

# Ontological framework to model Critical Infrastructures and their interdependencies

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## Abstract

*This paper presents a Knowledge Base System (KBS) as a key component of a federated simulation framework which allows the investigation of (inter)dependencies among Critical Infrastructures (CIs). The KBS supports the federated simulation framework by using the ontological formalism to represent specific CI domains and their dependencies. The main advantage of the proposed ontological formalism consists on the abstraction of the description from the technological (i.e. simulation) level: the scenario can be described with a formalism used by the experts of the various CI domains.*

*The proposed approach has been validated on a realistic scenario with actual data derived from the Rome city area. This scenario has been then used as testbed for a federated distributed simulation.*

## 1 Introduction

The study of Critical Infrastructures Protection (CIP) has been indicated by the European Commission as a fundamental research topic [1] for the development and improvement of the European economy and society. The main concepts and definitions that are fundamental to understand the critical infrastructures protection problem are summarized in [2]. One of the main issue in this field is the Modeling and Simulation (M&S) of CI interdependencies (bidirectional relationships between CI domain components) as the different critical infrastructure domains are physically and logically interdependent. As pointed out in [3], only dependencies (i.e. unidirectional relationships) among Critical Infrastructures (CIs) are of major interest to understand the global behavior of the whole complex system. In fact, dependencies are the mean to propagate toward other domains the effects of what is happening on a certain domain. Therefore, we focus on M&S of dependencies.

This work is developed in the framework of the DIESIS (Design of an Interoperable European federated Simulation

network for critical InfraStructures) project [4], aimed at studying the feasibility of an European Infrastructures Simulation and Analysis Centre (EISAC)<sup>1</sup> for Critical Infrastructure Protection.

Currently, two major general M&S approaches [5] are used in the CIP research field: integrated vs coupled or federated modeling approaches. In both the cases, the scenario description (CI networks and their interconnections) is embedded in the whole simulation framework and this fact makes very hard to generalize the technologies developed to model a different scenario. In this work we describe our approach to model and simulate the dependencies among CIs. We propose the use of the ontological framework [6, 7], based on a Knowledge Based System (KBS), to model both the basic structures and relations within each domain and the dependencies among the different domains. By using ontologies, we are able to describe each domain by means of its basic components and relations, allowing the creation of an abstract layer which hides all the technical details necessary to actually model the simulated domain on a computational platform. Ontologies are used as a mean to abstract the functionalities of a domain from their technological implementation/simulation: the actual modeling of a given domain into the ontological framework requires to connect the basic components and their relations with the entities (and their related values) accessible through the underlying simulation technology. Such a modeling, which maps the domain entities into the simulation counterparts, has to be done only once. The adoption of the ontological framework allows to model the dependencies among domains in a simple and intuitive way, by introducing ontological rules to connect entities belonging to different domains. It is worth to be underlined that dependencies can be modeled neglecting the technological layer.

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## 2 KBS architecture

The KBS has been aimed at establishing a common formalism, for scenario and domains knowledge experts, to represent the main aspects, elements and properties of the considered domains and their interconnections. The Infrastructure domain ONTOlogies (IONTs) represent the specific knowledge of the considered critical infrastructure domains with respect to different views or different levels of detail, that is, they define the set of concepts and properties sufficient to formalize the domains at a certain level of detail. In our tests we referred to three interconnected domains, namely the telecommunication, the railway and the electric domain. The IONTs are based on the World ONTOlogy (WONT), a general ontological template. The WONT allows to model Critical Infrastructure as a set of inter-connected components. A IONT is defined through the specialization of the WONT definitions to the particular CI domain. More precisely, given a CI domain  $i$ , let  $C_i$  be the set of all the components of  $i$  and let  $R_i$  be the set of the relationships between the components of  $i$ .

$$R_i = \{r(a, b) | a, b \in C_i\} \quad (1)$$

All components are characterized by their name and their properties, i.e. a component  $a \in C_i$  is defined as

$$a = \langle name, [property]_{1+} \rangle \quad (2)$$

Other than some peculiar properties, which depend on the type of the component being modeled, all the components share some common properties like *latitude*, *longitude*, *functioning status*, *domain type*, ... The generic IONT <sub>$i$</sub>  describes the components (with their properties) and their relationships, i.e.

$$IONT_i = \{C_i, R_i\} \quad (3)$$

Once the domain IONTs have been created, they can be used to describe a certain scenario by instantiating as many IONT components (with the relative connections) as required by the actual scenario. In order to model a scenario involving different domains, the corresponding IONTs have to be instantiated. Furthermore, to model the dependencies among the domains, a Federation ONTOlogy (FONT) must be defined to formalize the relations among the components belonging to the different domains and causing the inter-domain dependence: as explanatory example, consider the FONT rule which could be devised to model the dependence of the functioning status {ON || FAULT} of a railway signal on the functioning status of the communication channel used to tele-control the signal. The FONT has to include all the objects and the relationships that are key elements to model the dependencies. As we are dealing with a scenario involving different domains, the corresponding IONTs have

to be considered; interconnections among such heterogeneous domains are enabled by the underlying WONT which allows to express the set of the FONT rules  $FR$  as

$$FR = \{r(a, b) | a \in C_i, b \in C_j, i \neq j\} \quad (4)$$

$FR$  is built to include all the inter-domain relationships and, consequently, is sufficient to model the failure propagation effects (the so called cascading effect).

## 3 KBS testbed

This section describes the test case used to validate the proposed KBS architecture. While developing the KBS, the following steps have been executed: (1) WONT definition, (2) Domain IONTs definition; (3) FONT definition; (4) IONT instantiation and (5) FONT instantiation. The KBS for the testbed has been developed by including three critical infrastructure domains: we defined the IONTs for the electric, telecommunication and railway domains. Furthermore, an external event generator (a flooding simulator) has been modeled and integrated in the federated simulation environment.

In particular, the WONT template entails the definition of the derived IONTs as a network of interconnected *systemComponents* characterized by a value representing their *functioningStatus*. The WONT definition is enriched with other classes that will support a federated simulation experiment. In order to describe the ontological modeling phase, let us go into (a quite) detailed definition of the railway domain. Three different aspects have to be considered to correctly define the railway domain: (a) the infrastructure topology, (b) the rolling stock data and (c) the formalization of the railway services. The infrastructure topology has been described by several system components: *train station*, *vertex*, *edge*, *switch*, *signal*, ... In particular, a railway track is defined as a series of adjacent *edges*; each edge is delimited by two *vertices* that indicate the position of *signals*, *switches* or *train stations*. The rolling stock data describe the trains through the typology of the *locomotive* and their composition (one or more locomotives with a fixed number of *wagons*). The services include the definition of *itineraries*, *paths* and *courses*. In particular, an itinerary is a list of train stations, a path is characterized by an initial train station, a final train station and a timetable schedule; a course is a series of adjacent paths. With a similar approach and an equivalent level of detail, the electric and telecommunication domains have been included into the KBS. Using these definitions a realistic scenario has been created, that is, the instances of the IONTs have been populated to represent the CI (electric, telecommunication and railway) networks of a specific district of Rome. The population of the KBS to represent a given scenario consists on the instantiation of the IONT components specialized with their

actual characteristics (name, typology, geographical coordinates,...). It should be noted that the electric and telecommunication IONT instances have been populated with realistic data coming from a previous European project [8], whereas the railway IONT has been populated by acquiring public available data and knowledge about the domain.

In order to define the set of the FONT rules *FR*, the available data have been deeply analyzed to catch the dependencies among the domains. In the following we summarize the structure of *FR*:

**Flooding to other domains.** The CI domains are affected by flooding effects. In particular, in each domain there are some components that are *points of interest* for the flooding. If the value of the water level of a point of interest is greater than a fixed threshold, the functioning status of the corresponding system component is set to *FAULT*.

**Power grid to Railway domain.** Each railway *edge* is fed by an electric station. If this electric station has functioning status *OFF* or *FAULT*, then the functioning status of the related edges is set to *NOT AVAILABLE*

**Power grid to Telco domain.** Each *telco site* is a load for the electric domain. If this load is *OFF* or *FAULT*, then the functioning status of the telco site, such as all subcomponents, becomes *NotFed*.

**Railway to Telco domain.** A *TelcoSite* requests to the closest railway station its need to refuel the UPS system when its energy supply goes down. A refueling train service will start, if possible, within a certain time-window. When the refueling request is generated, a time counter starts. The time counter is used to check if the refueling arrives in time to allow the continuity of the Telco services. If the refueling train fails to arrive in time, the function status of the *TelcoSite* is set to *OFF*.

**Telco to Railway domain.** When a Telco node, used to control some railway signals, goes down, the functioning status of the railway controlled signals is set to *OFF*.

The described KBS structure has been integrated in a federated simulation environment where the federated simulators have been encapsulated within wrappers which were in charge to implement the FONT rules; the FONT rules have been manually translated from the owl language - used by the ontological framework adopted to represent IONTs and FONT - into the java language used to code the wrappers. Within each simulation domain we defined as source FONT variables all the variables produced by the other simulators and involved in the FONT rules affecting the simulation domain. Each simulator wrapper, before performing a simulation step, receives the source FONT variables which are transformed, through the FONT rule, into some local (target) values which influence the next simulation step. The whole federated simulation was run on a geographically distributed network involving 6 different systems (the three simulator servers, the external event generator, the KBS

server and a centralized Federation Control Server).

## 4 Conclusion

In this paper we proposed to use an ontological framework, embodied within a Knowledge Base System (KBS), to model both critical infrastructures and their interconnections. This approach enables the federation of different Critical Infrastructure (CI) domain models into a virtual federated simulation environment to study the resulting "System of Systems" behavior under different conditions and constraints (e.g. parameter variations or changes of the environmental conditions). The KBS architecture uses three types of ontologies: the World ONTOlogy (used as general ontology template), the Infrastructure ONTOlogies (IONTs) which model the specific domains and the Federation ONTOlogy (FONT) which represents the dependencies among the CI domains. Both the IONTs and the FONT have been used to implement a federated simulation environment, involving three different CIs (telecommunication, electric power distribution, railway network) and an external event generator (flooding simulator). The federated simulation environment was implemented over a geographically distributed network constituted by 6 servers. It is worth to be underlined that the proposed approach makes a clear separation between the modeling phase (scenario definition and instantiation) and the federated simulation phase.

## References

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