DIESIS: An Interoperable European Federated Simulation Network for Critical Infrastructures

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ABSTRACT: *Critical Infrastructures (CI) that are vital for a society and an economy, such as telecommunication systems, energy supply systems, transport systems and others, are getting more and more complex. Dependencies emerge in various ways, due to the use of information and communication technologies, legislation, market liberalisation, and other factors. The understanding of the complex system of CI with all their dependencies and interdependencies is still immature. Yet these systems need to be protected, for instance, against cascading failures that may affect several sectors. Research in the area of Critical Infrastructures Protection (CIP) therefore has to rely on using simulation systems. For simulating complex scenarios with dependencies between different sectors, typically heterogeneous federated simulations are used, but general modelling interoperability approaches or standards are missing. The EU funded project DIESIS proposes to establish the basis for a European modelling and simulation research facility based upon open standards to foster and support research on all aspects of CI with a specific focus on their protection. DIESIS performs a thorough conceptual design study in order to prepare the establishment of such a research facility. A part of this design study – the technical proof-of-concept – is a federated simulation employing three different CI simulators. The interoperability approach is scenario-based and employs CI ontologies at three different levels: federation, infrastructure domain, and simulator. A quality-of-service-enhanced communication middleware will enable distributed simulation. This article describes the main aspects of the work within the DIESIS project.*

1. Introduction

Infrastructures operate globally and are increasingly dependent and interdependent: a breakdown or disruption of functions may have serious national or even multinational consequences. The disruptions of the power grids in eleven European nations and Morocco on November 4, 2007 affecting 15 million people are a case in point. It is for this reason that such infrastructures can be called Critical Infrastructures (CI). A CI is defined by [5] as an asset, system or part thereof which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact as a result of the failure to maintain those functions.

Advances in Information and Communication Technologies (ICT), an increased reliance on electronic commerce, restructuring, deregulation, privatisation and market forces cause tremendous and continual changes to CI. Concentration by companies on their core business to successfully manage competition often results in outsourcing of functions – such as billing systems or maintenance – which may generate new dependencies and related risk, in addition to the already high traditional dependencies and interdependencies between infrastructures. Following the initial definition by the EU Commission in its Council Directive 2008/114/EC [5], CI are those related with the following – initially three – "critical sectors": energy (including the electricity infrastructure and facilities for generation and transmission of electricity in respect of supply electricity, oil and gas production, refining, storage and distribution by pipelines), transport (including road, rail, air, inland waterways transport, ocean and short-sea shipping and ports), and ICT. The directive requires that Member States of the EU undertake steps to identify their national CI [5].

In contrast to the utmost importance of CI like energy supply and telecommunication for all European citizens, the European economy and the European society at large, the understanding of the complex system of CI with all their dependencies and interdependencies is still immature. For a couple of years now, research in the area of Critical Infrastructure Protection (CIP) is not only addressing the understanding of dependencies and interdependencies, but also new or improved methods for CIP. An essential method for studying CI is modelling, simulation and analysis (MS&A) of CI, their dependencies, and dynamic effects of interacting CI, like cascading failures ([3], [8], [10], [11], [13]). Whenever larger scenarios involving more than one CI need to be simulated, it is required to couple several infrastructure simulators together to form a federated simulation. This is a challenging task that takes a considerable share of a research project's time – time that is not available for addressing the real research questions. Reasons for this include non-existing dedicated standards for interoperable CI simulations, different time and execution models of the simulators that shall form a federation, difficulties getting data on CI as a basis for valid modelling, and more.

In order to overcome these difficulties and to foster progress in M&S based research for CIP, the EU funded project DIESIS (Design of an Interoperable European federated Simulation Network for CI, [2]) proposes to establish a pan-European research facility for CIP MS&A. DIESIS will form the foundation for this facility, titled EISAC (European Infrastructures Simulation and Analysis Centre), by performing a design study. This design study shall assess the technical, economic, organisational and legal feasibility of the so-called research *e-Infrastructure* EISAC. As a first characterisation, EISAC shall offer methods and technology for achieving semantic interoperability of simulators in a federation, tools for supporting various tasks in MS&A in CIP, repositories of data and CIP research results, and consultancy on various aspects of MS&A in CIP.

It should also be mentioned that the task of getting a better understanding of CI and developing methods for CIP cannot be performed by researchers alone. The study of complex infrastructure systems demands joint interdisciplinary efforts of researchers, industrial stakeholders and governmental organisations. Federated CI simulations require know-how and data of the CI domains, proposed CIP methods need to be tested and benchmarked, and the implementation of new methods for CIP need to be supported by CI operators and governmental organisations. In this respect, the proposed research facility EISAC may also offer a platform for this type of collaboration.

In this position paper, we give an overview on the work of the DIESIS project. The paper is structured as follows. We start with a brief characterisation of similar facilities or programmes. We continue with describing the objectives of DIESIS and present the work done so far. We conclude by summing up the main points and by giving an outlook on the future work of DIESIS.

2. Related Work and Initiatives

The idea of a research facility dedicated to modelling and simulation for CIP is not a singularity. There are – but only a few – facilities and initiatives in the world that address similar or related topics. In this section, we will briefly characterise them.

NISAC, the National Infrastructure Simulation and Analysis Center of the USA [14], has been founded in 2000 as a collaboration between the Sandia National Laboratories and the Los Alamos National Laboratory. A bit later, it became a part of the US Department of Homeland Security. NISAC addresses seventeen CI sectors at national, regional, and local levels and provides strategic, multi-disciplinary analyses of dependencies and the consequences of infrastructure disruptions. NISAC provides its services to several US American departments and agencies.

In Canada, I2SIM, the Infrastructure Interdependencies Simulation team, has been founded in 2005 [8]. It aims at a better understanding of infrastructure dependencies and at operations coordination among multiple infrastructures. I2SIM employs infrastructure dependency simulation for CI in the areas electrical power, telecommunications, and airports. I2SIM is publicly funded.

In the EU, the Open Modelling Initiative OpenMI [18] emerged in 2005 from the water sector. Its current activities are funded by the LIFE Environment programme. OpenMI addresses standards for federated modelling and simulation for a wide range of technical, organisational and economic aspects related to water (sea, dikes, ground water, water management, and more).

The most recent initiative is Australia's CIPMA programme [1], started in 2007 as a collaboration of the Attorney-General's Department, CSIRO and Geoscience Australia. CIPMA aims at developing technology for modelling and analysing relationships and dependencies between Australia's CI systems and addresses specifically the sectors energy, telecommunications, banking and finance. The technology comprises simulation models, databases, economic models, and GIS. CIPMA supports also the work of the Trusted Information Sharing Network for CIP (TISN), a collaboration platform of operators of Australian CI [22].

All these facilities, programmes and initiatives are publicly funded, and none of them has the same scope as proposed for EISAC. Also, most of them – except OpenMI – operate only on a national scale. Given the particular situation in Europe, where national CI of Member States get more and more intertwined with CI of other Member States, it is essential that EISAC addresses transnational dependencies.

In the framework of the Italian national initiative named CRESCO project, aimed to improve the national capability to study complex systems, has been done a preliminary activity on how to model into the same framework heterogeneous infrastructures and how model the different interdependency phenomena that exist among these infrastructures and between them and the surrounding environment. The research faces these problems proposing a simulation framework where several sector specific simulators are integrated into a simulation environment for interdependencies simulation. In this way, the interdependencies simulator is used to model inter-domain relationships and to merge heterogeneous information; while the highly specialised software implemented in the sector specific simulators are used to better model the intra-domain dynamics [20].

3. DIESIS

The goal of DIESIS is to perform a design study for an e-Infrastructure enabling federated simulations of CI systems and supporting research on CIP. The establishment of such a distributed infrastructure in more than one country requires careful preparation. Thus, DIESIS is performing a thorough conceptual design study in order to prepare the establishment of such a research e-Infrastructure. The work of DIESIS includes:

- Analysing in detail the requirements for the research e-Infrastructure coming from researchers, industrial stakeholders, decision makers and governmental organisations.
- Assessing the feasibility (scientific, technical, financial and legal) and the potential impact (scientific and technical) of such an e-Infrastructure.
- Developing a strategy and roadmap for the deployment of the e-Infrastructure, including a business model, an organisational model of the operating entity of the EISAC, a list of possible sponsors of the e-Infrastructure, a list of possible services to be offered, and a list of potential users and customers.

In the following subsections, we will present the nature of these tasks and current achievements in more detail.

3.1 Technical Work

The technical work of DIESIS comprises the following tasks, namely defining a set of requirements for the interoperability technology to be used for federated CI simulation, analysing available interoperability middleware, reviewing and characterising available CI simulators, developing a communication middleware and an ICT architecture for federated CI simulation and, last but least, identifying a process or workflow for setting up federations of CI simulators. A part of the technical concepts shall be demonstrated in a sample federation. The general structure of the setup is displayed in Fig. 1.

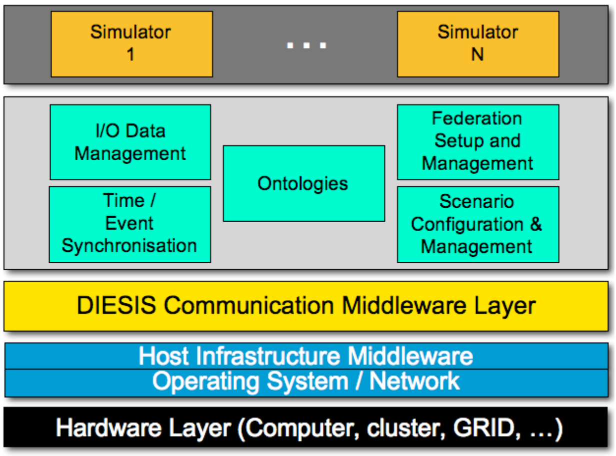

Fig. 1: Relation between CI simulators, DIESIS middleware, host infrastructure and hardware layer.

3.1.1 Technology Analysis and Requirements

This part of the work includes three subtasks: identifying a set of requirements for the technologies to be developed in EISAC, analysing and assessing the available interoperability technology, and reviewing the available CI simulators.

The creation of the requirements was a three-step process involving also external know-how. First of all, existing knowledge of all DIESIS partners in the CIP and MS&A fields were used to construct two questionnaires. One addressed the potential CIP research e-Infrastructure requirements, the other the current availability of simulators and models in Europe. The questionnaires were sent to over 300 potential stakeholders all across Europe and to relevant organisations in some other nations. This included the academic communities in various EU Member States, the ECIP point-of-contacts in the EU Member States, the CIP point-of-contacts in the international CIIP Directory, national government C(I)IP contacts, key industry contacts within the various critical sectors, regulators, and relevant EU agencies. Moreover, questionnaires have been sent to holders of databases and adjacent models that may interact with CI MS&A, e.g., key economic data per postal code area, flood/rain models.

Secondly, both the returned questionnaires and the existing knowledge of the consortium partners were used to create the requirements document. A formal requirements language approach was taken to derive an unambiguous set of requirements. A draft version of the requirements document was presented and discussed with potential stakeholders of the CIP research e-Infrastructure at the first DIESIS workshop.

Thirdly, an updated version of the document reflects all discussions during the workshop and inputs received from other communities such as the OPEN-MI community

The analysis and assessment of the available interoperability technologies able to support a federated simulation framework has been performed, based on a set of specific evaluation criteria. Those criteria have been used in order to verify if analysed technologies meet the primary technology requirements of the DIESIS project. Moreover, a method for technology assessment has been elaborated. The assessment process, based on requirements and criteria, has resulted in a meaningful picture of the fitness level of analysed technologies for DIESIS purposes. The current view is that the middleware High Level Architecture (HLA) [9], BPEL (Business Process Execution Language, [16]) and WSRF (Web Services Resource Framework, [17]) express the best fitness to support the DIESIS technology framework.

And finally, an overview on available CI simulators has been created. One focus of this overview was the identification of properties related to interoperability, particularly time models and execution models of the simulators and their compliance with existing interoperability middleware.

Several project reports present the results of the technology assessment and requirements design. They are published on the DIESIS website www.diesis-project.eu.

3.1.2 Communication Concepts

In order to support distributed federated simulation over various types of networks, a suitable communication middleware is required. One of the DIESIS project partners develops a quality of service enhanced communication middleware that shall work both via standard Internet (IPv4 and IPv6), high-speed networks like GÉANT [7], and private networks.

Essential communication requirements of distributed federations have been identified in order to guide the design of the communication protocols and algorithms. The most important communication requirements for large-scale federations have been identified as reliable and real-time (deadline-based) group communications.

According to an evaluation of these requirements, a solution was proposed that groups all communications facilities required by the federates and the federation management system into a communication layer (CL). The CL is responsible for the delivery of federation messages under quality-of-service (QoS) criteria set by the communication requirements of the federation, also taking security and privacy aspects into account. An adaptive and reliable software architecture for the CL has been proposed that offers flexibility to support large-scale distributed federations and allows the incorporation of optimisation algorithms for group communications and security algorithms to provide communication security and privacy.

3.1.3 Ontologies of Critical Infrastructures

One part of the method to achieve semantic interoperability is the use of ontologies at different levels. On one hand, *Domain Ontologies* are derived from CI domain knowledge in order to formalise the conceptualisation of CI domains. They are tailor-made to the investigation at hand and depend, for instance, on the fidelity (or granularity) of the intended simulation. On the other hand, the concrete ontologies to be used are instances of *Domain Ontologies*. The instances are derived from available CI data, harnessed within the ontological conceptualisation of the domain. For each involved CI there must be at least one ontology. The simulators themselves and the federation may also require ontologies. Then, a *Federation Ontology* is realised to formalise the knowledge of cross-domain interconnections; while appropriate rules are defined to model the behaviour of those interconnections. A rule specifies the way two interconnected objects interact, allowing the propagation of effects from domain to domain. The rules are part of the implementation of the interoperability middleware. Additionally, when information needs to be exchanged between simulators in a federation that requires a transformation (e.g., transformations of units of measurements or coordinates, working ranges of parameters of infrastructure elements and so on), ontologies address the problem of the transformation factors. In general, rules and facts are stored in a knowledge-based system. Based upon a technology assessment, DIESIS has chosen to use a rule engine based on Jess for this task. A first publication describing this ontology concept has been presented at the IFIP WG 11.10 conference 2009 [12].

3.1.4 ICT Architecture

In the last decade, some powerful simulation tools emerged from several application areas related to CI. These tools are able to simulate technological systems (energy supply systems, telecommunication systems, railway traffic systems, …), logistic situations (military and civil operations, logistic chains, …) and common societal interrelations (e.g., economy simulations).

As a general rule, the involved simulators are closed system worlds. Typically, the design of these system worlds either disregarded the ability of coupling with other simulators or, in the best case, only to a very limited extent. Currently there are a number of projects that aim at coupling several stand-alone simulators in order to simulate large-scale systemic relations, like EPOCHS [8] and IRRIIS [10].

The market for simulator coupling middleware is dominated by highly proprietary solutions and differing implementations of a few standards like HLA. This situation leads to a strongly competitive acting of involved vendors. This adds to the problem of coupling simulators another – not primarily technological – dimension that makes the efforts of harmonising and coupling simulators even more difficult.

We concluded that purely generic approaches for coupling of simulators are not feasible from current state-of-the-art. The design space of "all possible simulators" in one application area, as for instance CI, is too large for making all required ICT-mechanisms available in a generic manner.

Thus, DIESIS takes a different approach towards coupling CI simulators. Architectural core concepts in this approach are:

- Scenario orientation. The first step for creating a federation of CI simulators for a given investigation or research task is the description of this task by means of a network of agents and application-oriented services. This network is then gradually transformed into a technological service network that guides the realisation of the federation.

- Lateral coupling of simulators, enabling the reuse of existing coupling solutions, e.g., if the simulators to be coupled are HLA compliant. If no solution for a certain coupling exists, a new one may be created and stored in a repository (taking into account possible sensitivities of the federation). This allows for a quick start for creating federations and will lead to an increasing inventory of coupling solutions.

- Distinguishing simulator couplings based on four different types of functions (data links, function links, time links, and control links). This leads to clearer design and facilitates the reuse of the coupling solutions.

3.1.5 Technical Demonstrator

DIESIS will realise a demonstrator for a subset of its technical concepts, including communication concepts for distributed simulation, ontologies for CI, and the outlined ICT architecture approach for achieving interoperability of the federated simulators. The demonstrator will include an electricity network simulator (SINCAL, [21]), a telecommunication network simulator (NS2, [15]), a railway simulator (OpenTrack, [19]) and a simple flood simulator. The scenario to be simulated is the disruption of CI services in a large urban region in Europe due to local flooding.

3.2 Organisational, Legal and Economic Aspects

Core aspects of the assessment of the business feasibility are the assessment of possible organisational and legal forms of the pan-European research infrastructure EISAC, a description of possible products and services, the identification of target users and customers, and the assessment of the economic feasibility.

3.2.1 Possible Organisational Forms

The organisational form of EISAC will depend partly on the legal form that it shall assume. It is clear that EISAC should have several sites in different Member States, in order to be able to provide localised services, like know-how in the specifics of national CI, but also to be able to attract national stakeholders, agencies, and ministries for the intended collaboration in CIP. The sites should cooperate closely in order to use synergies. If ERI shall be used as a legal form, then it makes sense to have an EISAC headquarter with strong relations to the national sites ("hub and spokes model").

3.2.2 Legal Aspects

It should be mentioned here that the creation of European research infrastructures (RI) is a strong policy of the European Commission. Currently, there are about 40 active projects designing or preparing the deployment of research infrastructures. All of them have to cope with their specific organisational, legal, and economic aspects. They need to clarify the statutory seat and the legal and organisational form – aspects that are not independent from each other. In order to facilitate the foundation of pan-European research infrastructures, the European Commission has generated a proposal for a regulation on the Community legal framework for a European Research Infrastructure (ERI, [6]) that might be adopted in 2009. If it comes into effect, it would be the ideal legal form for most of the proposed RI.

Other legal aspects that need to be assessed are those related to the specific products – in the economic sense of the word – and services that EISAC offers, IPR, licensing issues, and more. The assessment is currently underway, assisted by lawyers of the DIESIS partners and legal experts from the European Commission. There is also cooperation between the European RI projects on this matter.

3.2.3 Economic Aspects

The economic assessment part of the design study includes the identification of target users and customers, the identification and description of a business model for EISAC including a detailed description of products and services and customer benefit, and, last but least, getting support from Member States. The currently discussed portfolio of EISAC offerings has been shaped both by the DIESIS consortium and potential users and stakeholders. The latter have been involved by sending out questionnaires and by holding a public workshop for receiving feedback on the initial portfolio.

An essential step towards realisation of EISAC will be the inclusion of EISAC in the research infrastructure roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) [4], a body that provides support to policy makers of the European Commission.

4. Conclusion

We have presented an overview of the work of the EU project DIESIS, which performs a design study for a new pan-European Research Infrastructure for CIP MS&A. DIESIS is forming the basis for this facility, titled EISAC, by studying the technical, organisational, legal and economical feasibility of EISAC.

We have conceptually characterised the elements of the interoperability framework to be used for coupling CI simulators to form a distributed federation, namely a particular ICT architecture for an incrementally growing inventory of coupling solutions, a QoS-enhanced communication middleware compliant with several network architectures, and an ontology-based approach for semantic interoperability. We have also described the work of

DIESIS for assessing the organisational, legal and economic feasibility of EISAC.

The next steps within the duration of the DIESIS project will be the realisation of the technical demonstrator, a federated simulation of a scenario involving three CI simulators and a flood simulator. We will continue to invite potential users and stakeholders of EISAC to help shaping the services, tools and technology that EISAC shall offer. As far as the organisational, legal, and economic feasibility are concerned, DIESIS will agree on an organisational model that is compliant with a suited legal form, preferably an ERI. Inclusion of EISAC in the ESFRI roadmap and receiving national support by means of expressions of interest from governmental organisations in EU Member States are strategic objectives for the remaining project term. If DIESIS achieves these objectives, the realisation of EISAC might continue by entering a preparatory phase, followed by a construction phase and finally the deployment and operation of the facility.

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