Topic 4: Cognitive and Socio-technical Challenges

C2 of joint autonomous intelligent units – a research project

Björn J E Johansson, PhD[1] (corresponding author)

Kristofer Bengtsson[1]

Per-Anders Oskarsson[1]

Peter Svenmarck, PhD[1]

Rogier Woltjer, PhD[2]

[1]Swedish Defence Research Agency, Department of C4ISR, Linköping, Sweden

[2]Swedish Defence Research Agency, Department of Defence and Security, Systems and Technology

1. Abstract

This paper describes a recently started research project at the Swedish Defence Research Agency called "C2 of joint autonomous intelligent units", which will run between 2018 and 2020. The project aims to investigate how the introduction of autonomous intelligent units, with the capability to interact with other autonomous intelligent units as well as humans, will affect C2 and supporting systems. Relevant aspects that will be included in the project are human decision makers, technology, and organisational aspects. The paper includes a general description of the problem domain, international collaborations, and the way ahead.

Keywords: Command and Control, Intelligent Autonomous Units, Joint systems, Human-Autonomy Teaming

2. Introduction

C2 of autonomous units is a topic that has received significant attention during the last years. As pointed out in the UK Joint Concept Note 1/18 (DCDC, 2018), it is not a question of if, but when autonomous units[1] will enter military organisations and the battlefield. However, most studies have mainly considered aspects of human-autonomy teaming or specific aspects of interaction and/or interface design for autonomous units (Barnes, Jentsch, Chen, Haas, & Cosenzo, 2008). Some notable exceptions can be found in the presentations at ICCRTS last year, such as Alexander Kott's (2017) presentation on AI, robotics, and cyber and their possible impact on C2. Likewise, Galdorisi, Jones, Pastore, and Volner (2017) discussed C2 of unmanned vehicles, and Hieb, Peterson, Kelly, Riecken, and Vassillou (2017) discussed trust issues in hybrid human/robotic forces. While many studies focus mainly on the development of technical aspects of autonomy, few studies address the issues that potentially will arise concerning C2 once these capabilities have been developed. Meanwhile, autonomy, in different forms, will most likely be introduced in all branches and fundamentally change the way we view what a military unit is, and what capabilities it has. The impact of autonomous capabilities becomes evident if we consider the fact that different autonomous units may become able to interact with each other, and possibly even "command" each other in the future battle space. This

[1] The JCN 1/18 uses the term RAS (Remote and Automated Systems).

has led to the initiation of a research and development (R&D) project called "Command and Control of Joint Systems of Autonomous Intelligent Units"[2] at the Swedish Defence Research Agency, which will run between 2018 and 2020. The project aims to investigate how the introduction of autonomous intelligent units with the capability to interact with other autonomous intelligent units, as well as humans, will affect C2 and supporting systems (C4ISR). How "Autonomous Intelligent Units" is defined will be explained below.

The project was preceded by the pilot study "Command and control of systems of systems with autonomous capabilities" (Woltjer, Bergfeldt, Svenmarck, Nilsson, & Johansson, 2017), which identified predictable needs for future research studies within the area. The project conducted a number of explorative interviews with officers from the Swedish Armed Forces and presented a wide range of challenges associated with autonomous capabilities, such as navigation, guidance and processing of sensor data, self-protection, military effects, communications, and automation of military effects. From a C2 point of view, automation of lethal military effects was seen as the most problematic issue. Further, the increasing degree of complexity associated with the introduction of competent autonomous functions was also predicted to challenge C2 further. The degree of complexity is due to different characteristics of autonomous functions compared to human agents and additional interdependencies in cooperative engagements with human agents. Importantly, the findings were that the allocation of functions, capabilities, and decision rights in autonomous units must be flexible in order to support C2 of dynamic and uncertain situations (Woltjer et al., 2017).

3. Autonomous systems

As pointed out by several authors, the term "autonomy" is often used in a misleading and anthropomorphic sense (Bradshaw, Hoffman, Johnson, & Woods, 2013; Stensson & Jansson, 2014). The usage of the term is problematic in the sense that the actual meaning of "autonomous" is self-governing, and the types of systems that we today label as autonomous are not self-governing in the true sense of the word. Rather, they are highly automated and could be labelled as possessing "semi-autonomous" capabilities under specific circumstances and conditions. A more nuanced interpretation and usage of the term autonomous system is that it has certain capabilities to present goal-directed behaviour and adapt to changing circumstances. Such an interpretation suggest that autonomous systems mostly demand some degree of human monitoring or intervention, rendering them closer to "semi-autonomous". However, it is reasonable to assume that the usage of this type of autonomous systems in warfare will increase rapidly over the next 10-20 years, and that the technical development and maturity of such systems will be swift, which thus most likely will entail a move towards autonomy in its true sense (DCDC, 2018).

4. Autonomous Intelligent Units

"Intelligence" is usually described as the ability to reason, analyse, learn and understand, or to deal with new or demanding situations, which takes things a step beyond than what usually is described as autonomous, as autonomous do not necessarily comprise learning or understanding[3]. The term "Autonomous Intelligent Units" (AIU) has therefore been adopted by the "Command and Control of Joint Systems of Autonomous Intelligent Units" project in an effort to illustrate that the project considers artificial agents with capabilities beyond what we today consider "autonomous". AIUs thus possess the following three characteristics, which will be discussed below:

---

[2] Ledning av Sammansatta System av Intelligenta Enheter, LASSIE.

[3] The question whether an artificial system ever will "understand" something is heavily debated in the discussion about "strong" vs "weak" artificial intelligence, see for example Searle (1980) or Dennett (2017).

They are intelligent and does not need human control

They solve problems, understand, obey orders, and learn.

They communicate and coordinate, both with each other and with human agents.

4.1 Intelligent and does not need a lead

The AIUs are to be considered as effective assets in a joint human/AIU team. As the units are considered to be intelligent and can act independently, without continuous management actions by human operators, but still take actions that harmonise with the plan in general and strive towards common goals, they have the potential to contribute to overall team efficacy (Bengtsson & Woltjer, 2017). However, the use of such units might cause a challenge with regard to the established military theory and practice linked to command and control and general operational management in a military setting (Lamballis Tessensohn, Vecht, & Eikelboom, 2018). Not actually controlling the AIUs, as they are sufficiently intelligent to act on their own in accordance with given orders and tasks, emphasises the need for trust (Hancock et al., 2011) and also the need for mutual understanding (Klein, Woods, Bradshaw, Hoffman, & Feltovich, 2004) in order to achieve this potential elevation of team and operational efficacy (Hieb et al., 2017). Also, the fact that different AUIs may interact with each other as joint systems further challenge our understanding of C2, on a conceptual level as well as from a practical point of view.

4.2 Solve problems, understand, obey orders, and learn

As there is a built in intelligence in the units, hence the name AIU, they can actively solve problems, understand and obey orders, and learn from both own experience (Ayodele, 2010; Argall, Chernova, Veloso, & Browning, 2009) and the experience of other AUIs. Such capabilities will be essential on the future battlefield with its vast amount of data where the ability to aggregate, interpret, and act upon these amounts of data in the fastest possible manner will be crucial for operational success. However, the only way to properly use the problem solving abilities provided by the intelligent units is by allowing them to act as real members of the military organisation in a way that does not demand constant supervision. To enable this kind of trust from human commanders and soldiers is of the essence, but also one of the main problems and hindrances, as can be seen in literature on research approaches with the stated objective to actually help create these joint action teams of humans and AIUs (Klein et al., 2004).

4.3 Communicate and Coordinate

Communication and coordination of AIUs are primarily done between themselves in their own groups but also between the assets and their human co-workers. Communication between humans and AIUs is one of the more pressing matters when it comes to the effective use of and collaboration with AIUs (Klein et al., 2004; Parasuraman, Barnes, Cosenzo, & Mulgund, 2007; de Visser & Parasuraman, 2011). The building of human trust in the AIUs and their capabilities is therefore, once again, essential for effective teaming endeavour. As a part of this, the mutual understanding and abilities from both sides, human as well as the AIUs, to properly interact with one another will help in establishing and developing trust (Klein et al., 2004).

5. Autonomy and C2

Assuming that it is possible to create AIUs that are widely trusted by operators, several questions still remain that concern the role of AUIs in military organisations and their possible impact on C2 and C2 support systems. Currently, C2 processes and systems, as well as the professionals working in the system, the officers, are all attuned to direct and control forces mainly composed of humans rather

than AIUs. The role of the future commander, given that it is a human being, is likely to change when various forms of AIUs and artificial intelligence is introduced widely. Figure 1 illustrates a situation where fighting units are largely made up by AIUs. Airborne as well as ground-based AIUs collect sensor information which can be accessed by any node in the network. Communication is also largely managed by AIUs. Several platforms have the capability to create kinetic effects, and the choice of effectors can be negotiated within fractions of a second by the AIUs, depending on a multitude of factors such as type of target, available means for engaging it, and ammunition status of the involved AIUs. Potentially, the entire sensor-to-shooter chain could be fully autonomous. The role of the human component in the system may thus very well be reduced to a garbage can for accountability.

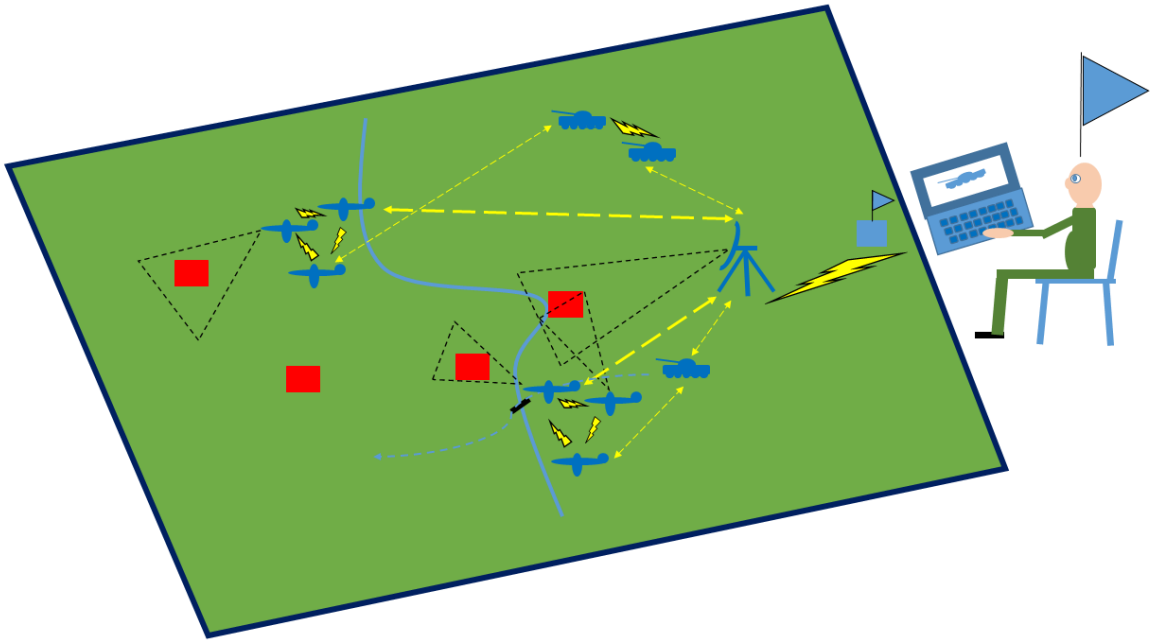

Figure 1. Potential C2 situation using AIUs in combat.

Another possibility is to carefully set the degree of automation for each decision-point of significance, such as sensor usage or fire orders to assure human control of critical processes. Such an approach will, however, leave the humans in charge of critical decisions that the AIUs cannot or are not trusted to manage, something that may not be desirable, both since it will be cognitively challenging and because it will probably slow down the pace of fighting significantly compared to a fully automated system. A middle way may be to use the approach of "adaptable" systems, where the humans in the system can alter the degree of automation as the situation unfolds (Hancock et al., 2011). Yet another approach is suggested in co-active design of automation that focus on effective and reliable joint performance from teamwork between humans and automation (Johnson et al., 2014). Since humans and automation have both overlapping and complementary capabilities it is important to support mutual interdependencies by appropriate interfaces for observability, predictability, and directability (OPD) of other agents. Observability assures that the interface provides adequate information about an AIUs status and knowledge about the task or environment. Predictability assures reasonable estimates of other agents' behaviour when considering own actions. Directability assures the ability to direct other agents. Coactive design derives the OPD requirements by considering potential alternatives for teamwork where sometimes neither AIU nor human may be fully able or reliable to perform tasks on their own. However, by identifying interdependencies between AIUs and OPD requirements for combining their capabilities, joint performance may still be sufficient. Coactive design

provides flexibility by supporting many ways of performing tasks and provides resilience by utilising human judgement when the automation is brittle.

Consequently, some approaches to the design of human-automation teaming do exist, which is promising given the expected increase in utilization of autonomous capabilities. However, few or no, approaches have been found that investigate the impact of introducing AIUs on a large scale in military organisations, particularly from the socio-technical perspective of C2. The research project "Command and Control of Joint Systems of Autonomous Intelligent Units" will undertake such studies by investigating the research questions outlined in the following section.

6. Research Questions

The "Command and Control of Joint Systems of Autonomous Intelligent Units" project will investigate the following research questions:

1. Which abilities might autonomous systems contribute with, in the perspective of 2030-2035, and what consequences can be foreseen with regard to military C2 systems?
2. How should the C2 system (doctrine, organisation, training, materiel, leadership and education, personnel, and facilities) be designed and developed in order to enable autonomous systems to enhance the capabilities of military units?
3. What degree of flexibility is required within C2 systems and autonomous capabilities to enable these to function in different situations and settings?
4. How should the complexity that follows with the introduction of autonomous capabilities be handled?

Research question 1 will be based on technological forecasts, interviews, workshops, and the already performed study "Command and control of systems of systems with autonomous capabilities" by Woltjer et al. (2017), mentioned above. Research question 2 will be addressed by experimental studies sand demonstration-based workshops. Research question 3 will be investigated in collaboration with the NATO STO SAS-143 research task group (see below). Research question number 4 will be approached by studying aspects of human-automation interaction in experimental settings, but also by reviewing existing literature and following international research efforts within the field.

7. Interactions with international research partners

Partnering with other research efforts is considered as crucial for the "Command and Control of Joint Systems of Autonomous Intelligent Units" project, especially as the project concerns a novel field of research. Consequently, the project carefully coordinates all activities with national research efforts in Sweden, as well as international partners. Currently, the project is involved in the NATO STO research task group SAS-143 "Agile Multi-Domain C2 of Socio-Technical Enterprises in Hybrid Operations", the NATO STO HFM ET 178 "Meaningful Human Control Over AI-Based Systems", and the MCDC "Information Age C2" workgroup. These efforts provide insights into international initiatives concerning automation and C2, human-automation interaction, and future C2 concepts involving C2 of autonomous units. This cooperation also provides a network of partners, which can enable joint experimentation and participation in various demonstrations and exercises, as well as the possibility to invite internationally recognised experts to participate in, or observe, studies conducted by the project.

8. Conclusions and the way ahead

Automation and autonomous units have received a lot of attention both in the civilian and military fields recently. As described above, a large body of research on automation and autonomous units, such as robots, already exist. However, focus is largely on technology as such, or on aspects of

operator-systems interaction, rather than the issues related to C2 and the usage of autonomous intelligent units considered from a socio-technical standpoint. Introducing AIUs in large socio-technical systems pose a number of unique challenges, such as how C2 should be organised in terms of allocation of decision rights between humans and AIUs, how staff functions should be designed to support effective utilization of AIUs, and how supporting C2 systems should be designed and implemented to allow for a sufficient degree of flexibility to preserve, or even develop C2 agility. The "Command and Control of Joint Systems of Autonomous Intelligent Units" project will begin investigating such aspects according to the research questions presented above.

The Swedish Defence Research Agency has recently set up a flexible C2 research lab that will allow for studies of different aspects of C2 and decision-making. This lab will most likely be a vital part of the infrastructure for the coming studies within the "Command and Control of Joint Systems of Autonomous Intelligent Units" project. The lab is largely formed around conventional hardware solutions such as individual and shared workspace that easily can be adapted to different set-ups, e.g. individual or shared work spaces, to support a wide range of studies. Various types of simulation software can be used to challenge research participants with situations where they need to manage and interact with different kinds of AIUs exhibiting both pre-programmed behaviours and/or being controlled by experiment leaders through Wizard of Oz research designs (Dahlbäck, Jönsson, & Ahrenberg, 1993).

Currently, the project is undertaking a series of workshops to assess which simulation systems that are suitable for conducting studies of C2 Joint AIU systems. Simulation experts are invited to the workshops, where the aims of the project are presented and discussed. This will be followed by a series of workshops with stakeholders from the Swedish Armed Forces, as well with experts from different fields of automation, in an effort to assess which autonomous capabilities that should be the focus of coming studies. These workshops are intended to provide the knowledge needed to refine the above presented research questions into a set of hypotheses. This will be followed by a series of experiments and demonstrations that aim to test these hypothesises in human-in-the-loop experiments and demonstrations.

Finally, it can be concluded that although the project recently started, there are good conditions for progress, both locally in terms of research infrastructure, and internationally in terms of joint research initiatives.

References

Argall, B. D., Chernova, S., Veloso, M., & Browning, B. (2009). A survey of robot learning from demonstration. *Robotics and autonomous systems*, 57(5), 469-483.

Ayodele, T. O. (2010). Machine Learning Overview. In Zhang, Y. (Ed.) *New Advances in Machine Learning*, InTech, ISBN: 978-953-307-034-6.

Barnes, M., Jentsch, F., Chen, J.Y.C., Haas, E., & Cosenzo, K. (2008). Five Things You Should Know About Soldier-Robot Teaming. In *Proceedings of the 26th Army Science Conference*, 1-4 December, Orlando, FL.

Bengtsson, K., & Woltjer, R. (2017). *Autonomi och obemannade system - Inriktning av forskning inom delområdet Manned-Unmanned Teaming (MUM-T)* (English translation: Autonomy and Unmanned Systems - Directions for Research within the domain of Manned-Unmanned Teaming (MUM-T)). FOI-R - - 4522- -SE, Totalförsvarets Forskningsinstitut, Stockholm.

Bradshaw, J. M., Hoffman, R. R., Johnson, M., & Woods, D. D. (2013). The seven deadly myths of "autonomous systems". *IEEE Intelligent Systems*, 28(3), 54-61.

Dahlbäck, N., Jönsson, A., & Ahrenberg, L. (1993). Wizard of Oz studies—why and how. *Knowledge-based systems*, 6(4), 258-266.

DCDC (2018). *Joint Concept Note on Human-Machine Teaming 1/18*. Ministry of Defence, Forms and Publication Section, Bristol, UK.

De Visser, E., & Parasuraman, R. (2011). Adaptive Aiding of Human-Robot Teaming – Effects of Imperfect Automation on Performance, Trust, and Workload. *Journal of Cognitive Engineering and Decision Making*, 5(2), 209-231.

Dennett, D. (2017). *From Bacteria to Bach and Back – The Evolution of Minds*. W.W. Norton, NY.

Galdorisi, G., Jones, A., Pastore, T., & Volner, R. (2017). Command and Control (C2) of Cross-Domain Unmanned Vehicles (UxVs): Progress of an Early Prototype. In *Proceedings of the ICCRTS*, 6-8 November, LA.

Hancock, P. A., Billings, D. R., Schaefer, K. E., Chen, J. Y., De Visser, E. J., & Parasuraman, R. (2011). A meta-analysis of factors affecting trust in human-robot interaction. *Human Factors*, 53(5), 517-527.

Hieb, R.M., Peterson, M.S., Kelly, S.P., Riecken, M., & Vassilou, M. (2017). Exploring Trust and Autonomy in a Hybrid Human/Robotic Force. In *Proceedings of the ICCRTS*, 6-8 November, LA.

Johnson, M., Bradshaw, J., Feltovich, P., Jonker, C., Riemsdijk, B. van, & Sierhuis, M. (2014). Coactive Design: Designing support for Interdependence in Joint Activity. *Journal of Human-Robot Interaction*, 3(1), 43–69.

Klein, G., Woods, D. D., Bradshaw, J. M., Hoffman, R. R., & Feltovich, P. J. (2004). Ten challenges for making automation a" team player" in joint human-agent activity. *IEEE Intelligent Systems*, 19(6), 91-95.

Kott, A. (2017). AI, Robotics and Cyber: How much will they change C2? Keynote address at the ICCRTS 2018, slides available In *Proceedings of the ICCRTS*, 6-8 November, LA.

Lamballis Tessensohn, T., Vecht, v.d. B., & Eikelboom, A. (2108). How to Cooperate with Intelligent Machines: Lessons for Defence Operations from the Integration of AI and Robotics across Multiple Domains. In *Proceedings of the 23rd International Command and Control Research and Technology Symposium*, 6-9 November, Pensacola, FL.

Parasuraman, R., Barnes, M., Cosenzo, K., & Mulgund, S. (2007). Adaptive automation for human-robot teaming in future command and control systems. *The International C2 Journal*, 1(2), 43-68.

Searle, J. (1980). Minds, Brains and Programs. *Behavioral and Brain Sciences*, 3 (3): 417–457

Stensson, P., & Jansson, A. (2014). Autonomous technology – sources of confusion: A model for explanation and prediction of conceptual shifts. *Ergonomics*, 57(3), 455-470.

Woltjer, R., Bergfeldt, J., Svenmarck, P., Nilsson, P., & Johansson, B.J.E. (2017). *Ledning av sammansatta system med autonoma förmågor – En explorativ Intervjustudie*. (English translation: Command and control of systems of systems with autonomous capabilities (FOI-R--349--SE), Totalförsvarets Forskningsinstitut: Stockholm.