Problems and considerations of sensor C2 in a future operational environment★

PhD Mats Carlerby[a,*]

[a]*The Swedish Defence University, Science of Command and Control and Military Technology Division, Box 278 05, SE-115 93 Stockholm, Sweden*

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ABSTRACT

The development of ballistic missiles, more effective cruise missiles, and increased sensor capabilities imply both new capabilities and challenges in a future operational environment. One effect this has is that the time from detection of a threat, to being able to respond, and to act on it will be significantly reduced. This article illuminates some current and future threats that are emerging and will be part of an increasingly complex battle space. The purpose of the research is to test and evaluate different C2 solutions for future ISR. The benefit of the proposed research is that it can provide design propositions for future ISR systems and its C2 function. In addition, the research may support design and acquisition of future automated systems and AI. Framing a conceivable development of a future battlefield and its character is important to obtain sufficient realism under the conditions that the proposed experimental series is intended to test. For the experimental series, the microworld C3Fire is currently under consideration as a platform for the trials. This, among other things, for its good configuration possibilities and being able to create reliable experimental conditions.

1. Introduction

All nations are affected by what happens geographically, by global trends, events, and relationships. Sweden is no exception where the Swedish Defence after nearly twenty years with expeditionary missions again has turned its attention to the threats in the immediate vicinity of the Baltic Sea area. The political, military and economic competition between the great powers increasingly define their interests as national. This competition is taking place globally, even in Swedens immediate area. In this context, both military resources remain central, as are cyber and information. These latter areas have received much attention within the field of command and control (C2) because of the rapid development of information and communication technology (ICT) and artificial intelligence (AI). More recently, this has also contributed to the development of the concept of multi-domain operations (MDO). Notwithstanding this, an operational environment is envisioned that will become increasingly challenged from potential adversaries across the whole range from small groups of terrorists to hostile states. Aside from this, more and more powerful weapon systems are

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*Corresponding author
mats.carlerby@fhs.se (M. Carlerby)
https://www.fhs.se
ORCID(s): 0000-0002-6930-5596 (M. Carlerby)

being developed that are both smarter and can achieve supersonic speed. One consequence of this is that such weapons systems are becoming increasingly difficult to detect and that the ability to fight them in time are becoming increasingly limited. What the concept of hybrid warfare and MDO really means for future operations is still under debate (e.g., see Atkins, 2018; Wass de Czege, 2020), however following the definition of how hybrid warfare should be understood contributes to create a conceivable development of future operations (Cullen and Reichborn-Kjennerud, 2017; Monaghan, 2019):

> [T]he synchronized use of multiple instruments of power tailored to specific vulnerabilities across the full spectrum of societal functions to achieve synergistic effect.

In turn MDO is intended to wrest the advantage from potential adversaries and restore a credible conventional deterrent and war-fighting capability against peer competitors (Johnson, 2018) and can be characterised as a combination of operations from multiple domains for example by the following attributes:

- An operation in one domain can support operations in another domain.
- It can generate offensive and defensive effects independently in and from different domains.
- It is capable of presenting multiple, simultaneous dilemmas for an adversary.
- It is conducted at a tempo that an adversary cannot match.

Accordingly, both concepts have common characteristics that are about combining resources from different domains to achieve a set of objectives as efficiently and as quickly as possible. Nevertheless, considering an adversary as well as friendly forces, both probably will have means to operate in or from several domains. The instruments used to achieve these objectives can be by targeting one or several societal vulnerabilities as depicted in figure 1.

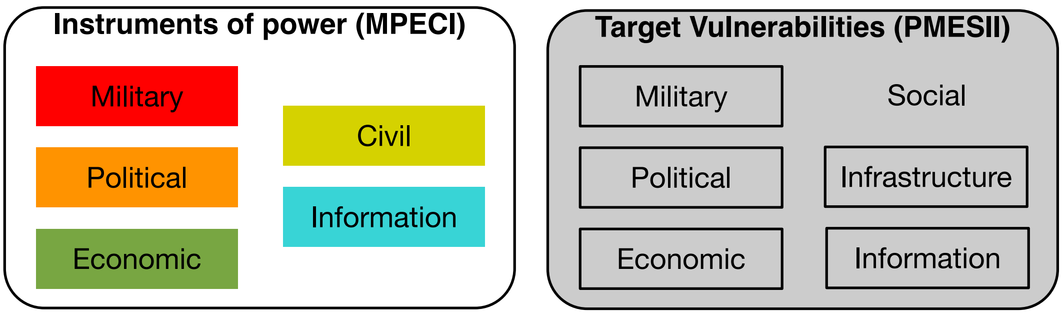

Figure 1: Military, political, economic, civilian and informational (MPECI) instruments of power aimed at the political, military, economic, social, informational and infrastructure (PMESII) vulnerabilities of a target system. *Adapted from* (Monaghan, 2019)

Current and future technology development contributes to change how battles will spread by compressing time conditions while increasing their spatial conditions. This because of missiles with increased range, higher approach speeds, and higher precision as well as cyberspace attacks. A combination of these with unmanned systems results in difficulties for a defender to understand the situation and act at the right time and with the right means (Försvarsmakten, 2018). This article frame the problems of exercising sensor C2 in an upcoming experimental series where the sensor C2 function is supposed to discover, provide support for, and help prioritise which counter weapons should be utilised and when to effectively engage and neutralise different types of fast incoming threats. This whether it is military units, infrastructure, the sensors themselves or other potential important assets aimed for as targets by an adversary. In addition, the proposed experimental series will be developed over time for implementing foreseeable and plausible development within the fields of automation, autonomy, and AI (e.g., see Wade, 2019). By this, we strive to be able to evaluate where and how such technologies can contribute to and give the most benefit in purpose of defence or deterrence.

2. Current and future threats

Except from terrorists and non-state actors, there is currently only one nation that can pose a real threat and have military capability for offensive operations in the Baltic Sea region under the period until 2035 - Russia. After the fall of the Soviet Union, Russia launched an armament programme in 2011. In volume and extent this exceeded previous post-Soviet procurement programmes by far (Malmlöf, 2017). In 2008 and 2014 Russia demonstrated its aggression and willingness to use military force for political purposes against Georgia and Ukraine respectively. This served as wake-up calls for all the smaller countries in Russia's vicinity, including Sweden. In addition, Russia has pursued a type of information warfare, especially against the Baltic states. Furthermore, long-range missiles have become increasingly common in the Swedish vicinity where Russia has deployed the *Iskander* surface-to-surface missile and the *S-400* surface-to-air missile in the Baltic Sea region (Berglund et al., 2017). In addition, in late 2015 Russia demonstrated its capability attacking targets in Syria with sea-launched land-attack cruise missiles (SLCMs) (table 1).

Table 1: SLCM Strikes Conducted by Russia late 2015. *Excerpt adapted from* (Koh, 2016)

Date	Objective	Bellingerents	Launch plattforms	Number of LACMs[1]
October 2015	Strikes against Daesh in Syria	Russia vs. Daesh	1 frigate and 3 corvettes of Russian Navy's Caspian Flotilla	26 *Kalibr-NK* SLCMs
December 2015	Strikes against Daesh in Syria	Russia vs. Daesh	1 conventional submarine of Russian Navys Black Sea Fleet	Unknown number of *Kalibr-PL* SLCMs

It is difficult to say anything about the future, it is, however, possible to analyse trends and make educated assessments how different areas will develop over longer terms (e.g., see Försvarsmakten, 2018; DCDC, 2015; Hull Wiklund et al., 2017; Westerlund and Oxenstierna, 2019). In Westerlund and Oxenstierna (2019) an assessment is made from the Russian armed forces available for military operations in 2019 and in which directions development of future missile threats will point at until 2029. For the scope of this article, only capabilities regarding land operations and long-range missiles will be considered (see

[1] Land attack cruise missile (LACM)

tables in Appendix A and B). From this, it is possible to make some immediate reflections. First, current available LACMs available should be noticed, second the potential increase of such weapons in the timespan of ten years, third other trends for future high-tech missile development until 2035 and beyond.

3. Some future trends

3.1. Weaponization by AI

Although there are considerable ethical dilemmas regarding development and implementation of AI in weapons, the earlier debate wether or not AI should be used for battle seem overplayed (e.g., see Del Monte, 2018; Future of Life Institute, 2015; Tegmark, 2017). Instead, the debate and trend currently is centered around how much independence to give them. Some arguments further driving the development are (Del Monte, 2018):

- Economic: Reducing costs and personnel.
- Operational: Increasing the speed of decision-making, reducing dependence on communications, reducing human errors.
- Security: Replacing or assisting humans in harm's way.
- Humanitarian: Programming killer robots to respect the international humanitarian laws of war better than humans.

Although representatives from armed forces still are arguing for the importance of having a "man in the loop," disregarding how capable an automated or autonomous system can become, the logic leading to autonomous systems seems inescapable (Adams, 2012). In addition, considerable investments are announced from both US, China, and Russia to further exploit and develop weapons with novel AI and autonomic applications. Also, in the European Union steps are currently taken in this direction (Franke, 2019). In addition to weapons development and relevant for this article, Franke (2019) highlights two areas obvious for future development of AI support — C2 and intelligence, surveillance, and reconnaissance (ISR).

3.2. High-tech missile threats

Another general trend is that the development of high-tech long-range weapon systems will continue at an unchanged pace. In addition, they seem to be increasingly cheaper to manufacture. Accordingly, cruise missiles, which used to be the trademark of a superpower, are about to become available to many countries or even non-state actors and, as mentioned above, maybe also to terrorist groups (Wade, 2019; Hull Wiklund et al., 2017).

Supersonic missiles that exceed speeds of over Mach 2.5 (3000 km/h) are becoming more frequent and currently put in operational use. However, new and hypersonic weapons that exceed speeds Mach 5 and above are under development. One example of this is the Russian-Indian *BraMos II* that is being designed to reach > Mach 6. Thus, a plausible assumption is that material and other technology will be developed in near time for implementation in other weapon systems like LACMs to achieve supersonic speed that reaches Mach 5 and above (Durak, 2015; Jing et al., 2019). Further enabling such weapon systems by support of improved AI and automation, capabilities of changing the flight route in supersonic speed, and if needed autonomously change the choice of target, will definitely contribute to major challenges for future missile defences.

3.3. Means for defence and deterrence

A current trend is to engage Western countries in cooperating among networking sensors, C2 functions, weapon platforms, weapons, etc., that are aimed for quickly establish situational awareness when carrying out a mission. Under such operations the purpose is to, in real-time, provide coordinated counter measures against incoming threats (Hull Wiklund et al., 2017). In (Atkins, 2018), it is argued that response to the emerging and increasingly complex battle space defy current approaches and anti-access/area-denial (A2/AD). An answer to this is the current development of the MDO concept. Similar insights presented in MDO have also been made in other countries, which have resulted that corresponding concepts are initiated for development.

Accordingly, there is a trend in providing means for response in an emerging and increasingly complex battle space that is characterized by complex problems that defy current approaches and anti-access/area-denial (A2/AD). To gain superiority and prevail success in this context, it can be achieved by combining resources from different domains at the right time and place (Atkins, 2018). This leads to more combinations of opportunities and risks to identify and consider. Accordingly, new requirements arise for ISR systems viewed as wholes, but also their C2 function viewed as a system in its own right. In line with the reasoning above it is possible to derive both several assumptions and questions how to provide suitable C2 solutions for future ISR. It seems clear that C2 for ISR will face some general problems, especially when active sensors are in operation. Active sensors generally have capability to detect targets at long distances with high resolution. However, it is also possible for an opponent to detect active sensors and take countermeasures, for example try to target the sensors themselves. An alternative is to utilise passive sensors that are difficult or even possible to detect at all. Accordingly, the need for protection is not as demanding and the sensor type can be used more continuously. However, although modern passive sensors have a long reach, they do not have the same performance or provide the same resolution as active sensors on lengthy distances. As pointed out above, high-tech long-range weapon systems tend to be cheaper to procure. The same trend does not hold for sensor and defence systems. Instead new air and missile defense systems against super and hypersonic missiles are beyond the financial capabilities of many states (Durak, 2015). This unbalance in costs implies that defence systems will probably be few and exclusive assets that also have to be protected for meeting demands of endurance. Consequently, to avoid the risk of being eliminated in the complex environment depicted above, with ever shorter time to deal with an opponent's attack, planning, implementation, and follow-up for the ISR system's C2 function will be both more difficult and important than before. This leads to the purpose of this paper, to present a proposal for an experimental series to test and evaluate different C2 solutions for future ISR.

4. A proposal for an experimental series

The experimental series proposed here is the first step of investigating C2 of the ISR system where the C2 function has to handle emerging problems in a future battle space. Under the experimental conditions, delimitations will be made only to consider attacks from ballistic and cruise missiles with super or hypersonic capability. Examples of problems that the ISR C2 function should be able to encounter under such experimental conditions can be:

- To place sensors for optimal coverage to discover threats from several directions, which also might appear simultaneous.
- Consider which sensors should be used and when to prevent an attacker from detecting them and thus prioritise them as targets.
- To coordinate use of different type of sensors, e.g., active or passive sensors, for continuous surveillance.
- To prioritise which threats that are most immediate to communicate to defence assets for counter attack.

This first experiment will form the basis for further studies where following steps aim for investigating whether placement of AI, automated and/or autonomous sensors have any bearing on C2 performance. The participants, formed as teams, will not have any technical support such as decision support, automatic alarms, autonomous units, etc., but try to solve a given task by coordinating different resources by communication. However, to be able to cooperate the participants will have access to a representation of a current situation that can be used for taking countermeasures against a threat. The degree of complexity that the participants will have to deal with is a matter of its own. Given the results reported in (Persson and Rigas, 2014), it is important that the degree of complexity does not fall to a level that the participants experience their task as trivial. Nor must the degree of complexity reach such a high level that it is not possible to conduct effective C2.

4.1. Design

The first experiment is intended to be carried out as a mixed (split-plot) design with repeated measures [number of controlled units] and [speed of threat] within groups and the independent variable C2 architecture [local or central C2] between groups. Threats are of two types. First, "direct threats" which are attacks against own defending assets (sensors and air defence). Second, "indirect threats," which are attacks against infrastructure or other assets that are of societal value. Performance will be measured by how many assets that are remaining after each scenario. The independent variable C2 architecture between groups implies that each group will stay under the same C2 architecture for all trials. The choice of using C2 architecture as independent variable for this experiment is multifaceted. An example of this are the two philosophies regarding both C2 and communication in the future battle space. One philosophy emphasizes that all units should be interconnected in a network. In this way, a common and comprehensive understanding of the situation can be obtained. As sensor data from all domains are compiled centrally, incoming threats can be detected and attacked with limited assets by being prioritised. Another philosophy is that one of the earliest objectives an opponent will target is precisely the communication and sensor network. Thus, the situational understanding obtained locally is with this philosophy considered to be better and faster than that compiled centrally. However, problems can arise with this latter philosophy when prioritising which targets to attack first.

4.2. Materials

For the experiment, the microworld C3Fire currently is considered. C3Fire general characteristics often apply to the type of problems that military commanders have to face, including situations that require collaboration and coordination to solve a task (see, Granlund, 2020). In addition, C3Fire has great configuration capabilities. This contributes to the possibilities of trying different organisational forms, communication possibilities with delays and layers, sensor ranges and their characteristics, different types of threats, etc. Thus, C3Fire can contribute to reach sufficient reliability for the proposed experimental series.

4.3. Benefits of the research

The benefits of conducting the proposed research is that it can answer questions about the design of future ISR systems and its C2 function. These questions include how communication paths can be abridged between sensor and defence systems without sacrificing situation understanding, responsibility, security, and endurance. Other questions are about answering where sensor data should be processed to respond in time to threats that arise. This can provide answers to where fire permits should be placed depending on different situations. In addition, such answers can help to develop guidelines for effective communication, coordination and collaboration between different stakeholders. The proposed research also have potential to support design and acquisition of future automated systems and AI. This since such systems can play a central role for sensor data analysis and target prioritising if available assets for defence are limited.

5. Discussion

From the results of this first experiment, a basic performance level is obtained where only people are part of the C2 process. This initial performance level can be used as benchmark for evaluating other experimental conditions where different technical capabilities are added to support C2 for future ISR. Accordingly, experimental conditions can be developed where technical capabilities are added step by step. For example, conditions with higher or lower degree of automation of different sensors or defence systems or conditions with autonomous units that decide for themselves when to be active, passive, or act upon a situation. AI that reflects future C2 capabilities is also planned to be included as a condition. Currently The Wizard of Oz method is being considered for use since it is considered as a powerful way to prototype technologies yet not available or underdeveloped (e.g., see Benyon, 2019, pp. 201). There are benefits of conducting this research; for example, to create foundations to decide upon how to design C2 capabilities that ensure an effective and timely response from discovery of a threat to implement countermeasures. Other advantages are that questions about where it may be most appropriate to implement automated C2 and AI support can be answered. Concerns with the arrangement of the experimental series may arise since many participants may be needed to achieve statistically acceptable results.Thus, it can be necessary to find other applicable solutions without risking that the results are affected in a negative manner.

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Note: The tables in appendix A and Appendix B are adapted from Westerlund and Oxenstierna (2019)

A. Systems with stand-off strike capacity against land targets 2019

Platform	Missile	A	B	C	D	E	F	Authors' assumptions
Land-based Kalibr	9M729 Kalibr (SSC-8 Stone)	1 650	16	16	8	3	Bn	3 SSM Bn rearmed from Iskander to land- based Kalibr - one each in 112. (Shuya), 12. (Mozdok), 119. (Kamyshlov) SSM Bde; 4 TEL/Bn, 2+2 LACM/TEL, NW assignment 8/Bn in line with assumption for Iskander
Tu-160 (Blackjack)	Kh-55/101/102 (AS-15 Kent)	3 000	12	3	3	11	a/c	25% of a/c available for non-strategic missions (factored into assumed number of missiles); 1 NW/ALCM
Tu-95 (Bear)	Kh-55/101/102 (AS-15 Kent)	3 000	8	2	2	30	a/c	25% of a/c available for non-strategic missions (factored into assumed number of missiles); 1 NW/ALCM
Tu-22M3 (Backfire)	Kh-22 (AS-4 Kitchen)	600	3	1.5	1.5	30	a/c	50% of a/c available for land targets (factored into assumed number of missiles), 1 NW/ALCM (Sutyagin 2012 assumes 34 NW/Regt)
VICTOR III	S-10 Granat (SS-N-21 Sampson) 3M14K Kalibr (SS-N-30A)	3 000 1 650	16	4	4	1	SSGN	1 out of 4 tubes with LACM, 4 LACM/tube, 1 NW/LACM
SIERRA II	S-10 Granat (SS-N-21 Sampson) 3M14K Kalibr (SS-N-30A)	3 000 1 650	24	8	8	2	SSGN	2 out of 6 tubes with LACM, 4 LACM/ tube, 1 NW/LACM
AKULA	S-10 Granat (SS-N-21 Sampson) 3M14K Kalibr (SS-N-30A)	3 000 1 650	16	8	8	2	SSGN	2 out of 4 tubes with LACM, 4 LACM/tube, 1 NW/LACM
SEVERODVINSK	3M14K Kalibr (SS-N-30A)	1 650	40	20	20	1	SSGN	4 out of 8 missile silos assigned LACM, 5 LACM/silo, 1 NW/LACM (Sutyagin 2016 assumes 16 NW for LACM/SSGN)
KILO	3M14K Kalibr (SS-N-30A)	1 650	4	4	4	5	SSG	4 out of 4 missile silos assigned LACM, 1 LACM/silo, 1 NW/LACM
GORSHKOV	3M14K Kalibr (SS-N-30A)	1 650	16	8	8	1	FFG	8 out of 16 missile silos assigned LACM, 1 LACM/silo, 1 NW/LACM in line with similar vessels (Sutyagin 2016 assumes no NW for LACM)
GRIGOROVICH	3M14K Kalibr (SS-N-30A)	1 650	8	4	4	3	FFG	4 out of 8 missile silos assigned LACM, 1 LACM/silo, NW assignment in line with Admiral Gorshkov

Platform	Missile	A	B	C	D	E	F	Authors' assumptions
GEPARD	3M14K Kalibr (SS-N-30A)	1 650	8	8	8	1	FFG	1 of 2 FFG with LACM, 8 out of 8 missile silos assigned LACM, 1 LACM/silo, 1 NW/LACM in line with similar vessels (Sutyagin 2016 assumes 8 - 12 NW for LACM)
GRAD SVIIAZHSK	3M14K Kalibr (SS-N-30A)	1 650	8	8	8	7	CRG	2 in Baltic Fleet, 2 in Black Sea Fleet, and 3 in Caspian Flotilla; 8 out of 8 missile silos assigned LACM, 1 LACM/silo, 1 NW/LACM in line with similar vessels (Sutyagin 2016 assumes 8 - 12 NW for LACM)
URAGAN	3M14K Kalibr (SS-N-30A)	1 650	8	8	8	2	CRG	2 in Baltic Fleet; 8 out of 8 missile silos assigned LACM, 1 LACM/silo,1 NW/LACM in line with assumptions for Buyan-M
Iskander system	9K720 Iskander-M (SS-26 Stone)	500	16	16	8	33	Bn	12 Bde less 3 Bn rearmed with land- based Kalibr; 4 TEL/Bn, 2+2 SSM/TEL, NW assignment 8/Bn (Sutyagin 2016 assumes 8 - 12 NW/Bn)

Notes: Column A – operational range (km); B – maximum number of missiles per platform entity; C – assumed number of missiles per platform entity; D – NW assignment per platform entity; E – available number of platform entities; F – platform entity. a/c – aircraft; ALCM – air-launched cruise missile; Bde – brigade; Bn – battalion; CRG – guided-missile corvette; FFG – guided- missile frigate; LACM – land-attack cruise missile; NW – nuclear warhead; Regt – regiment; SSG – guided-missile submarine; SSGN – guided-missile submarine, nuclear propulsion; TEL – transporter-erector-launcher.

B. Systems with stand-off strike capacity against land targets 2029

Stand-off missiles against land targets						
		Available 2019		Factor change	Available 2029	
Platform	Equipment category	Platforms	Missiles	1.88 - 2.48	Platforms	Missiles
Tu-160 (Blackjack)[a]	Strategic bombers	30	60	1.98	59.4	119
Tu-22M3 (Backfire)[a]	Nuclear-powered submarines (SSN/SSGN)	1	4	2.10	2.1	8
645 Kondor (Sierra II)[b]	Nuclear-powered submarines (SSN/SSGN)	2	16	2.10	4.2	34
671 Shchuka-B (Akula)	Nuclear-powered submarines (SSN/SSGN)	2	16	2.10	4.2	34
885 Yasen	Nuclear-powered submarines (SSN/SSGN)	1	20	2.10	2.1	42
636.3 Varshavyanka (Kilo improved)	Diesel-electric submarines	5	20	2.11	10.55	42
Admiral Gorshkov	Frigates	1	8	1.56	1.56	12
Admiral Grigorovich	Frigates	3	12	1.56	4.68	19
Gepardh	Frigates	1	8	1.56	1.56	12
Buyan-M	Corvettes	7	56	1.73	12.11	97
Karakurt	Corvettes	2	16	1.73	3.46	28
Iskander system (Bns)	Ground missile systems	33	528	1.91 - 2.82	63.03 - 93.06	1 008 - 1489
Land-based Kalibr (Bns)	Ground missile systems	3	48	1.91 - 2.82	5.73 - 8.46	92 - 135
	Grand total:		890			2 566 - 3 294

Notes: Bns – battalions; a) 50% of Tu-22M3 available for sea targets, and 50% for land targets (factored into assumed number of missiles); b) 25% of strategic bombers available for non-strategic missions (factored into assumed number of missiles.