Towards a holistic metamodel for systems of Critical Infrastructures

The Implementation-Service-Effect (ISE) metamodel describes Critical Infrastructures from different perspectives in a well-defined way to provide a sound basis for the analysis of their dependencies and interdependencies

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The aim of the European Union *Integrated Project IRRIIS (Integrated Risk Reduction of Information-based Infrastructure Systems)* is to increase the dependability of large and complex critical infrastructures. In order to achieve this goal a common, well-defined modelling approach is needed. The *ISE (Implementation – Service – Effect) metamodel* provides a modelling framework taking the various viewpoints from different sectors and professions into account. But the ISE metamodel is not limited to this specific project. It provides rather a general modelling approach for systems of critical infrastructures. While not neglecting the technical basis, it provides the necessary abstractions needed for risk or emergency management of critical infrastructures in a complex environment.

Risk management of CIs needs sound models taking the whole CI system into account.

Current Problems in Critical Infrastructure Modelling

The modelling of complex infrastructure systems together with their dependencies is a big challenge and there is no general methodology to accomplish this task. There are several problems one typically has to face:

- The *data-chicken-egg-problem*: Many research projects have severe problems getting the data needed for research. Due to sensitivity concerns no data is available unless risks have been identified. But risks can only be identified, if relevant data is available.

- The *level-of-abstraction-problem*: It is difficult to find the right level of abstraction to match the modelling purpose. If the level is too high, only trivial results can be achieved. If the level is too low, there is too much data and interesting structures may not be found ("Seeing a lot of trees, but no forest.").

- The *particular-answers-problem*: As the system-behaviour is dependent on many low-level technical facts, small changes can have big effects on the overall system-behaviour. So, it is difficult to assess the validity of results.

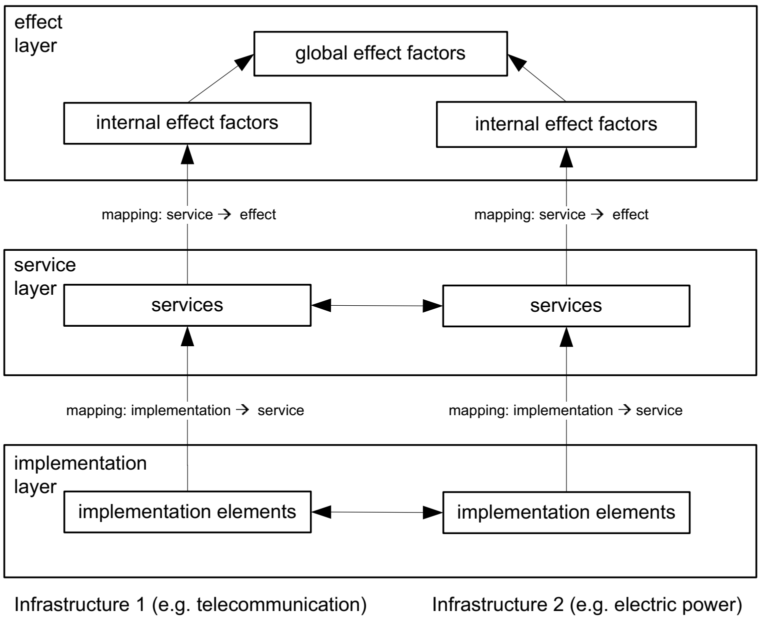
- The *different-views-problem*: Naturally, the management of an infrastructure operator has a very different view on the same infrastructure as a technical engineer. Experts from different sectors use different terminologies. But in the end all these views and terminologies relate somehow to the same system of critical infrastructures.

Another problem is concerned with the analysis that follows the modelling process. Again, there are no general methods for systems of complex infrastructures and their dependencies (apart from the usual methods from complexity science dealing only with very abstract networks). The lack of a common modelling methodology and analysis methods makes it difficult to share models and compare results.

The ISE metamodel provides a way to minimise these problems to some extent by providing a stepwise modelling approach that links the different views on critical infrastructures. By giving a sound mathematical foundation, systems of dependent critical infrastructures can be described in a well-defined way and analysis using well-established methods from other fields is possible.

The ISE Metamodel

An ISE model is composed of several ISE sub-models. Each of the sub-models consists of three kinds of elements: *implementation elements*, *services (public and internal)* and *internal effect factors*. A full ISE model is created by combining several of these sub-models, describing their *dependencies* (within and across sub-models) and adding *global effect factors*. The model consists of three layers: the *implementation layer*, the *service layer* and the *effect layer*. The relationships between these layers are described by two mappings: the *implementation-service mapping* and the *service-effect mapping*. The general structure of an ISE model for two infrastructures is shown in the figure on this page. A simple example for telecommunication and electric power infrastructure service and implementation layer is given on the next page (dependencies between layers are not shown for clarity).



The *service layer* is the central layer. Services are either delivered to the end-consumer, to some other critical infrastructure (public services) or to some other part of the same infrastructure (internal services). As public services are products that are sold and delivered to customers and are usually accompanied by service level agreements, they should be easy to identify and provide a good starting point for modelling. Internal services usually can be identified by looking at the internal organisation of the individual company.

Services are realised by implementation elements at the *implementation layer*. Implementation elements are everything that is necessary for the provision of a service: physical equipment, operators, procedures, single infrastructure components but also whole systems.

The *effect layer* describes the effects of the successful delivery of services or of the failures to do so. Effects could e.g. be measured with money, risks or effected people. Besides the internal effect factors of each sub-model there are global effect factors to combine other effect factors (e.g. to describe economic or societal effects).

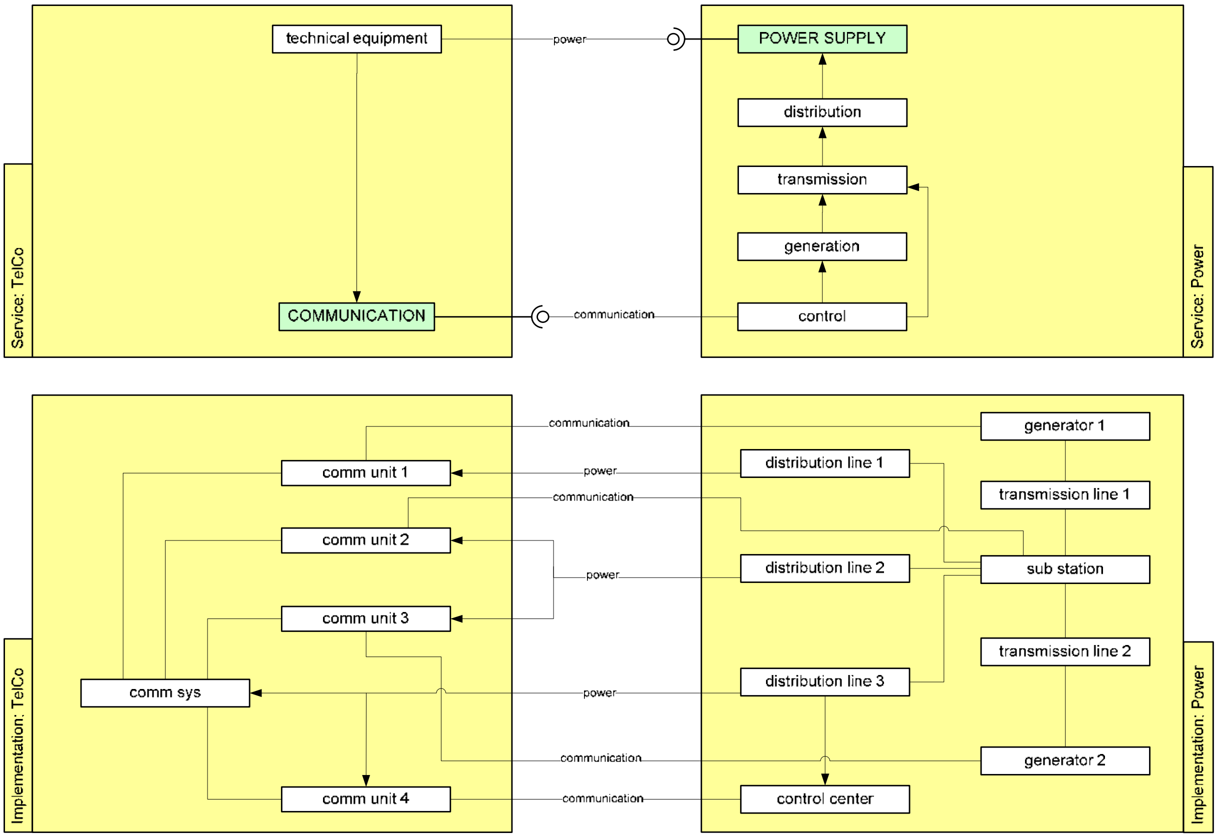
It is important to note that in an ISE model dependencies between elements of different sub-models can only appear within the same type of layer. Dependencies within one sub-model are always within the same layer or appear in a clear top-down manner. All of these dependencies can be described as directed graphs. All in all there are five graphs:
- The *implementation dependency graph* on the elements of the implementation layers.
- The *service dependency graph* on internal and public services
- The *effect dependency graph* on internal and global effect factors.
- The *implementation service dependency graph* between services and implementation elements.
- The *service effect dependency graph* between services and effect factors.

With this rather general structure a huge amount of different actual models of critical infrastructures can be realised. ISE does not prescribe a certain level of detail and not all layers have to be included in the actual model. One can start with very simple models on only one layer and include other layers or split single elements to several elements during successive refinement steps.

Analysing Critical Infrastructures with ISE

Based on the principal structure of the ISE metamodel and the nature of the dependency descriptions, different types of actual models and different kinds of analysis are possible.

- *Topological Models*
The graphs on the different layers can be analysed using methods from graph theory and complexity science. In addition, each dependency on the service layer must have its counterpart on the implementation layer and vice versa.



These relationships can be described in terms of graph theory and be used to check the model's consistency and to relate dependencies on one layer to elements and dependencies on the other layer. Taxonomies of interdependencies can be built, general structures can be detected and general strategies to deal with interdependency problems may be derived.

- *Boolean Models*

While topological models can only indicate where problems might occur, Boolean models go a step further. In a Boolean model the status of each element is described by a Boolean value (working / not working). In addition, there is a Boolean expression for each element to determine its value based on the current values of the preceding elements. By changing the values or expressions of specific elements a "what-if-analysis" to investigate the spreading of failures can be performed.

- *Numerical Models*

Real values or vectors can be assigned to each element. Values should be calculated based on the values of the preceding elements. These dependencies can be described by difference equations or differential equations and may also include random variables. It may be possible to analyse these models mathematically but usually their behaviour will be simulated over time and investigated with stochastic methods.

- *Simulation Models*

In simulation models each element may carry arbitrary attributes of any kind. The attribute values are dependent on the attribute values of the preceding elements. The way of interaction is described in form of algorithms attached to each element. These models can be simulated in a computer, e.g. using agent-based simulations. The results from the simulation can then be analysed using all kinds of stochastic methods and visualisation techniques.

Summary

The ISE metamodel provides a generic way to model critical infrastructure systems for different purposes. It is able to bridge the gap the engineering and the business view on critical infrastructures. Dependencies are described in a well-defined way which allows all kinds of analysis. This model will be applied in the IRRIIS project but could also be well-suited for other projects dealing with critical infrastructures or the delivery of services in general. Especially, the application in the context of risk or emergency management seems to be very promising. The development of an agent-based simulation environment called SimCIP (Simulation for Critical Infrastructure Protection) based on the ISE principles is currently under way at Fraunhofer IAIS.

Contact & Information:

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