CONSIDERATIONS ON MODELLING RESILIENCE GOVERNANCE FOR DECISION SUPPORT SYSTEMS

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Resilience and resilience governance are nowadays major topics of discussion as threats are continuously changing and specialists are trying to build systems that could cope with complex threat vectors. The present paper proposes a resilience governance architecture model that can be embedded within organizations as a decision support system. By means of these managers are able to visualize at a glance an updated situation of the living system they deal with – their organization. The major result of this methodology is the framework that might be included in software tools that help managers in the decision-making process. The solution architecture is a generic solution framework meant to support system resilience architecture instruments due to the fact that digitalized normal and complex situations cannot be handled without a solution today

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1. Introduction

Over the last decades, scientists have not managed to come up with a unitary definition for resilience. The *Oxford Dictionary* defines resilience as “the capacity to recover quickly from difficulties; toughness” [1]. In the specialized literature dedicated to the field, authors have often used interchangeable terms such as *security, protection* and *resilience,* the common idea being that these items ensure the continuity of the activities of the infrastructure sectors, with clear benefits for social functionality.

According to Gunderson L.H et al. [2], resilience “measures the strength of mutual reinforcement between process, incorporating both the ability of a system to persist despite disruptions and the ability to regenerate and maintain existing organization”, while IDS (The Institute of Development Studies) [3] considers that “resilience can be defined as the ability to deal with the impacts of adverse changes and shocks”. Furthermore, Thai, HS [4] stated that “resilience

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thinking highlights the need to build capacity and manage general system properties in a complex, constantly changing world".

The concept of *resilience* is growing more and more as an integrator, allowing for new conceptual architectures (e.g. *governance*).

Tierney K and Bruneau M. [5] identified "four dimensions or domains of resilience: technical, organizational, social, and economic (TOSE):

- The technical domain refers both to the physical properties of systems — operation, strength, or failure, as well as to the physical components used to provide system redundancy.
- Organizational resilience relates to the organizations and institutions that manage the physical components of the systems.
- The social dimension encompasses population and the community characteristics that make social groups either more vulnerable or more adaptable to hazards and disasters.
- Economic resilience has been analyzed both in terms of the inherent properties of local economies —such as the ability of firms to adjust and adaptat during non-disaster times — and in terms of their capacity for post disaster improvisation, innovation, and resource substitution".

According to Ganin et at. [6], resilience can be computed using the following equation:

$$R_{\varphi}(E,[0,T_C]) = \frac{\frac{1}{|E|}\Sigma_E \int_{t=0}^{T_C} \varphi(t;N,L,C)}{\int_{t=0}^{T_C} \varphi^{nominal}(t;N,L,C)} \quad (1)$$

Where: E – the set of disruptions, N – the number of nodes, L – the number of links/connections, T_C – control time and $\varphi^{nominal}$ – the undisrupted network performance level.

Greater resilience is needed in the case of the human hazards management system [7, 8], yet within our demarche, we did not apply the multi-level governance concept [9, 10]

Resilience governance entails a complex set of tasks, such as the gathering of data, site selection, risk assessment from the point of view of an all-hazards approach.

2. Materials and methods

The starting point of this demarche is the framework proposed by D. Lange et al. [11] within the chapter "Incorporation of resilience assessment in critical infrastructure risk assessment frameworks". Starting out from the risk management process stated by ISO 31000, the authors embedded the resilience analysis steps.

In examining the attributes and determinants of resilience, Tierney K and Bruneau M. developed the R4 framework of resilience:

- Robustness — systems' ability to remain undamaged or unaffected by critical (natural/unprovoked or artificial) events or without significant degradation or loss of performance;
- Redundancy — the extent to which systems, system elements, or other units are substitutable, that is, capable of satisfying functional requirements, if significant degradation or loss of functionality occurs;
- Resourcefulness—the ability to diagnose and prioritize problems and to start solutions by identifying and mobilizing material, monetary, informational, technological, and human resources; and
- Rapidity—the capacity to restore functionality quickly and with no or few damages [5].

Starting the incorporation of resilience assessment in critical infrastructure risk assessment and the R4 framework, R. Pulfer [12] proposes within his PhD dissertation a multi-attribute decision support model based on comprehensive models and holistic indicators. This approach enables stakeholders to understand a complex situation faster and more comprehensively, to apply proper measurements, and to draw conclusions for sustainable management. Dynamic capabilities to manage complex situations represent a paradigm shift for the system of systems engineering and systemic risk management implemented as system resilience governance architecture. All the instruments of this architecture are model-driven to manage complexity and complex change and to provide multi-attribute decision support. The entire approach to system resilience governance instruments is database-driven, redundancy-free, evidence-driven, economically used and multi-visual.

The *system resilience governance architecture* is a solution framework that helps specialists to deal with the paradigm shifts in the system of systems engineering and risk dependency management. By means of the integrated *system resilience governance instruments*, a complex situation can be completely and systematically documented as a multi-attribute system of systems description while also taking risk opportunity management into consideration. This digitalized virtual picture of a real system of systems or a specific system context can be used for advanced analyses, operations, transformation, assessment, and benchmarking tasks.

3. Results

According to Toretta et al. [13] Decision Support Systems (DSS) are designed to assist decision makers with a particular complex problem in a computer-based environment. Basically, a Decision Support System allows for the selection of an option from o set of alternatives or associates a rank for each alternative. Regardless of the methods used in decision-making, the result is obtained based on the analysis of criteria, weights or the importance associated to the criteria. A DSS uses both the measured data and the knowledge of the decision maker. More than that, a DSS is flexible, powerful and user-friendly and the result obtained after applying a multi-criteria method is easy to interpret.

Di Petro et al. [14] introduce a new concept of DSS. In their opinion DSS "should account for, and support all phases of the risk analysis process: event forecast (where applicable/predictable), prediction of reliable and accurate damage scenarios, estimate of the impact that expected damages could have on services (in terms of reduction or loss of the services) also accounting for perturbation spreading via cascading effects".

The present research aims to model such a DSS in order to help managers visualize at a glance an updated situation of the living system they deal with — their organization. The major result of this methodology is the framework that might be included in the software tools that help managers eliminate uncertainty faster during the decision-making process.

3.1. System Resilience Governance Architecture Model

The proposed system resilience governance architecture model summarizes how dynamic capabilities management of (normal) complex situations can be documented. The model shows the essential three steps: How can a complex situation be managed systematically and what are the dynamic capabilities that are required?

The model-driven system of systems operation and transformation approach, based on a multi-attribute system description, is the basis of rules, conditions, attributes, methods, and exceptions (dynamic capabilities) that help to manage (normal) complex situations. There are some differences between a normal and a complex situation. In general, both situations are similar — except the fact that complex situations are often unknown and unexpected, and the system context (involved in and related to the system of systems) and the required information are not available or do not have the required quality and maturity.

The system of systems management describes all the techniques, rules, and principles needed to document, control, and transform a real system of systems landscape with all the definitions and dependencies. The system resilience governance evaluation is the summary of all the instruments supporting a multi-attribute system context evaluation, assessment, and an advanced system context profiling. A stressor, according to N.N. Taleb [15, 16], is the creator, reason, or event for a complex situation. A complex situation is unknown and unexpected.

The complex situation management, driven by stressors (events), covers the instruments (dynamic capabilities) to document, evaluate, manage, and transform a complex situation. In a complex situation, only a part of a living system of systems and their dependencies are usually involved. This is the reason why the first step to handle a complex situation is the creation of a System Context. After the evaluation of the essentials, all the techniques to handle a normal situation are reused from the system resilience governance evaluation. Consequently, the profile as a key element covers both situations. This has a huge advantage in terms of cost, efficiency and effectiveness of operation and transformation.

3.2. System Resilience Governance Architecture Instruments

The system resilience governance architecture can be measured, managed, and transformed into a holistic way with the greatest stakeholder empowerment and value by using 14 instruments. The system resilience governance architecture consists of four specific instruments. These instruments represent the dynamic capabilities to manage complex (or normal) situations. Each instrument follows definitions and rules and has a visualization focus. The target of all instruments is to make real systems, after digitalizing, available as virtual pictures, where they are represented as unique model-driven multi-attribute system descriptions. A model (a multi-attribute system description) is based on artefacts instantiated from a standardized classification system where artefacts are available as node, edge or are interconnected to each other. The holistic view of a digitalized real system landscape can be measured, controlled by the multi-attribute indicators. Based on holistic assessments, evaluation, and ratings, the information about the model can be visualized in comprehensive and simple diagrams or in highly collaborative pictures and documents and it can also be reused by other instruments. Moreover, the governance can be comprehensively documented and transparently visualized. Every system context is documented in a comprehensive way as a standardized model (virtual picture).

In the following list, all the instruments and their focus are described in brief. All instruments are documented, visualized, represented, and applied as a multi-attribute model description based on the favorite object-oriented concepts (encapsulation, inheritance, class object, and message).

1. *The system of systems engineering* principles cover all the concepts, definitions, templates, visualization techniques, quality definitions, and rules to document a system of systems in general, a living system as a digitalized virtual picture of real systems or as a specific system context.
2. A *living* system of systems is the digitalized virtual picture of a real system representation in all possible dimensions. This picture is available

as a multi-attribute system of systems description. It is mainly maintained by the discover, map, and visualize utilities.

3. *Risk evaluation* is a comprehensive assessment and visualization of all the risk types of a living system or system context. There is an incorporated process for defining, assessing, measuring, mitigating, and monitoring risks as well as the required definitions and rules for risk-control frameworks, incidents, and action management. A risk evaluation can be enriched by a risk dependency map.

4. Based on the *dashboard*, all the facts and figures, indicators, and measurements of a living system of systems with their formulas and equations are represented. There are many different visualization options available.

5. The *scenario* allows for and supports a rule-based multi-assessment of a living system of systems in terms of vulnerability, performance, conformance, risk, and change or against other configurable aspects.

6. By means of the assessment, the specific system context of a living system can be validated against standardized topics specified by rules. This assessment can also be used for a system context involved in a complex situation.

7. The *indicator is a fuzzy set*-calculated comprehensive number from a set of standardized assessments. This number shows the temperature of a system context — like measuring a fever—within a normal and a complex situation. There is also an option to produce an indicator on a higher aggregation like a system landscape.

8. With a *scorecard*, every single assessment can be detailed and supplemented with a timeline (past, current, target) to visualize changes and sensitivity shown by specific thresholds. The scorecard also presents the benchmark functionality per assessment topic.

9. The *roadmap* covers all the actions (task, measure, activities) applied while using the instruments of the system resilience architecture in operation and transformation, supplemented by resources and other attributes. By means of this instrument, actions can be structured, aggregated, prioritized, and set in a certain order.

10. The *profile* represents various system contexts as a comprehensive multi-attribute decision support for visualization. Not only the context but also risks, dependencies, and technical and resource restrictions, with advanced ratings, measures, and qualifications are incorporated. The profile is the highest possible aggregation of a system context in a complex or normal situation in this architecture. It is also a visualization and

representation of the dynamic capabilities as a specific context-sensitive and holistic system landscape with the encapsulation of all the relevant essentials.

11. A *complex situation* is usually initialized by a special event or call stressor and shows a living system or a system of systems under special circumstances. Therefore, in a complex situation, a special context, not the entire system, is under analysis. The key features of a complex situation are often the time pressure, the availability of information, the lack of responsibility, and the quality and maturity of the relevant and essential information. Most of the time, the event was unknown and unexpected for all the involved and concerned stakeholders.

12. The *risk dependency map* is a special instrument for managing, analyzing, simulating, and visualizing the dynamics, the dependencies, the influence, and the flow of risks and their causality. With this map, even loops and mappings can be identified as well as the problems and the possible risk solutions.

13. Under special circumstances with risk development, many produced risk, the evaluation results, produced over time or in special simulation scenarios, can be shown in a special kind of *timeline diagram*.

14. With the analyses of the predetermined breaking points, there is an option to analyze and visualize the risks of *possible damage* of as well as to apply breaks in order to avoid or protect a system from total damage. This instrument can also be used to separate two systems, like in the case of building construction.

The architecture solution and procedures support the understanding, encapsulating, and visualizing of the complexity of a complex situation and the systemic dependencies, identifying the information demand in a dynamic environment, forecasting risk and possible impact, simulating resilience, and implementing action patterns to control and handle continuous change.

With this model-driven system of systems description approach, the discovered, mapped, and visualized content about a system of systems, a living system or a specific system context can be aggregated, stored in a content- and context-sensitive way, and a multi-attribute decision support can be used. As far as the standards, language, and taxonomy utilized and applied in the classification system are regarded, we are of the opinion that people can be empowered and a mutual understanding can be supported. System resilience governance can be documented and managed by means of a standard approach. A system can be systematically digitalized and visualized in 14 steps. Different results can be developed by using this procedure. Based on the standard results, management, empowerment, and comparability can be supported.

Within the meta-model, resilience can be maximized using the following equation developed by Fang et al.[17]:

$$R(T) = \frac{\sum_{t=1}^{t=T}[\sum_{f \in v_D} f_j(t) - F_{min}]}{T(\sum_{j \in v_D} P_j^D - F_{min})} \quad (2)$$

Where $\Sigma_{j \in vD} P_j^D$ represents the target systems performance.

Fig. 1 emphasizes the related meta-model of all the utilized instruments and their relations within this architecture. Based on these instruments, a living system of systems can be standardized and digitalized in order to handle normal and complex situations.

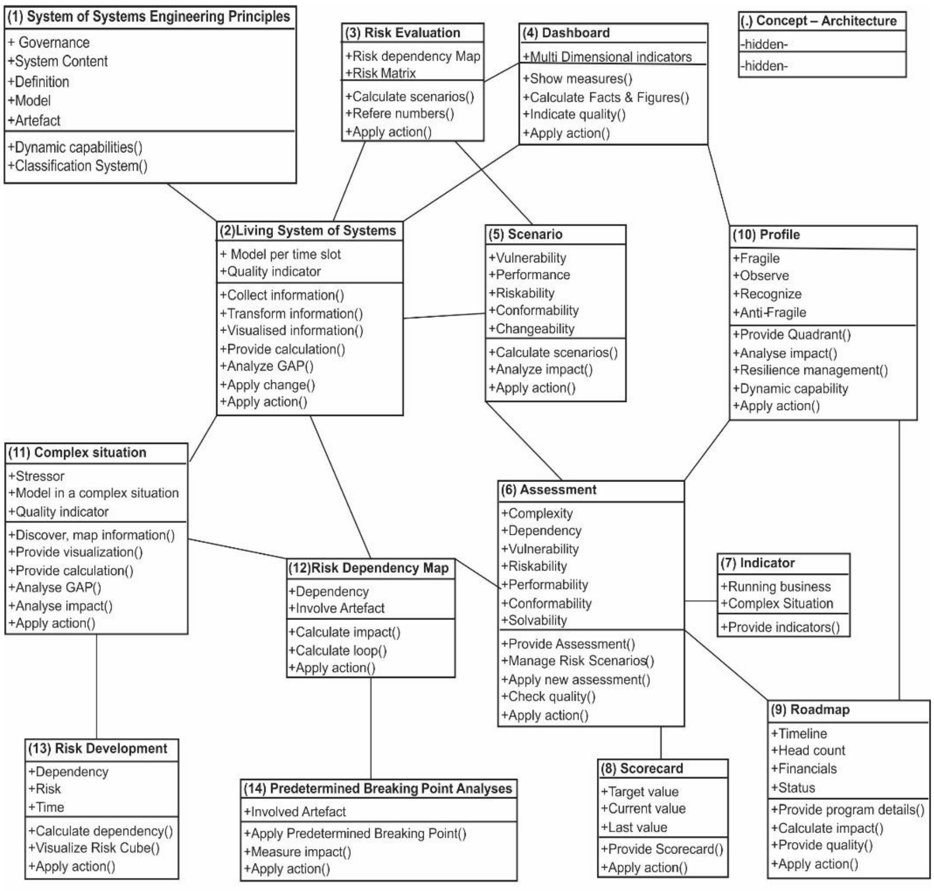

Fig. 1. System Resilience Governance Architecture Instrument Model (adapted after [11])

The multi-attribute decision support is a comprehensive balance between performance, conformance, risk, change, and the applied actions implemented and available as a model-driven multi attribute system of systems description. With this methodology, which is documented in the following chapters, the approach and the solution requirements, challenges, and issues documented in [18-21] can be addressed. Additional business and leadership value can be generated as well.

If a system is resilient, it is considered to adopt a “good governance” in case of complex situation influences and better management of possible damage. Additionally, all dependencies are kept under control in order to avoid any unmanageable impact.

3.3. System Resilience Governance Framework

The system resilience governance framework provides a comprehensive approach to manage normal and complex situations. This approach is an improvement of the original Methodology introduced by R. Pulfer in his PhD dissertation [12]. The added value of the present scientific demarche compared to the thesis is the focus on a superior level of comprehensibility on defining the technical, systemic and operational elements necessary to set up a resilient critical infrastructure. Supported by various techniques, a system of systems can be systematically documented. All the results focus on offering a comprehensive multi-attribute decision support for many different stakeholders. An initialization starts, because a need (e.g. an actual business situation) exists. During initialization, general conditions, goals, and dependencies are developed. During evolution, one or more project template(s) are put into practice. This can be done with several cycles and sub-cycles. Evolution is subdivided into ten sub-cycles, all of which belong to four specific cycles called analysis/design (elaborate and assessed solution proposals), specification (solution documentation and integration design), construction (develop or purchase a solution), test (check and verify), and introduction/education (empowering of the stakeholders). On the successful completion of introduction and education, the operation or use of the solution begins. This cycle generates value with the result produced by the solution and seeks to manage and control the conformance and correctness of all results. The approach shows how deliverables accumulate during system of systems engineering. Some of the deliverables have to follow standards, guidelines or other rules, or must have some maturity to fulfill. This cycle supports the pragmatic result-driven approach, and is market-proved, adaptable, and configurable for special purposes.

Today, information is always available from different sources and contexts. During digitization, the source can be documented and linked to support the maturity process of the linked information, and the ownership should be documented simultaneously with the description. If the digitization has a pure quality, maturity is not traceable and the history is not available, thus the analysis and interpretation could be misleading. A special emphasis should always be put on dependency management. Interfaces, relations, dependencies and into-dependency documentation as well as their ownership is often weak. A good system description includes a dependency description.

4. Discussions and conclusions

According to ActionAid [22] “resilience is most effectively built through initiatives that establish and strengthen community institutions, and build collective action and partnerships across and between the local, district, national, regional and/or international levels”.

The software applications used to implement the model help us view the whole system without redundancy. Breaking the organization into objects and identifying the (hidden) links/dependencies between certain elements (which may not be obvious at first glance) can improve the speed of reaction (in terms of deciding quicker) in case of a malfunction/discontinuity of the normal process. Basically, the manager has the real-time image of the situation and can also model different "future" depending on the decision he wants to take; he can visualize the chain reaction caused by a certain decision.

Nowadays, a system resilience governance architecture solution market-proof product is available. This product supports most of the instruments — some on a highly executable level and others on a prototype level. This market-proof product has been changed and extended due to the system resilience governance architecture definitions. This took place, on the one hand, to validate the system resilience governance architecture instruments in practice, and, on the other hand, to document complex situations.

The tool that embedded all elements of the architecture is called TopEase. This software is an Object-Oriented Programming (OOP) tool that applies all the key elements (classes, objects and messages) and key mechanisms OOP (encapsulation, inheritance and polymorphism) [23, 24].

The critical infrastructure analysis within safety culture and subsequently, modeling related to specific aspects, requires a prospect of a "system of systems" given by the interdependencies and missions of security components, while most approaches provide only a list of individual components. A relevant example concerning this framework is highlighted by Badea et al. [25], using a short mathematical model in order to simplify the quantitative approach of critical infrastructures interdependencies. It could be pointed out that a system of critical infrastructures (national network for transporting oil products by pipeline) consisting of 7 subsystems (tanks, pipelines, railways, central dispatch, three local dispatches) can have a maximum of

$$C_7^2 = 21 \text{ connections}$$

while through their classification into two groups (central and local dispatches) of 4 and 3 subsystems are only needed

$C_4^2 + C_3^2 + 1 = 10$ connections.

The solution proposed by this article can be used for some mobile instruments and web applications. Apps are mainly configured and parameterized and can be flexibly adapted based on the requirements of the stakeholders. There are different interactive mobile and web services offered by this component. A user is able to orchestrate his/her own application with all the services, workflows, and required navigation functionality.

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