Heuristics for Systems-of-Systems Design

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Abstract. *A System-of-Systems (SoS) is an arrangement of independent systems that work in synergy to fulfill a common mission. SoS can be observed in several domains such as urban mobility, healthcare, and smart cities, to mention a few. A significant concern of SoS professionals refers to the independence of the constituent systems, which have the autonomy to stop contributing or abandon an SoS, making it difficult to guarantee the quality of SoS at design time. There are concerns involving the design of SoS. Managers, developers and users should understand how an SoS will operate, aiming to mitigate potential problems anticipated at design time, and defining the requirements and resources necessary to develop and maintain the SoS before it starts operating. This Master's thesis aims to investigate good practices and recommendations that can be applied to the design of SoS to assure its proper operation. Therefore, we herein adopted the term "heuristics" to refer to such good practices and recommendations. A systematic mapping study (SMS) was conducted to identify which heuristics have been applied in SoS design. The SMS results were discussed in a focus group to organize the heuristics in a catalog. To facilitate the understanding and implementation, the heuristics in this catalog have been organized into groups. Each heuristic was categorized according to its suitability for use based on the coordination level of an SoS. We developed a tool that incorporates some heuristics from the catalog to verify how the heuristics can facilitate the SoS design process. A feasibility study was conducted with practitioners to evaluate the ease of use and the usefulness of the tool. We expect that the heuristics catalog support professionals to identify critical issues during the SoS design process.*

1. Introduction

Organizations aim to improve productivity to promote competitiveness and social development. In this context, information systems (IS) are essential resources for companies and governments to accomplish goals. New technologies such as cloud computing and the Internet of Things (IoT) have fostered new possibilities to develop IS by providing infrastructure that simplifies the deployment of new solutions.

Such a scenario increases the pervasiveness of software systems in the organizations, and the integration of these systems enables the emergence of new capabilities. This scenario led professionals to adopt solutions such as systems-of-systems (SoS), characterized by the managerial and operational independence of the constituent systems (CS), which are often developed and maintained by different teams. Examples of SoS are smart

cities [Boscarioli et al. 2017], in which public and private organizations work in coordination through the integration of systems.

The independence of CS raises several concerns. In traditional systems, the operation of the systems' components is fully controlled by only one entity. In SoS, there is more than one decision-maker, and the CS are not necessarily known at design time [Cavalcante et al. 2016], which can make the architecture highly dynamic and complex. CS can experience changes in the life cycle and be modified according to their individual goals. However, there is a lack of standards to deal with the challenges imposed by the SoS specific characteristics.

This research aimed to develop a catalog of heuristics by identifying rules, guidelines, good practices, and recommendations that can be applied to the design of SoS. We expect the catalog helps professionals in designing SoS with better chances of success. As a secondary objective, we developed a tool that assists professionals in modeling an SoS and checking issues that can be addressed at design time.

2. Research Methodology

A research question was defined to guide our research and help us organize, evaluate, and understand the data collected in the research: **"Which heuristics can be applied to the design of SoS?"**. We followed the methodological steps described below:

- **Literature review characterization:** The objective of this phase was to understand the SoS concepts and the challenges in the research field. This step allowed us to define the scope of research;
- **Exploratory study:** In this phase, we conducted an exploratory study in a Brazilian public organization to verify the perception of professionals on issues related to an SoS in operation;
- **Systematic mapping study (SMS):** The study aimed to identify the challenges of designing SoS reported in the literature and the approaches to solve them. In this phase, we extracted the first set of heuristics;
- **Heuristics refinement and evaluation:** We divided this phase into two parts. First, we conducted a focus group to discuss the usefulness and applicability of the heuristics identified in the SMS. Then, we refined the focus group results with a survey with experts in a second-round evaluation;
- **Tool specification and development:** In this phase, we identified the requirements for a tool that implemented the set of heuristics using an mKAOS notation [Silva et al. 2015] and defined the appropriate infrastructure to support the tool;
- **Feasibility study:** A feasibility study was conducted with with professionals from the industry to verify the ease of use and usefulness of the tool, allowing to identify errors and make improvements to the tool;
- **Refinement:** The first version of the tool was deployed on the web using the feedback from the feasibility study and named mKAOS Studio Lite in reference to the original mKAOS Studio [1].

[1] mKAOS Studio Lite deployed at http://www.mimamura.com/diagram

3. Main Results

Based on the SMS results, it was possible to extract a set of 40 heuristics. After the SMS, a focus group was conducted to adjust the set of heuristics, revising the statements and rationales, combining heuristics with similar purposes and removing heuristics not suitable for SoS design. The focus group discussions also made it possible to create a sequence in which the heuristics should be applied, grouping them into five categories: **initiation**, **constituent systems**, **interoperability**, **emerging behaviors**, and **monitoring**.

A survey was conducted to evaluate the refined set of heuristics, aimed to evaluate the applicability of the heuristics catalog regarding SoS design from the perspective of experts in the SoS context. Only one heuristic related to interoperability was considered not valid to SoS design and was removed from the final catalog. In order to verify how the heuristics can be used in practice, a web-based graphical tool was built aiming to help users deal with issues that affect SoS even before its construction. The tool should provide a better understanding of how the system works, who is engaged in supplying resources and capabilities, and what the impacts are for SoS design decisions.

4. Conclusion

IS are increasingly present in the the people and companies' daily lives, performing functions such as financial services, health support, and even entertainment. The amount of capabilities provided by these systems makes it increasingly unfeasible to build new systems from scratch, leading designers to think of solutions such as SoS, that integrate capabilities of several independent systems to deliver new functionality.

Designing an SoS can be a challenge using techniques intended for traditional systems because the degree of uncertainty brought by the independence of the CS. The main research question in this dissertation was used to guide the investigation of what are the heuristics that can be applied to SoS at design time. The detailed methodology and results can be found in the Master's thesis [Imamura 2021].

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