Proceedings of 4th International Conference CNDCGS'2024
ISSN 2669-2023 (print) / ISSN 2538-8959 (on-line) / DOI 10.3849/cndcgs.2024.463

The Complexity of Military Force Readiness to Respond to Changes in the Electromagnetic Environment

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Abstract

This article examines changes in the electromagnetic environment and their implications for the operational environment and the military forces. The first part defines the context with operating environment and how electromagnetic energy shapes it. It then presents the research results in the form of consolidated text and visualizations using a futures wheel and images illustrating the approaches to military force capabilities proposed by the authors applicable in the future electromagnetic environment. Finally, it discusses the development of military capabilities applicable to future operations and generalized recommendations in response to the challenges for military forces in the electromagnetic environment.

KEY WORDS: *capabilities, electromagnetic energy, electromagnetic environment, electromagnetic spectrum, futures wheel, changes, military forces, operating environment.*

Citation: Hlavizna, P., Falta, M. (2024). The Complexity of Military Force Readiness to Respond to Changes in the Electromagnetic Environment. In Proceedings of the Challenges to National Defence in Contemporary Geopolitical Situation, Brno, Czech Republic, 11-13 September 2024. ISSN 2538-8959. DOI 10.3849/cndcgs.2024.463.

1. Introduction

Sun Tzu said: *"Water shapes its course according to the nature of the ground over which it flows; the soldier works out his victory in relation to the foe whom he is facing. Therefore, just as water retains no constant shape, so in warfare there are no constant conditions. He who can modify his tactics in relation to his opponent and thereby succeed in winning, may be called a heaven-born captain."* [1].

Despite the changing nature of the operating environment (OE), this quote is still valid centuries later. Indeed, military approaches to warfare seek to reflect not only the physical terrain or the meteorological and oceanographic (METOC) aspects of these environments. They also continuously respond to the capabilities of adversaries and enemies, or their own capabilities, which are naturally developed in the context of trends affecting the nature of the OE. It is clear that the changing nature of the OE gives rise to not only predictable effects, but also stochastic side effects, which together create the potential for change in military art. Then, the accuracy of the OE prediction is to some extent a reflection of the ability to take a holistic approach, considering all the details that have the ability to shape this environment.

The OE is so comprehensive and complex that it can be examined from many perspectives. One of these perspectives is the electromagnetic environment (EME), which is an integral part of the OE. An interesting trend that may influence the shape and cause changes in the EME is for example the development of assets and technologies based on the use of electromagnetic (EM) energy. The importance of exploring the EME in terms of current and the future OE is due to the fact that the EME is pervasive and permeates all parts of the OE. It therefore has the potential to influence all operational domains. Since the North Atlantic Treaty Organization (NATO) defines an audience as *"an individual, group or entity whose interpretation of events and subsequent behaviour may affect the attainment of the end state"* [2, rec. 40605], and *"the audience may consist of publics, stakeholders and actors"* [2, rec. 40605], we can conclude that the EME has the potential to affect all audiences in the OE.

In line with the above, it is irrelevant what activities and in what operational area or environments of the OE military forces perform. The EME, as part of the OE, has the ability to significantly influence not only the nature of military campaigns and operations, but also to change the fighting power of individual actors in the OE. Consistent with military art theory,

the deliberate application of military force in the electromagnetic spectrum (EMS) can be viewed as a game changer in combat. It follows the premise that EM energy can be an effective and *"a potent force multiplier"* [3, p. I-3] for any actor in a military operation. The term actor is to be understood, in accordance with NATO, as *"an individual, group or entity whose actions are affecting the attainment of the end state"* [2, rec. 40602].

It is no longer possible to conduct any military operation today without trying to maintain freedom of action in the EMS. The reason is that modern technology and techniques are, with few exceptions, dependent on EM energy, or are at least influenced by EM energy. Therefore, it is essential for the military forces to implement specific EMS activities to exploit EM energy in order to achieve desired effects on targeted users of the EMS. To sum up, the challenge is to determine what are the challenges that military forces must be prepared to deal with as the EME changes.

2. Methodology and limitations

Some of the results of the research presented in this article were prepared by one of the authors in 2022 as part of his final thesis for the General Staff course *"Conduct of electromagnetic operations from the perspective of the strategic level of command and control of the Czech Armed Forces"* [4]. Data and information to predict the nature of the OE were obtained through a systematic literature research, brainstorming and discussion with experts. One of the products developed was the futures wheel, which was used to identify and visualize the primary (first order) and secondary (second order) consequences of the trend *"development of assets and technologies based on the use of EM energy"* [4, p. 49]. The consequences of the futures wheel formulated in [4] were subsequently used by the authors of this article to draw implications and formulate proposed measures for military force development. These measures reflect the changing nature of the OE caused by the influence of EM energy.

However, only one generalized example will be given to illustrate possible approach of dealing with the consequences of the futures wheel. The reason is the sensitivity of the EME/EMS issue being addressed, more specifically the use of EM energy for military purposes. Since this topic is usually subject to protection and secrecy, the results presented need to be generalized. This generalization does not affect the validity of the presented results or their theoretical and practical contribution. The results elaborated by the authors can be used by military professionals as reference material in the context of solving operational requirements, or searching for specific capabilities of military forces that should be acquired for success in the future OE. Likewise, the results can be used for the development of military art in relation to the activities of military forces in all operational domains. The presented output can also be used as an additional background material for the subsequent development of a methodological approach to the development of military force capabilities, based on reflection of changes in the OE.

3. Electromagnetic energy as a factor shaping the operating environment

From a NATO perspective, the OE is defined as *"a composite of the conditions, circumstances and influences that affect the employment of capabilities and bear on the decisions of the commander"* [2, rec. 874]. It consists not only of audiences, but also of systems and combinations of many variables and environmental factors that do not originate solely from military activity, military technology, or the implementation of technology in military equipment and weaponry. These include the factors and effects of civilian aspects that influence the final form of the OE. [5, p. IV-8, IV-29], [6, p. 77–79] Thus, the modern concept of the OE is a mixture of variables, interdependencies, and potential synergies, making it a complex challenge for military planners and strategists. A visualization of the OE is depicted in Fig. 1.

Closely linked to the OE is operational readiness, defined by NATO as *"the preparedness of a unit, formation, weapon system or item of materiel to perform the missions, tasks or functions for which it is organized or designed"* [2, rec. 14960]. In the context of the above, this readiness needs to be developed by the military forces, with the aim of ensuring it in all operational domains (land, air, maritime, space and cyberspace) currently recognized by NATO. This is due to the unquestionable existence of the interdisciplinarity of the OE, which is related to the multi-domain approach to planning and conducting combat activities in military operations of the near future. A very important role here is then presented by EM energy, respectively the EME and specific EMS activities (electromagnetic warfare (EW), signals intelligence (SIGINT), navigation warfare (NAVWAR), intelligence, surveillance, target acquisition, reconnaissance (ISTAR), directed energy weapons (DEW), etc.).

The dependence of OE audiences on EM energy, its directed use, and military activities in the EMS have led the United States (US) armed forces to introduce the term electromagnetic operational environment (EMOE). This addresses only those sources of EM energy that can affect the activities of military forces in the conduct of military operations. The EMOE is described as physical, pervasive, constrained, congested, contested and dynamic. The characteristic aspects of the EMOE are related to extensive use of the EMS by a wide range of users. [3, p. I-2–I-3] The term EMOE is not yet officially introduced in NATO, but its content corresponds to the NATO term EME.

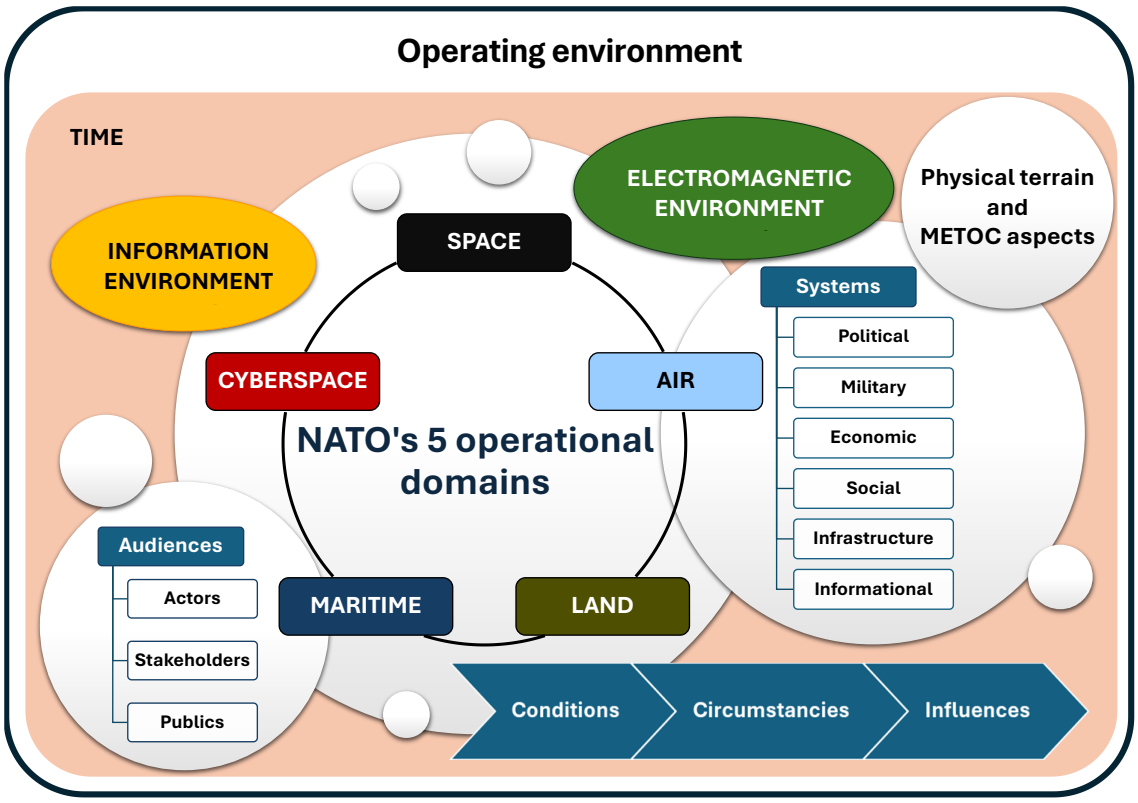

Fig. 1. Visualization of the OE (by the authors based on [5, p. IV-8], [6, p. 79])

The importance of the EMS and its use as a tool to achieve the end state of military operations have thus become not only commonplace, but also an indispensable foundation in a multi-domain approach to their conduct. This approach deals with the synchronization and orchestration of activities in different operational domains and environments of the OE. The goal is to expose adversaries and enemies to not only separate, but also complex dilemmas conducive to gaining battlespace superiority. In this relatively new concept of so-called multi-domain operations (MDO), introduced by the US Army, EM energy and related specific EMS activities of military forces play an irreplaceable role. However, the use of EM energy in military operations is not only a US prerogative. It is an issue that is currently being intensively considered also in NATO, and therefore in many NATO member states. Understanding the EME and its qualified prediction are therefore very important, if not essential, from the perspective of the future OE for the development of the military art and the effective operations of military forces in any operational domain. Indeed, EME intersects with both its physical and non-physical domains of the battlespace. [7, p. C1–C3]

4. Effects of electromagnetic energy on the nature of the operating environment

The issue of generating fighting power, which is closely linked to the capabilities of the military forces tied to its *"three interrelated components: the moral, conceptual and physical"* [2, rec. 40692]. Through their interaction, *"the ability of the armed forces to shape, contest, and fight"* [2, rec. 40692] is then achieved. In order to develop the capabilities of military forces in a broad and focused manner, it is necessary to be able to continuously conduct a predictive analysis of the future OE instead of simply describing the current state of the OE in order to achieve the maximum effect of the generated fighting power.

The view of the OE through EM energy, which has the potential to change the nature of the EME at a specific place and time, appears to be quite interesting and sometimes unfortunately neglected. Since the EME encompasses all operational domains and can theoretically be used to influence all audience in a military operation, it is inevitable to give it due consideration [8, p. 1–2]. Therefore, the question is not only what impact the development of assets and technologies based on the use of EM energy will have on the changing nature of the OE and with which problems will the military actors have to deal with in the near-future military conflicts. In addition to the above predictable problems associated with the EME, there is also a number of very dynamic issues. Military actors must be prepared to respond to those issues in an unplanned and ad-hoc manner. The readiness of military forces to respond to changes in the EME is a fairly complex issue that requires a balanced approach across all functional areas. These areas are known in military environment by the acronym DOTMLPFI *("doctrine, organization, training, materiel, leadership development, personnel, facilities, and interoperability"* [2, rec. 36370]).

Given future military operations, it is very likely that the capabilities available to military forces today will not be sufficiently effective in future OE. In fact, with the challenges associated with the EME, it is almost certain that military

actors' reliance on the EMS will have to be reduced or even eliminated at some point and time in the future military operations. Only such an approach, in parallel with the application of electromagnetic protection measures (EPMs) and specific EMS activities, can be effective and have the potential to reduce the likelihood of success for adversaries and enemies in achieving their EMS superiority.

5. Prediction of the nature of the operating environment

From a military perspective, understanding the OE is a key prerequisite for successfully achieving the end state of any military operation. However, the OE is so complex and variable that it must be addressed well in advance. It is therefore the task of many state and non-state entities to be able to predict the future nature of the OE as accurately as possible, so that the capabilities of the military forces operating in it can be adequately adapted to it. This prediction can be approached by using a wide range of scientific methods. The OE can be examined holistically or, alternatively, by analysing the impacts and influences of individual trends causing changes in its nature. Research on the OE is systematically addressed in the US. The outputs that are provided to the general public, for example, address the OE and implications of development to 2050, emphasising a holistic and heuristic approach to describing the future OE [9, p. 3]. The US Army Training and Doctrine Command (TRADOC) has identified 12 trends that fundamentally influence the nature of the future OE. As shown in Table 1, these trends were grouped into four categories – Emerging science & technology trends; Information, space, cyber & computing; Society, biomed & performance; and Strategic world. It is clear from the above content that a detailed analysis of 12 trends and a prediction of the OE based on this analysis is very time and resource consuming (human, financial, knowledge, etc.).

Table 1.

US Army TRADOC prediction of the nature of the OE [by the authors based on [9, p. 3]]

Trends	**Categories**
Power generation and storage	Emerging science & technology trends
Technology, engineering & manufacturing	
Robotics	
Big data	Information, space, cyber & computing
Cyber and space	
Artificial intelligence	
Human computer interaction	
Collective intelligence	Society, biomed & performance
Increased level of human performance	
Climate change and resource competition	Strategic world
Demographic and urbanization	
Economic rebalancing	

The research conducted by the authors of this article examined the consequences associated with changes in the EME, which is a fixed component of the OE. Its output was, among other things, a futures wheel [4, p. 49] that visualized the primary and secondary consequences of the examined trend on the nature of OE in the context of current knowledge. All of this was based on a foreign and domestic literature search, brainstorming and field research conducted through an interview method with military and civilian experts primarily in the fields of EW, EMS, and intelligence support. In order to make the futures wheel as usable as possible, the selected impacts were addressed not only from the perspective of military actors, but also from the rest of the audiences. Its visualisation is shown in Fig. 2. In the middle is the trend under study, i.e. “Development of assets and technologies based on the use of EM energy”. The primary consequences of this trend are shown on the blue ellipse, the secondary consequences on the green ellipse. Their causality is shown by different coloured lines and arrows.

Although there is not enough space in this article to explain the whole futures wheel in detail, an example of interpretation can be given as follows: the trend under examination, which is “Development of assets and technologies based on the use of EM energy” will primarily (among other things) result in “Easier availability of assets using the EMS by individual users” and “Expanding the portfolio of assets based on the use of the EMS designed to operate in one or more operational domains" (see Fig. 2, the trend is linked to the primary consequences by red arrows). The combination of these primary consequences then secondarily generates “The growing importance of the EMS management in the execution of MDO”, which is, however, also influenced by another secondary consequence, formulated as “Clash of generationally different military assets using the EMS” (see Fig. 2, linking these primary and secondary consequences by blue lines and arrow). The existence of this additional secondary consequence is linked to the already mentioned primary consequence “Expanding the portfolio of assets based on the use of the EMS designed to operate in one or more operational domains” and

the not yet mentioned primary consequence “Development of modern systems based on modularity and open architecture” (see Fig. 2, linking these primary and secondary consequences by the yellow lines and arrow).

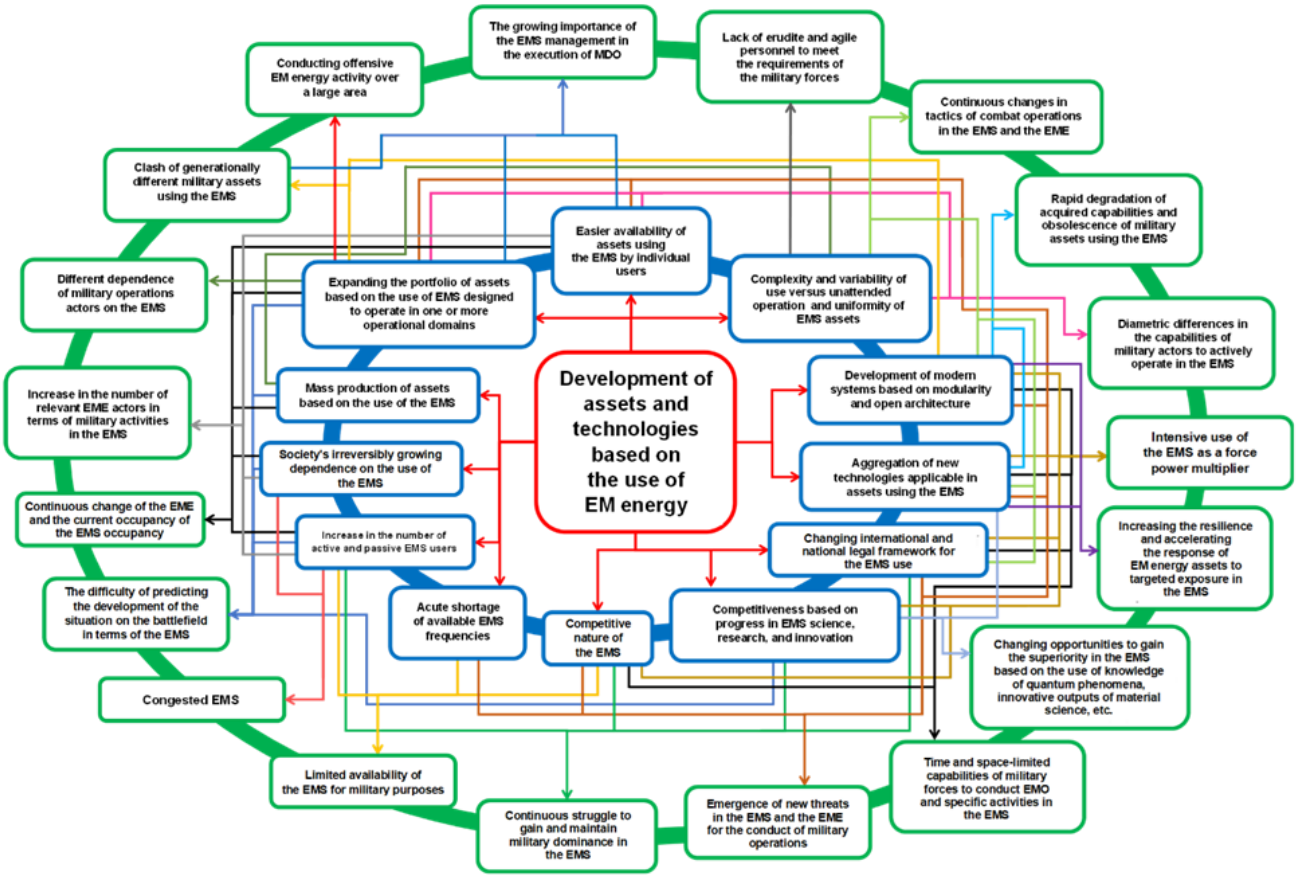

Fig. 2. Prediction of the future OE from the EMS perspective [4, p. 49]

From the above, it is clear that the futures wheel can be used to describe the interdependencies between the various primary and secondary consequences. As it is a representation of the prediction of the future OE from the EMS perspective, it can also be used to develop measures, methods and approaches of military forces to the EME and the EMS. The visualization of the expected changes in the nature of OE brought about by technical and technological advances has clearly shown that if military forces are to survive in future military operations, they must be prepared to conduct their own combat operations even in the complex EME. The EME must be viewed in terms of its existence, whereby the EME is pervasive and coexists independently of the will of anyone in the OE audience. This means that regardless of the operational area in which military forces are destined to conduct their own combat, they must simultaneously be able to operate effectively in the EME. Their EM activities (military forces' activities associated with EM energy-based equipment and technologies serving military units to support their own activities in their assigned operational domain), including specific EMS activities for some of them, must provide them with access to effective use of the EMS, i.e. freedom of action in the EMS.

Each military actor in the OE must be prepared to conduct its own combat activities in its assigned domain and simultaneously in the EME. This means that both existing and emerging military capabilities must be developed to be applicable in the future EME. Fig. 3 shows the development of military capabilities applicable in the future EME, regardless of whether it is a revision of existing capabilities, or the building of entirely new capabilities. It shows that the operational readiness of military forces for their effective use in the future EME is only possible when multiple factors of the future OE are simultaneously considered and defined. They may include, but are not limited to, implications based on direct and indirect consequences caused by trends changing the nature of the OE, opportunities and challenges associated with predicted changes in the nature of the OE, realistic ambitions that the military forces have in relation to the OE, constraints imposed by time and resources, or proposed recommendations that are shaped by the measures, methods, and approaches to the OE and the EME, respectively.

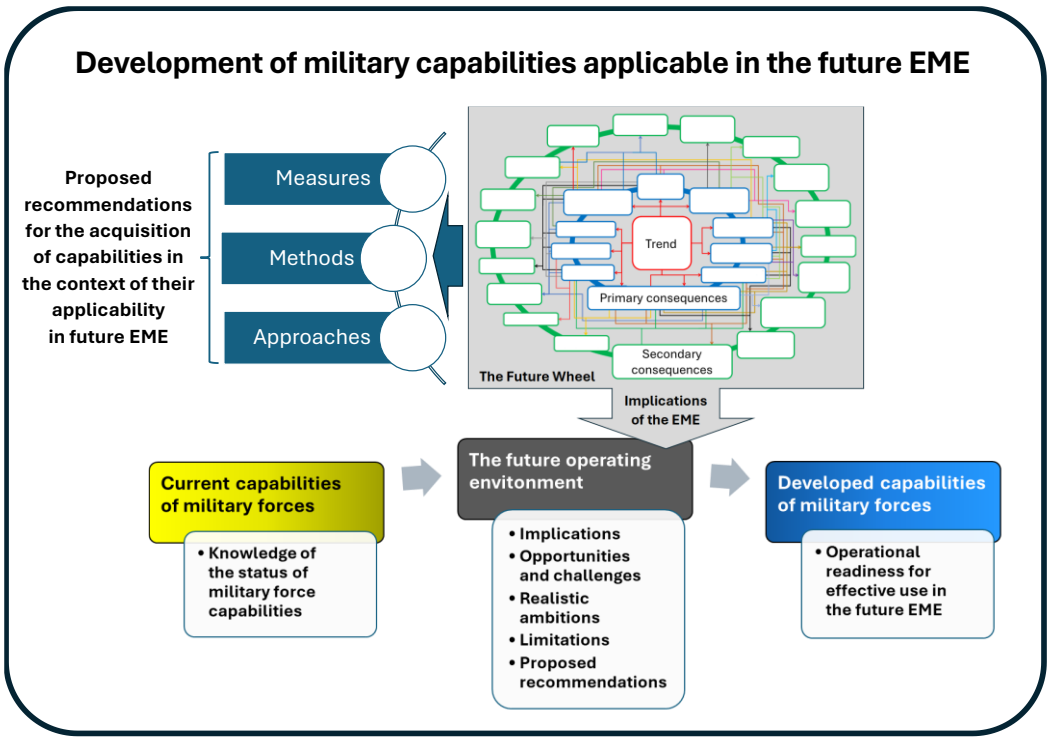

Fig. 3. Development of military capabilities applicable in the future EME [by the authors]

6. Military forces and their readiness to respond to changes in the electromagnetic environment

The details of tactics and approaches to the conduct of actual combat by military forces are themselves a very sensitive matter. Equally sensitive is the issue of their EM activities (including specific EMS activities), which is sometimes even subject to classified information protection. The following explanation of the use of the prediction of the future OE from the EME perspective will be made using a generalized example, without much detail. However, this does not diminish the quality of the presented results. In fact, the futures wheel is applicable to anyone dealing with the issue of adequate readiness of military forces and development of their capabilities for future operations, in accordance with the procedure described below.

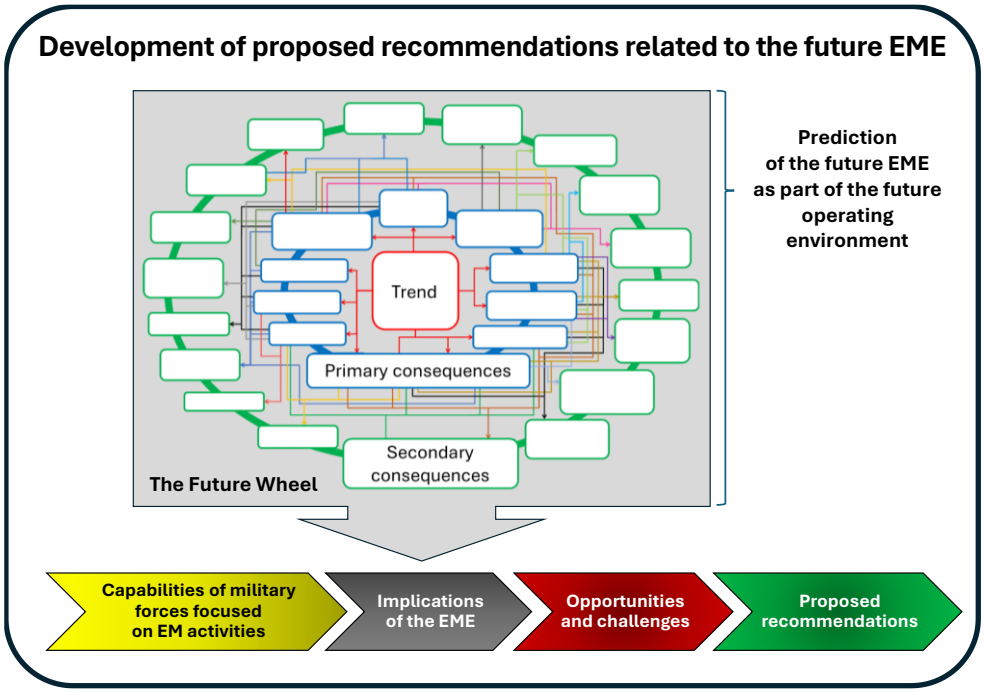

Fig. 4. Development of proposed recommendations for the future EME [by the authors]

Fig. 4 shows a simplified development of the proposed recommendations for the future EME. These recommendations are based on the clarification of capabilities of military forces focused on EM activities. The impact of the future EME on military forces is assessed through its predicted consequences caused by the explored trend. The degree of involvement of military forces in EM activities, which reflects their certain dependence on EM energy and indirectly their possible influenceability by specific EMS activities of enemies and adversaries, then expresses what opportunities and challenges military forces are facing. If the proposed recommendations are to be truly effective, they must reflect not only anticipated changes in the nature of the EME, but also the specific state of military forces, ambitions, limitations, etc.

Selected details that need to be addressed for the proposed recommendations leading to a revision of existing capabilities or the building of entirely new capabilities of military forces to operate in the future EME are shown in Fig. 5.

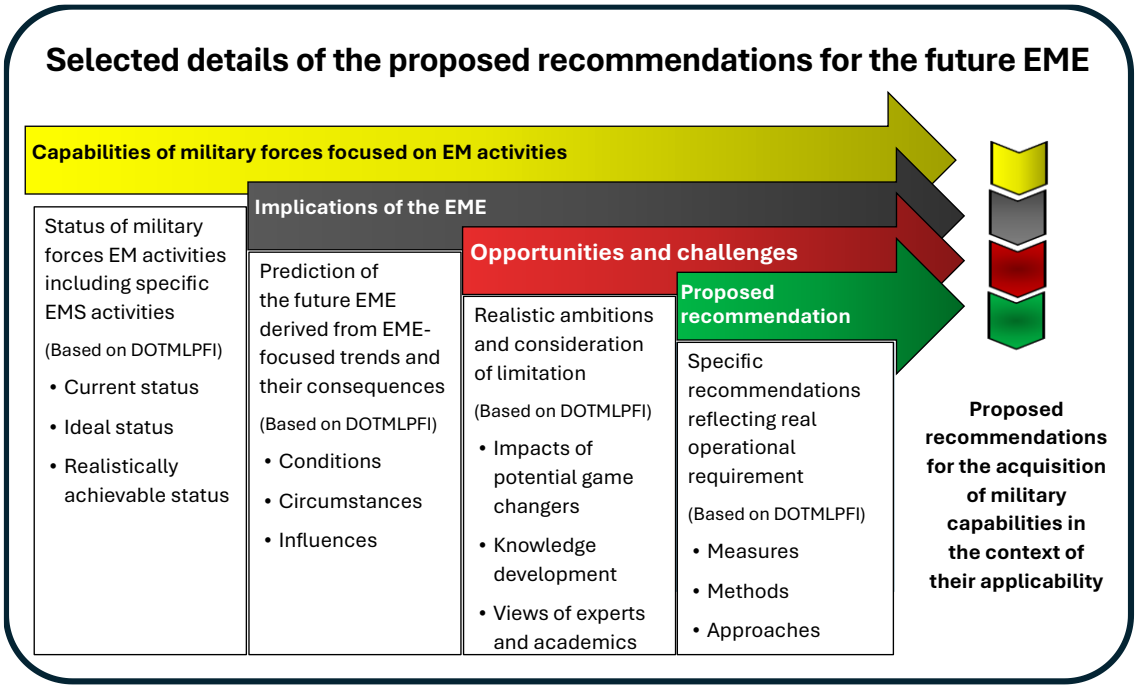

Fig. 5. Selected details of the proposed recommendations for the future EME [by the authors]

It is important to note that if the proposed recommendations are to be effective, it is appropriate to assess their impact in the different components that feed into them, considering the functional areas of the DOTMLPFI. This is the only way to ensure that none of the important areas to be addressed by the proposed recommendations are overlooked.

The research has shown which details of the different components involved in the development of the proposed recommendations should not be neglected. There is a total of four different components. The first relates to the capabilities of military forces focused on EM activities. To obtain the required information in this area, it is necessary to examine the status of military forces' EM activities, including specific EMS activities. Not only the current state and the so-called ideal state, i.e. the state we ideally want to achieve, should be assessed. Adequate recommendations should also be based on a realistically achievable state that substantially reflects the current reality of the capabilities of military forces in the context of what is achievable. The second component concerns the implications of the EME. It is based on predictions of future EME derived from EM-oriented trends and their consequences, which must include all related conditions, circumstances and impacts. The third part refers to opportunities and challenges. These are based on realistic ambitions and take into account limitations, reflecting the impact of potential game changers, knowledge development and the views of experts and academics. So-called potential game changers, whose actions will significantly influence the form of the proposed recommendation, are included, for example, in [8]. These include EM energy-related EW, DEW, cyber, space; internet of things, camouflage, cover, concealment, denial, deception, etc. The fourth component is related to the proposed recommendations. It is critical that proposed recommendations for revised or newly developed capabilities of military forces reflect the real operational requirements. The proposed recommendations must be a set of clear and focused measures, methods, and approaches that have the potential to achieve military force applicability in the future EME. In this context, the importance of EM energy as a potent force multiplier must not be overlooked. Even new sophisticated military technology with higher combat value may not automatically guarantee success and superiority over the enemy if the enemy is able to expose it to the effects of its own EMS activities.

7. Conclusions

It is logical that to achieve success in future military operations, it is important to know the OE in which these operations will take place. The complexity and variability of this environment are challenges that many military forces face today. Predication of the OE is a very complex and difficult matter. Outputs predicting the changing nature of the OE should ideally be reflected in the capabilities of military forces, as only then they will be able to adequately meet the future challenges associated with achieving the end state of military campaigns and operations. The ways in which the identified opportunities and challenges of the future OE can be addressed may vary. However, in all cases, proposed actions to develop individual military forces' capabilities should be considered across the full spectrum of DOTMLPFI functional areas. Only by following this approach the conditions for synergic development of the relevant military capabilities can be created.

EM energy is a factor that significantly influences the nature of the OE. The extent of this influence is based on the very physical nature of the propagation of EM energy. The fact that EM energy can be an effective multiplier of fighting power makes it an effective tool for future military operations as well. Although the EME is a fixed part of the OE, its importance is sometimes greatly underestimated. This is also proved by the current separation of operational domains, where NATO does not refer to the EME as a separate operational domain. This fact is sometimes the cause of a distorted perception of the potential impact of EM energy on the activities of military forces, both from the point of view of own forces as well as adversaries and enemies.

The futures wheel visualized in this article, the trend "Development of assets and technologies based on the use of EM energy", showed the magnitude and complexity of the interdependencies of first- and second-order consequences. The outlined process of the subsequent formulation of implications, the opportunities and challenges identified on their basis, and the proposed measures then completed the picture of the necessary and unavoidable complexity of military force readiness to respond to changes in the EME. The direct and indirect consequences of changes in the nature of the EME are then a real challenge for all military actors as they use EM energy in EM activities in support of the conduct of their own combat activities in their assigned operational domain. A special case is then the forces and assets of military forces destined to perform tasks related to specific EMS activities, whose task is to conduct combat activities in the EMS. Perhaps the greatest challenge associated with changes in the nature of the EME for future military operations is the very realization of the inherent dependence of military forces on EM energy and the vulnerability that this dependence presents. Equally important is the understanding of the personal and collective responsibility of all military actors to implement their own EPM, as well as a willingness to implement these measures by reducing dependence on the EMS use or eliminating it in a time and space constrained manner.

In any case, however, it will be necessary to monitor the influence of EM oriented trends on the nature of the EME and/or the OE. Research has shown that the development of assets and technologies based on the use of EM energy is, and will undoubtedly continue to be, a driver of change in the EME. These changes will certainly have a major impact on the ultimate nature of the OE. Thus, military forces in all operational domains will face many dilemmas as a result of dynamic changes in the OE. A good example of such challenges can be the effective integration of cyber and EW capabilities which is a key prerequisite for NATO ability to operate successfully in the future multi-domain environment [10, p. 518].

If military forces are unable to adequately address these dilemmas, their operational readiness may be significantly compromised by EM energy. It is therefore very important that all measures responding to the variability of the EME are addressed and implemented in all functional areas of DOTMLPFI. In addition to the assumption of continuous change in the EME, these measures must also reflect anticipated developments in the technical and technological fields, both on the part of the own forces and those of enemies and adversaries. It is an irrefutable truth that the importance of EM energy and the EME must neither be underestimated nor overestimated in the context of operational readiness and the conduct of future military operations. Both of these approaches create the potential to endanger not only military materiel but also human lives.

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