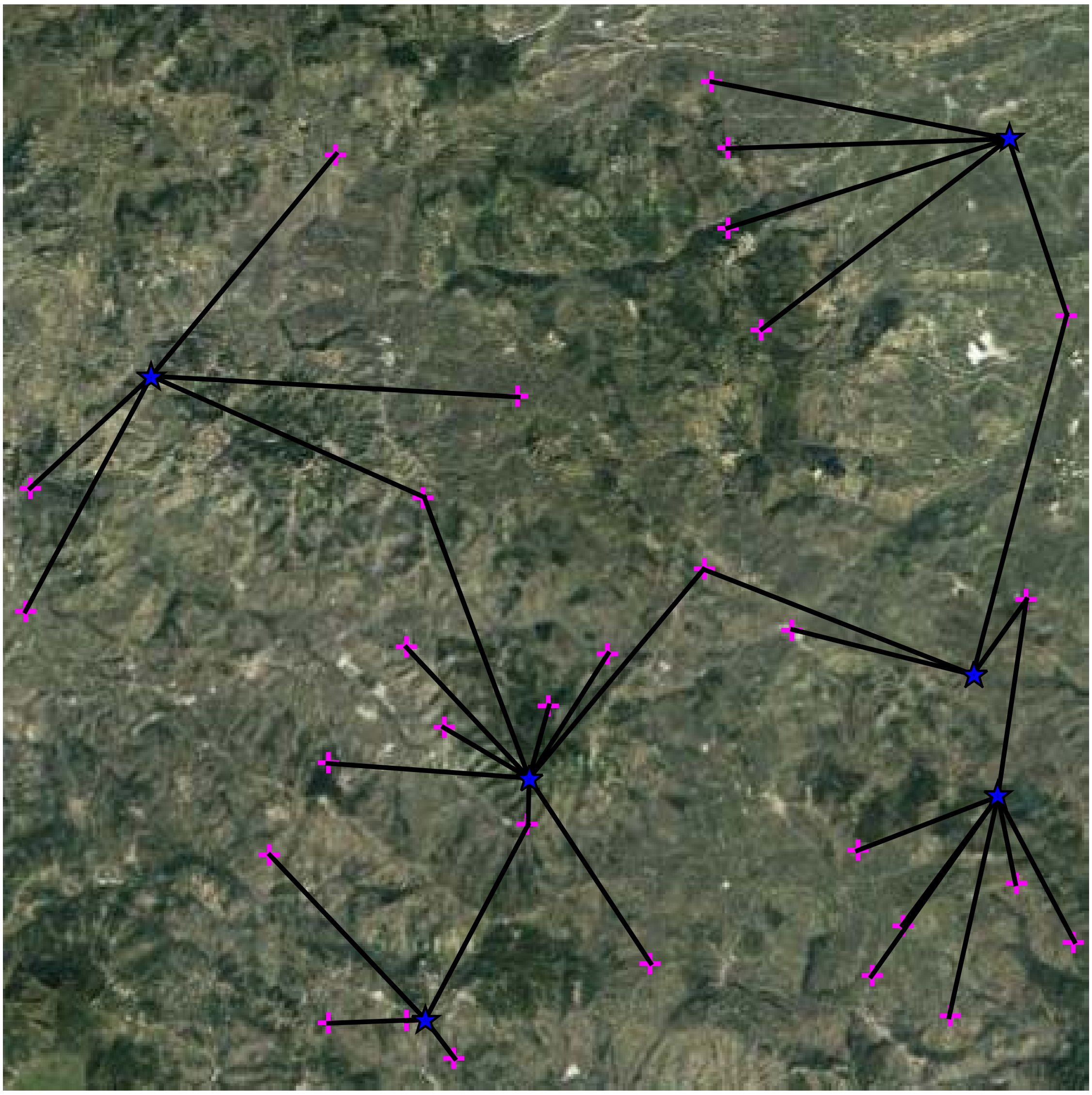

Figure 13: Water Distribution Network connecting the water distribution centres to the urban areas. The network is composed of 35 links.

The different drinking water distribution centres are interconnected by a network that constitutes the drinking water distribution network. We provide in the next table the details of the network. For each link, we specify the two endpoints (from a water distribution centre to a urban area).

Table 13: Links in the Water Distribution Network.

ID	From	To
WDN1	UA1	WDC1
WDN2	UA3	WDC1
WDN3	UA12	WDC1
WDN4	UA16	WDC1
WDN5	UA19	WDC1
WDN6	UA23	WDC1
WDN7	UA25	WDC1
WDN8	UA28	WDC1
WDN9	UA30	WDC1
WDN10	UA10	WDC2
WDN11	UA13	WDC2
WDN12	UA14	WDC2
WDN13	UA16	WDC2
WDN14	UA4	WDC3
WDN15	UA5	WDC3
WDN16	UA8	WDC3
WDN17	UA15	WDC3
WDN18	UA28	WDC3
WDN19	UA9	WDC4
WDN20	UA17	WDC4
WDN21	UA25	WDC4
WDN22	UA26	WDC4
WDN23	UA29	WDC4
WDN24	UA2	WDC5
WDN25	UA7	WDC5
WDN26	UA10	WDC5
WDN27	UA21	WDC5
WDN28	UA22	WDC5
WDN29	UA6	WDC6

WDN30	UA11	WDC6
WDN31	UA13	WDC6
WDN32	UA18	WDC6
WDN33	UA20	WDC6
WDN34	UA24	WDC6
WDN35	UA27	WDC6

2.2.2.9 Gas Transport Backbone

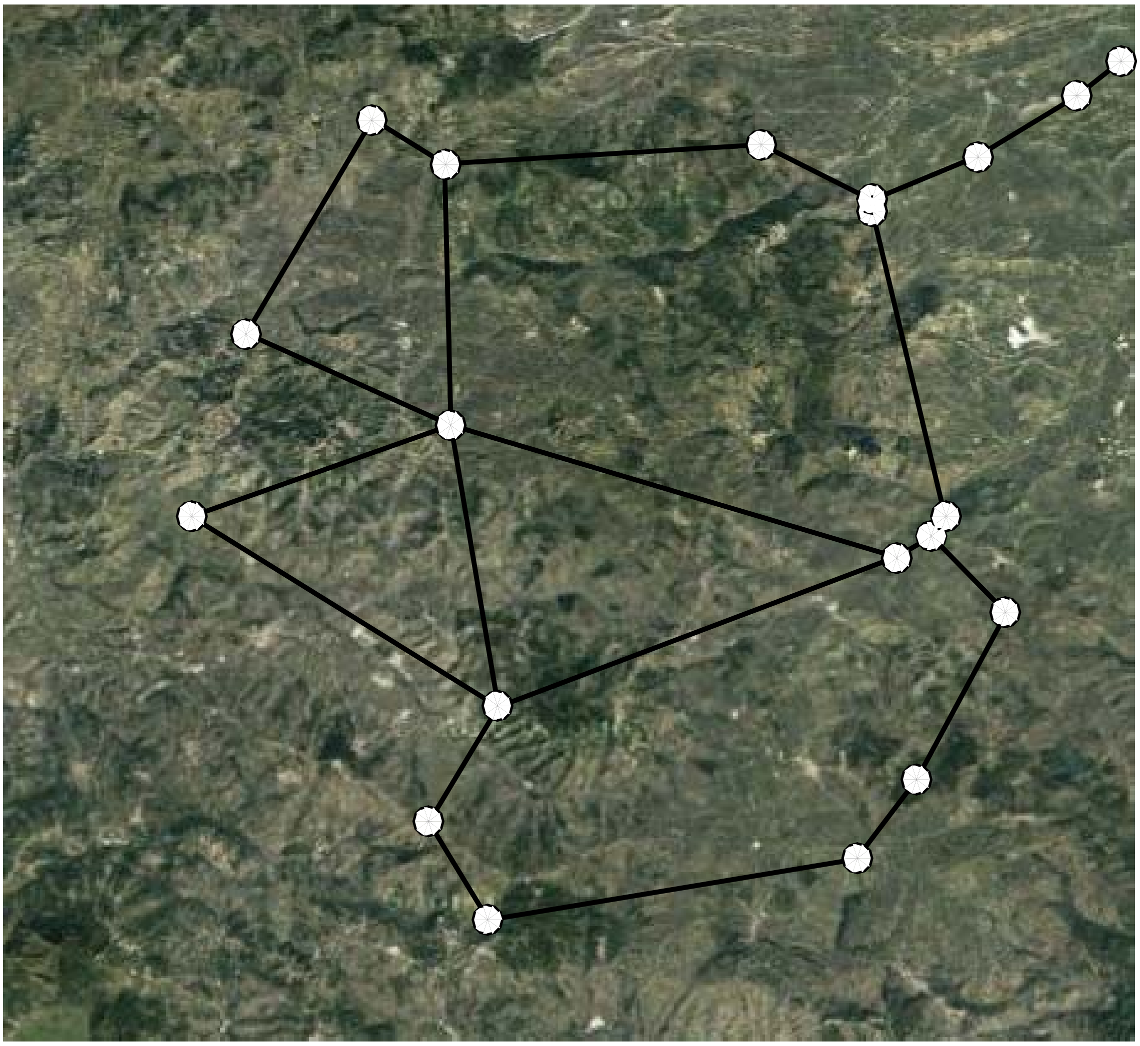

Figure 14: Gas Transport Backbone within Esperantia. The network is composed of 24 links.

The gas transport backbone supplies the distribution stations. We provide in the next table the details of the network. For each link, we provide the two endpoints (from and to).

Table 14: Links in the Gas Transport Backbone.

ID	From	To
GBKN1	GDN1	GDN3
GBKN2	GDN4	GDN6
GBKN3	GDN3	GDN7
GBKN4	GDN2	GDN8
GBKN5	GDN7	GDN8
GBKN6	GDN2	GDN9
GBKN7	GDN6	GDN10
GBKN8	GDN1	GDN11
GBKN9	GDN6	GDN11
GBKN10	GDN4	GDN13
GBKN11	GDN10	GDN13
GBKN12	GDN4	GDN14
GBKN13	GDN6	GDN15
GBKN14	GDN9	GDN15
GBKN15	GDN11	GDN15
GBKN16	GDN1	GDN16
GBKN17	GDN5	GDN16
GBKN18	GDN5	GDN17
GBKN19	GDN14	GDN17
GBKN20	GDN6	GDN18
GBKN21	GDN15	GDN18
GBKN22	GDN12	GDN19
GBKN23	GDN17	GDN19
GBKN24	GDN12	GDN20

2.2.2.10 Gas Distribution Network

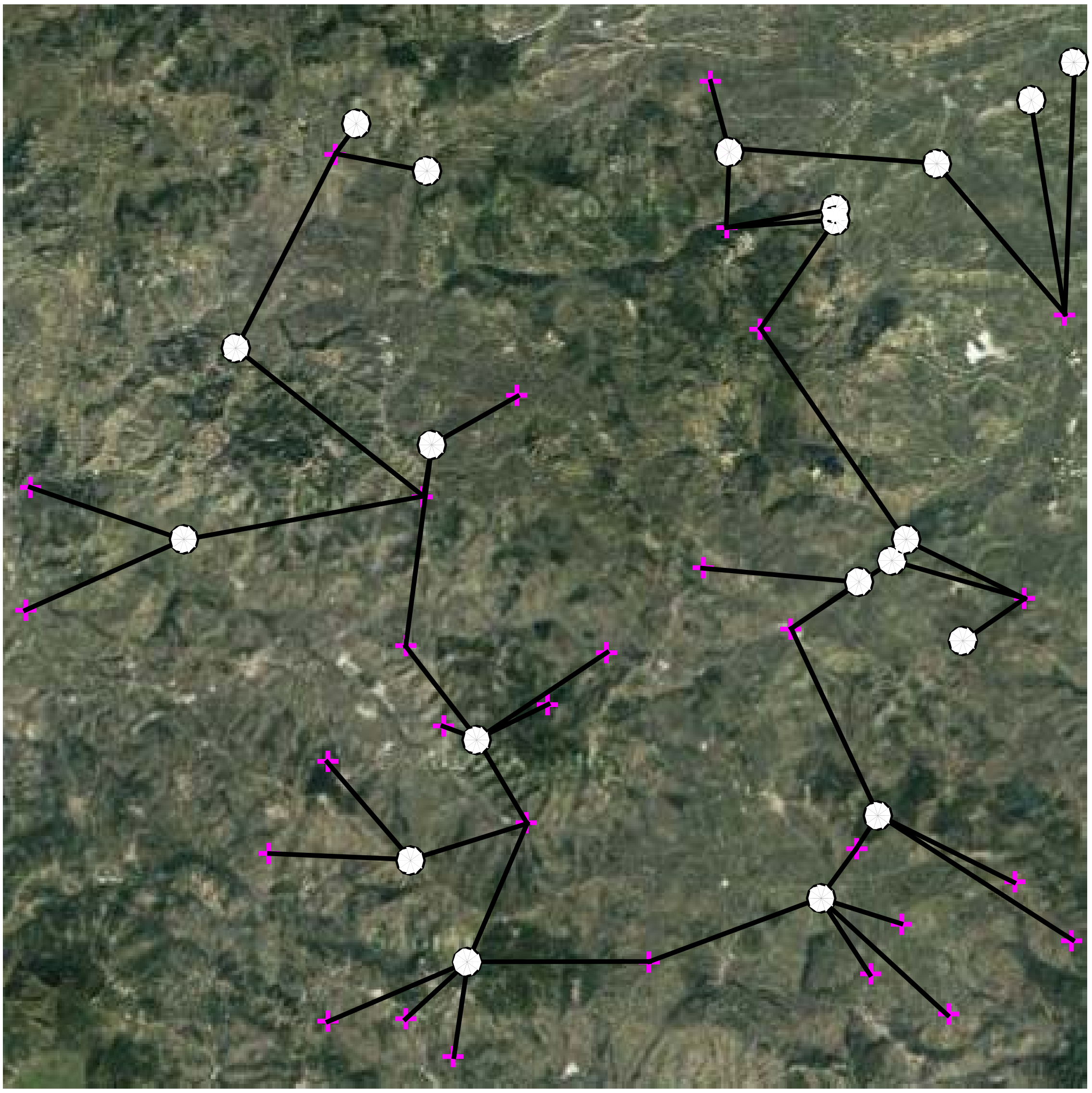

Figure 15: The Gas Distribution Network connecting the gas distribution centres to the urban areas. The network is composed of 49 links.

The different gas distribution stations and urban areas are interconnected by a network that constitutes the gas distribution grid. We provide in the next table the details of the network. For each link, we detail the two endpoints (from a gas distribution station to an urban area).

Table 15: Links in the Gas Distribution Network.

ID	From	To
GDNWK1	UA13	GDN1
GDNWK2	UA14	GDN1
GDNWK3	UA9	GDN2
GDNWK4	UA12	GDN2
GDNWK5	UA17	GDN2
GDNWK6	UA25	GDN2
GDNWK7	UA26	GDN2
GDNWK8	UA13	GDN3
GDNWK9	UA4	GDN4
GDNWK10	UA2	GDN5
GDNWK11	UA21	GDN5
GDNWK12	UA5	GDN6
GDNWK13	UA19	GDN6
GDNWK14	UA28	GDN6
GDNWK15	UA6	GDN7
GDNWK16	UA14	GDN7
GDNWK17	UA24	GDN7
GDNWK18	UA27	GDN7
GDNWK19	UA6	GDN8
GDNWK20	UA11	GDN8
GDNWK21	UA12	GDN8
GDNWK22	UA18	GDN8
GDNWK23	UA20	GDN8
GDNWK24	UA1	GDN9
GDNWK25	UA25	GDN9
GDNWK26	UA29	GDN9
GDNWK27	UA4	GDN10
GDNWK28	UA28	GDN10
GDNWK29	UA14	GDN11

GDNWK30	UA16	GDN11
GDNWK31	UA10	GDN12
GDNWK32	UA4	GDN13
GDNWK33	UA7	GDN14
GDNWK34	UA21	GDN14
GDNWK35	UA22	GDN14
GDNWK36	UA3	GDN15
GDNWK37	UA19	GDN15
GDNWK38	UA23	GDN15
GDNWK39	UA25	GDN15
GDNWK40	UA30	GDN15
GDNWK41	UA2	GDN16
GDNWK42	UA13	GDN16
GDNWK43	UA21	GDN17
GDNWK44	UA8	GDN18
GDNWK45	UA15	GDN18
GDNWK46	UA28	GDN18
GDNWK47	UA7	GDN19
GDNWK48	UA10	GDN19
GDNWK49	UA10	GDN20

2.2.3 Dependencies

2.2.3.1 Common cause failure potentials

As said above, the cartographic images provided in the figures of this document are in no way descriptive of the real structure of the terrain in Esperantia.

In this subsection, we describe three different networks that represent relations among the entities with respect to common causes of failure. Specifically, we report a network representing the set of elements that are likely affected simultaneously by an avalanche, then we show the network obtained with respect to flooding, considering a fictional river, and to a tsunami considering a fictional sea shore.

For the sake of simplicity, we limit the scope to substations, telecommunication base stations and urban areas.

To be more general and flexible we consider three possible locations of Esperantia: one is located in a mountain region, the second case close to the sea (in the upper border of the region) and in the third case in a river valley. However, these are just fiction locations. The interested user can decide whether to consider them separately, at the same time, or to consider other type of failures in order to create one’s own framework.

2.2.3.1.1 Avalanche

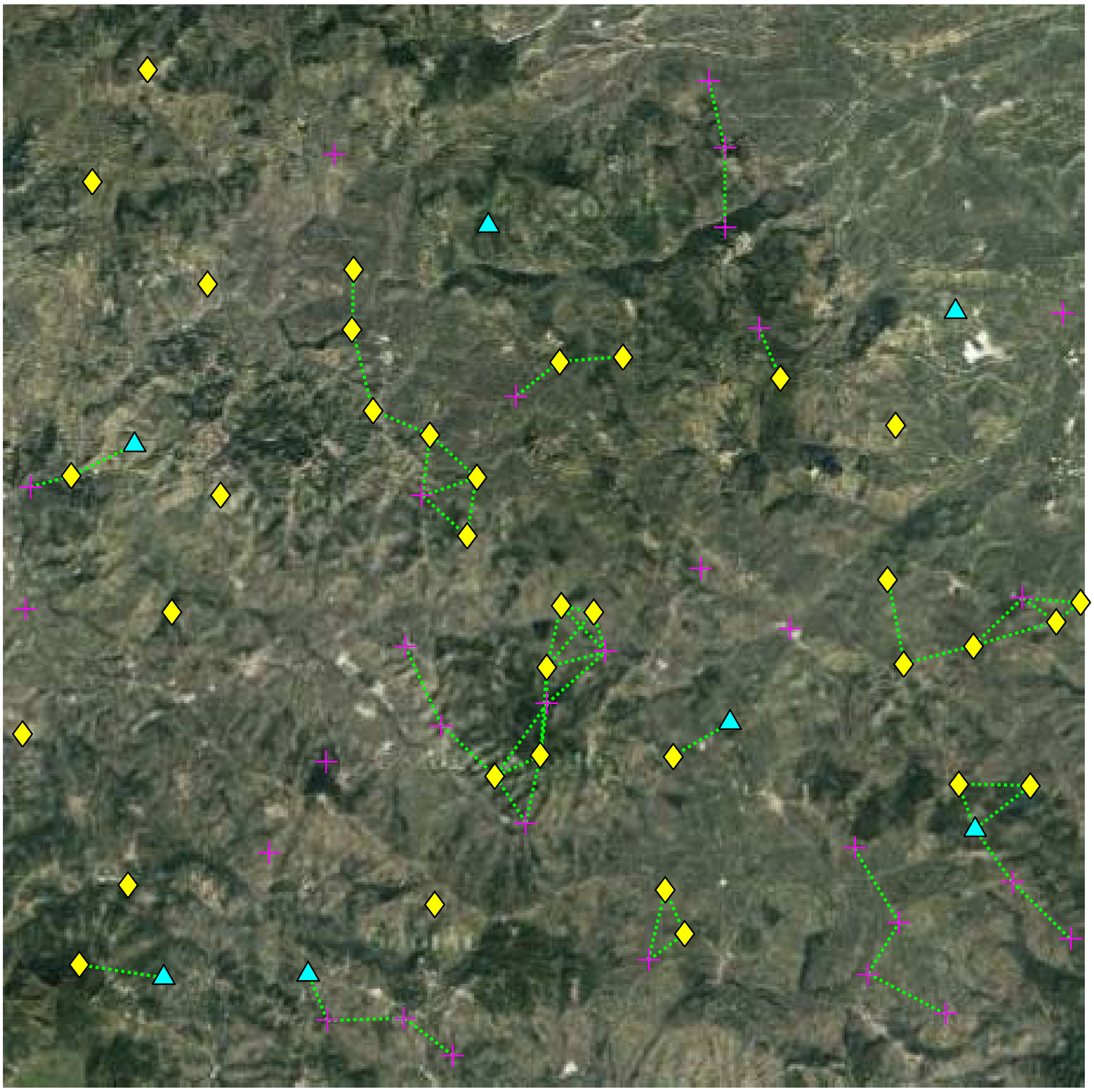

Figure 16: Network of common cause potentials, where each link represents the fact that an event affects multiple entities concurrently. The network is composed of 54 potentials.

We model the fact that two entities are likely to be affected simultaneously by an avalanche if the distance of two entities is less than 9 km. In the figure above, we show the network that summarises such potential common failures. In the next table we provide these potentials. For each link, we detail the two endpoints (from and to).

Table 16: Common cause failure potentials with respect to an avalanche.

ID	From	To
CCFA1	UA17	UA9
CCFA2	UA18	UA6
CCFA3	UA18	UA11
CCFA4	UA20	UA11
CCFA5	UA21	UA7
CCFA6	UA22	UA7
CCFA7	UA23	UA19
CCFA8	UA26	UA17
CCFA9	UA27	UA24
CCFA10	UA30	UA3
CCFA11	SS3	UA24
CCFA12	SS7	UA9
CCFA13	BS2	UA3
CCFA14	BS2	UA25
CCFA15	BS5	UA3
CCFA16	BS5	UA23
CCFA17	BS5	UA25
CCFA18	BS5	BS2
CCFA19	BS6	SS3
CCFA20	BS8	UA28
CCFA21	BS12	UA30
CCFA22	BS13	UA28
CCFA23	BS13	BS8
CCFA24	BS13	BS11
CCFA25	BS14	SS3
CCFA26	BS14	BS6
CCFA27	BS18	BS10
CCFA28	BS18	BS11
CCFA29	BS19	UA12

CCFA30	BS20	UA13
CCFA31	BS21	UA13
CCFA32	BS21	BS20
CCFA33	BS22	UA5
CCFA34	BS22	BS4
CCFA35	60BS23	UA28
CCFA36	BS23	BS8
CCFA37	BS24	SS1
CCFA38	BS25	UA15
CCFA39	BS25	SS6
CCFA40	BS26	UA12
CCFA41	BS26	BS19
CCFA42	BS28	UA13
CCFA43	BS28	BS3
CCFA44	BS28	BS20
CCFA45	BS29	UA3
CCFA46	BS29	UA30
CCFA47	BS29	BS2
CCFA48	BS29	BS12
CCFA49	BS30	BS3
CCFA50	BS32	SS5
CCFA51	BS33	UA2
CCFA52	BS34	UA30
CCFA53	BS34	BS12
CCFA54	BS34	BS29

2.2.3.1.2 Tsunami

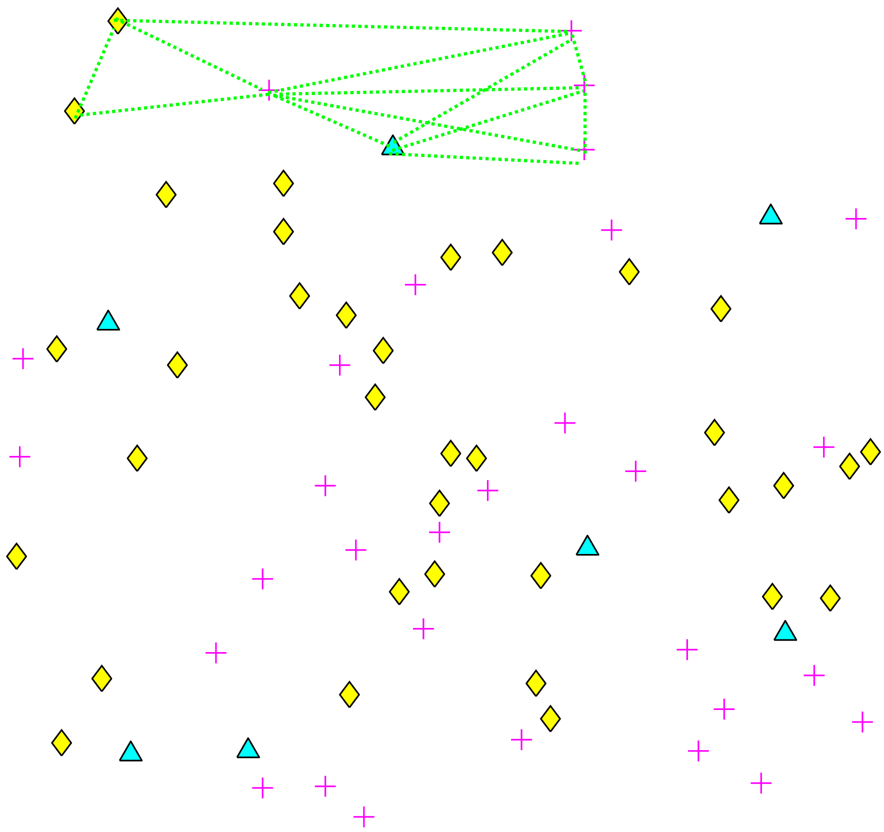

Figure 17: Network of common cause potentials, where each link represents the fact that an event affects multiple entities concurrently in case of a tsunami approaching Esperantia from a sea shore on the upper side. The network is composed of 13 potentials.

We model the fact that two entities are likely to be affected simultaneously by a tsunami approaching Esperantia from a sea shore at the upper side of the synthetic area. We show in the figure above the network that summarises such potential common failures. In the next table, we provide these potentials. For each link, we detail the two endpoints (from and to).

Table 17: Common cause failure potentials with respect to a tsunami.

ID	From	To
CCFT1	UA4	UA7
CCFT2	UA4	SS7
CCFT3	UA4	UA21
CCFT4	UA4	UA22
CCFT5	UA4	UA16
CCFT6	UA4	UA17
CCFT7	SS7	UA22
CCFT8	SS7	UA21
CCFT9	SS7	UA7
CCFT10	UA17	UA16
CCFT11	UA16	UA22
CCFT12	UA22	UA21
CCFT13	U21	UA7

2.2.3.1.3 Flooding

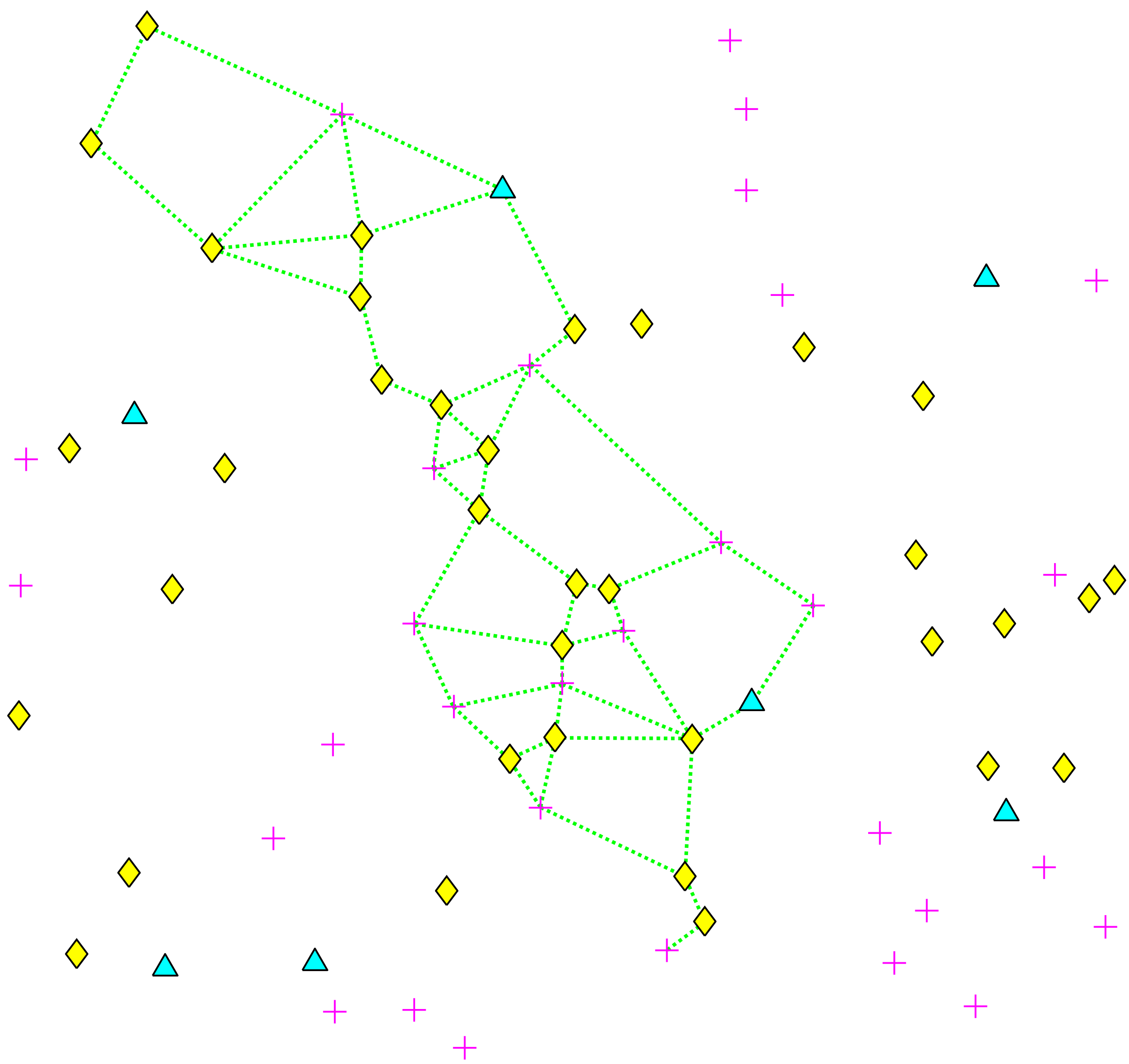

Figure 18: Network of common cause potentials, where each link represents the fact that an event affects multiple entities concurrently in case of a flooding. The network is composed of 50 potentials.

We model the fact that two entities are likely to be affected simultaneously by a flooding if the two entities are both at a distance less than 10 km from a fictional river and its affluents, and their relative distance is less than 25 km. In the figure above, we show the network that summarises such potential common failures. In the next table, we provide these potentials. For each link, we detail the two endpoints (from and to).

Table 18: Common cause failure potentials with respect to a flooding.

ID	From	To
CCFF1	UA3	UA6
CCFF2	UA5	UA6
CCFF3	UA6	UA13
CCFF4	UA10	UA15
CCFF5	UA11	UA22
CCFF6	UA21	UA22
CCFF7	UA5	UA23
CCFF8	UA6	UA23
CCFF9	UA13	UA23
CCFF10	UA15	SS1
CCFF11	UA24	SS5
CCFF12	SS3	SS5
CCFF13	UA21	BS1
CCFF14	UA21	BS5
CCFF15	UA22	BS5
CCFF16	BS1	BS5
CCFF17	SS1	BS6
CCFF18	UA21	BS9
CCFF19	BS1	BS9
CCFF20	UA11	BS12
CCFF21	UA22	BS12
CCFF22	UA3	BS14
CCFF23	UA24	BS14
CCFF24	UA10	BS17
CCFF25	UA11	BS17
CCFF26	SS3	BS17
CCFF27	BS12	BS17
CCFF28	UA11	BS21
CCFF29	UA22	BS21

CCFF30	BS6	BS21
CCFF31	BS5	BS24
CCFF32	BS6	BS24
CCFF33	BS21	BS24
CCFF34	UA21	BS27
CCFF35	UA24	BS27
CCFF36	BS9	BS27
CCFF37	UA4	BS29
CCFF38	UA5	BS29
CCFF39	BS14	BS29
CCFF40	UA4	BS30
CCFF41	BS29	BS30
CCFF42	UA21	BS31
CCFF43	SS5	BS31
CCFF44	BS12	BS31
CCFF45	UA24	BS32
CCFF46	BS9	BS32
CCFF47	BS27	BS32
CCFF48	BS30	BS32
CCFF49	UA13	BS33
CCFF50	UA23	BS33

2.2.3.2 Cyber Dependencies

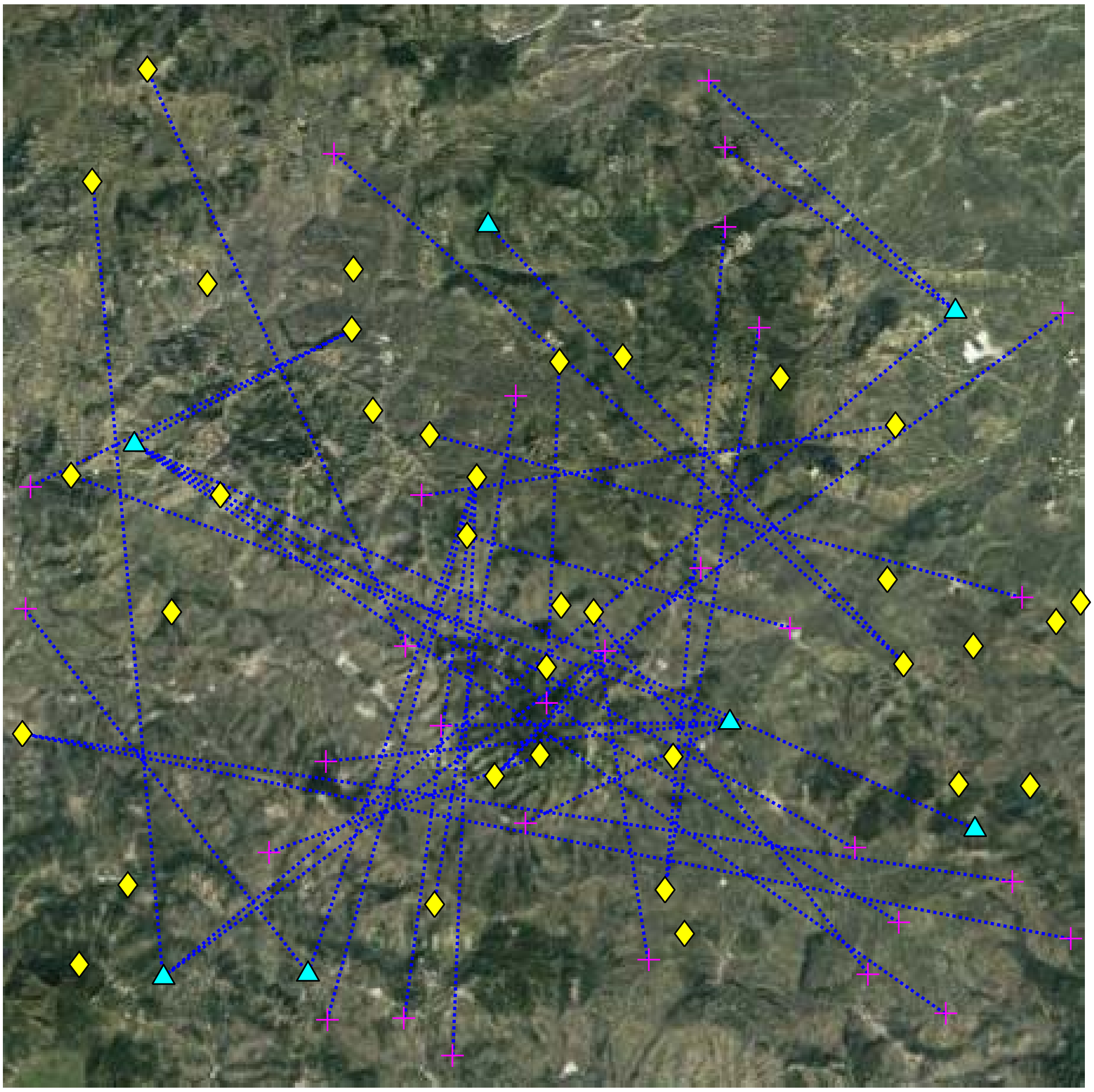

Figure 19: Network of cyber dependencies, where each link represents a dependency of an entity on a particular telecommunication base station. The network is composed of 37 links.

The entities within Esperantia are connected to each other by a network that constitutes the cyber dependency network. We show in the above figure the network that summarises such interactions.We provide in the next table the details of the network. For each link, we detail the two endpoints (from and to).

Table 19: Links in the cyber dependency network.

ID	From	To
CD1	SS1	UA10
CD2	SS4	UA7
CD3	SS4	UA22
CD4	SS4	SS1
CD5	SS5	UA1
CD6	SS5	UA23
CD7	SS5	UA25
CD8	SS6	UA6
CD9	SS6	UA18
CD10	SS6	UA20
CD11	SS6	SS3
CD12	SS7	UA8
CD13	BS1	UA28
CD14	BS2	UA29
CD15	BS3	UA4
CD16	BS3	SS2
CD17	BS5	UA16
CD18	BS5	UA30
CD19	BS7	UA24
CD20	BS7	UA27
CD21	BS8	UA9
CD22	BS8	UA17
CD23	BS8	UA26
CD24	BS8	SS7
CD25	BS12	UA11
CD26	BS12	UA12
CD27	BS13	UA13
CD28	BS15	UA5
CD29	BS16	UA19

CD30	BS17	SS1
CD31	BS18	UA15
CD32	BS18	SS6
CD33	BS22	UA3
CD34	BS23	UA14
CD35	BS25	SS5
CD36	BS26	UA2
CD37	BS26	UA21

2.2.4 Entity Functional Behaviour

In this subsection, we characterise the functional behaviour of the elements in Esperantia. We assume that element is associated to an *operative level*, i.e., a measure between zero and one, where one stands for complete operativeness and zero represent the complete halt.

In order to support the modeller that will use the Esperantia reference data set, we provide a coarse grain description of the dynamics of the operative level OL_A of each element A, considering the effect of the dependencies highlighted above.

Specifically, for each entity A we consider all the entities B on which A is dependent and we characterise the degradation of the operative condition of A based on the condition of the services provided by B (e.g., power), whose operative level is degraded when it is affected by a failure, disruption or attack. To keep the model simple, we depict such a degradation over time in terms of a sigmoid function, using the following formula:

$$\sigma_{A,B}(t) = \max\left\{ \frac{e^{-k[t(1-OL_B(t))-t_{half}]}}{1-OL_B(t)+e^{-k[t(1-OL_B(t))-t_{half}]}}, \sigma_{A,B,\min} \right\}$$

where k represents the slope (the larger is k, the steepest is the descent to zero operativeness), t_{half} represents the time corresponding to an operative level of 0,5, $\sigma_{A,B,min}$ is the minimum level of operativeness achievable (i.e., to model that in spite of the total disruption of the elements it depends upon, and *A* preserves some although degraded operativeness).

If $OL_B(t)<1$, the curve is scaled in order to account for the partial degradation experienced at B at time t.

We assume that the above function is always normalised, that is, we consider a function:

$$\tilde{\sigma}_{A,B}(t) = \frac{\sigma_{A,B}(t)}{\sigma_{A,B}(0)}$$

so that A has full operative level at t=0.

Notice that if $\sigma_{A,B,min}>0,5$ then at time t_{half} the operative level is $\sigma_{A,B,min}$; in this case the parameter has to be intended simply as a way to characterize the shape of the curve.

We consider for all functions a time horizon of T=24 hours assuming no restoration takes place.

The next figure provides an example of degradation profile for t_{half}=12 hours and k=2,5, $\sigma_{A,B,min}$=0,2, assuming that, for all t, $OL_B(t)=0$ (upper plot), $OL_B(t)=0,2$ (central plot) and $OL_B(t)=0,9$ (lower plot).

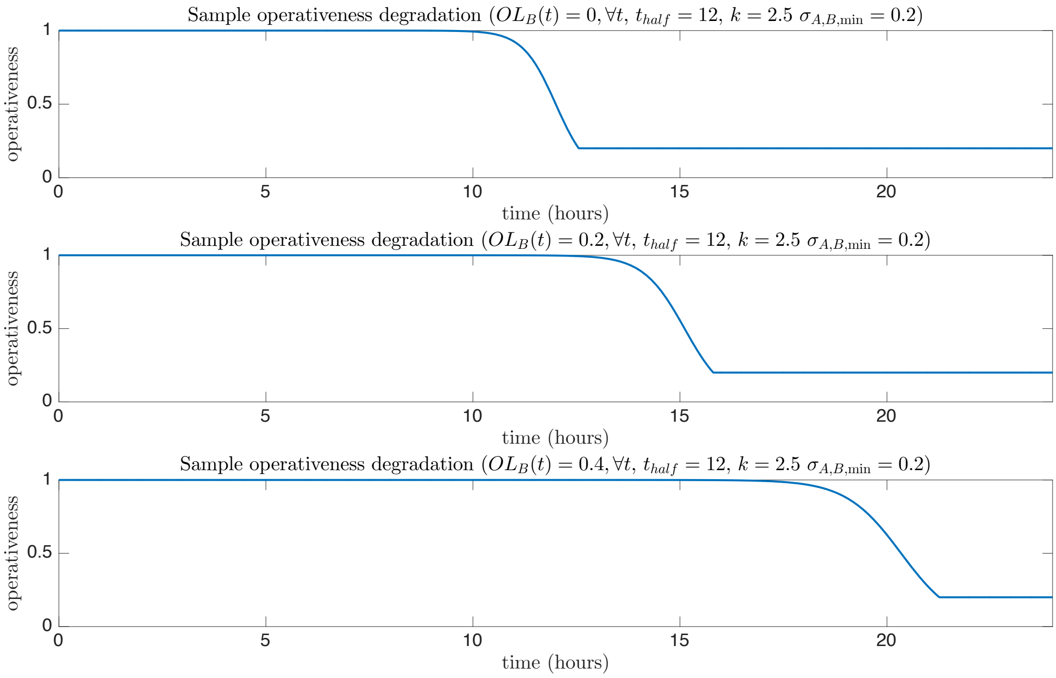

Figure 20: Sample degradation profile of the operative level of an element A within the Esperantia scenario, assuming that for all time instants t OLB(t)=0 (upper plot), OLB(t)=0,2 (central plot) and OLB(t)=0,4 (lower plot).

Notice that, in the case where A has multiple simultaneous dependencies on several other elements B, C, etc., we compose the above single effects as follows:

$$\Sigma_A(t) = \prod_{B \in \mathcal{N}_A(t)} \tilde{\sigma}_{A,B}(t)$$

where $N_A(t)$ is the set of elements that influence A at time t.

2.2.4.1 Urban Areas

2.2.4.1.1 Dependencies on other urban areas

We show next the degradation profile obtained when the links representing the local roads and highways connecting the urban areas are completely unusable, e.g., due to a natural event or to intense traffic.

Table 20: Degradation profiles for the urban areas with respect to unavailability of local roads and highways.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
UA1	19,11	0,80	0,74
UA2	16,08	0,55	0,71
UA3	16,16	0,65	0,83
UA4	17,61	0,45	0,78
UA5	17,86	0,40	0,82
UA6	17,90	0,73	0,71
UA7	17,90	0,28	0,74
UA8	18,95	0,50	0,72
UA9	17,68	0,67	0,75
UA10	17,62	0,36	0,74
UA11	18,17	0,55	0,65
UA12	18,11	0,98	0,76
UA13	17,40	0,29	0,77
UA14	18,16	0,18	0,66
UA15	17,72	0,76	0,79
UA16	18,08	0,39	0,79
UA17	17,80	0,56	0,80
UA18	18,90	0,34	0,76
UA19	17,89	0,01	0,77
UA20	17,88	0,29	0,83
UA21	17,11	0,35	0,76
UA22	18,38	0,34	0,76
UA23	17,97	0,03	0,81
UA24	18,01	0,67	0,75
UA25	18,50	0,68	0,74
UA26	17,77	0,57	0,84
UA27	18,38	0,45	0,75
UA28	17,67	0,29	0,70
UA29	17,05	0,49	0,73
UA30	17,94	0,55	0,75

The next figure shows some of the degradation profiles (e.g., for UA1—UA6), assuming the complete inoperability (e.g., $OL_B(t)=0$) of the element on which the urban areas are dependent.

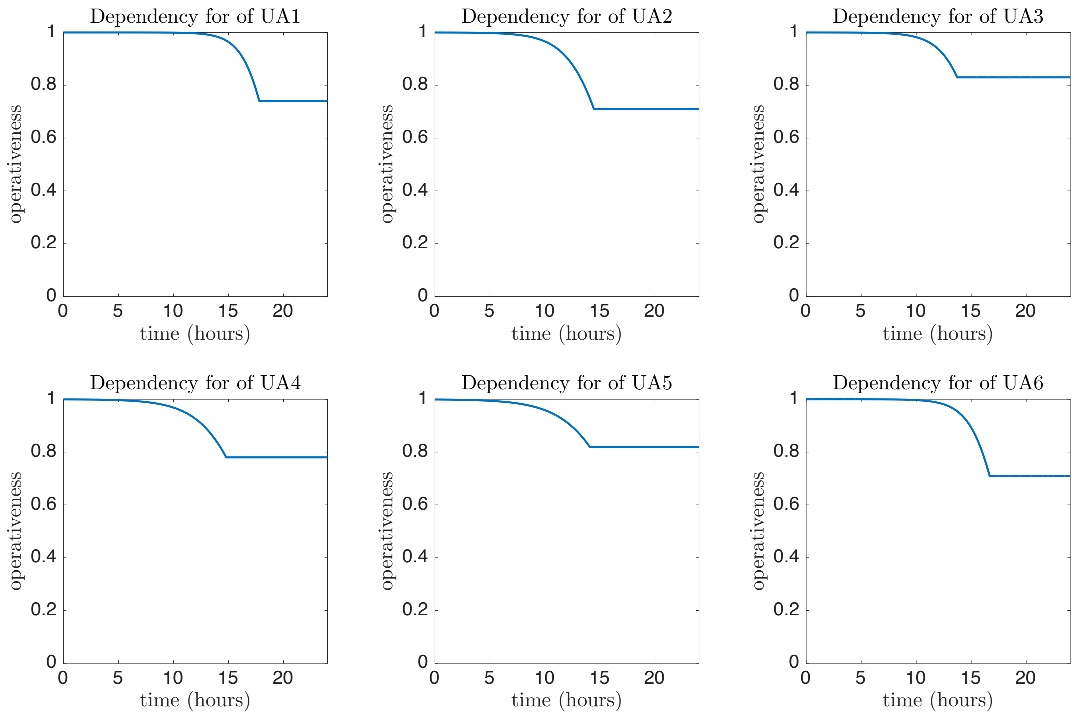

Figure 21: Degradation profiles for UA1—UA6 with respect to the dependencies on other urban areas.

2.2.4.1.2 Dependencies on power distribution

We show next the degradation profile obtained when no power is provided by the primary cab-ins.

Table 21: Degradation profiles for the urban areas with respect to unavailability of power.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
UA1	2,90	4,65	0
UA2	1,02	4,54	0
UA3	3,91	5,80	0
UA4	4,89	4,95	0
UA5	3,52	4,72	0
UA6	0,21	5,05	0
UA7	2,90	4,70	0
UA8	3,58	5,48	0
UA9	1,92	5,76	0
UA10	2,40	4,84	0
UA11	1,49	5,11	0
UA12	2,81	4,22	0
UA13	2,35	5,38	0
UA14	2,83	5,50	0
UA15	3,78	4,75	0
UA16	0,75	5,54	0
UA17	1,69	5,35	0
UA18	4,17	5,33	0
UA19	0,89	5,00	0
UA20	2,39	6,19	0
UA21	5,05	5,55	0
UA22	2,61	5,61	0
UA23	1,76	4,23	0
UA24	1,95	5,33	0
UA25	1,95	5,66	0
UA26	2,24	5,01	0
UA27	2,79	5,06	0
UA28	2,35	4,66	0
UA29	2,47	4,51	0
UA30	2,88	4,56	0

The next figure shows some of the above degradation profiles (e.g., for UA1—UA6), assuming the complete inoperability of the substation the urban areas are dependent upon.

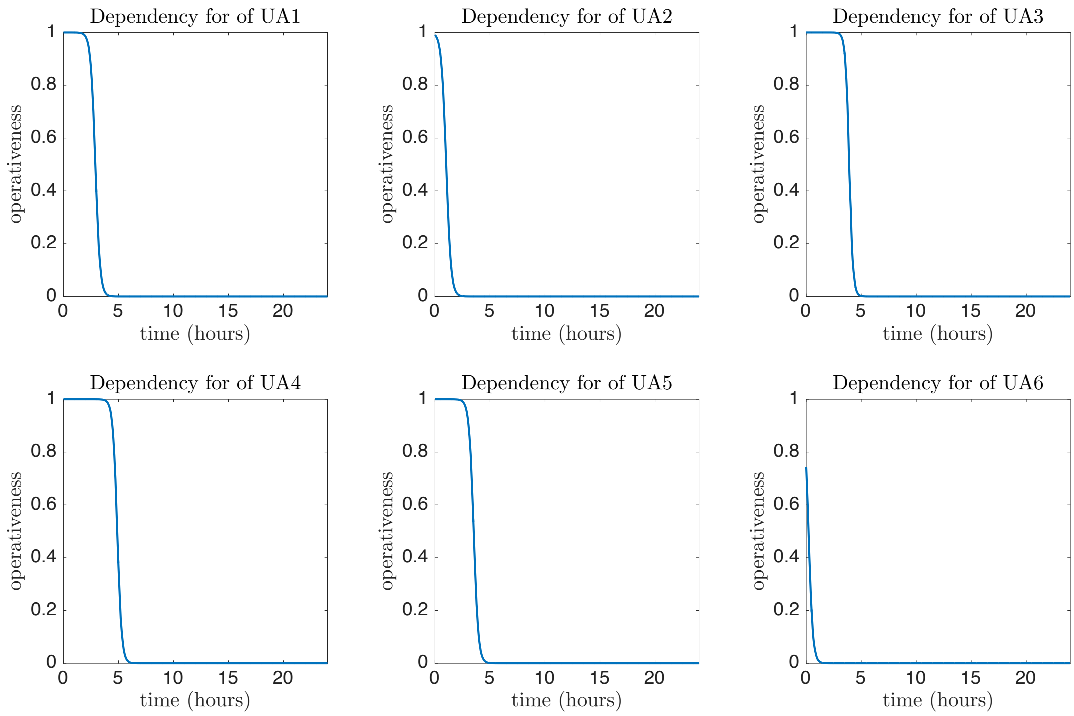

Figure 22: Degradation profiles for UA1—UA6 with respect to the dependencies on power.

2.2.4.1.3 Dependencies on Telecommunication Network

We show next the degradation profile obtained when no telecommunication services provided by a base station are available.

Table 22: Degradation profiles for the urban areas with respect to unavailability of telecommunication services.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
UA1	11,96	1,34	0,21
UA2	8,17	1,60	0,17
UA3	9,44	1,32	0,21
UA4	10,64	1,62	0,22
UA5	11,22	1,77	0,18
UA6	9,37	1,64	0,26
UA7	12,91	1,45	0,19
UA8	11,68	1,40	0,22
UA9	10,19	1,78	0,21
UA10	8,55	1,76	0,14
UA11	10,83	1,45	0,23
UA12	14,02	1,61	0,19
UA13	9,63	1,58	0,18
UA14	10,49	1,75	0,23
UA15	11,21	1,98	0,20
UA16	12,10	1,85	0,16
UA17	10,47	1,40	0,17
UA18	10,40	1,71	0,24
UA19	6,06	2,06	0,18
UA20	8,71	1,21	0,22
UA21	10,66	1,57	0,19
UA22	8,96	1,32	0,13
UA23	11,25	1,46	0,21
UA24	7,75	1,42	0,17
UA25	12,81	1,94	0,25
UA26	12,73	1,54	0,16
UA27	12,29	1,27	0,25
UA28	8,23	1,67	0,14
UA29	9,75	1,56	0,21
UA30	7,06	1,71	0,21

The next figure shows some of the above degradation profiles (e.g., for UA1—UA6), assuming the complete inoperability of the element on which the urban areas are dependent.

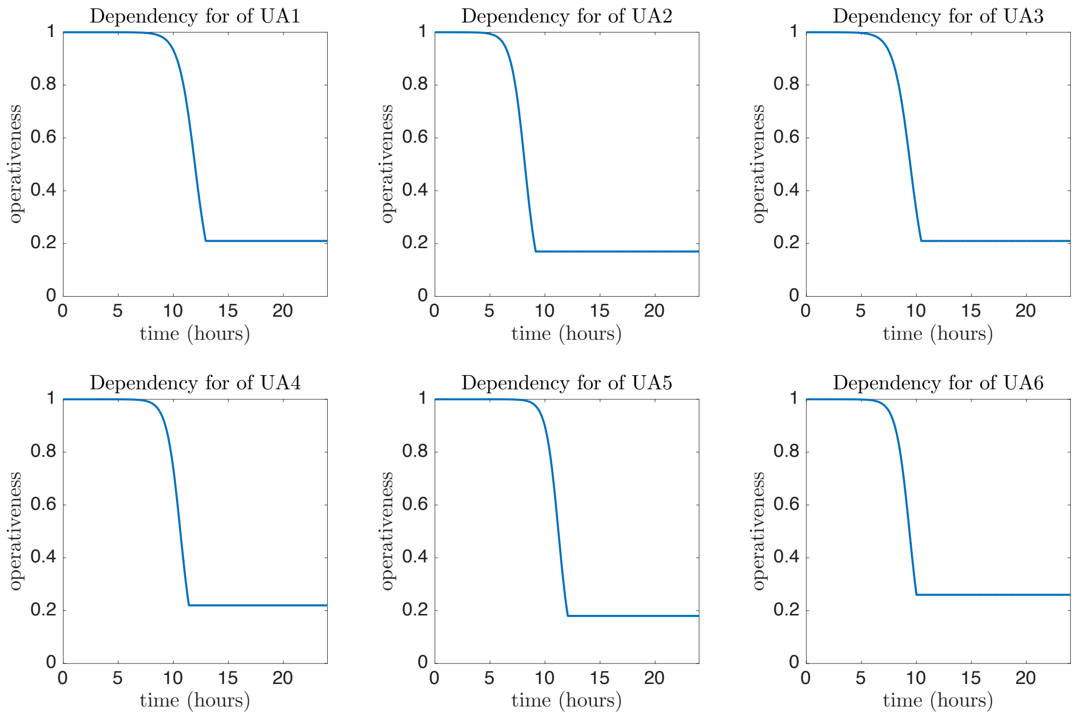

Figure 23: Degradation profiles for UA1—UA6 with respect to the dependencies on TLC.

2.2.4.1.4 Dependencies on Drinking Water

We show next the degradation profile obtained when a urban area lacks drinking water.

Table 23: Degradation profiles for the urban areas with respect to lack of drinking water.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
UA1	16,06	1,90	0,09
UA2	15,26	2,05	0,08
UA3	17,01	1,17	0,09
UA4	17,21	1,64	0,08
UA5	18,04	1,08	0,08
UA6	16,04	1,98	0,12
UA7	17,79	1,41	0,09
UA8	17,07	1,79	0,10
UA9	16,22	2,19	0,11
UA10	17,77	1,29	0,08
UA11	17,26	2,48	0,10
UA12	16,76	2,84	0,10
UA13	18,87	1,53	0,10
UA14	17,60	3,61	0,10
UA15	16,88	0,91	0,09
UA16	17,27	2,10	0,10
UA17	17,08	1,01	0,09
UA18	17,17	2,15	0,09
UA19	17,45	1,17	0,10
UA20	16,39	1,92	0,11
UA21	16,20	1,75	0,09
UA22	17,36	1,31	0,09
UA23	18,88	0,43	0,10
UA24	16,69	3,06	0,11
UA25	15,98	4,50	0,10
UA26	16,76	4,72	0,10
UA27	16,51	2,00	0,09
UA28	16,67	2,45	0,10
UA29	17,47	2,03	0,09
UA30	16,86	2,57	0,11

2.2.4.1.5 Dependencies on Gas

We show next the degradation profile obtained when an urban area lacks gas:

Table 24: Degradation profiles for the urban areas with respect to lack of gas.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
UA1	17,59	5,68	0,27
UA2	19,14	6,15	0,28
UA3	20,28	6,08	0,31
UA4	18,50	3,88	0,29
UA5	18,37	5,51	0,30
UA6	18,06	5,07	0,31
UA7	18,72	3,46	0,29
UA8	18,79	4,17	0,29
UA9	19,13	5,18	0,29
UA10	18,11	6,32	0,30
UA11	19,08	5,27	0,29
UA12	18,39	5,76	0,29
UA13	18,63	4,60	0,28
UA14	18,16	3,34	0,29
UA15	18,71	5,59	0,29
UA16	22,56	4,54	0,29
UA17	22,40	6,67	0,29
UA18	20,14	7,23	0,28
UA19	19,78	5,12	0,30
UA20	17,72	6,69	0,27
UA21	18,41	6,45	0,30
UA22	18,38	4,08	0,30
UA23	19,53	5,46	0,29
UA24	19,48	5,76	0,29
UA25	19,10	6,02	0,30
UA26	18,65	6,17	0,29
UA27	18,07	6,17	0,29
UA28	19,00	6,17	0,30
UA29	20,13	5,18	0,29
UA30	19,42	5,87	0,30

2.2.4.1.6 Dependencies on Railways

We show next the degradation profile obtained when the railways serving an urban area are completely out of order.

Table 25: Degradation profiles for the urban areas with respect to unavailability of rail transport.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
UA1	22,09	2,30	0,43
UA2	21,32	1,03	0,39
UA3	21,01	1,45	0,55
UA4	19,83	1,85	0,53
UA5	21,49	0,24	0,33
UA6	19,78	0,46	0,30
UA7	22,59	1,07	0,49
UA8	21,52	1,57	0,56
UA9	21,26	3,29	0,51
UA10	20,60	2,29	0,34
UA11	18,82	1,05	0,34
UA12	19,80	0,87	0,58
UA13	21,36	3,03	0,48
UA14	23,41	4,23	0,46
UA15	21,74	1,66	0,63
UA16	21,30	1,02	0,42
UA17	20,45	0,08	0,51
UA18	21,12	2,47	0,54
UA19	21,96	1,78	0,58
UA20	20,74	2,66	0,41
UA21	22,89	0,59	0,53
UA22	19,77	1,74	0,77
UA23	20,62	0,84	0,34
UA24	21,05	2,77	0,54
UA25	19,04	0,94	0,47
UA26	21,56	1,41	0,41
UA27	21,07	1,15	0,41
UA28	21,08	2,49	0,54
UA29	21,79	1,92	0,73
UA30	22,04	0,49	0,42

2.2.4.1.7 Cyber Dependencies

We show next the degradation profile obtained when an element that has a cyber influence on an urban area is completely faulted or destroyed due to a cyber attack.

Table 26: Degradation profiles for the urban areas with respect to cyber dependencies.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
UA1	21,28	0,32	0,41
UA2	21,28	0,31	0,35
UA3	21,49	0,31	0,34
UA4	21,00	0,32	0,40
UA5	19,41	0,32	0,40
UA6	20,16	0,31	0,41
UA7	20,02	0,35	0,38
UA8	19,40	0,22	0,38
UA9	21,34	0,38	0,41
UA10	19,56	0,27	0,37
UA11	20,93	0,26	0,40
UA12	19,12	0,30	0,39
UA13	19,80	0,23	0,32
UA14	19,71	0,20	0,38
UA15	19,62	0,28	0,37
UA16	20,68	0,35	0,41
UA17	20,08	0,37	0,38
UA18	18,71	0,26	0,49
UA19	19,95	0,40	0,40
UA20	18,38	0,27	0,42
UA21	19,39	0,30	0,42
UA22	22,06	0,37	0,42
UA23	20,09	0,24	0,36
UA24	22,41	0,36	0,38
UA25	19,98	0,33	0,42
UA26	19,19	0,30	0,40
UA27	19,28	0,32	0,35
UA28	20,14	0,25	0,41
UA29	18,55	0,25	0,43
UA30	19,47	0,27	0,44

2.2.4.2 Primary Electric Substations

2.2.4.2.1 Dependencies on other primary substations

We show next the degradation profile obtained at a primary substation A when a primary substation B connected to A completely lacks power.

Table 27: Degradation profiles for the primary substations with respect to lack of power in substations connected to them.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
SS1	0,40	2,02	0,68
SS2	1,30	1,97	0,72
SS3	1,58	1,96	0,71
SS4	1,03	1,81	0,68
SS5	1,37	2,36	0,70
SS6	1,32	2,02	0,72
SS7	1,49	1,98	0,69

2.2.4.2.2 Dependencies on Telecommunication Network

We show next the degradation profile obtained at a substation A when a telecommunication base station completely fails to provide its connection services.

Table 28: Degradation profiles for the primary cabins with respect to lack of telecommunication services provided by the telecommunication base stations.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
SS1	16,65	3,87	0,81
SS2	17,21	4,30	0,85
SS3	17,90	3,81	0,79
SS4	14,43	3,59	0,83
SS5	18,92	2,87	0,81
SS6	18,10	3,52	0,82
SS7	14,45	3,73	0,84

2.2.4.2.3 Cyber Dependencies

We show next the degradation profile obtained when an element that has a cyber influence on a substation is completely faulted or destroyed due to a cyber attack.

Table 29: Degradation profiles for the primary substations with respect to cyber dependencies.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
SS1	6,75	3,36	0,17
SS2	8,57	2,38	0,24
SS3	7,26	2,20	0,19
SS4	6,46	2,02	0,15
SS5	9,02	1,26	0,13
SS6	6,76	0,720	0,16
SS7	8,99	2,31	0,24

2.2.4.3 Telecommunication Base Stations

2.2.4.3.1 Dependencies on other Base Stations

We show next the degradation profile for a base station A when a base station B fails to provide its telecommunication services (each row in the table below refers to the effect on the base station A).

Table 30: Degradation profiles for the base stations with respect to unavailability of telecommunication services provided by other base stations.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
BS1	9,30	3,39	0,07
BS2	9,03	2,25	0,09
BS3	10,71	4,17	0,09
BS4	8,71	4,54	0,10
BS5	9,58	4,75	0,14
BS6	9,38	3,34	0,11
BS7	9,47	2,45	0,10
BS8	11,00	3,32	0,10
BS9	8,84	6,91	0,07
BS10	8,73	2,43	0,10
BS11	8,33	4,16	0,09
BS12	8,78	4,51	0,10
BS13	10,4	4,59	0,10
BS14	8,80	4,15	0,12
BS15	8,00	5,32	0,15
BS16	7,76	3,51	0,09
BS17	9,78	5,39	0,12
BS18	10,84	3,46	0,11
BS19	10,37	3,30	0,08
BS20	10,35	4,17	0,12
BS21	7,34	3,55	0,10
BS22	10,62	3,98	0,06
BS23	9,44	5,22	0,12
BS24	7,48	3,59	0,11
BS25	11,38	3,41	0,13
BS26	11,03	3,52	0,10
BS27	9,94	4,32	0,11
BS28	8,53	4,13	0,08
BS29	10,48	3,95	0,08
BS30	9,80	5,18	0,11

BS31	9,43	2,83	0,09
BS32	9,09	3,54	0,12
BS33	12,89	4,30	0,08
BS34	9,24	5,26	0,11
BS35	10,46	3,22	0,08

2.2.4.3.2 Dependencies on power

We show next the degradation profile for a base station A obtained when an electric substation B fails to provide power (each row in the table below refers to the effect on the base station A).

Table 31: Degradation profiles for the base stations with respect to unavailability of power provided by the primary substations.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
BS1	15,66	6,97	0,00
BS2	16,37	6,72	0,00
BS3	17,16	7,58	0,00
BS4	16,10	9,24	0,00
BS5	16,13	7,12	0,00
BS6	16,76	7,41	0,00
BS7	15,53	6,26	0,00
BS8	16,52	8,38	0,00
BS9	17,58	5,32	0,00
BS10	15,19	6,13	0,00
BS11	16,32	7,63	0,00
BS12	16,15	7,00	0,00
BS13	15,93	7,25	0,00
BS14	18,75	7,31	0,00
BS15	16,64	6,48	0,00
BS16	15,51	7,00	0,00
BS17	14,79	5,65	0,00
BS18	16,67	6,57	0,00
BS19	15,35	7,24	0,00
BS20	16,77	6,59	0,00
BS21	16,36	7,91	0,00
BS22	15,06	6,95	0,00
BS23	17,73	6,96	0,00
BS24	15,59	7,50	0,00
BS25	15,86	6,54	0,00
BS26	16,36	6,46	0,00
BS27	17,22	6,97	0,00
BS28	15,09	8,01	0,00
BS29	14,39	7,48	0,00
BS30	16,70	5,65	0,00
BS31	16,48	7,86	0,00

BS32	14,55	7,00	0,00
BS33	16,61	7,58	0,00
BS34	15,66	5,41	0,00
BS35	16,79	7,20	0,00

2.2.4.3.3 Cyber Dependencies

We show next the degradation profile obtained when an element that has a cyber influence on a base station is completely faulted or destroyed due to a cyber attack.

Table 32: Degradation profiles for the base stations with respect to cyber dependencies.

ID	Time t_{half} for 50% operativeness (hours)	Slope k	Final operative level $\sigma_{A,B,min}$
BS1	15,33	3,14	0,71
BS2	15,06	3,34	0,28
BS3	14,63	1,04	0,01
BS4	17,31	2,21	0,01
BS6	15,39	3,41	0,24
BS7	16,11	2,93	0,43
BS11	16,04	3,53	0,28
BS12	15,27	2,52	0,09
BS14	15,66	0,70	0,23
BS15	16,29	3,56	0,52
BS16	17,49	1,77	0,26
BS17	15,87	0,82	1,04
BS21	15,11	1,71	0,94
BS22	16,05	1,34	1,06
BS24	16,31	2,43	0,66
BS25	16,13	3,11	0,61

2.3 Esperantia City Urban-Scale Reference Set

The Esperantia City urban-scale Reference set represents a subset of the main entities in a 10Km wide square portion of Esperantia City, the main city within the Esperantia reference set.

Specifically, we consider three BTSs, eight hospitals and a power distribution network involving five primary electric substations and 101 secondary electric substations, of which three are automated and telecontrolled by a BTS, 50 are telecontrolled via BTS, and 48 are not telecontrolled.

2.3.1 Entities

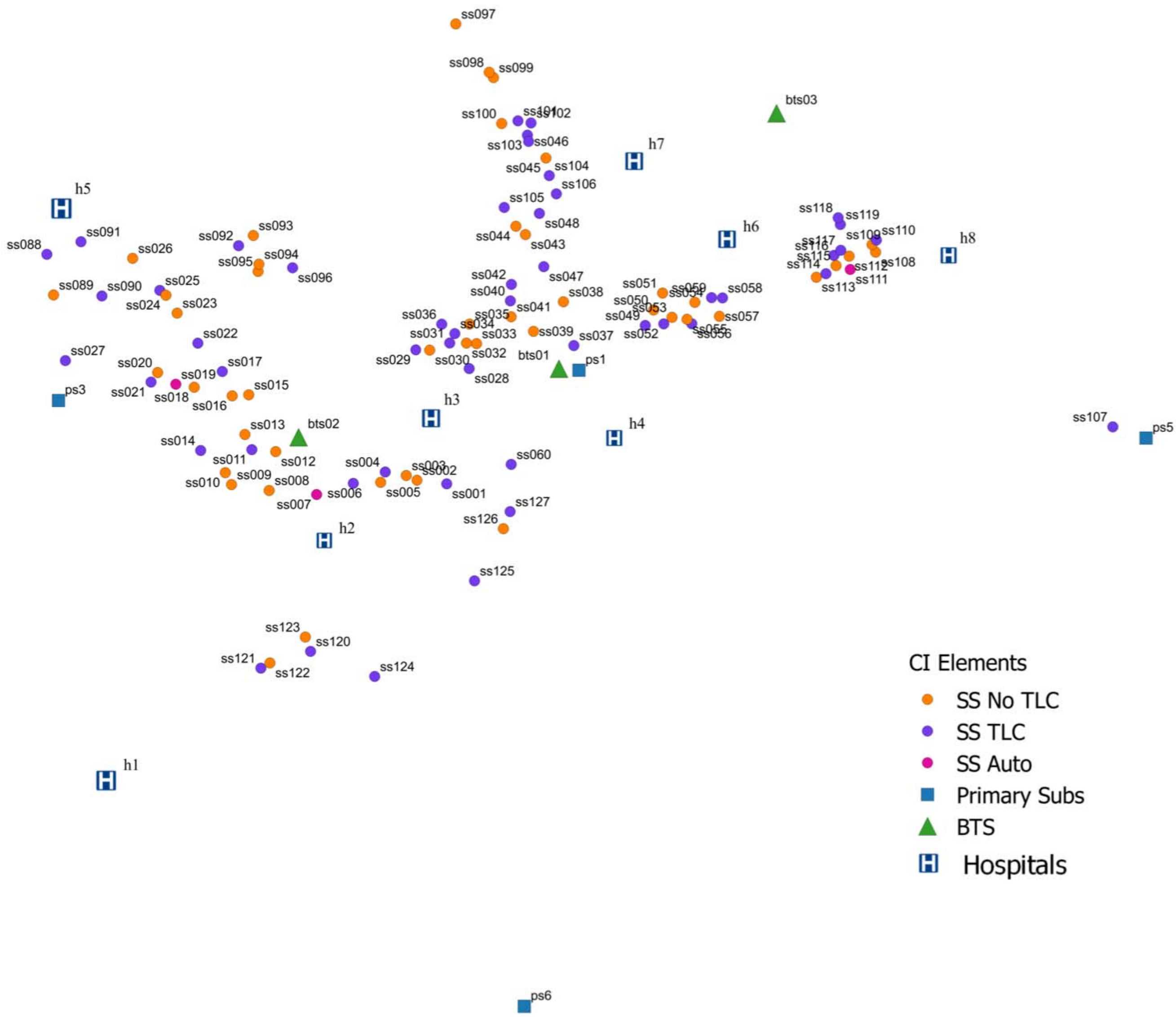

Figure 24: Entities considered within the Esperantia City Urban Scale Reference Set.

The proposed urban-scale reference set features several different entities, distributed as shown in the above figure. In the Figure, each entity is associated to a unique identifier, which is lower-case in order to distinguish it from the regional scale identifiers.

The next table details the position of the entities within a square, 10 * 10 Km wide portion of the main city within Esperantia, Esperantia City.

Table 33: Position of the different entities within the urban-scale reference set.

ID	TYPE	Ordinate (Km)	Abscissa (Km)
bts01	BTS	4,79	3,63
bts02	BTS	3,13	4,28
bts03	BTS	6,20	1,33
ps1	Primary Substation	4,93	3,63
ps3	Primary Substation	1,61	3,92
ps5	Primary Substation	8,57	4,24
ps6	Primary Substation	4,56	9,39
ss001	Tele-controlled Substation	4,09	4,67
ss002	Not controlled Substation	3,91	4,63
ss003	Not controlled Substation	3,81	4,55
ss004	Tele-controlled Substation	3,68	4,52
ss005	Not controlled Substation	3,68	4,64
ss006	Tele-controlled Substation	3,51	4,64
ss007	Automatic Substation	4,79	3,63
ss008	Not controlled Substation	2,99	4,69
ss009	Not controlled Substation	2,70	4,67
ss010	Not controlled Substation	2,68	4,55
ss011	Tele-controlled Substation	2,83	4,35
ss012	Not controlled Substation	3,01	4,35
ss013	Not controlled Substation	2,80	4,23
ss014	Tele-controlled Substation	2,49	4,32
ss015	Not controlled Substation	2,84	3,85
ss016	Not controlled Substation	2,73	3,87
ss017	Tele-controlled Substation	2,66	3,64
ss018	Not controlled Substation	2,48	3,78
ss019	Automatic Substation	3,13	4,28
ss020	Not controlled Substation	2,24	3,63
ss021	Tele-controlled Substation	2,20	3,75
ss022	Tele-controlled Substation	2,51	3,39
ss023	Not controlled Substation	2,40	3,11
ss024	Not controlled Substation	2,31	2,96
ss025	Tele-controlled Substation	2,25	2,90
ss026	Not controlled Substation	2,09	2,63
ss027	Tele-controlled Substation	1,64	3,56
ss028	Tele-controlled Substation	3,88	3,44
ss029	Tele-controlled Substation	4,26	3,60
ss030	Not controlled Substation	4,00	3,47

ss031	Tele-controlled Substation	4,11	3,36
ss032	Not controlled Substation	4,29	3,41
ss033	Not controlled Substation	4,21	3,39
ss034	Tele-controlled Substation	4,14	3,27
ss035	Not controlled Substation	4,24	3,24
ss036a	Tele-controlled Substation	4,05	3,20
ss036b	Not controlled Substation	4,50	3,15
ss037	Tele-controlled Substation	4,93	3,41
ss038	Not controlled Substation	4,84	3,00
ss039	Not controlled Substation	4,64	3,26
ss040	Tele-controlled Substation	4,49	2,94
ss041	Not controlled Substation	4,60	2,39
ss042	Tele-controlled Substation	4,50	2,78
ss043	Not controlled Substation	4,53	2,30
ss044	Not controlled Substation	4,71	1,74
ss045	Not controlled Substation	5,40	3,11
ss046	Tele-controlled Substation	4,75	1,86
ss047	Tele-controlled Substation	4,62	1,56
ss048	Tele-controlled Substation	4,70	2,69
ss049	Tele-controlled Substation	4,69	2,21
ss050	Not controlled Substation	5,48	2,96
ss051	Not controlled Substation	5,54	3,18
ss052	Tele-controlled Substation	5,36	3,23
ss053	Not controlled Substation	5,69	3,03
ss054	Not controlled Substation	5,63	3,15
ss055	Not controlled Substation	5,86	3,11
ss056	Tele-controlled Substation	5,47	3,21
ss057	Not controlled Substation	1,62	2,94
ss058	Tele-controlled Substation	5,67	3,27
ss059	Tele-controlled Substation	5,86	3,00
ss060	Tele-controlled Substation	5,81	2,97
ss088	Tele-controlled Substation	4,49	4,39
ss089	Not controlled Substation	2,85	2,41
ss090	Tele-controlled Substation	1,54	2,57
ss091	Tele-controlled Substation	1,91	2,96
ss092	Tele-controlled Substation	1,76	2,50
ss093	Not controlled Substation	2,89	2,65
ss094	Not controlled Substation	2,89	2,75
ss095	Not controlled Substation	4,15	0,48

ss096	Tele-controlled Substation	2,77	2,53
ss097	Not controlled Substation	4,34	0,90
ss098	Not controlled Substation	4,40	0,99
ss099	Not controlled Substation	4,45	1,42
ss100	Not controlled Substation	6,85	2,59
ss101	Tele-controlled Substation	3,11	2,72
ss102	Tele-controlled Substation	4,56	1,38
ss103	Tele-controlled Substation	4,64	1,41
ss104	Tele-controlled Substation	4,60	1,48
ss105	Tele-controlled Substation	4,47	2,15
ss106	Tele-controlled Substation	4,81	2,02
ss107	Tele-controlled Substation	8,34	4,14
ss108	Not controlled Substation	6,80	2,48
ss109	Not controlled Substation	6,67	2,60
ss110	Tele-controlled Substation	6,85	2,48
ss111	Automatic Substation	6,20	1,33
ss112	Not controlled Substation	6,46	2,81
ss113	Not controlled Substation	4,46	5,08
ss114	Not controlled Substation	6,60	2,71
ss115	Tele-controlled Substation	6,53	2,75
ss116	Not controlled Substation	2,96	6,28
ss117	Tele-controlled Substation	6,57	2,62
ss118	Tele-controlled Substation	6,63	2,56
ss119	Tele-controlled Substation	6,57	2,26
ss120	Tele-controlled Substation	6,61	2,33
ss121	Tele-controlled Substation	3,23	6,15
ss122	Tele-controlled Substation	2,91	6,36
ss123	Not controlled Substation	3,16	6,03
ss124	Tele-controlled Substation	3,64	6,45
ss125	Tele-controlled Substation	4,27	5,54
ss126	Not controlled Substation	2,92	6,16
ss127	Tele-controlled Substation	4,49	4,87
h1	Hospital	1,92	7,35
h2	Hospital	3,31	5,17
h3	Hospital	3,98	4,07
h4	Hospital	5,17	4,26
h5	Hospital	1,64	2,16
h6	Hospital	5,87	2,43
h7	Hospital	5,29	1,74

h8	Hospital	7,30	2,58

2.3.2 Dependencies

2.3.2.1 Dependency of Secondary Electric Substations on Base Transceiver Stations

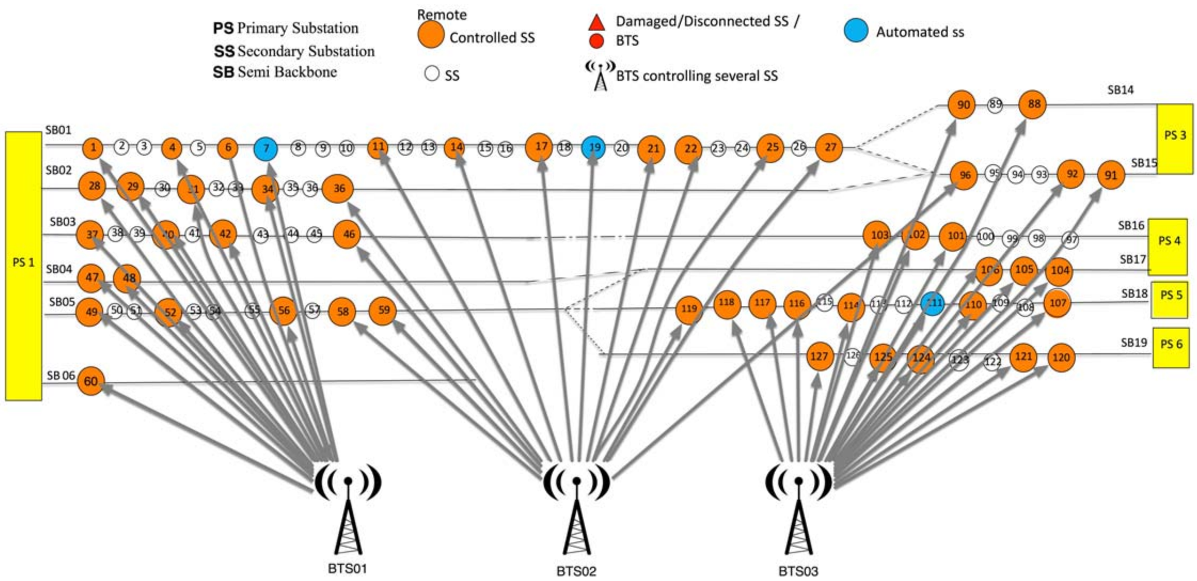

Figure 25: Dependency of secondary electric substations on BTS.

In this subsection, we outline the dependencies of secondary electric substations on BTSs, as shown also in Figure 24.

We collect the information conveyed by Figure 14 in the following table.

Table 34: Dependency of secondary electric substations on BTS.

Controlled Substation	Controlled by
ss001	bts01
ss004	bts01
ss006	bts01
ss007	bts01
ss011	bts02
ss014	bts02
ss017	bts02
ss019	bts02
ss021	bts02
ss022	bts02
ss025	bts02
ss027	bts02
ss028	bts01
ss029	bts01
ss031	bts01

ss034	bts01
ss036	bts02
ss037	bts01
ss040	bts01
ss042	bts01
ss046	bts02
ss047	bts01
ss048	bts01
ss049	bts01
ss052	bts01
ss056	bts01
ss058	bts02
ss059	bts02
ss060	bts01
ss088	bts03
ss090	bts03
ss091	bts03
ss092	bts03
ss096	bts02
ss101	bts03
ss102	bts03
ss103	bts03
ss104	bts03
ss105	bts03
ss106	bts03
ss107	bts03
ss110	bts03
ss111	bts03
ss114	bts03
ss116	bts03
ss117	bts03
ss118	bts03
ss119	bts02
ss120	bts03
ss121	bts03
ss124	bts03
ss125	bts03
ss127	bts03

2.3.2.2 Dependency of Base Transceiver Stations on Secondary Electric Substations

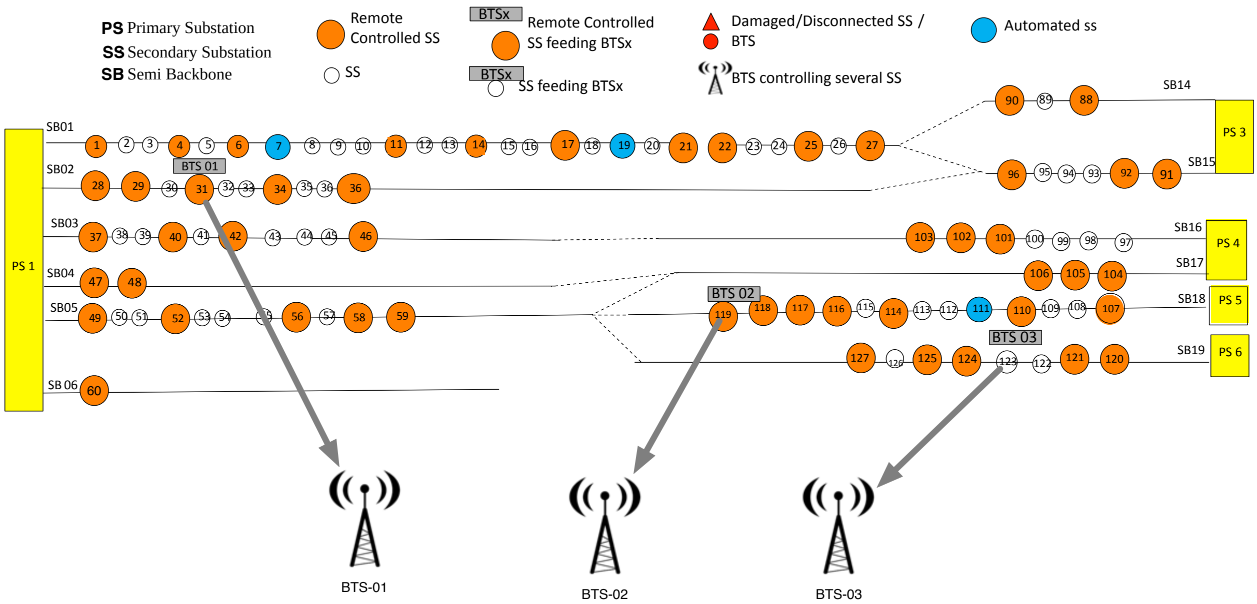

Figure 26: Dependency of BTS on secondary electric substations.

In this subsection, we outline the dependencies of BTS on secondary electric substations, as shown also in Figure 24.

We collect the information conveyed by Figure 24 in the following table.

Table 35: Dependency of BTS on secondary electric substations.

Dependent BTS	Depends on Substation
bts01	ss031
bts02	ss119
bts03	ss123

2.3.2.3 Dependencies of Hospitals on Secondary Electric Substations

In this subsection, we model the dependency of hospitals on substations, as shown in the next table.

Table 36: Dependency of hospitals on secondary electric substations.

Dependent hospital	Depends on Substation
h1	ss121
h2	ss007
h3	ss028
h4	ss060
h5	ss091
h6	ss058
h7	ss106
h8	ss110

3 Conclusions

This document provided a description of the initial data reference set to be used as a benchmark for CIP modelling and simulation approaches.

Such a reference set encompasses regional-scale and an urban-scale sets of elements, their dependencies and a set of threat potentials. The regional scale reference set consists of a fictional region, namely Esperantia, where a set of urban areas, electric primary cabins, telecommunication base stations as well as drinking water, gas and transport infrastructures are interconnected via several types of dependencies.

The result is a multigraph that characterises the different relations among the entities. Such relations are modelled as a *multigraph*, i.e., a superposition of network topologies where each network models a specific typology of relation.

The urban scale scenario models a portion of the fictional main urban area of the Esperantia Region, Esperantia city.

As noted in Section 1, the Esperantia reference data set aims at becoming a reference set for the testing and validation of dependency models, impact/consequences analysis tools and methodologies. Therefore, this initial data set is intentionally general and abstract and does not refer to any particular modelling approach for the dynamic behaviour of the different entities in place.

Moreover, the initial reference set does not yet contain specific functionality in and of network elements (nodes and links) such as:

1. Power: power generation node, busbars, transformation, phasors, capacitors, demand profile per hour/day of the week/season per UAi, etc.;
2. Telecommunications: Home location register (HLR), visitor location register (VLR), gateway(s) to fixed networks and the Internet, glass fibre rings, etc.;
3. Roads: capacity profile per road, volume traffic profile per hour/day of the week of vehicles from UAi to UAj;
4. Railways: signalling system (and its power dependency), power dependency for traction, central railway supervision post(s), GSM-R(ail), volume traffic profile per hour/day of the week of vehicles from UAi to UAj; #of trains/capacity per hour/day of week from UAi to UAj, etc.;
5. Drinking water: production plants, production dependency on surface water (e.g. contamination), demand profile per hour/day of the week/season per UAi;
6. Gas: production plant(s), storage, LNG ship terminal(s), gas mixing station(s), demand profile per hour/day of the week/season per UAi; etc.

Such functionalities can simply be added and assigned to specific nodes by the individual researcher, preferable using the same structure as presented in this initial data reference set. In future, donations of such elements / functions in an alike manner may be used to enhance the data reference set.

4 Bibliography

[1] Rinaldi, Steven M., James P. Peerenboom, and Terrence K. Kelly. "Identifying, understanding, and analyzing critical infrastructure interdependencies." *IEEE Control Systems* 21,6 (2001): 11-25.

[2] EU Commission. "Green Paper on a European Programme for Critical Infrastructure Protection COM (2005) 576." (2005).

[3] D. Mendonca and W.A. Wallace, ``Impacts of the 2001 World Trade Center attack on New York City critical infrastructures," Journal of Infrastructure Systems, vol. 12, n. 4, pp. 260--270, 2006.

[4] R. Zimmerman and C.E. Restrepo, ``The next step: Quantifying infrastructure interdependencies to improve security," International Journal of Critical Infrastructures, vol. 2, n. 2/3, pp. 215--230, 2006.

[5] J. Johansson and H. Hassel, ``An approach for modelling interdependent infrastructures in the context of vulnerability analysis," Reliability Engineering and System Safety, vol. 95, n. 12, pp. 1335--44, 2010.

[6] R. Setola, ``How to measure the degree of interdependencies among critical infrastructures," Int. J. of System of Systems Engineering, vol. 2, n. 1, pp. 38--59, 2010.

[7] C. Nan and I. Eusgeld, ``Adopting HLA standard for interdependency study," Reliability Engineering and System Safety, vol. 96, n. 1, pp. 149--159, 2011.

[8] G. Oliva, R. Setola and S. Panzieri, "Critical Clusters in Interdependent Economic Sectors. A Data-Driven Spectral Clustering Analysis", European Physics Journal – Special Topics (EPJ– ST) (to appear).

[9] Barabási, Albert-László, and Réka Albert. "Emergence of scaling in random networks." *science* 286,5439 (1999): 509-512.

[10] Watts, Duncan J., and Steven H. Strogatz. "Collective dynamics of 'small-world'networks." *nature* 393,6684 (1998): 440-442.

[11] Holme, P., Kim, B. J., Yoon, C. N., & Han, S. K. (2002). Attack vulnerability of complex networks. *Physical Review E*, *65*(5), 056109.

[12] L. Faramondi, G. Oliva, F. Pascucci, S. Panzieri and R. Setola, "Critical Node Detection based on Attacker Preferences", 24th Mediterranean Conference on Control and Automation (to appear, 2016).

[13] Ouyang, Min. "Review on modeling and simulation of interdependent critical infrastructure systems." *Reliability engineering & System safety* 121 (2014): 43-60.