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The systematic review of variety of military, weapon, combat and warfare system-of-systems wuth their new classification and ontology depiction for further concept and design development for the Armed Forces of Ukraine

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Abstract. A system-of-systems is a special complex structure in which new capabilities arise from interacting independent pieces that are controlled by multiple operators. One special kind of similar structure are military, or weapon, system-of-systems. The architecture of weapon SoS consists of the constituent systems (pieces), of interfaces and IT, of communication and exchanges occurring between the systems. The architecture of the SoS is always in a state of flux, but in warfare the demands to change the structure of weapon SoS are emphasized. To save lives and to win both in close battles and long war is the main mission of HQ, common combat forces and supporting efforts.

In the article the architecture of created SoS in different countries (mainly in U. S., but also in NATO and P. R. C.) are presented – their schemes, components, purposes and key peculiarities. These features allow to get the ontology for typical variant of SoS – they all were divided into five classes. So, we suppose that SoS may by differed by their creation, or evolution, or transition, or combination, or due to attaching to non-SoS.

In general, the development planning of the military or weapon SoS is a challenging strategic analysis work because it involves various aspects, such as mission tasks, capability requirements, weapon effectiveness, and economic benefits. But in demands of lifesaving in warfare the expectable replacing soldiers via an autonomous vehicle SoS are straightforward, so it is need to understand the concept and main features of SoS.

Keywords: military system-of-systems, command and control, design concept, ontology, Zbroini syly Ukrainy.

Introduction

In the modern warfare the military system-of-systems (SoS) is a highly complex system which contains all the common combat forces (land forces, navy, air forces, special forces, etc.), aerospace forces, nuclear triad, C^4ISR (command, control, communication, computer, intelligence, surveillance,

reconnaissance), cyber-space forces, electro-magnetic warfare, supply & support, etc. That's why there are a lot of domains where military SoS (MSoS) are investigated for a long time, but in recent years the interest hasn't decreased.

For example, to develop a military SoS, Liu et al. (2023) focused on the strategic, operational, services and resources layers of a MSoS, following a top-down design process, and got the Unified Architecture Framework, which is designed for the modeling of a SoS. The authors got a "vision-goal-mission-capability-operation-service-resource" logic chain, which can lead to a solution-seeking as well as a warfare system-of-systems construction in order to meet the needs of the stake-holders of the SoS. Using a modularized architecture, the described domain meta-model can provide a flexibility of changing different layers in order to better find solutions. With an implementation of measurements from strategic layer down to the resources layer, the SoS model can finally leads to the requirements of the future generation equipment and the system level solution.

Yang et al. (2023) proposed a model-driven human-in-loop architecture design method for weapon systems (WS) based on the challenges and difficulties brought by system complexity and emergence that cannot be solved by traditional document-based architecture design methods. The method drives the SysML model of Magicdraw and the equipment entity model in UE4 (The Unreal Engine 4 landscape building function). The virtual battlefield environment was constructed and a communication server was developed to perform visual simulation of interoperability between WS.

Under the guidance of capability-based planning, Hu et al. (2023) addressed the generation and trade-off problem of weapon SoS (WSoS) development and planning under the double uncertainty of the scene and the key weapon system attributes using a multiobjective network-based optimization method combined with fuzzy set theory as a hybrid solution approach.

By investigating the effectiveness of air forces, Gao et al. (2022) proposed the concept of the SoS influence degree and conducted a scientific quantitative evaluation to quantitatively measure the effect of aviation equipment as the key to affecting the overall search and rescue action that are an important part of joint operations and one of the key supports for ensuring combat effectiveness.

There is an important problem for unmanned aerial vehicles (UAV) action in a hostile environment where no GPS is used. It is known that one of the main challenges of the perception component is the simultaneous localization and mapping (SLAM). So, in the context of multi-robot system and more generally for technological SoS, Mahdoui et al. (2019) proposed a multi-UAV framework for SLAM-based cooperative exploration under limited communication bandwidth.

How to integrate WS on a single platform and what will be the further enhancing the integration of multiple killing means—components of SoS are shown by Li et al. (2023). The authors also gave the brief analysis of the development direction of the combined artillery and weapon.

As we see all research fields are different completely and have unique planning and design methods. The immaturity of the researches in this area (no security aspects), the lack of citations of existing works and a lack of consensus on how the SoS architecture is described were the main features for the SoS interest mushrooming (Axelsson, 2015; Guessi, 2015).

That's why Barachini and Stary (2022, 77) underlines that applying SoS thinking is considered an effective way of handling complex adaptive systems with their self-regulation, self-management and self-organization.

Because of there are a lot of complex WS during Russian-Ukrainian war it is supposed to create a basis for analysis of systems and weapon equipment that have the key features of SoS. The mentioned sphere is absolutely new in Ukraine, so our aim is to initiate the discussions about military SoS and further development directions.

For this first stage of our research, we will use the traditional document-based analysis to systemize the key content in the field of SoS and propose the ontology for specific kinds of SoS. It is also the definitions and terms that are varies from multiple sources will be explained.

On the second stage the Ukrainian variants of SoS are expected for the analysis.

Literature review

The best way to initiate the discussion is to start with some official statements.

So, there is a following definition for SoS in International Standard (ISO/IEC/IEEE, 2019) – "Set of systems or system elements that interact to provide a unique capability that none of the constituent systems can accomplish on its own." The such systems are man-made and are configured with one or more of the following: hardware, software, humans, procedures and facilities. It is mentioned that there is a wide variety of systems in terms of their purpose, domain of application, complexity, size, novelty, adaptability, quantities, locations, life spans and evolution.

Such wide variety allows alternative definitions with proper explanation even in later papers. From Introduction it is easy to notice both military SoS and weapon SoS, but some authors used also warfare SoS, combat SoS and autonomous vehicle SoS. As we see, the definition and next difficulties are caused (and enforced too) by the facts that: (1) the SoS are designed to wide spectrum of entities (for National level leaders, for coalitions of partners or for Multi-National Forces (MNF), for organizations (for national systems in sphere of defense and/or security, for combat forces—from Army to warfighters); (2) there are investigations in different countries and the main purpose for them is to use the results in military systems/warfare that are protected by some secrets.

Naturally that first researches in future sphere of SoS were in Army, some of them, without any doubts, were started during WWII. Kammhuber Line (Halenko, 2023) or Mid-Ocean Escort Force (Hague, 2000) had the "hardware, software, humans, procedures and facilities".

The "system-of-systems" paradigm has been defined in different ways and domains by different authors since as far back as the 1950s—research work in Bell Labs (Kelly, 1950), in the Radio Corporation of America Labs (Engstrom, 1957), in the Survey Research Center at the University of Michigan (Boulding, 1956) and other that were summarized by Goode and Machol (Goode, 1957).

And the serious practice results were obtained in space or defense (National Research Council, 1967). For example, U. S. Ballistic Missile (BM) defense efforts can be traced to the World War II years, in an attempt to respond to the German V-2 missile, which was a threat for European allies (1st result—US guided missile test, 1960). The program has received different names during the years of the Antiballistic Missile Treaty (1972–2002). U. S. Navy also was on a top of achievements for complex adaptive systems planning in the 1990s own future. Further, at the end of 20th c., focusing on the construction of weapons and equipment systems, the U. S. military successively formulated the "NASA Technology Roadmaps", "Unmanned Systems Integrated Roadmap", "Army Unified Network Plan", etc. Judging by the implementation effect, U. S. military planning has undoubtedly played a positive role in promoting the construction of weapon highly complex system that got the name of the SoS sooner—in 2015 U. S. researchers had the predominant participation in this topic (Axelsson, 2015).

The birth of the term "System of systems" is referred to Mark Maier (Maier, 1998), who proposed a unifying definition of SoS in computer science, leveraging the features that characterize the concept in this domain. He first postulated five distinguishing traits (operational and managerial independence, evolutionary and emergent behavior, and geographic distribution) and later he explained that operational independence means that each of the constituent systems (CSs) of the SoS is capable of independent operation, even when isolated from the other CSs; managerial independence means that each of the CSs can be managed independently from other CSs, that is, multiple decision-making authorities can be present (Maier, 2005).

The fact that the term emerged in computer science instead of military science sphere is evidencable because of with the evolution of warfare in the direction of networking, informatization, and intelligence, greater challenges have arisen for the planning and construction of "a collection of independent systems as parts of a larger and more complex system that delivers certain capabilities" (Boardman, 2006). So, the concept of SoS suited well to the application of a large number of distributed platforms, sensors, weapons and networks.

Materials and Methods. Methodological Framework

Due to historical evolution of Systems Engineering nowadays there are a lot of methods for modern research the SoS.

Klein and van Vliet analyzed almost 200 studies and provided an overview of the SoS architecture in this systematic review (Klein, 2013). They showed that the known approaches developed solutions for specific SoS problems but did not provide a general perspective suitable for widespread adoption.

The openness of SoS for new operational concepts and disruptive technology make the future – not only far but close even – battlefield more difficult to predict.

To cope deeper with uncertainty in planning the future design of WSoS, the U. S. Department of Defense (DoD) proposed capability-based planning (CBP) (Davis, 2002), which focuses on capacity development rather than direct measure.

There are other approaches to understand all is possible in the whole variety of SoS. A method process for collecting and organizing existing studies in a research field to respond to a series of research questions that is known as Systematic Mapping Studies (SMSs) (Budgen, 2006) was often used. For example, Axelsson in his SMS tried to structure scientific developments in SoS studying nearly 3000 articles dedicated mostly to SoS architecture, modeling and simulation (Axelsson, 2015). Some reviews were dedicated to SoS architecture (Guessi, 2015) or such quality attributes of SoS as security, performance, and interoperability (Bianchi, 2015). Olivero et al. used SMS to capture a broader range of studies and to draw a map of the research area, possibly identifying existing gaps. One of the gaps was closed by exploring the state of the art in security, privacy, and trust in SoS (Olivero, 2023). The classification of SoS according to their purpose using the identified SoS characteristics to identify new research lines was published by Nielsen et al. (Nielsen, 2015).

It is necessary to mention that SoS have a prominent piece of information technology (IT), which is based on a combination of discrete and componentized pieces of software that are loosely coupled and communicated through standard web protocols, cloud computing and infrastructure. The key approach for SoS design here is service computing and software engineering that was originated from service-oriented architecture (Papazoglou et al., 2007).

Because of such widespread SoS, we decided to restrict the number for several classes using the such distinguishing criteria as evolvability of SoS. With this restriction, the materials for our research are military, or weapon, or warfare, or combat SoS depicted in accessed works. The main focus is for U. S. DoD programs—Brigade Combat Team Modernization Program (BCT), Ballistic Missile Defense System (BMDS), Defense Information Systems Agency (DISA), for some simulations SoS and for nascency of SoS in Ukraine as a first results of warfare since 2022.

To characterize the SoS we will propose five classes that can demonstrate how the SoS was transited during its action.

Our methodological framework is an ontology approach with the distinguishing criteria.

Results

I. Abbreviations and definitions

Some definitions and abbreviations are important part of our research so we should begin with explanations.

So, $\tilde{\mathcal{A}}$ is a symbol for SoS that has some architecture (state) combined different $\mathcal{A}_i$ components of SoS (constituent systems and supporting efforts) with certain purpose.

First of all, to differ the kinds of SoS we use the following “units of measure”:

[pcs] = pieces—components of SoS, each of them was created during the separate program;

[SME] = single module for evolvability, it means that each piece of SoS can be upgraded as a separate module and upgrades of some modules in parallel are possible;

[CSs] = constituent systems of a weapon;

[SEs] = supporting efforts for uncountable components (entities, IT);
[ICS] = integrated combat system that consists of CSs that could be modernized.

Some abbreviations are depicted in the article when they are mentioned at first, but common abbreviations (that are linked with SoS in general) are below:

BMS Battle Management System;
C2 Command and Control (so C2BMS means "C2 + BMS", C2SIM means "C2 + SIM", C2S is the C2 System, C2ISR is the C2 Intelligence, Surveillance, Reconnaissance);
CN communication networks;
~IS information system (so CIS is the computer IS, GIS is the geographic IS, etc.);
JIE joint information environment;
RESE rapidly evolving security environment;
SIM training model, or system for simulations.

II. The basic principles and terms

A military SoS is typically a directed SoS, in which the "component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose" (DoD, 2008), therefore SoS is "a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities".

Such SoS can be researched through three domains: physical domain, information domain and cognitive domain (Albert, 2000).

The physical domain includes personnel, equipments, environments, and so on, and is the domain that the strikes are expanded in the circumstances of land, sea, sky and outer space, that is the domain composed of the physical platforms, and the CN linking these physical platforms.

The information domain is the domain that the information exists, in which the information is generated, collected, processed, and shared. The information existed in the information domain perhaps reflects the real things, also maybe not.

The cognitive domain exists in the consciousness of man, in which senses, recognitions, comprehensions, persuasion and worthiness are placed, and is the domain that the decision making must be made through reasoning.

Three features are general for Military SoS, they: (1) are social technical systems, (2) are purposeful systems, and (3) linked together ("cobbled together" from erstwhile previously independent pieces, or designed from scratch with specific properties) (see Table 1).

Table 1. The features of Military SoS with explanations, examples and consequences

Feature of SOS	Explanation	Examples	Consequences
sociotechnical (in physical domain)	possess some observable structure	BMDS, combat entities (HQ, BDE, BN)[1], CN, CIS	the human element provides many of the emergent capabilities and the technical elements augment, facilitate, or otherwise promote these emergent capabilities
purposeful (mission SoS)	all elements have an aim, must derive their activity from their knowledge of the SoS purpose, and their role in achieving it	to win, to intercept BM	SoS are not static structures, but dynamic entities that must drive to a desired end state that emerges from their collected purposeful activity
linked together	there is a defined and purposeful relationship among all elements of SoS	information flow models and IS models (*in information domain*), C2S and decision models (*in cognitive domain*)	it is organized a server-based architecture for SoS that allows each its component to be used (or to be tested) in physical and/or information domain individually without being in touch with all other CSs

Notes: [1]HQ—headquarters, BDE—brigades, BN—battalions.
Source: created by authors.

Military SoS design concept includes key peculiarities. Some of them are below:

- operating in dynamic and interconnected world and in a RESE (a SoS should operate in contexts for which it was not originally intended);
- being an important form in the information-based warfare and having some non-fix architecture (or state) $\tilde{\mathcal{A}}$ allowing to be transited to architecture (or state) $\tilde{\mathcal{B}}$ ($\tilde{\mathcal{C}}$, $\tilde{\mathcal{D}}$, ...);
- corresponding to the concept of evolvability (having an ability of the architecture to support possible future capabilities) to respond quickly to changing warfighter needs (see fig. 1);
- realizing C2 or other warfare principles;
- forming the whole system from interacting components that make possible control by multiple independent operators;
- investigating the best design for SoS that demands powerful IT for simulations and all possible kinds of analysis (course of action (COA) for combat applications, prediction using machine learning and deep learning etc.).

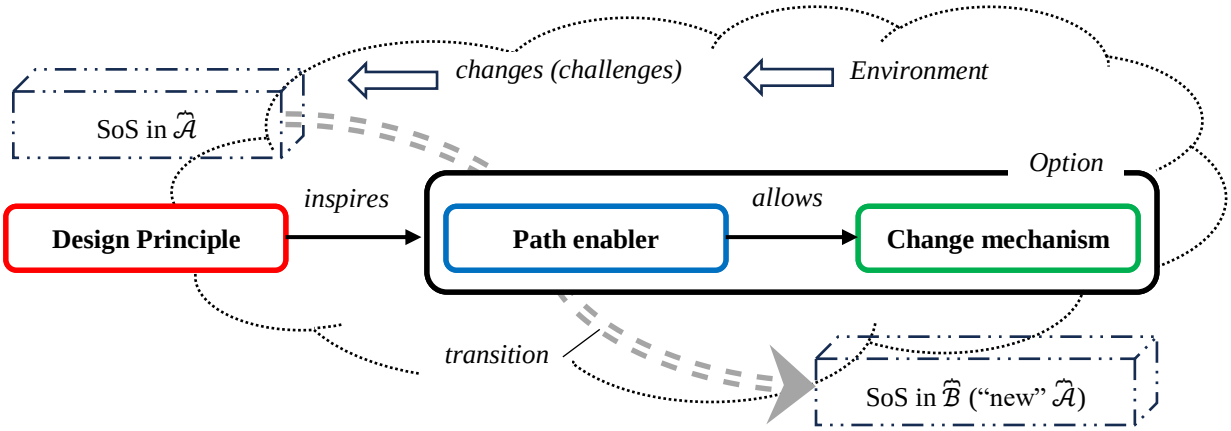


Figure 1. The diagram showing an option of SoS transition from $\tilde{\mathcal{A}}$ to $\tilde{\mathcal{B}}$ for an evolution event, where the design principle is a known term from systems engineering, the path enabler is a physical object, an action or a decision that is a key for executing of the change and the change mechanism is the method through which a SoS goes from $\tilde{\mathcal{A}}$ to $\tilde{\mathcal{B}}$

Source: created by authors from Ricci (2014) with additional elements.

Naturally, new state $\tilde{\mathcal{B}}$ (or $\tilde{\mathcal{C}}$, $\tilde{\mathcal{D}}$, ...) becomes a main state of current SoS "transforming" in $\tilde{\mathcal{A}}$.

III. The depictions of classes for military SoS and how they have transformed

There is a lot number of designed and created SoS. We have analyzed them and decided to represent all of them in five common classes. They are:

- created SoS,
- existed and transited SoS,
- combined SoS,
- evolved SoS,
- attached SoS.

We have collected some examples of SoS and systemized the key features for each of them in the Table 2.

Table 2. The variants of Military SoS with some aspects of its creation or evolution

Country(ies), institution(s)	Title, year, class	Declared target	Change of the current SoS to new architecture
P. R. C., Commanding Communications Academy, Wuhan	SoS combat SIM, 2011 (*created SoS*)	to construct a SoS (as a CN), which suppresses, breaks, destroys or controls enemies SoS	it had been just a system before evolution and became a SoS after upgrading
MNF coalition: U. S. & UK Armies; DARPA; NATO, NCI Agency; Sweden, Saab; France, Thales; Spain, GMV; Denmark, Systematic	C2SIM, 2014 (*created SoS & evolved SoS*)	to perform training, COA analysis, and mission rehearsal, working through their own C2 systems to access the SIM	a basis (a generic, consistent approach to interoperability) is the Battle Management Language; as regular, IT (software for JIE) has next evolution, for example instead of JADOCS is used JTIC2S —Joint Targeting Integrated Command and Coordination Suite
U. S., DoD	BMDS, 2004–2018, as a mission SoS (*existed and transited SoS*)	to enable a robust, layered defense against BM in all phases of flight	in 2008 due to C2BMC the THAAD interceptor battery was added
			sea-based sensors mounted on the ship has spread the possibilities to intercept BM
			land-based sensors on new terrains
U. S., DoD	BCT, 2009, as a platform SoS (*combined SoS*)	to respond quickly to changing warfighter needs in a RESE	by modularizing the structure of the BCT, interdependencies are reduced, and it is simpler to implement an evolution increment
U. S., DoD	DISA IT-SoS, 2014, with ⟨capability⟩ $\tilde{\mathcal{A}} \ni 1{,}5 \cdot 10^3$ [users] (*evolved SoS*)	to provide IT and communication support to all entities	JIE Mobile Solutions, a central information sharing solution, is designed to take the separate networks (was a reason of low efficiency for information sharing) and collect these into a shared architecture (upd. 2016–2020), $\left(\tilde{\mathcal{B}} \to \tilde{\mathcal{A}}\right) \ni 10^5$ [users]
Air Forces of Ukraine; France-UK, MBDA	Su-24M, 2023 (*attached SoS*)	to arm the Su-24M with Storm Shadow / SCALP-EG	Su-24M has become a carrier for SoS missiles that designated to operate in RESE (using C2S, GIS and other IS)

Let's show the structure of known or guessed military SoS and give the ontologies for them.

1. SoS combat SIM was created as a combination of combat entities, CIS, and CN to create the SIM on network-centric architecture (Hua Tian, 2011). For this class of created SoS the ontology is next (with units of measure:

$$\tilde{\mathcal{A}} \ni \overline{\mathcal{A}} \wedge \mathcal{A}_i \text{ [pcs]} \cup \text{[SMEs]}, \tag{1}$$

where $\overline{\mathcal{A}}$ shows that the system wasn't a SoS, so the including $\mathcal{A}_i$ into it made $\tilde{\mathcal{A}}$ as a SoS.

2. C2SIM SoS for MNF is IT to enable an environment where national C2SIM can exchange information freely and each nation's military operations can be represented accurately, each operating their own SIMs (Pullen, 2016). It is also a created SoS (that can be easily evolved SoS by changing the set of components of SoS), so the ontology is as:

$$\tilde{\mathcal{A}} \ni \wedge_{i=1}^{N} \mathcal{A}_i = \tilde{\mathcal{A}} \ni \{\mathcal{A}_1 \wedge \mathcal{A}_2 \wedge \ldots \wedge \mathcal{A}_i \wedge \ldots \wedge \mathcal{A}_N\} \text{ [pcs]} \cup \text{[SMEs]} \cup \text{[SEs]}. \tag{2}$$

C2SIM SoS, that was designed and tested according MSG-085 Standardization for C2-Simulation Interoperation (ended in 2014), was a process of maturing the technical (Technical Readiness Level (TRL)) and operational (Coalition BML) basis for MNF use of standardized C2SIM.

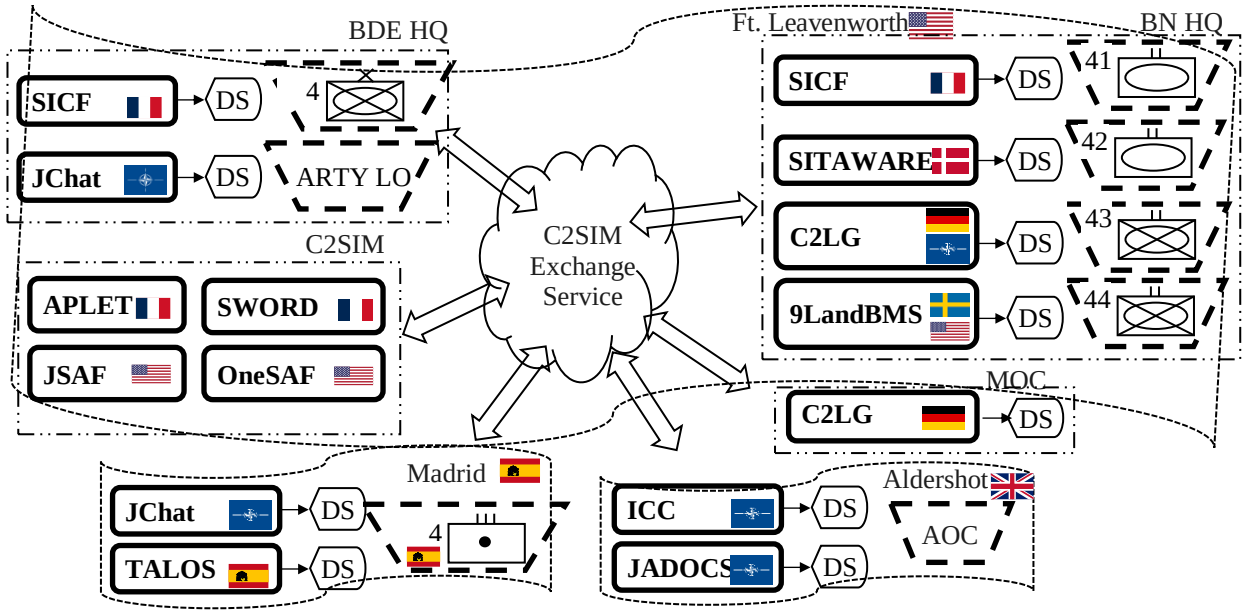


Figure 2. The SoS according to MSG-085

Notes: [1]we use thick lines for separate systems as components of SoS, thin lines for a system with determined process, f.e. to display smth (orders, reports, situation) as DS—display systems; dash for uncertain (in cognitive domain) SoS which unite platform SoS, separate systems, supporting efforts (HQs, units, warfighters), IT etc., where the humans have a key role);
[2]SoS architecture included: a set of BMS (SICF by Thales Communications, SITAWARE by Systematic, C2LG by Fraunhofer Institute for Communication, Information Processing and Ergonomics, 9LandBMS by Saab) and C2S (TALOS by GMV), a set of C2SIM (APLET, OneSAF, SWORD, JSAF), a set of IT (both JChat and ICC from NCI Agency, JADOCS from DARPA, C2SIM Exchange Service), supporting efforts (BDE HQ, BN HQs, Arty LO—artillery liaison officer, AOC—Air Operations Centre)).
Source: updated by authors using Pullen's base scheme (2016).

3. The BMDS SoS architecture included: networked sensors (space-based, ground-based and sea-based radars for target detection and tracking); ground-based and sea-based interceptor missiles for destroying a BM using either direct collision ("hit-to-kill") technology, or an explosive warhead; command, control, battle management, and CN providing the operational commanders with the needed links between the sensors and interceptor missiles (Ricci, 2014).

Architecture $\tilde{\mathcal{A}}$ (in 2004) included five long-range Ground-based Midcourse Defense (GMD) interceptors (at Fort Greely, Alaska), the Aegis SM-3 interceptors for medium-range defense of the terminal segment (near US territory), PAC-3 interceptors for short-range defense.

In Architecture $\tilde{\mathcal{B}}$ (in 2008) there were the inclusion of the Terminal High Altitude Area Defense (THAAD) interceptor battery instead of GMD interceptors to provide the BMDS with additional capability to intercept and destroy BM inside or outside the atmosphere and it was a new change mechanism (the method) through which a SoS went from $\tilde{\mathcal{A}}$ to $\tilde{\mathcal{B}}$. The path enabler for executing the change mechanism was the C2BMC, which provided the communication and data-management backbone for easily integrating THAAD within the current C2 nodes of the SoS.

The ontology is similar to (2), just the "units of measure" due to evolution increment for some pieces of existed SoS are inner.

At first there was a SoS architecture as:

$$\tilde{\mathcal{A}} \ni \bigwedge_{i=1}^{N} \mathcal{A}_i = \tilde{\mathcal{A}} \ni \{\mathcal{A}_1 \wedge \mathcal{A}_2 \wedge \ldots \wedge \mathcal{A}_i \wedge \ldots \wedge \mathcal{A}_N\} \text{ [pcs]}, \quad (4)$$

and an evolution event causes the transiting SoS to its new architecture:

$$\left(\tilde{\mathcal{B}} \to \tilde{\mathcal{A}}\right) \ni \{(\wedge_{i=1}^{N} \mathcal{A}_i \setminus \mathcal{A}_j) \wedge \mathcal{B}_j\} \text{ [pcs]}, \quad (5)$$

where $\mathcal{A}_j \notin \tilde{\mathcal{A}} = (\mathcal{A} \setminus \mathcal{A}_j)$.

Due to evolution event, it is possible to combine two or more existed SoS in a new SoS.

So, in Architecture $\tilde{\mathcal{C}}$ (Phase Adaptive Approach (PAA) initiative, 2009) there were the combination of highly mobile Aegis BMD ships (guided-missile USS Monterey ship equipped with a sophisticated Aegis radar system) in the Mediterranean Sea (since 2011) and a forward-based X-band radar on European land (in Turkey, since 2011).

The ontology looks like:

$$\left(\tilde{\mathcal{B}} \to \tilde{\mathcal{A}}\right) \ni \wedge_{i=1}^{N} \tilde{\mathcal{A}}_i = \left(\tilde{\mathcal{B}} \to \tilde{\mathcal{A}}\right) \ni \left\{\tilde{\mathcal{A}}_1 \wedge \ldots \wedge \tilde{\mathcal{A}}_i \wedge \ldots \wedge \tilde{\mathcal{A}}_N\right\} \text{ [SoS]}. \quad (6)$$

Fig. 3 shows the results of evolution events on SoS transformation (SoS evolution) where according to mentioned approach (see Fig. 1) there are "red" design principles that are well-known in system design that make capable the evolution of any system and there are "blue-and-green" options to realize the capability using a path that ensure an effect or a change.

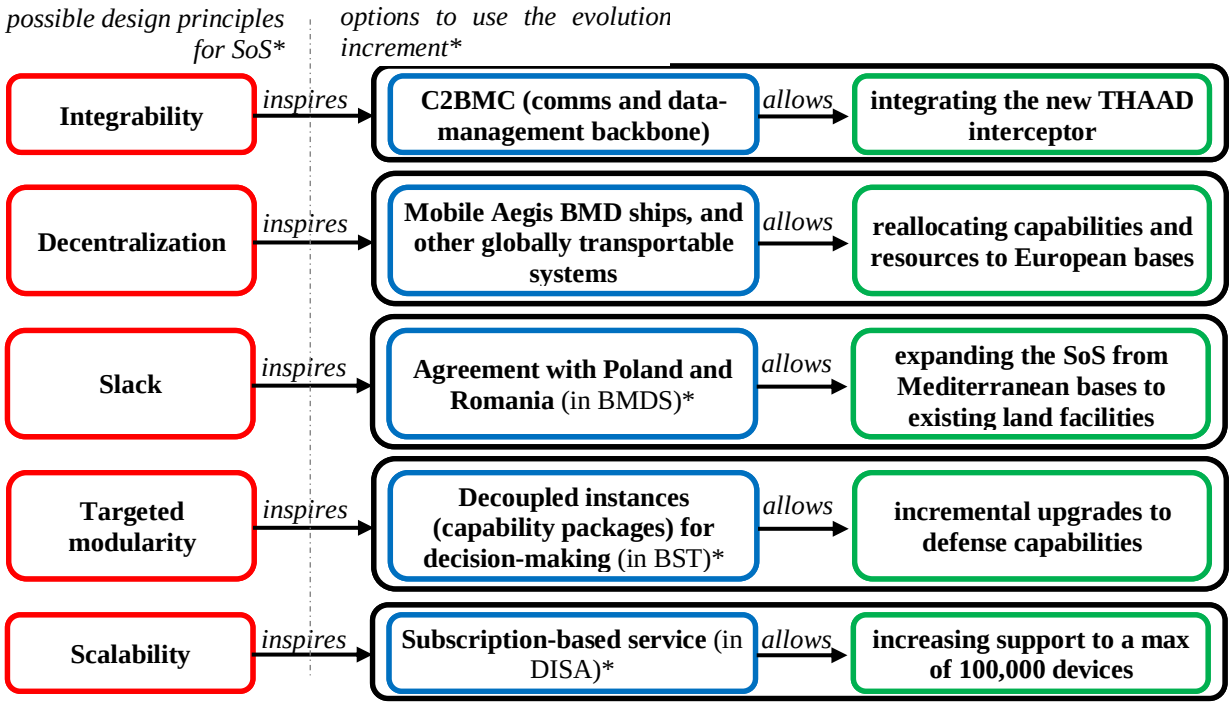


Figure 3. The examples how different SoS are transited to ensure the its evolution
Source: created by combining from using Ricci (2014) by authors, symbol (*) shows added elements.

4. The BCT (Headquarters, 2021) was announced in 2009 to replace the Future Combat System (FCS) program, 2003, which was cancelled due to cost and schedule overruns.

Similar to (4) at first there was a SoS architecture for BST as:

$$\tilde{\mathcal{A}} \ni \{\mathcal{A}_1 \wedge \mathcal{A}_2 \wedge \ldots \wedge \mathcal{A}_i \wedge \ldots \wedge \mathcal{A}_N\} \text{ [SMEs]}. \quad (7)$$

The ontology with some evolution increment (see also Fig. 3) is as:

$$\left(\tilde{\mathcal{B}} \to \tilde{\mathcal{A}}\right) \ni \{(\mathcal{A}_1 \vee \mathcal{B}_1) \wedge (\mathcal{A}_2 \vee \mathcal{B}_2) \wedge \ldots \wedge (\mathcal{A}_i \vee \mathcal{B}_i) \wedge \ldots \wedge (\mathcal{A}_N \vee \mathcal{B}_N)\} \text{ [SMEs]}. \quad (8)$$

5. The DISA IT-SoS architecture (DISA, 2014) includes CN, JIE (including the Mobile Device Management system, the Mobile Application Store, etc. IT software) and users' infrastructures (mobile devices, apps, email and other functions, and wireless networks) for securely operating and rapidly adaptation to changing technology and increasing numbers of users (to allow a diversity of current and future devices to be integrated into the SoS).

To realize the evolution demand (see Table 2) it is necessary to change some specifications in DISA IT-SoS, so the ontology looks like:

$$\mathcal{B}_i\begin{bmatrix} \cdots \\ \vdots \quad \ddots \quad \vdots \\ \cdots \end{bmatrix} = \mathcal{A}_i\begin{bmatrix} \cdots \\ \vdots \quad \ddots \quad \vdots \\ \cdots \end{bmatrix} \times K_i\begin{bmatrix} \cdots \\ \vdots \quad \ddots \quad \vdots \\ \cdots \end{bmatrix} [\text{SME}], \tag{9}$$

where $K_i[\ \ ]$ presents some "coefficients" to improve the SME (updating) according to evolution event (here the operational capability is the improving specification of SoS, see Table 2).

The second stage of the SoS evolution is (8).

6. The attached SoS means that existed integrated combat system of higher level has obtained some changes due to attached SoS that are subordinated to this ICS not becoming a SoS.

The such situations took place in Ukraine since 2022 for Zbroini syly Ukrainy (ZSU).

First of all, we underline three prerequisites for our following statements: (1) key peculiarities of SoS design concept mentioned above are justified for our examples; (2) simple weapons can also emerge through interactive collaboration (Di Pietro, 2021); (3) each AV forms an independent system that can serve a purpose on its own but, when massed together or partnered with pre-existing military formations, AVs form an SoS with the potential for emergent behavior (Klingensmith, 2018).

Using the prerequisites let's show two examples of SoS.

At first, the adaption of SCALP-EG cruise missile to Su-24M bomber of Air Forces of ZSU is an example for an attached SoS. Due to missile's specifications (TERCOM system, GPS and other sensors) it is a component of some Defense SoS. For this case the ontology would be as:

$$\left(\overline{\mathcal{C}} \to \overline{\mathcal{A}}\right) \ni \overline{\mathcal{A}} \wedge \widehat{\overline{\mathcal{B}}}\ [\text{ICS}], \tag{10}$$

where $\overline{\mathcal{A}} \ni \{\mathcal{A}_1 \wedge \mathcal{A}_2 \wedge \ldots \wedge \mathcal{A}_i \wedge \ldots \wedge \mathcal{A}_N\}$ [ICS], although $\widehat{\overline{\mathcal{B}}}$ corresponds (2).

When we also take a look on general features for military (see Table 1) we can notice how combat use of UAV and unmanned surface vehicles (USV) (such as MAGURA V5, Sea Baby) made an effect on warfare. The principles and options for SoS creation in Ukraine is shown below.

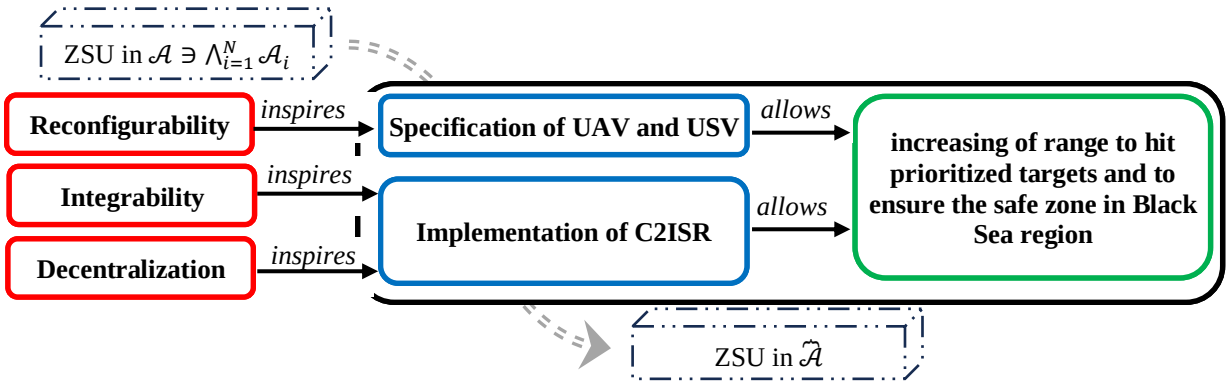


Figure 4. The emergence of SoS in ZSU (since 2022)

Source: created by authors.

For the such SoS in ZSU the ontology is following (including everything for warfare):

$$\left(\mathcal{A} \to \tilde{\mathcal{A}}\right) \ni \overline{\mathcal{A}} \wedge \tilde{\mathcal{A}} \text{ [pcs]} \cup \text{[SMEs]} \cup \text{[SEs]} \cup \text{[ICS]} \cup \text{[CSs]}. \quad (11)$$

To compare the effect is very simply, just should look at two maps—what ceasefire violations took place in Ukrainian east in 2021 (OBSE, 2022) on Fig. 5 and which tendency take place in Russia concerning secure and insecure areas for russian army of occupation (RAO). So, Russian territory that is under the strikes from ZSU in two years after 2022-03-24 (Sarcastosaurus, 2024) is on Fig. 6.

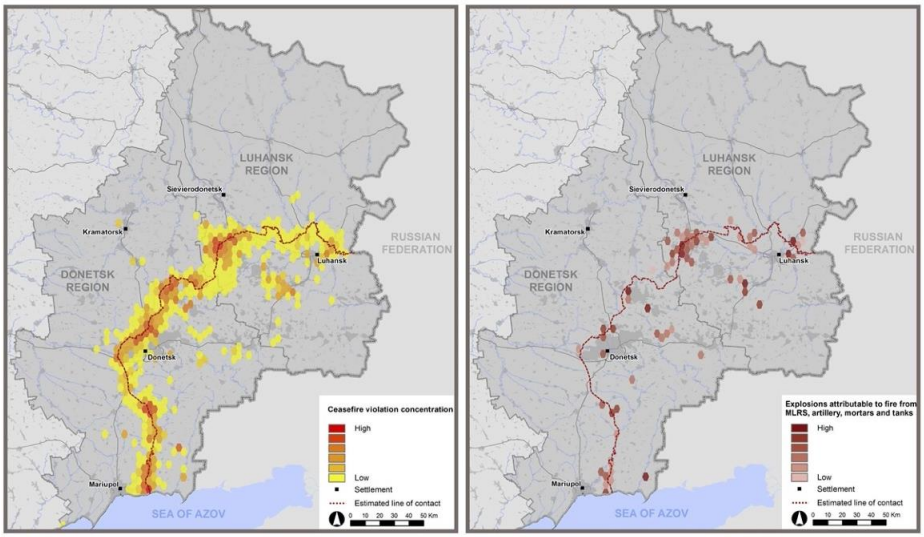


Figure 5. Insecure area on The temporarily occupied territory of Ukraine with ceasefire violations (on the left) and long-range WS use (on the right) during 2021
Source: used only a fragment of the 2021 Trends and observations sheet (OSCE, 2022).

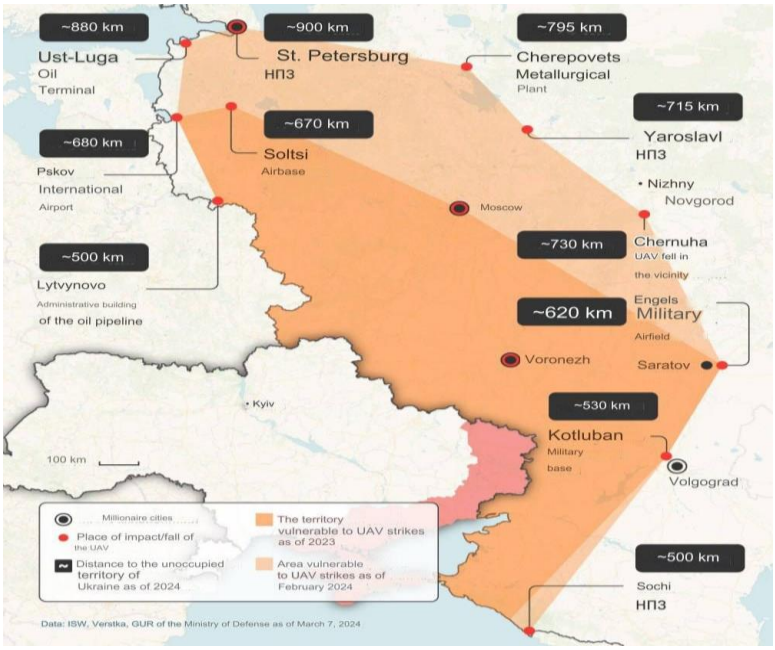


Figure 6. "Cotton belt of Russia"—the territory of Russia vulnerable to ZSU strikes
Source: probably The New Voice of Ukraine, but the map is taken from Sarcastosaurus (2024)

Second example of SoS is potential C2ISR for artillery of Ground forces of ZSU. The modern structure of artillery reconnaissance control point (Tymchuk, 2024) allows the additional processing of signals, information and data using sensors such as radar, UAV cameras, hostile artillery locator, CIS, GIS, machine learning system (MLS) and other pieces (Tymchuk, in press). The structure of C4ISR SoS is shown on Fig. 7, any CIS is an optional piece for SoS if it is possible to solve additional mission in JIE supporting such feature of SoS as purposeful one.

The ontology for such SoS is the same as (2).

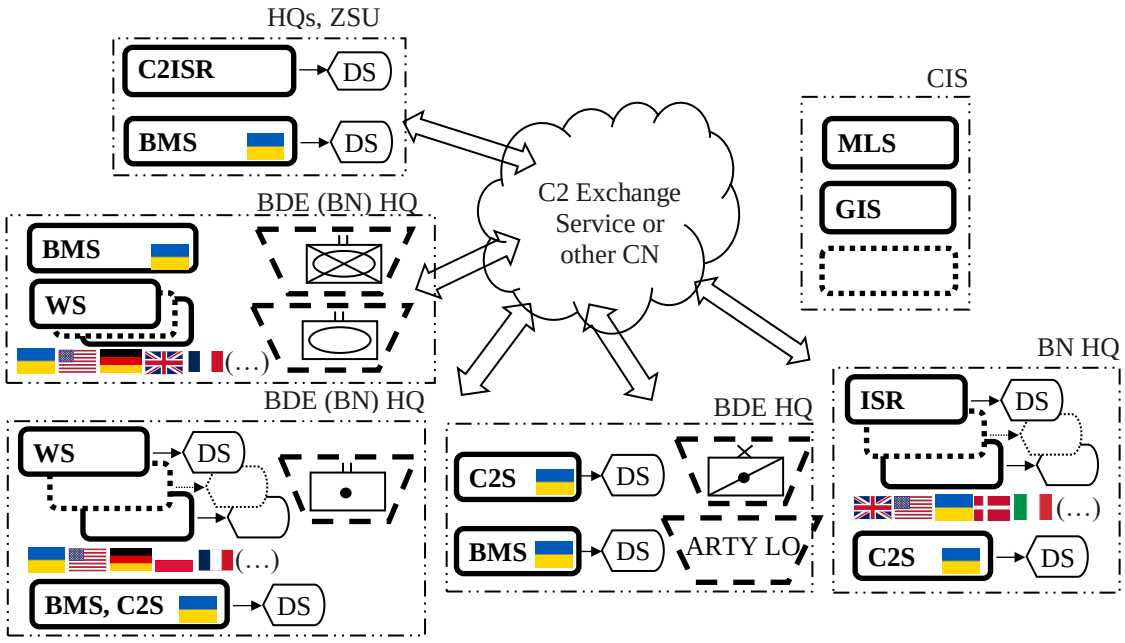


Figure 7. The probable C4ISR SoS in Ground forces of ZSU on the brigade level

Notes: SoS architecture included: BMS ("Delta" is a situational awareness and BMS) and C2S ("Kropyva" by Logika), a set of C2SIM (APLET, OneSAF, SWORD, JSAF), a variety of WS (main battle tanks, AHS Krab with Topaz artillery fire control system, AS-90 with Turret Control Computer, CAESAR with its autonomous systems, etc.), ISR (systems and sensors, f.e. 1L220UK Zoopark-3, AN/TPQ-37, AN/TPQ-37, ARTHUR, HALO, RQ-35 Heidrun, …), supporting efforts (BDE HQ, BN (division) HQs, Arty LO = artillery reconnaissance control point)).

Source: created by authors.

Discussions

The results of systematic review for military, or weapon, or combat, or warfare, or autonomous vehicles SoS allows us to divide them on five classes depending on the evolution stage of SoS – created ones, evolved ones, existed & transited ones, combined ones, and attached ones.

Such classification will be useful for next development planning of the military or weapon SoS when analyzing the key issues demanded for the best action of SoS during warfare, estimating resource allocation and time process for the design, construction and control.

Conclusion

The operation application of the weapon SoS can determine the success of a war. Ukrainian reality of war with a purpose to stop Russian military aggression and occupation have demonstrated the key and turn effects of evaluated weapon and tactics that cause the creation and action the such phenomena as SoS.

The systematic review for the main SoS in military sphere is done. The examples of SoS that are observed in ZSU are added too. It was possible to make due to unique approach of systematization SoS according to such main feature as its evolvability. The ontology for different classes that were

proposed by authors are prepared.

So, the concept of SoS will be useful for Ukrainian militarists and scientists.

A systematic review for engineering methods, processes, and tools that are used in SoS design is an important direction for further research. It is also necessary to describe the relationships of the elements in the SoS to solve the problem of complexity of a weapon or military SoS. Additional direction for further research is ways search for improvement of operational capabilities in created, combined and attached SoS in ZSU.

Recommendations

The construction of the WSoS emphasizes the interconnection and interoperability between weapons, so it's necessary to study the concept of SoS by commanders and military scientists of ZSU.

The initial steps in military SoS design should be mission tasks, capability requirements, weapon effectiveness, and economic benefits.

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