Towards a Conceptual Framework for System of Systems

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Abstract

In the shadow of the Ukrainian war, many western countries will increase their armed forces capabilities and this in an environment where new technology will have strong influence. The increased capabilities will be implemented in a context of automation, machine learning and other types of artificial intelligence (AI). At the same time, the new or enhanced capabilities must harmonize with multi-domain operations, where the need for speed, flexibility and interoperability are essential. Additionally, future defense forces will be forced to manage new and old systems and methods and integrate these so that the desired functionality and capability is achieved. At the same time, as new technical systems are introduced, methods and processes will develop. Consequently, new technology will bring possibilities of solving military problems in new ways.

Keywords

Sociotechnical systems (STS), system of systems (SoS), capability development

1. Introduction

For military capabilities development, it is a prerequisite that several systems effectively interact and integrate as a *system of systems* (SoS). SoS could be described as an arrangement of systems that occurs when several individual and independent systems are integrated into a larger system. This results in a more complex system with the objective of achieving a higher level of functionality and performance than the sum of the individual systems involved [1]. SoS can consist of several technical systems that are integrated, but also of *socio-technical systems* (STS), i.e., systems where both people and technical artefacts are included as system elements [2]. The socio-technical domain also includes organizations and the processes and methods that are used [3].

The theories defining SoS includes an approach where the design of an SoS can be based on two different perspectives. One perspective is that the design of the technical artefact affects human behavior (system affects people). The other perspective is that human behavior is allowed to influence how the system or SoS is designed (people affect system). An extension of those arguments should be that designer of SoS must consider that these perspectives cannot be considered as separate, but as a whole [4].

In the areas of networks and information systems (IS) and information technology (IT), there are several dilemmas when individual systems must integrate to a SoS. One dilemma is that individual systems rarely are designed to work in a SoS, and this makes development of SoS particularly challenging. Another related challenge is that designers of individual systems tend to optimize their system, sometimes at the expense of the capability of a superior SoS. For that reason, system control, *governance*, is important. Governance can include control of technical protocols for data transfer and information architecture [3].

When developing a SoS, designers must consider that some systems with specific purposes already exist and contribute to the overall purpose. They must also consider that new systems will be added and become part of SoS. SoS must accordingly be able to handle planned new systems as well as updating existing ones [5].

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To summarize, several factors arise that together affect the design of SoS. This is possibly even more challenging in a military context. As a designer, it is wise to adopt an agile approach in this context, which can result in an openness to changing requirements but also an openness and awareness that the purpose of the SoS can change and develop over time. To this end, the objective of this paper is *to present a preliminary design for a PhD thesis project on a conceptual framework for managing SoS`s from a holistic perspective.*

The rest of the paper is structured follows. Section 2 presents the background and the status of current research. In Section 3, the problem is discussed and explained. Section 4 presents this thesis research goals. Section 5 presents the tentative research methodology and Section 6 presents concluding remarks and the next steps in this research.

2. Current research

Several nations have applied systems engineering (SE) as a method to deliver the requested capability and products at the right price and in the right period. SE includes a systematic approach to ensure the design, implementation, operation, management, and decommissioning of a system [6]. From the early 2010s, SE has been questioned within the military procurement complex. Amongst the issues that have been raised is if SE can handle the increased complexity of military systems [7]. One assumption was that SE is possibly not optimized for the acquisition of systems that are part of a SoS in the military domain. In this regard, there was a call for a broader, *comprehensive approach* where the focus is on facilitating integration into an overlying SoS [8].

During the last decade, a new approach has become recognized. More specifically, a socio-technical approach to capability development that results in systems that deliver solutions to identified capability requirements. Baxter and Sommerville [2] argue that the actual need to embrace a socio-technical approach to system development is recognized, but not yet generally established in practice. They also state that *socio-technical systems engineering* (STSE) could help designers to understand the dynamics between organization and system development and that this deployed approach is predicted to eventually become a tool to bridge and support analysis of organizational changes and their impact on system development.

Al-Amin and Dagli [9] underline, within the same area, the need to understand and predict a system. This means that designers must identify the relationship between participating systems, otherwise they end up with a SoS that is not deterministic.

Klein and Kleinman [10] suggest that more focus on organization and method can clarify the need for technological development. A deeper analysis can possibly identify how technology, methods, and organization interact. This highlights the need for a fusion of the results achieved in these disciplines together, specifically organizational development, method development and technology development.

3. Problem discussion

The application domain of this thesis proposal is cross-disciplinary; it integrates computer and systems science with military studies. Hence, the first step is to discuss the problem from the point of view of armed forces. The next step discusses the problem from the computer science position.

From a military perspective, fundamentals of warfare heavily rest on three activities: situational awareness, decision-making, and choice of effectors. These steps are carried out at all levels, from the strategic to the tactical level. Although the content and context differ, there are more similarities than differences and the foundations are recognized in several theories and doctrines.

An example at operational level is *joint targeting*[2] where NATO has operationalized the targeting process. Another example is the *OODA-loop* [11] where military planning is described overall in the steps *observation phase*, *orientation phase*, *decision*, and *act*. There is relevant criticism against both joint targeting, which can be perceived as un-dynamic, and against the OODA loop, which is perceived by many as too shallow. However, to some extent they are accepted, which indicates that a holistic view of the process should be adopted when designing system of systems. This should encourage designers

[2] AJP 3.9 – Allied Joint Doctrine for Joint Targeting

to shift focus from studying parts of the system and instead focusing on the entire chain. What often happens when the holistic approach is not followed is that designers tend to focus on optimization of the existing systems. An example could be the development of a new field artillery system. Developers often find themselves in a process that essentially is about achieving more firepower, better protection and mobility. This, in short, means focusing on an improved version of an earlier version the system. A more relevant focus would be to focus on the whole chain, and identify how the chain can be improved, and how a new artillery piece can not only integrate but also develop the existing chain. An incorrect starting point, for example. optimization of parts of a chain, leads to technical subsystems that becomes difficult to integrate with methods and organization, and vice versa. When parts of the system do not harmonize with other parts, the SoS will become slow, less precise, and less effective. Additionally, the ongoing information revolution will most likely result in a transformation of the decision-making process. One question all developers must ask is not how new technology can improve the ability to do what we do today - but how new technology can let us do things in a different way. In conclusion, new technology is important, but new and holistic thinking is probably even more important. A successful concept does not have to be a new artifact or new technology. In some cases, a new way of using the existing systems is more effective. To make the situation even more complex, military units will, for decades ahead, use a combination of new and old technical systems. The challenge is not only to make them interact and work together, but also to understand how they can be used in new and innovative ways. A good example of this is the B-52 (*Stratofortress*) aircraft which entered service in 1952 and is still in service. [12].

At the end of the last millennium military capability developers tended to spend excessive energy on technology, believing that the acquisition of new technical systems would be the main component of the transformation many armed forces were facing. This phenomenon is probably an even greater risk today, as technological development is even faster, and we are trying to upgrade existing military systems with new technology. A possible way forward, could be a deeper understanding of development regarding how the armed forces use technologies (including methods) and how they organize themselves. However, there are challenges with this approach. One is that those who are to integrate the system into an overlying system, regardless of whether it is a technical artifact or an STS, must allocate large resources for interaction. To reach to a point where all subsystems in a SoS are optimized and aligned, designers must analyze the whole system to achieve the benefits of an SoS, i.e., *one plus one equals three*. [12]

There are new and emerging technological developments in IT. The AI and machine learning technologies show notable successes and will become a vital component of military networks and command structures; in some cases, solutions based on these technologies is already a reality. Computer science as a discipline, strives to combine and identify a scientific foundation for design, programming, algorithmic solutions, and the algorithmic process itself. The main concern of computer science is to identify what can be automated. [14] However, humans are still superior in many aspects, for example, balancing risk management and evaluating ethical implications based on a certain action, which puts forward the requirement to integrate these solutions with human systems. The goal when designing future systems and SoS should not be to reduce the number of people in the systems, but to let people focus on decision-making. [12]

The decision-making process, which should be considered as a part of a SoS [3], must, because of the above reasoning, be reformed, as the entire system has changed. Tomorrow's military systems will consist of a mix of manual and automated technical systems and processes with human decision-making at the center. The overall purpose is to shorten the decision cycles and make the decisions more precise. Methods, processes, and organizations must therefore develop to become more dynamic and resilient.

Bob Johansen [13] arguing that designers the need to open their definition of what an organization is. Today's, and especially yesterday's, fixed organizations with well-defined roles and methods will develop towards an organization where the content changes as subsystems, in the form of both technology and organizational development, change. This also means that the common understanding of an organization with fixed technology solutions will develop towards an approach where developers and designers must accept continuous technology development. Consequently, this will expose management and leadership to challenges, where they must manage an optimization between STS and technical systems and constantly assess the possibility to optimize and shape the organization.

A clear example where the SoS perspective are missing can be found in the development of battlefield management systems (BMS) within land forces. On several occasions, developers in the first development stage have only embraced the technical system, while methods and organization were developed later. This approach has resulted in that users, commanders at every level, do not believe that the technical components of the management system support the methods applied.

As a response to these challenges, developers and designers must accept that the performance of subsystems in a SoS are less important than how the subsystems are integrated and connected. In a military context, this may mean that a sensor's ability to share information with a weapon system is more important than the sensor's performance. Alternatively, the other way around, the weapon system's ability to receive sensor data is more important than the weapon system's performance. This also applies to the development and integration of methods and organizations.

Overall, this means that the ability to change will become more important than stability. Technical solutions together with organization and applied methods must be considered as temporary rather than stable, despite the difficulties that such mindset requires. Change must therefore be embraced and accepted as continuous, and therefore the ability to change should be built into the organization and in its methods and in its leadership. [14]

Existing studies and research indicate a clear knowledge gap. Several early methods for system development have been criticized as they had a one-sided technical perspective on IT systems. Therefore, the human and organizational aspects were neglected [15]. As a result, methods with a distinct social focus were developed. However, those turned out to be ill-suited for the development of SoS, as the technical characteristics of the IT system were ignored. The socio-technical perspective was developed and as a backlash. This perspective gave the IT systems equal importance as the social aspects [16]. One example is Nurcan et al. that suggest a method, *The Enterprise Knowledge Development - Change Management Method* (EKD-CMM), that allows developers a structured way to organize and to conduct organizational change management. This method proposes an iterative approach to develop a hierarchy of change goals. It involves examining how contextual forces affect existing goals and identifying the effects of the proposed changes on current business processes. [17]

Another framework that aims for a holistic approach is NATO Architecture Framework (NAF). NAF provides standard for developing architectures for both military and business use and support system integration by, for instance, ensuring a common approach for understanding, comparing, and integrating architectures. [18]

Theories behind STS have been developed over several decades, but at the same time technology development has accelerated. In the dynamics between technical development and theories that support the development of organization and method, the latter lag behind. It is therefore both likely and desirable that the socio-technical domain gains ground. [19] Clegg et al. arguing that, from an STS perspective, designers must understand and accept the any change in any part of the STS, will result, trigger, and possibly change other parts of the STS due to STS's complex nature. [20]

Raz, Guariniello and Balasubramani [21] implies that there is a research gap regarding identifying what information requires linking in a SoS. This mapping is likely to be so complex that simplifications must be identified before the required linking could be identified. Within the same area, there is also a gap regarding how different variants of machine learning affect a SoS regarding methods and organization.

Problem statement summary

In the light of an accelerating technological development (IT, AI, cyber and data management), with simultaneous requirements to integrate earlier versions of systems, tomorrow's designers must thereby relate to and consider the whole SoS when they identify the requirements for different subsystem, technical or sociotechnical. This means that today's methods regarding capability development must expand to be more holistic, flexible, and comprehensive.

There are no studies or methods available that fully explains and predicts the dynamics between information systems, methods and processes and organizational development in a SoS. When the capability development lacks a systematic approach that considers all this, the risk of developing irrelevant information systems, organizations and methods is noteworthy. One way to approach these challenges could be to adopt incremental capability development, i.e., building on the capabilities

already in place, combined with focusing on overall (SoS) capability requirements and architectures, rather than focus on detailed technical requirements [22]. Another approach is to assume that the initial capability requirements always are incorrect, and difficult to formulate. The reason is that a clearly defined starting point does not exist or is difficult to identify due to the rapid development [23].

4. Research goals

Capability management is in many aspects facing a paradigm shift. One of the reasons is the accelerating technology development that together with, for example, automation and machine learning will affect and support all parts of military capability. With respect to the challenges outlined previously, now is the time to break from the current approach of trying to use new technology to improve what we already do, and instead find out how new technology can allow us to do things differently.

To this end, the overall goal of this PhD thesis, is to identify a conceptual framework, with models and methods, that would help designers to evaluate and better understand the potential of a SoS, and how the different sub-systems influence a SoS. The main goal is divided into following sub-goals:

G1. To investigate, describe, and conceptualize a (military) command and control system, a socio-technical system, with organization, methods, and technology.

G2. To explore how an emerging technology affects method and organization in a (military) command and control system, and vice versa.

G3. To develop a framework to support a holistic and flexible approach when designing a new or improve an existing SoS.

G4. To explore how technical- and sociotechnical systems interact and how capability requirements should be designed.

G5. To demonstrate and evaluate the conceptual framework.

5. Tentative Research Methodology

This PhD thesis will use *Design Science* (DS) research methodology [24] as the overall research framework. The method is appropriate for the creation of the design artefact, namely, the *conceptual framework.* DS is applicable because of its iterative approach to artifact development which would be needed for targeting issues experienced in an execution phase. *Action research* is the strategy that will frame this thesis. The strategy is chosen because its focus to address practical problems. Action research does also strive to solve real problems, for example problems that users and operators in an STS experience in their practice. Action research will be used for DS phases problem explication and requirements elicitation [25]. During these phases, the data collection methods will be interviews of *focused group* in combination with *observation* of the selected and defined STS will be used, as well as literature review.

During problem explication, this thesis will clarify if or how the defense domain, from a system of systems perspective, is distinct from other organizations due to its unique characteristics.

6. Conclusions

This paper outlines a new PhD thesis research project in terms of problem are, research goals, strategies, and methods for the purpose of developing av conceptual framework that could help designers to evaluates and better understand the potential of a SoS. The next step will include additional decomposition of the research goals and after that, refine both the research strategy and the method for data collection, analysis, artefact construction, demonstration, as well as evaluation.

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