An Enterprise Architecture-Based Approach Towards More Agile and Resilient Command and Control

Ovidiu Noran[a] and Peter Bernus[b]
IIIS Centre for Enterprise Architecture Research and Management, Griffith University, Brisbane, Australia

Keywords: Defence, Command and Control, Resilience, Architecture Frameworks, Enterprise Architecture, Power and Energy, Autonomous Hybrid Power and Energy Intelligent Mobile Module, Hybrid Intelligent Tactical Microgrid.

Abstract: Challenges to the global power balance leading to the possibility of peer warfare and technological advances enabling autonomous and swarming-capable vehicles performing increasingly complex operations in contested environments have prompted a stringent need towards more agile and resilient Defence doctrines. On the other hand, Disaster Response efforts also require a more versatile and robust Command and Control (C2) approach in the context of increasing intensity and frequency of natural disasters triggered by climate change. The efforts towards addressing these C2 challenges typically consider the required aspects in isolation, although more often than not they are closely related and as such, changes to one C2 aspect may have unintended effects on the others. Therefore, a holistic approach is required considering the overall effects of the envisaged transformation, so as to maintain the consistency of the C2 evolution effort. This paper proposes such an integrated method that employs Enterprise Architecture modelling artefacts facilitating an overarching approach towards more agile and resilient C2 evolution. A case study is employed to illustrate the concepts proposed and further analyse the relation between the changed warfare and disaster response paradigms and more agile and resilient C2 approaches.

1 INTRODUCTION

The world is changing at an accelerating pace. World powers attempting to change the global post-war order and impose a model similar to their forms of government (Adler et al., 2023) bring the prospect of near-peer warfare. Ever more present unconventional warfare (Kilcullen, 2019) is increasingly using AI-enabled robotic and autonomous systems displaying self-organisation and swarming behaviours often surpassing their manned counterparts. On the civilian side, the increasing intensity and frequency of natural calamities owing to climate change also requires a shift in strategy so as to ensure continued effective disaster response and management.

As there is a similarity between conditions in a contested military operation environment and unstable, rapidly changing situations during a natural disaster, a synergy between the two domains emerges. Thus, both of the above-mentioned domains need more agile and resilient Command and Control (C2) approaches (Australian Defence Force, 2020), also considering changed human computer interaction, trust and risk aspects. Beyond mere automation, existing processes must be actively redesigned in view of the new approaches (Pilling, 2015).

Current attempts at tackling this challenge appear to look at these aspects in isolation, although they are typically related and as such changes in one area may produce unintended ripple effects in others. This paper proposes an integrated approach that aims to preserve the integrity of the required C2 evolution effort, using Enterprise Architecture artefacts.

The rest of the paper is structured as follows: a brief description of main C2 concepts and challenges is refined into concrete lines of action towards C2 evolution. The EA artefacts and principles to be used are introduced next, followed by the presentation of the case study and definition of a novel concept that requires evolved C2 approaches. The outlined C2

[a] https://orcid.org/0000-0002-2135-8533
[b] https://orcid.org/0000-0001-5371-8743

Noran, O. and Bernus, P.
An Enterprise Architecture-Based Approach Towards More Agile and Resilient Command and Control.
DOI: 10.5220/0012443700003690

In *Proceedings of the 26th International Conference on Enterprise Information Systems (ICEIS 2024) - Volume 2*, pages 622-633
ISBN: 978-989-758-692-7; ISSN: 2184-4992

lines of action are then employed for the case study, using the proposed EA approach. The paper closes with conclusions and proposed further work.

2 STATE OF THE ART

The military domain has defined the term 'Command and control' as the application of […] direction by a suitably designated authority over assigned resources with the purpose of accomplishing a common goal (Stanton, Baber, & Harris, 2018). Command is considered more high level, communicating intent, while control is typically specifying more detail in how that intent is to be accomplished. There is an extensive body of knowledge in relation to C2, which has been reviewed in synthesizing some of the most important C2 challenges in view of the changed nature of conflict and disaster response.

2.1 Defence HQ C2 - Issues

Faced with the significant challenges described in the Introduction, an evolved Defence HQ (currently designated as '5th Generation' (Yue, Kalloniatis, & Kohn, 2016)) should be *agile* - i.e., be able to promptly adopt suitable organisational structures matching the complexity of-, and dealing with a set of plausible scenarios (Ashby, 1958; Mintzberg, 1979). As such, extensive research has been performed into the agility of Defence HQ and especially C2. NATO's C2 Agility report (NATO, 2014a) features prominently in this specific body of research, outlining 'Approach archetypes' tied to the levels of a well-defined 'NATO Network Enabled Capability C2 Maturity Model' (N2C2M2) (NATO RTO, 2010). The approaches are represented as areas within a system of tri-dimensional axes comprising levels of information distribution, patterns of interaction and allocation of decision rights respectively. The approaches deemed to perform the best in the presence of uncertainty typical in rapidly changing and contested environments are those featuring the higher values along this axis system, i.e. the C2 'Collaborative' and 'Edge' approaches.

The N2C2M2 model has been tied to C2 agility (Moffat, Huber, & Alberts, 2012) and has also been validated in several real situations (Farrell et al., 2013); however, traditional reluctance and resulting slow progress present in the military towards adopting the more inclusive and collaborative approaches depicted in the model (Meddings, 2020) significantly affect current efforts towards more Agile C2. Moreover, it is highly likely that several C2 approaches may need to coexist at the same time within Joint Forces (Alberts & Conley, 2015; NATO, 2014b) often featuring heterogeneous participants such as international (Allied) Forces, Defence Force components (Army, Navy, Air Force), or Army units interacting with civilian organisations (e.g. in case of disaster response and relief (Ries, 2022)), which adds to the complexity of the situation.

As a result, there is a need to acquire preparedness towards a) adopting each of these C2 approaches but also towards b) the ability to change the C2 approach following changed internal and/or external conditions. The chosen C2 approach must match the situation and be underpinned by adequate information where and when required, collected using appropriate communication and interaction (Vassiliou & Alberts, 2013). Note that the apparently simplest solution of going directly for the most agile C2 approach rather than building capability to switch on demand is typically not the best solution as it is neither trivial nor inexpensive to achieve (NATO, 2014a). Thus, a highly agile C2 approach requires organisational preparedness involving a substantial degree of trust featuring highly distributed decision rights, information sharing and the existence of suitable policies and processes (Vassiliou, 2010) supporting adequate interaction patterns; importantly, it also carries an increased amount of risk (NATO, 2014a). Hence, the best strategy is to match the C2 approach agility to the situation and be prepared to switch as required.

The impending perspective of near-peer warfare situations requires enhanced control so as to maintain initiative in a complex operations environment (Systematic, 2023). In addition, the firmer establishment and evolution of unconventional warfare as seen in recent and current conflicts requires doctrine evaluation, update and if necessary, even discontinuation (Kilcullen, 2019).

Another current C2-related issue is the need to separate Control from Command in order to allow for proper AI involvement (Alberts & Conley, 2015), as AI is intended to be involved mainly in the Control part. To accomplish this task, one needs a tool that allows clear modelling of the boundaries between Command, Control and Execution.

The increasingly automated and autonomous systems' capabilities also require new suitable C2 approaches (ibid.) which will not arise naturally but need to be deliberately designed and adopted.

Swarming is an increasingly important aspect of the autonomous paradigm involving a group of simply-behaving entities that together achieve desired results or behaviour (Bürkle, Segor, &

Kollmann, 2011). Despite noise in the environment, errors in processing information and performing tasks, and a lack of a global communication system (highly likely in an anti-access (A2) or area denial (AD) situation), swarm-capable assets remain efficient at performing group-level tasks, which is paramount in successful execution of missions. Thus, the swarming paradigm needs to be considered as well in the C2 evolution effort.

The Science, Technology and Research (STaR) Shots Agile Joint C2 program (Defence Science and Technology Group, 2020) defines additional facets of C2 agility that have to be addressed, which, together with the other above-mentioned aspects, have been compiled in **Table 1**. Note that, in the table, 'sub-issue' indicates a specific area of the issue and 'scope' designates the context / area of application.

Table 1: Compiled C2 Issues.

Issue	Sub-issue	Scope
Agility	Approach	Overall
	Approach Switch	
	Coexistence	
Human-machine teaming	Human Computer Interaction	Decision making
Artificial Intelligence		
Autonomy	Swarming	
Real time mission simulation		
Situational Awareness and Sense - Making	Information	
	Visualisation	
	Augmented Reality	
	Virtual Assistants	
Resilience	Swarming	AA / A2 environment
Organisational Structures	Organisational Cultures	HQ Agility
C2 Architectures	Agility	Warfighter
Data Analytics	Large and Diverse Data Sets	Information
Innovative Systems	Human	Enable rapid execution of command intent
	Social	
	Cultural	
	Technical	

It is hypothesised that these aspects typically influence each other and therefore, should be analysed in an integrated manner.

2.2 Lines of Action (LOAs) Towards More Agile and Resilient C2

The previously identified issues can be used towards synthesizing several more concise Lines of Action (LoA) in regards to C2 evolution.

1. *Support an improved C2 manoeuvre agility* combining the use of an Extended OODA (Observe, Orient Decide and Act) paradigm (Meddings, 2020), the NATO NEC C2 maturity model (N2C2M2, (NATO, 2014a)), the Cynefin complex situation decision-making framework (Snowden & Boone, 2007) and suitable trust and risk models. This will facilitate understanding the factors and requirements involved in achieving and maintaining a suitable C2 manoeuvre agility as part of an iterative process.

2. *Evolve C2 towards supporting a harmonious co-existence of several C2 agility approaches and interoperability* (Alberts & Conley, 2015) as required e.g. in Joint and Disaster Relief operations (Ries, 2022).

3. *Clearly delineate Command from Control* in order to make use of significant recent AI developments (Alberts & Conley, 2015) and to represent the paradigm change required to deal with peer warfare involving A2 or AD (Russell, 2017) situations, typically encountered in contested environments featuring high uncertainty.

4. *Clarify how C2 must adapt to the new paradigms of Autonomy and Swarming* (Campion, Ranganathan, & Faruque, 2019; Madey & Madey, 2013). Due to technological advances, intelligent multiagent systems play an increasing role in military and disaster relief operations, both as an advantage and as a risk (McLennan-Smith & Adams, 2023).

5. *Promote C2 Resilience via Distributed Control*. The A2 / AD situations likely in a near-peer warfare situation or an ongoing natural disaster event imply a degraded network environment (Farrell et al., 2013) typically resulting in confusion and isolation. In this context, C2 *resilience* becomes paramount in order to execute the full required range of military or disaster relief operations (Hostage & Broadwell, 2014). In addition, the current Centralised Control paradigm needs to be evolved to a Distributed Control pattern (ibid.) so as to control the increasing complexity and required bandwidth of modern warfare. Uncertainty and high dynamics require representing current and emerging resilience needs, to enable adequate design.

6. *Assist C2 Evolution*. Explicitly represent the transition to the new C2 approaches and artefacts required for the new warfare and disaster management paradigms, importantly including temporary co-existence of legacy- and new solutions.

3 ENTERPRISE ARCHITECTURE

The increasing complexity encountered in the C2 domain in the context of peer, asymmetrical and accelerated warfare can be tackled by dividing and organising the relevant concepts according to various suitable criteria. This endeavour can be assisted by using a framework that will ideally make use of a metamodel supporting the integrity and consistency of this taxonomy. Within such a framework, the above-mentioned criteria would constitute *viewpoints* reflecting stakeholder group concerns.

This paper proposes adopting this approach for the C2 Agility endeavour, by using an artefact originating in the domain of Enterprise Architecture, namely ISO15704:2019 Annex A: The Generalised Enterprise Architecture and Methodology (GERAM) (ISO/IEC, 2019). GERAM has been chosen because it is an overarching Enterprise Architecture Framework (EAF) that synthesizes the elements of several other mainstream EAFs. In addition, GERAM is an established and proven concept, having been used in several projects in domains including Disaster Management (Noran & Bernus, 2011) and C2 Agility (Noran, 2023).

The Reference Architecture component of GERAM, namely GERA, contains a Modelling Framework (MF) comprising a set of viewpoints which can be used to produce a 'shopping list' of required aspects for a specific modelling endeavour, while maintaining the consistency of the resulting models. By tying the specific aspects into a shared underlying metamodel, the proposed MF supports a common stakeholder understanding of the present, future and necessary transition steps, which are essential in the current C2 endeavour. The GERA MF is represented in Figure 1, which also shows an example of how to create a modelling construct by selecting a set of viewpoints appropriate to a specific task.

The metamodel and ontology underpinning the C2 modelling effort can be expressed using the Generic Instantiation level, while the contents and suitability of candidate templates and relevant standards can be represented using the Partial model level (see Figure 1 top). The life cycle concept (deemed essential here as a context for managing the C2 agility aspects) is represented through the vertical dimension of the GERA MF.

Note that, although the life cycle aspect in the GERA MF does not include time, GERA itself does include a temporal aspect in the form of *life history*, which can be used to follow the relevant entities along their evolution (see Section 4.3.6 for an example).

The GERA MF can represent the extents of agility and resilience for the entities involved along their entire lives and how they relate to- and may influence the other entities' agility and resilience. This in turn shapes their desired co-existence (see Section 4.3 for a concrete example).

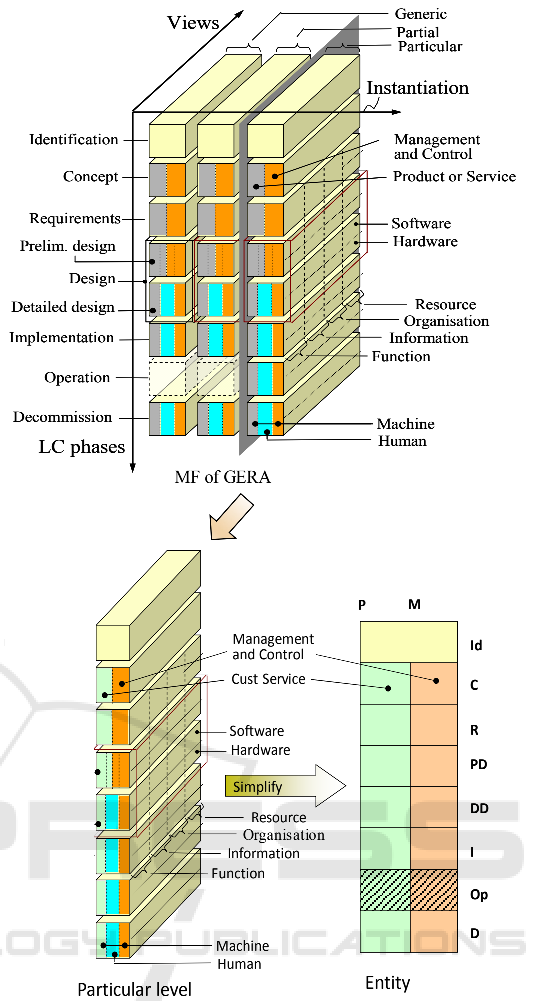


Figure 1: GERA MF and the example creation of a modelling construct for dynamic business models.

In addition, standards employed in this area (see e.g. STANAG 4603 (NATO, 2015)) able to support essential aspects such as federated interoperability in the IoT context (Brink, Vasilache, Wrona, & Suri, 2022; Manso et al., 2022) can also be represented by the chosen GERA MF using the Partial model level.

4 EA ARTEFACTS APPLICATION TO THE C2 LOA: CASE STUDY

The manner in which EA artefacts can assist the C2 LoAs is exemplified below within a case study that is relevant to Defence and Disaster Response but also applies to other situations involving uncertainty and high dynamics.

4.1 Setting

Continuous and adequate Power and Energy (P&E) availability is essential in order to complete missions (NAVFAC, 2016) whether military, or for disaster relief. This aspect involves three main requirements: reliability, resilience and efficiency (NAVFAC, 2021). Among these, resilience is especially important as P&E infrastructure is typically subjected to disruptions, either to starve the opponent of energy in a conflict (Samaras, Nuttall, & Bazilian, 2019) or as an after-effect of natural disasters.

There are several solutions proposed to this problem, usually employing fixed or portable backup power generators of various types. Such solutions have limitations in terms of mobility, prompt assembly into grids and subsequent dispersal, human operator presence requirement and typical mismatch between the power delivered and required (Matthews, 2015). These shortcomings become paramount in the context of near-peer, accelerated and other unconventional types of warfare.

Various concepts of mobile and intelligent microgrid type P&E delivery models are being investigated as possible answers to the above problems in the relevant literature (Matthews, 2015; Roza, 2023; Wood, 2020). However, it appears that currently there is no solution put forward that integrates all these concepts. Moreover, it also appears that an important aspect of this situation, namely how existing C2 approaches are to be evolved so as to adequately cope with the proposed P&E models, is not tackled.

Within the case study, this paper aims to answer these issues by advocating a potential integrated solution and subsequently investigating how an EA-focused approach may assist in evolving C2 to deal with such a situation.

4.2 Scenario

The situation proposed to test the concepts involves an accelerated warfare situation or conversely, a rapidly changing natural disaster situation, where the environment is either contested or unstable (e.g. due to cascading disaster events); these circumstances call for agile C2 and prompt execution. Thus, as per previous Section, there is a need for adequate and resilient P&E delivery solution in order to execute the necessary missions.

4.2.1 Concepts Used for the Scenario

In the scenario, a monolithic and predominantly stationary P&E delivery infrastructure type is not an ideal solution due to its low defensibility and resilience within an A2 / AD situation. Rather, these constraints would be better met by the 'small tactical microgrid' (Matthews, 2015) or nanogrid concepts, depending upon the desired granularity (Hamidieh & Ghassemi, 2022; NAVFAC, 2016; Peterson, Van Bossuyt, Giachetti, & Oriti, 2021; Varley, Van Bossuyt, & Pollman, 2022). In addition, a fully mobile solution has to be adopted, such as e.g. the Vehicle Centric Microgrid (VCM) (Heuvers, 2019), whether fully autonomous or partly manned (Juling, 2023). This will enable swift relocation in case of impending danger, or sudden change in environment adversely affecting proper operation.

To further improve defensibility and resilience, the P&E infrastructure should ideally be distributed and able to rapidly form – in other words, to promptly be assembled, deliver P&E and disperse upon mission completion, or in the presence of a threat of incoming attack. In addition, the P&E components should be modular and independent of the transport solution (i.e. vehicle type) and thus able to be readily integrated into a scalable P&E delivery solution.

In terms of matching the P&E delivery with the load, for moderate variations, an *elected leader* model used within the microgrid may activate more or less resources to match demand (Jane, Goldsmith, Parker, Weaver, & Rizzo, 2021). If the variations exceed the self-adjustment capabilities of the microgrid, a possible solution would involve networking (Chen, Wang, Lu, Chen, & Zhao, 2021), in this particular case with other relocatable VCMs. The above-mentioned modularity and networking requirements require adequate interoperability (Bower et al., 2014), which must also be present in order to support Joint Operations for military and disaster relief missions.

AI would greatly assist in the efficient integration and management of microgrids (Talaat, Elkholy, Alblawi, & Said, 2023) as well as in the reconfigurations required by load variation or by some components failing or being damaged.

Another significant enhancement in regards to mobility is represented by *swarming*. Previously analysed in the context of electrification (Sheridan, Sunderland, & Courtney, 2023), swarming would also assist e.g. in the load management (Singh, Ding, Raju, Raghav, & Kumar, 2022) and potential reconfigurations in the proposed scenario.

4.2.2 Proposed Integrated Concept

In response to the above, the paper proposes the concept of 'Autonomous Hybrid Power and Energy Intelligent Mobile Modules' (AHPEIMMs), able to form Hybrid Intelligent Tactical Mobile Microgrids (HITMMs, see **Figure 2**). This represents a coherent and integrated answer to the above-mentioned separate requirements and solutions. The proposed modules would be autonomous, mobile, easy to deploy, field rugged intelligent machines able to relocate, swarm and interconnect where and when required and seamlessly scale delivery to the demand.

There are two main questions that arise in regards to the scenario and the proposed concept:

1. How do the above identified C2 LoAs apply?
2. How can EA artefacts assist this endeavour?

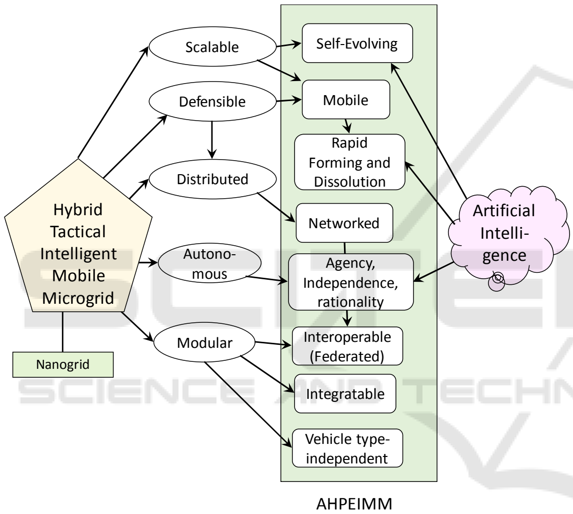


Figure 2: Autonomous Hybrid Power and Energy Intelligent Mobile Module (AHPEIMM) concept enabling the Hybrid Tactical Intelligent Mobile Microgrid (HTIMM) model.

4.3 C2 LoA Application to the Scenario

4.3.1 Support Better C2 Manoeuvre Agility

C2 manoeuvre agility expresses the capability of moving between various C2 approaches featuring various degrees of agility, as required by the actual situation. This is expressed for the scenario in the model described in **Figure 3**. The approach shown makes use of the Extended OODA paradigm (Meddings, 2020) whereby the Command Staff assist the Commander in observing the situation so as to provide a shallower, albeit *wider* perspective of the circumstances, which may yield additional information and situation awareness. In the chosen scenario, this means observing how well the current C2 approach works for the selected P&E solution and if required, choose a more suitable C2 approach from the Reference Models (RM) repository, which among others contains the NATO NEC C2 maturity model (N2C2M2) C2 approaches. The interoperability required with each C2 approach can be selected and customised from the RM as well, as it also contains various applicable NATO standards such as e.g. STANAG 4603 (NATO, 2015); this is highly relevant for the AHPEIMM and HTIMM concepts involved in the scenario, as they rely on 'day zero' (ready to go from first day) federated interoperability (NATO, 2023a). In this regard, the degree of autonomy of entities such as Operation, Mission or AHPEIMMs is reflected in the degree of detail specified in the RM used: the more autonomous the entity, the less specific the RM would be (see Figure 4 in Section 4.3.2 for an example).

The EA MF viewpoints such as Function, Information, Resource and Organisation (see Figure 1, top) can also help explain in more detail the requirements of each N2C2M2 tier. For example, Edge C2 requires wide Information Sharing (Information viewpoint) and Delegation of Decisions with a matching Interaction pattern (with the last two requirements expressed in the Function viewpoint).

The Cynefin complex situation decision-making framework (Snowden & Boone, 2007) is used to classify the specific situation and guide an appropriate degree of C2 agility in the model of the C2 Universe of Discourse ('Endeavour Space' in Figure 3). In the most difficult Cynefin areas, namely Complex and Chaotic, the only feasible approach is to Probe / Act, Sense and Respond, a cyclic approach akin to OODA. This process may also result in new RMs being created and added to the Repository, with the EA MF helping structure and classify them. Finally, the Confusion area of Cynefin may be resolved into one of the other areas by sense-making, with appropriate modelling provided by the GERA MF viewpoints.

The C2 Approach RMs repository can be also classified by levels of trust applied to individual team members and the networked collective (Evans, Cianciolo, Hunter, & Pierce, 2010), whether human, machine or hybrid, including autonomous types (Abbass, Scholz, & Reid, 2018) . The risk aspect of the adopted C2 approach also needs to be explored and included in the respective RMs. The above can be accomplished by adding Trust and Risk viewpoints to the EA MF, which will provide the life cycle context.

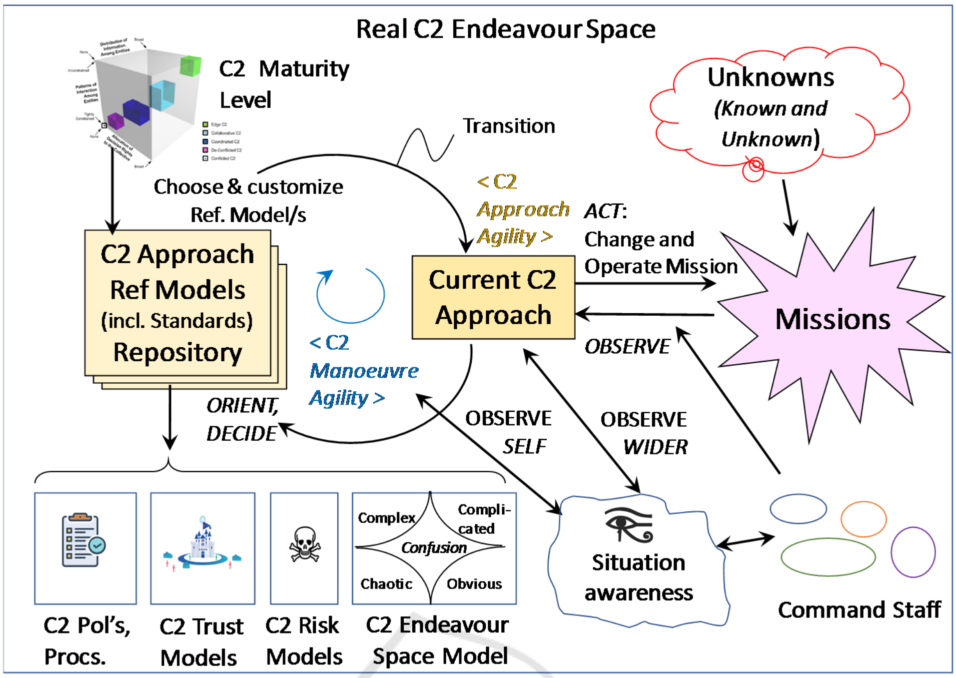


Figure 3: A multi-pronged iterative method for C2 Approach Agility (Meddings, 2020; NATO, 2014a; Noran, 2023).

Policies and procedures that must underpin a more decentralised C2 and, if necessary, overcome mid-level institutional cultural resistance (Vassiliou, 2010) also need to be considered. GERA MF can model such artefacts via its Organisation and Function viewpoints.

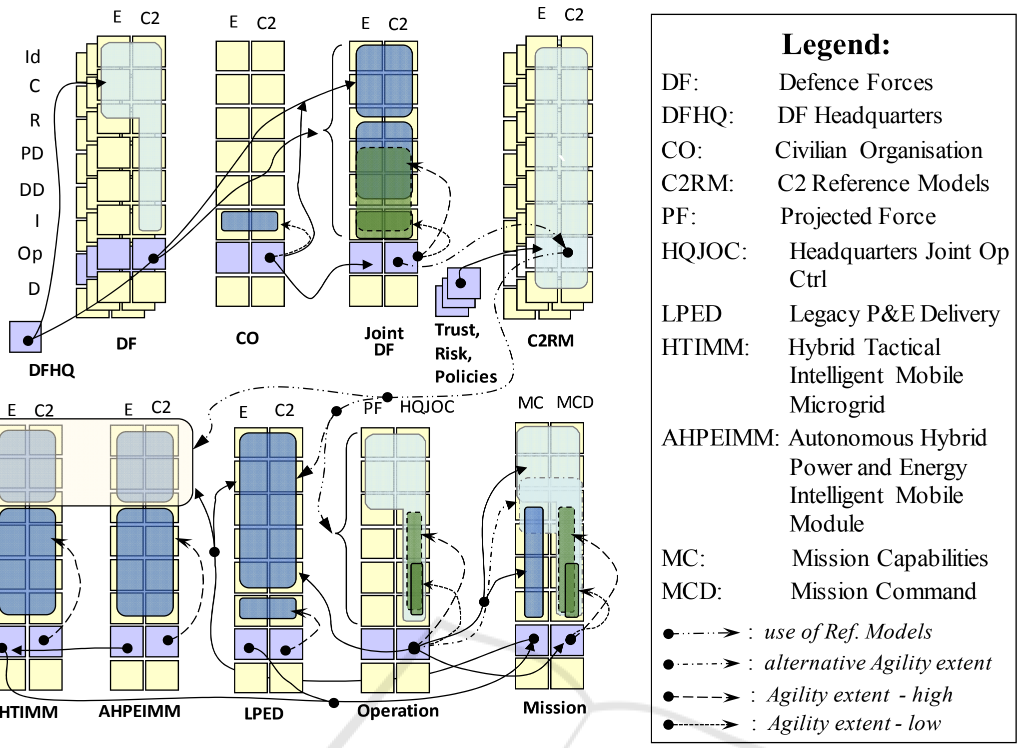
The iterative method proposed above can guide the selection of a more suitable C2 approach, which will be then used in practice via the Missions created in the Real C2 Endeavour Space.

4.3.2 Evolve C2 Towards Supporting the Co-Existence of Several C2 Approaches and Interoperability

Joint and disaster response operations typically involve heterogeneous organisations (or departments thereof), each featuring C2 approaches with various levels of agility. The harmonious co-existence of these approaches is paramount in enabling effective joint operation. In order to achieve this co-existence however, one must first understand the C2 style of each participating entity. For example, in the case study the Civilian Organisation (CO) has a less agile C2 style compared to the participating DFs. This is shown in **Figure 4** by the arrows going back to their upper life cycles to a lesser (CO) or more (Joint DF) extent. For more detail, one may represent the components of the C2 Approach Spaces involved in regards to their Decision Rights allocation and Interaction patterns as well as Information Sharing using GERA MF's Function and Information viewpoints, respectively.

In the scenario, the co-existence of legacy P&E delivery solutions with the proposed AHPEIMM concept within an evolutionary approach requires modelling the C2 agility extent of both alternatives. This is done in **Figure 4** in a combined AS-IS / TO-BE (present / envisaged future) representation due to the GERA MF atemporal approach; a time-bound perspective of this evolution is represented using the GERA Life History in Section 4.3.6. The figure also shows the differences between the autonomy and agility of proposed (AHPEIMM) vs. legacy P&E delivery (LPED) solutions and the corresponding restricted vs. extended influence on their life cycle phases, respectively by the Operation C2.

The interoperability aspect of AHPEIMMs is assisted here by specific reference models such as STANAG 4603 (Technical Interoperability), or NATO's Generic Vehicle Architecture (NGVA (NATO, 2023b)) and Reference Mobility Model Development (NATO, 2018). These can be integrated in the representation using GERA MF's Partial Model level of the framework (see **Figure 1**, top). In **Figure 4.**, they are represented as part of the C2 Reference Models (C2RM) used in setting up the Operation and further on, creating the proposed (AHPEIMM, HTIMM) and legacy (LPED) P&E delivery solutions.

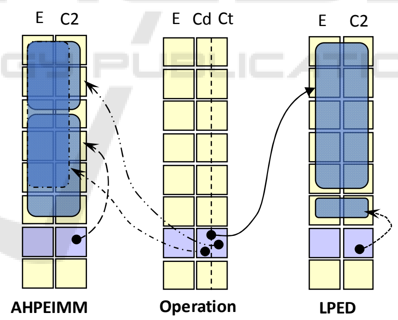


Life cycle phases: Id: Identification; C=concept; R=requirements, PD=prelim. design; DD=detailed design, I=implementation, Op=operation, D=decommissioning; ***Others:*** E=Execution, C2=Command and Control

Figure 4: Co-Existence of various C2 Approaches and P&E solutions (AS-IS and TO-BE combined representation).

4.3.3 Distinguish Command from Control

Due to the complexity and workload involved, there is a high C2 risk in micro-managing humans and especially autonomous systems such as the proposed AHPEIMM, which are to be numerous; hence, there is a need to shift from Centralised- to Distributed Control, which will also enable a more agile C2 (NATO, 2014a); the AI involvement in AHPEIMM (see **Figure 2**) is also typically intended for the C2 Control aspect. In order to achieve the above goals, there is a need to separate the Command and Control components of C2. From the EA point of view, the GERA MF addresses C2 in an amalgamated fashion through the Management (termed 'Command' in C2) and Control, vs. Production / Execution classification, as shown in the construct in **Figure 1** and subsequently used in **Figure 4**. However, an additional division can be created in the modelling construct, such as shown in **Figure 5** for the Operation entity (See Command 'Cd' and Control 'Ct'); this allows to represent how a significant part of the Control is relinquished when using autonomous and intelligent entities such as AHPEIMMs, as opposed to legacy P&E delivery (for rationale see Section 4.3.4).



Legend:

C2 = Command and Control, Cd = Command
Ct = Control

= Command Influence
= Control Influence
= C2 Influence (combined)
= Agility Extent – high
= Agility Extent - low

Figure 5: GERA MF Command / Control Separation and Autonomy and Swarming effect on C2 influence extent.

If necessary, additional C2 detail can be modelled using the GERA MF using the Functional viewpoint; in addition, C2 can also be decomposed using the level of detail they convey: thus, high level decisions (where the implementation detail is left to the lower tiers) are Commands, while lower level decisions (where all details are specified) are akin to Controls.

4.3.4 Autonomy and Swarming Effect on C2

In the case study, autonomy and swarming allow AHPEIMM to self-organise in order to cope with load variations and to congregate into HITMMs when and where there is a need for P&E delivery.

The research in swarming is ongoing; however, it has been established that careful selection of the C2 decision intent and proper adjustment of the Control extent can give a significant benefit when at a Force disadvantage, whether in a warfare, or disaster relief situation (McLennan-Smith & Adams, 2023).

There are several swarm C2 models, depending on the centralisation degree (ibid.). In this case, considering the potential A2/AD environment and to take full advantage of AHPEIMM autonomy and intelligence, it has been decided to enable either the consensus or emergent coordination C2 models, both resulting in a reduced extent of the Operation Control influence on AHPEIMM life cycle phases, as shown in **Figure 5**. As this representation relies on the separation of command and control, it is once again evident that the LoAs identified are related to, support and influence each other.

4.3.5 Promote C2 Resilience Through Distributed Control

C2 resilience can be increased through the use of AHPEIMMs and HITMMs, which reduce C2 fragility by limiting communication bandwidth and workload. Resilience and agility are inherently linked; thus, adaptive and transformative resilience approaches (Folke et al., 2010) enable more agile C2, which is required in complex, confusing and chaotic situations (see Figure 3) typically encountered in contested environments.

The GERA MF can help represent and achieve a common understanding of the required C2 resilience. An example is shown in Figure 6, whereby adaptive C2 resilience is achieved by the Mission itself during operation; for more significant environment changes, transformative C2 resilience is achieved based on an adequate RM under directions from the Operation.
In the scenario, the change from LPED to HITMMs will support Operation C2 resilience by shifting some of the Control load over to the autonomous modules (as shown in Figure 5), in line with the Distributed Control research findings (Hostage & Broadwell, 2014). As can be seen, Resilience is linked to the C2 Autonomy and Separation aspects.

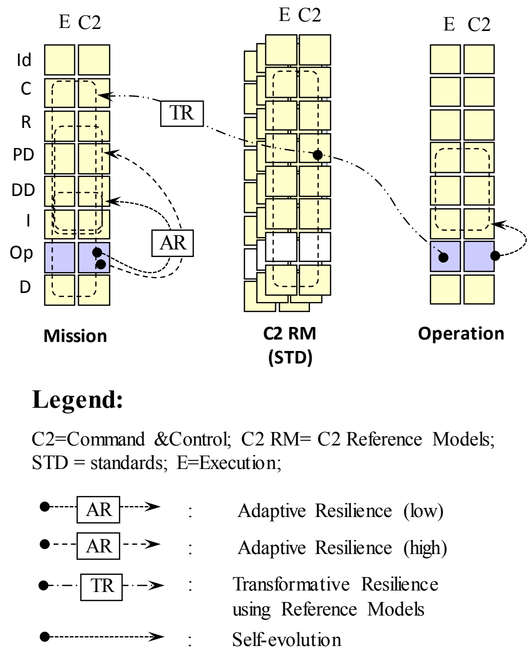


Figure 6: Adaptive and Transformative Resilience.

4.3.6 Assist C2 Evolution

While the GERA MF does not contain an explicit time dimension, it is possible to depict the combined present / future situation from Figure 4 in a temporal representation. Thus, in Figure 7, one can distinguish the creation of an Operation and the HTIMM concept and requirements by the Joint DF, followed by the creation of Missions, AHPEIMMs and the initial HITMM design by an Operation. Additional temporal detail such as concurrency and succession can also be shown. For example, Figure 7 shows the transition from legacy to new P&E delivery models involving their temporary parallel operation. This in turn requires the co-existence of several C2 approaches, again confirming the LoA interdependence.

5 CONCLUSIONS AND FURTHER WORK

The nature of armed conflict and natural disasters is changing and involving an increased use of autonomous and intelligent solutions. The existing C2 approaches need to also evolve in order to effectively cope with these changes. The paper has proposed and tested several main directions towards achieving this endeavour.

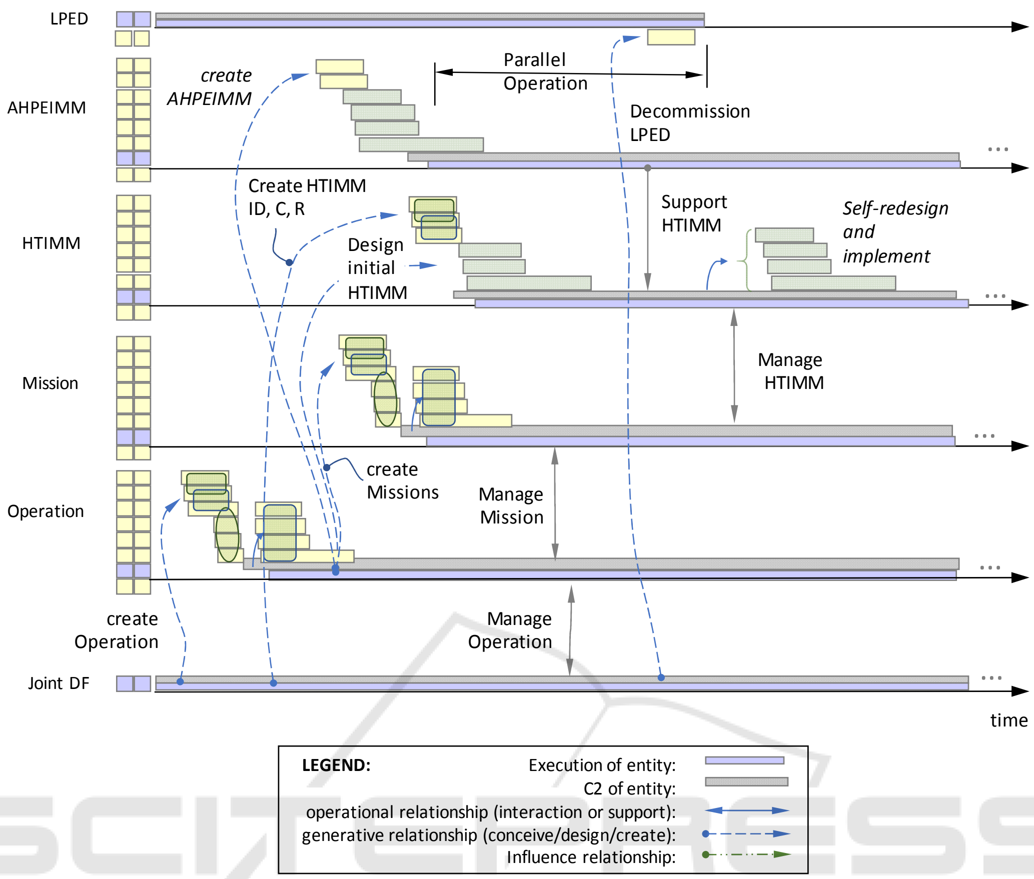


Figure 7: Life histories of the entities relevant to the LPED to HTIMM transition (excerpt).

The application of these directions to the case study has shown that they influence each other and as such, they need to be accomplished in an *integrated* manner, so that changes in all required areas occur coherently. This confirms the holistic, EA-based approach taken.

The contribution of this paper is twofold: a) it proposes practical directions for C2 evolution and investigates the role of EA artefacts in assisting C2 in dealing with the necessary changes and b) it analyses the application of these directions materialised as C2 evolution Lines of Action, tested through a case study involving the novel concepts of Autonomous Hybrid Power and Energy Intelligent Mobile Module and Hybrid Tactical Intelligent Mobile Microgrid, which represent the synthesis of several research directions in the area.

Future research will consider applying the existing Lines of Action to additional case studies in other domains featuring uncertainty and high dynamics in order to validate and potentially increase the applicability of this method to other areas.

REFERENCES

Abbass, H. A., Scholz, J., & Reid, D. J. (2018). *Foundations of trusted autonomy*: Springer Nature.

Adler, P. S., Adly, A., Armanios, D. E., Battilana, J., Bodrožić, Z., Clegg, S., Sheppard-Jones, K. (2023). Authoritarianism, Populism, and the Global Retreat of Democracy: A Curated Discussion. *Journal of Management Inquiry, 32*(1), 3-20. doi:10.1177/10564926221119395

Alberts, D. S., & Conley, K. (2015). Agility C2 Approach Autonomy. Retrieved from https://apps.dtic.mil /sti/pdfs/ADA617821.pdf

Ashby, W. R. (1958). Requisite variety and implications for control of complex systems. *Cybernetica, 1*(2), 83-99.

Australian Defence Force. (2020). Concept for Robotic and Autonomous Systems. Retrieved from https://tasdcrc.com.au/wp-content/uploads/2020/12/ ADF-Concept-Robotics.pdf

Bower, W. I., Ton, D. T., Guttromson, R., Glover, S. F., Stamp, J. E., Bhatnagar, D., & Reilly, J. (2014). The advanced microgrid. Integration and interoperability. doi:10.2172/1204100

Brink, W. t., Vasilache, B., Wrona, K., & Suri, N. (2022). Towards integration of Command and Control systems with Internet of Things. *Procedia Computer Science, 205*, 157-166. doi:https://doi.org/10.1016/j.procs.2022.09.017

Bürkle, A., Segor, F., & Kollmann, M. (2011). Towards autonomous micro uav swarms. *Journal of intelligent & robotic systems, 61*, 339-353.

Campion, M., Ranganathan, P., & Faruque, S. (2019). UAV swarm communication and control architectures: a review. *Journal of Unmanned Vehicle Systems, 7*(2), 93-106. doi:10.1139/juvs-2018-0009

Chen, B., Wang, J., Lu, X., Chen, C., & Zhao, S. (2021). Networked Microgrids for Grid Resilience, Robustness, and Efficiency: A Review. *IEEE Transactions on Smart Grid, 12*(1), 18-32. doi:10.1109/TSG.2020.3010570

Defence Science and Technology Group. (2020). Science Technology and Research (STaR) Shots. Retrieved from https://www.dst.defence.gov.au/sites/default/files/attachments/documents/DSC%202844%20STaR%20Shots%20brochure.pdf

Evans, K., Cianciolo, A., Hunter, A., & Pierce, L. (2010). Modeling Interpersonal Trust in Distributed Command and Control Teams. 46.

Farrell, D. P. S. E., Mitchell, D. W., Baisini, C., Belanger, M., Henshaw, P. M., & Norlander, M. A. (2013). *SAS-085 C2 Agility Model Validation Using Case Studies*.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience Thinking

Integrating Resilience, Adaptability and Transformability. *Ecology and Society, 15*(4). Retrieved from http://www.jstor.org/stable/26268226

Hamidieh, M., & Ghassemi, M. (2022). Microgrids and Resilience: A Review. *IEEE Access, 10*, 106059-106080. doi:10.1109/ACCESS.2022.3211511

Heuvers, J. K. (2019). Vehicle Centrifc Microgrid Development. Retrieved from https://jteg.ncms.org/wp-content/uploads/2020/06/07-Vehicle-Centric-Microgrid-Development-Dist-A.pdf

Hostage, G. M., & Broadwell, L. R. (2014). Resilient Command and Control The Need for Distributed Control. Retrieved from https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-74/jfq-74_38-43_Hostage.pdf

ISO/IEC. (2019). Annex B: GERAM. In *ISO/IS 15704:2019: Industrial automation systems - Enterprise Modelling And Architecture - Requirements for Enterprise-Referencing Architectures and Methodologies*.

Jane, R. S., Goldsmith, S. Y., Parker, G. G., Weaver, W. W., & Rizzo, D. M. (2021). Adaptive leader election for control of tactical microgrids. *The Journal of Defense Modeling and Simulation, 18*(4), 375-394. doi:10.1177/1548512920904785

Juling, D. (2023). Truck Platooning. *The RUSI Journal, 168*(1-2), 108-115. doi:10.1080/03071847.2023.2195897

Kilcullen, D. (2019). The Evolution of Unconventional Warfare. *Scandinavian Journal of Military Studies*. doi:10.31374/sjms.35

Madey, A., & Madey, G. (2013). *Design and evaluation of UAV swarm command and control strategies* (Vol. 45).

Manso, M., Furtak, J., Guerra, B., Michaelis, J., Ota, D., Suri, N., & Wrona, K. (2022, 28 Nov.-2 Dec. 2022). *Connecting the Battlespace: C2 and IoT Technical Interoperability in Tactical Federated Environments.* Paper presented at the MILCOM 2022 - 2022 IEEE Military Communications Conference (MILCOM).

Matthews, S. J. (2015). Small Tactical Electric Power. Retrieved from https://arpa-e.energy.gov/sites/default/files/Matthew_CERDEC_GENSETS_FINAL.pdf

McLennan-Smith, T., & Adams, T. (2023). King of the Hill: C2 for Next Generation Swarm Warfare. Retrieved from https://arxiv.org/ftp/arxiv/papers/2310/2310.00228.pdf

Meddings, W. (2020). The Future of Command and Control: Four Models to Provoke Thought. *Agile Warrior Quarterly*(1), 49-55.

Mintzberg, H. (1979). *The Structuring of Organisations*. New Jersey: Prentice-Hall.

Moffat, J., Huber, R., & Alberts, D. (2012). *Achieving Agile C2 by Adopting Higher Levels of C2 Maturity*. Paper presented at the International Command and Control Research and Technology Symposium, USA.

NATO. (2014a). *Command and Control (C2) Agility - Task Group SAS-085 Final Report*. Retrieved from http://www.dodccrp.org/sas-085/sas-085_report_final.pdf

NATO. (2014b). STO-TR-SAS-085 Annex A - Heterogeneous C2: When the “C2 Approach” Requires Many C2 Approaches. In *Command and Control (C2) Agility - Task Group SAS-085 Final Report*.

NATO. (2015). STANAG 4603: Modelling and Simulation Architecture Standards for Technical Interoperability: High Level Architecture (HLA). Retrieved from https://nmsg.sto.nato.int/amsp/hla

NATO. (2018). Next-Generation NATO Reference Mobility Model (NRMM) Development. Retrieved from https://apps.dtic.mil/sti/pdfs/AD1047407.pdf

NATO. (2023a). Federated Interoperability. Retrieved from https://www.act.nato.int/activities/federated-interoperability/

NATO. (2023b). STANAG 4754: NATO Generic Vehicle Architecture (NGVA) for land Systems. Retrieved from https://standards.globalspec.com/std/14590010/STANAG%204754

NATO RTO. (2010). *NATO NEC C2 Maturity Model Overview.* Paris: CCRP Publication Series.

NAVFAC. (2016). NAVFAC P-601 Microgrid Design Guide. Retrieved from https://www.wbdg.org/FFC/NAVFAC/PPUBB/P-601.pdf

NAVFAC. (2021). 3 Pillars of Energy Security (Reliability, Resilience, & Efficiency). Retrieved from https://www.wbdg.org/FFC/NAVFAC/PPUBB/P-602 _rev2.pdf

Noran, O. (2023). A Synergistic Approach Towards Agile and Resilient Command and Control and Collaborative

Networks. *IFIP Advances in Information and Communication Technology, 688*, 815-826.
Noran, O., & Bernus, P. (2011). Effective Disaster Management: An interoperability Perspective. *Lecture Notes in Computer Science, 7046*, 112-121.
Peterson, C. J., Van Bossuyt, D. L., Giachetti, R. E., & Oriti, G. (2021). Analyzing Mission Impact of Military Installations Microgrid for Resilience. *Systems, 9*(3), 69. Retrieved from https://www.mdpi.com/2079-8954/9/3/69
Pilling, M. (2015). Issues Regarding the Future Application of Autonomous Systems to Command and Control (C2). Retrieved from https://apps.dtic.mil/sti/pdfs/ADA620307.pdf
Ries, M. (2022). Global key concepts of civil-military cooperation for disaster management in the COVID-19 pandemic-A qualitative phenomenological scoping review. *Front Public Health, 10*, 975667. doi:10.3389/fpubh.2022.975667
Roza, D. (2023). Why the Military May Need Microgrids for Overseas Bases to Win a Near-Peer Fight. Retrieved from https://www.airandspaceforces.com/air-force-military-overseas-bases-microgrids-power/
Russell, A. (2017). Historical Perspective of A2/AD Strategy. In A. L. Russell (Ed.), *Strategic A2/AD in Cyberspace* (pp. 11-25). Cambridge: Cambridge University Press.
Samaras, C., Nuttall, W. J., & Bazilian, M. (2019). Energy and the military: Convergence of security, economic, and environmental decision-making. *Energy Strategy Reviews, 26*, 100409. doi:https://doi.org/10.1016/j.esr.2019.100409
Sheridan, S., Sunderland, K., & Courtney, J. (2023). Swarm electrification: A comprehensive literature review. *Renewable and Sustainable Energy Reviews, 175*, 113157. doi:https://doi.org/10.1016/j.rser.2023.113157
Singh, A. R., Ding, L., Raju, D. K., Raghav, L. P., & Kumar, R. S. (2022). A swarm intelligence approach for energy management of grid-connected microgrids with flexible load demand response. *International Journal of Energy Research, 46*(4), 4301-4319. doi:https://doi.org/10.1002/er.7427
Snowden, D. J., & Boone, M. E. (2007). A leader's framework for decision making. A leader's framework for decision making. *Harv Bus Rev, 85*(11), 68-76, 149.
Stanton, N., Baber, C., & Harris, D. (2018). *Modelling Command and Control Event Analysis of Systemic Teamwork*: CRC Press.
Systematic. (2023). Rethinking Command and Control in the Era of Peer Warfare: The Imperative of Enhanced Control. Retrieved from https://systematic.com/en-gb/industries/defence/news-knowledge/blog/rethinking-command-and-control
Talaat, M., Elkholy, M. H., Alblawi, A., & Said, T. (2023). Artificial intelligence applications for microgrids integration and management of hybrid renewable energy sources. *Artificial Intelligence Review, 56*(9), 10557-10611. doi:10.1007/s10462-023-10410-w
Varley, D. W., Van Bossuyt, D. L., & Pollman, A. (2022). Feasibility Analysis of a Mobile Microgrid Design to Support DoD Energy Resilience Goals. *Systems, 10*(3). doi:10.3390/systems10030074
Vassiliou, M. S. (2010). The Evolution Towards Decentralized C2. Retrieved from https://apps.dtic.mil/sti/tr/pdf/ADA517367.pdf
Vassiliou, M. S., & Alberts, D. S. (2013). *C2 Failures: A Taxonomy and Analysis*. Retrieved from https://apps.dtic.mil/sti/pdfs/ADA587551.pdf
Wood, M. (2020). Power and Energy Paper. Retrieved from https://researchcentre.army.gov.au/sites/default/files/20200323_Power%20%26%20Energy%20Paper.pdf
Yue, Y., Kalloniatis, A. C., & Kohn, E. (2016). *A concept for 5th Generation operational level military headquarters*. Paper presented at the 21st International Command and Control Research and Technology Symposium: C2 in a Complex Connected Battlespace, London, UK.