Enhancing semantic understanding in command and control: an ontological approach for message enrichment

1st Flavio Ferreira
Computer Engineering Department
Military Engineering Institute
Rio de Janeiro, Brazil
flavio.ferreira@ime.eb.br

2nd Julio Cesar Duarte
Computer Engineering Department
Military Engineering Institute
Rio de Janeiro, Brazil
duarte@ime.eb.br

3rd Maria Claudia Cavalcanti
Computer Engineering Department
Military Engineering Institute
Rio de Janeiro, Brazil
yoko@ime.eb.br

***Abstract*—Military operations are components of a comprehensive information system, encompassing planning, personnel, equipment, technologies, and processes, among others. All these elements need to be seamlessly synchronized to ensure the achievement of the objectives. The combination of planning and execution can involve operations in large areas of activity and, in many of these cases, the use of all three branches of the Brazilian Armed Forces is essential. However, this brings forth a formidable challenge – the need for semantic interoperability – since each branch has its own vocabulary and terminology. This work aims to propose a novel conceptual model tailored to describe knowledge of textual messages exchanged in a Command and Control scenario, taking into account semantic formalism and ontologies. With the development of this model, it is expected that the semantic understanding of the messages exchanged by users involved in an operation is improved while using the model as a basis for persistence in a database. Although this work aims to contribute to Command and Control operations, mainly in the armed forces, it can also be used and extended to other domains, where these types of text messages are exchanged.**

***Index Terms*—Command and Control; Semantic Interoperability; Domain Ontology; Natural Language Processing.**

I. Introduction

Currently, Command and Control (C2) operations, especially military ones, are highly susceptible to changes in the environment in which they are inserted, such as the inclusion of new technological equipment, communication failures, and cyber-attacks, among other factors [1]. Low-efficiency communication within these operations can result in substantial losses and may negatively impact the operation. Many delays in decision-making are linked to the lack of agility in gathering and transmitting data [2].

Military operations are part of a large information system, encompassing planning, personnel, equipment, technologies, and several processes, among other elements. These components need to be synchronized for the successful realization of the objectives [3], and the command structure must be provided with adequate resources to ensure operational effectiveness. This is vital for efficient planning, execution, monitoring, and the ability to adjust the decision-making process [4].

One of the challenges in military operations is ensuring the understanding of the dialogues between human operators and machines, which enables a reasonable response to task completion [5]. C2 serves as a management instrument that establishes leadership to control and decision-making authority that affects the entire operation [6]. It establishes the authority and direction commanders have over forces under command to conduct an operation, whether in military or civil scenarios [3].

In the context of exchanging messages in C2, it is possible to verify that the success of an operation hinges on several factors, with situational awareness being one of the most prominent aspects. Situational awareness empowers commanders with real-time information regarding operations under their command, enabling more precise and impactful decision-making throughout the entire chain of command involved in the process [7].

Communications carried out on battlefields predominantly rely on wireless networks, which can cause delays in message delivery, unlike communications carried out via cable-based systems, where deliveries are more reliable, considering factors such as terrain and technological infrastructure [8]. Thus, military communications must consider the medium, format, and data reliability as strategic elements in operational planning [9].

In terms of prioritization. all messages exchanged in C2 are important, but some must require higher attention and can be classified as standard, urgent, or extremely urgent [10]. In such cases, the C2 Communication Operator (OC3) needs to scrutinize the message content to identify key elements in the message, enabling them to quickly assign a priority, but the urgency level of a message is closely linked to the OC3s perception and assessment [10].

This presents a potential challenge, since the success of an operation may depend on the level of experience of the OC3. Therefore, C2 systems must incorporate processes designed to enhance message understanding, thereby mitigating the dependence on the OC3's expertise. One of the greatest challenges in achieving semantic interoperability lies in trying to reach a consensus on the form of communication among those involved, regarding common definitions, vocabularies, and metadata. Thus, computing systems must be able to employ these definitions to correlate the data they manage while preserving the inherent nature of their domains [11]. To address this type of problem, within the scope of data modeling, the notion of ontology emerges as a potential solution [12].

Considering these principles, this work proposes a conceptual model to describe the technical and operational knowledge of messages exchanged within a C2 scenario. It is expected that this model can contribute to improving the semantic enhancement and understanding of the messages exchanged by presenting the elements with greater clarity. Additionally, we present a taxonomy for categorizing entities frequently used in this scenario.

II. Theoretical Foundation

An ontology serves as a formal specification of a conceptualization, effectively representing an abstract model of the world it aims to depict. It provides a hierarchical structure of entity classes and offers a formal method for articulating their relationships with first-order expressivity while supporting logical reasoning and inference [13]. It consists of several elements including objects, concepts, properties, and their respective relationships. This term has been re-appropriated by computer science and is commonly understood as a collection of entities that communicate through relationships, restrictions, axioms, and specialized vocabularies [16].

While the role of ontology in computer science seems clear, there is still confusion regarding this concept when used in the context of conceptual modeling or in the context of Artificial Intelligence (AI) [17], [18]. In the context of conceptual modeling, an ontology is related to the modeling of a well-founded formal system of categories that can be used to define concepts and models in a specific domain of knowledge. Conversely, within the context of AI, an ontology is used, among other purposes, to build a concrete engineering artifact, often with less emphasis on the theoretical aspects of its foundation.

In [28], this confusion is clarified. The first definition may be called *reference* ontology, while the second one may be called *operational* ontology. Ideally, a reference ontology should be used as the basis for generating an *operational* ontology. In addition, a reference domain ontology should be conceived based on a top-level ontology, also known as foundation ontology, which is independent of specific domains and provides a solid and robust set of principles and constructs [19].

UFO is divided into three different parts, namely: UFO-A; UFO-B; and UFO-C [20]. UFO-A is known as the ontology of Endurants. The `Sortal` construct describes real-world objects and carries its identity principle that identifies them. `Rigid Sortals`, as is the case with the `Kind` construct, provide uniform principles of identity and persistence for their instances. 'Person' and 'Dog' are notable examples of `Kind`.

The `SubKind` construct is a specialization of a `Kind`, for example, 'Shitzu' may be considered a `SubKind` of 'Dog' (`Kind`). `Anti-rigid Sortals`, such as `Role`, categorize rigid elements under transient conditions [21]. For example, a 'Student' is a `Role` that specializes 'Person' (`Kind`), and represents a transitory condition of being enrolled in an educational institution.

III. Related Work

In [23], an ontology was developed to transcribe and optimize the communication exchanged between the pilot (commanded operator) and the controller (command operator). It uses Automatic Speech Recognition (ASR) techniques to improve the understanding and facilitate the work of the pilot and the controller in interpreting messages.

The work identified with the controllers, which were the most relevant and abstract concepts that needed to be mapped, to build an ontology tailored to their requirements. Their investigations were geared toward comprehending the related concepts and, from this, built an ontology based on the controllers' specific needs. They focus on the 'instruction' element, which always consists of a command or more operating conditions. The 'Command' is composed of a 'Type', one or more 'Values', 'Unit', and an optional 'Qualifier'. A message can consist of multiple instructions for the same pilot or even for different pilots. Differently from the present work, however, this ontology was created to standardize the speech among different air traffic controllers and does not focus on highlighting or prioritizing messages. In [24], a domain ontology named OPTaC is proposed to facilitate collaboration in multi-agent systems teams. Similarly to [23], it aims to standardize and enable consistent communication between Unmanned Aerial Vehicles (UAV).

OPTaC focuses on sports gaming techniques for collaboration and support demands for projects, tests, and operations of autonomous and non-autonomous teams. More specifically, it was based on the tactics of a football game, where each team member has a well-defined role in a match. OPTaC was built on BFO generic classes and as an extension of some of the Common Core Ontology (CCO) classes.

Although OPTaC has identified important entities in a communication scenario, such as the directives in message contents, plays, agents, roles in a play, and objectives, it is worth noting that it does not deal with the entities involved in the communication itself, such as the act of communication and the roles involved in it.

In [25], an ontological model is proposed in the military context for C2, Communication, Computing, Intelligence, Surveillance, and Reconnaissance (C^4ISR) of communication, that highlights the relevance of integrating the environment with machines. For example, on a mission, changes in climate conditions can impact the effectiveness of communication, making it necessary to change the communication ranges. In this situation, a computer-supported machine may autonomously change lanes if its sensors detect heavy rain.

The proposed model was established under constraints in the context of ontological communication and its main intention was to improve the effectiveness in obtaining situational awareness. Furthermore, algorithms were used to enhance the attainment of situational awareness through logical reasoning and intelligent systems. The dynamics adopted in the construction of this ontology occurred primarily with the construction of meta-concepts that were subsequently integrated into the communication model. These meta-concepts include 'Goal', 'Entity', 'Activity', and 'Capability'. In addition, a context meta-ontology was created to represent activities of a military mission, including communication tasks.

The work focuses on the unfolding of messages, regardless of the medium through which they are transmitted. However, it is not concerned with the semantics of the intricacies of the communication carried out, while not specifically highlighting the elements, which would facilitate the understanding of the messages' intended actions for the recipient.

In [26], an ontology was developed to deal with situations where floods occur. In this scenario, there may be numerous organizations working together to help victims and resolve problems arising from floods, such as electrical damage, landslides, rescues, and displacements, among others. At this time, communication difficulties may arise among the organizations involved, as well as the victims. For instance, when referring to a wetland, one organization may use the term 'river' while another may use the term 'lake', even though the terms have different meanings in a broad context.

To mitigate this problem and reduce the heterogeneity of concepts and terms between organizations and victims, a domain ontology that focuses on floods was proposed to reduce the concepts addressed in these operations. It also addresses aspects of communication with the victims, which is made among them and the organizations that assist. These key elements are 'Flood prediction', 'Flood control', 'Flood defense', and 'Evacuation'. However, the proposed ontology focuses only on the victim's response flow phase and does not take into account the other stakeholders involved in the process.

In [27], a domain and reasoning ontology is proposed to assist decision-making, mainly those related to airspace and anti-missile defense in a battlefield operation. The need to build the ontology is because there are operational requirements at different stages that need to be understood so that decisions can be made quickly, providing guidelines for agents on the battlefield.

The ontology was modeled by the object-oriented process and divided into three elements: 'Battlefield situation'; 'Combat services'; and 'Combat Resources'. It carries out the corresponding reasoning of the current battlefield situation information while obtaining the characteristics of the attributes of combat resources to produce the corresponding results of combat services and resources. As an operation is complex, rules were built based on the Semantic Web Rule Language (SWRL). Although this ontology uses the elements ('Battlefield Situation', 'Combat Services', and 'Combat Resources') and their deployments to support decision-making in the defense of airspace, it does not specifically focus on the exchange of messages between an element and his superior.

The works discussed in this topic propose ontologies to provide consistent and uniform communication in C2. These ontologies include many interesting classes that should be taken into account when analyzing the contents of messages during their exchange. Similarly to [25], MAISC^2 ontology proposes a model that encompasses the message exchange process, i.e., the elements involved in the communication act, as well as the message and its contents. It is also concerned with enriching the semantic understanding of the messages exchanged between those involved in a C2 operation since the interpretation of the message is fundamental for the Command to make more assertive decisions. Besides actions and agents, MAISC^2 ontology is concerned with other fine-grained elements in the message, that may be categorized as 'time', 'equipment', 'place', and 'direction'. The idea is to add them to the message itself, enhancing it as a way to assist in decision-making.

IV. MAISC^2 Ontology

The ontology proposed in this work is specifically designed to improve the understanding of the textual message exchange within C2 scenarios, while also serving as a basis for recording data throughout the entire message exchange application process. It was inspired by conjunct operations of the Armed Forces, with its primary purpose being the identification of key elements that constitute a message exchange in C2, as well as how they relate to each other. Moreover, the elements that result from message processing are also identified. Figure 1 presents a broad view of the complete ontology, where the ontological model is divided into two large blocks, referred to as Block A and Block B, each one representing a component of the C2 message exchange process.

The first block represents the exchange of messages among military units, while the second encapsulates the interception of the messages and the result of their processing. The construction of the ontology drew upon UFO [19] as recommended by SABIO [28].

Block A represents the main elements involved in communication within C2. It elucidates how messages are exchanged among two or more agents in a C2 scenario. This block exclusively employs UFO-A constructs, and it was based on a previous work that focuses on explicating social relations among elements [31].

In the context of message exchange in a C2 scenario, the participants can be defined as military actors, all of whom are affiliated with a military organization. So, the first element is a military organization, characterized as a `Category` and is called a 'Unit'.

A military unit embodies the main aspects of a military organization which can assume different designations, such as 'battalion', 'regiment' (specifically for the Cavalry Weapon), 'group' (specifically for the Artillery Weapon), 'park', or 'depot'. It also can be composed of several sub-units [30].

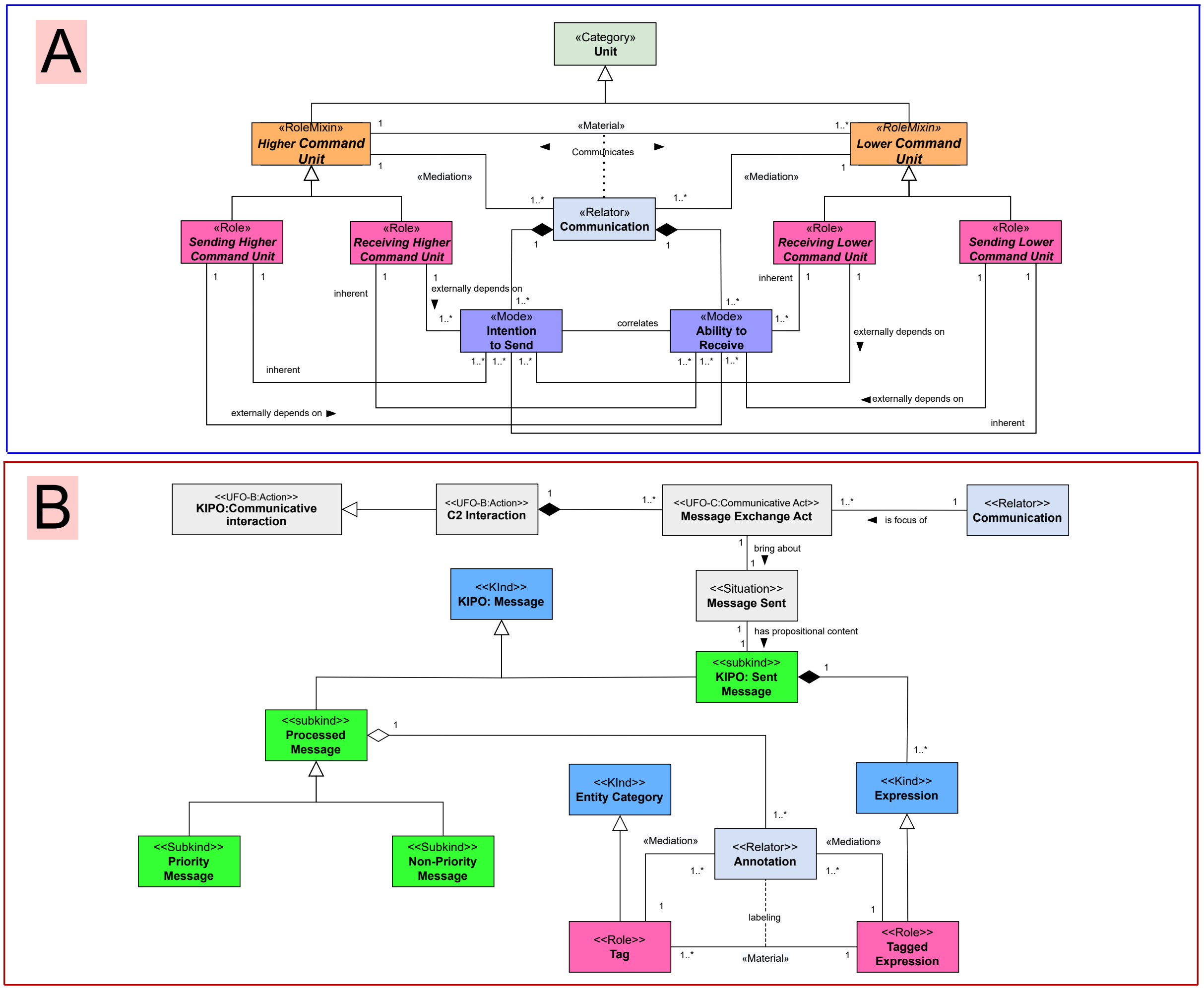

Fig. 1. MAISC^2 ontological model.

In the context of C2, this concept represents all military unit instances according to its definition. Due to this diversity, and because we have different criteria for identifying these units, the `Category` construct is deemed to be the most appropriate approach.

It is worth noting that in the context of this work, whose focus is the analysis of messages in C2 scenarios, there is no interest in knowing the officer involved in the communication, but rather the units that participate in the interactions and the roles they assume. Mainly, a unit may assume either the 'Higher' or the 'Lower Command' roles, while participating in a 'Communication'. These roles are characterized by the `RoleMixin` construct, meaning they aggregate individuals that follow different identity principles. In turn, both roles can take on the sub-roles of either a 'Sender' or a 'Receiver', which are characterized as `Roles`.

Analogously to the social relationships described in [31] the 'Communication' element is a `Relator` that connects the sending unit with the receiving unit. The sending units, 'Sending Higher Command Unit' and 'Sending Lower Command Unit' are distinguished by their inherent intention to transmit a message, called 'Intention to Send'. This intention is characterized in UFO as a `Mode` and is an inherent characteristic of the sending unit, regardless of whether it is from the 'Higher Command Unit' or the 'Lower Command Unit'.

At the same time, the 'Intention to Send' depends externally on the presence of the receiving unit to exist. Conversely, the receiving units, 'Receiving Higher Command Unit' and 'Receiving Lower Command Unit' are characterized by their 'Ability to Receive' a message, which is a `Mode` specific to the receiving unit, and which depends externally on the sending unit. Furthermore, we can correlate the 'Intention to Send' and the 'Ability to Receive', where the correlated pairs constitute the basis for effective communication. Ultimately, 'Communication' materializes communication between the 'Higher Command Unit' and the 'Lower Command Unit'.

Block B, modeled based on [29], represents the actual act of communication and associates it with the message itself and its contents. As discussed in Section II, a `Relator` is the focus of an episode, and thus, we can state that 'Communication' is the focus of the 'Message Exchange Act'. In [29], they proposed an ontology called KIPO that represents a 'Communication interaction' as an `Action` (UFO-B: Action), and present Speech Acts as part of such Action, categorized as 'Acts of Communication' (UFO-C: Communicative Act).

Analogously, we can assert that within a C2 scenario, we have the 'C2 Interaction', which is a specialization of the concept 'KIPO: Communicative Interaction', and that each 'C2 interaction' consists of a set of 'Message Exchange Acts', which are categorized as `UFO-C: Communicative Act`. Each 'Message Exchange Act' can 'Bring About' a 'Message Sent' situation (`UFO-B: Situation`), which in turn has as its propositional content the 'Sent Message' itself. Unlike the approach proposed in [29], this work does not treat sentences individually but considers the message as a unified whole.

The 'Sent Message' element is characterized by the `Subkind` construct, as it corresponds to a specialization of the 'KIPO: Message' concept. It is also related to another element called 'Expression' through a composition-type association. This element is represented in the model by the `Kind` construct and contains the terms that constitute a message.

Before the message is officially received by the recipient, it undergoes a Natural Language Processing (NLP) step to check whether it is a 'Priority Message' and whether there are relevant named entities to be annotated (highlighted). The input of such a process is the 'Sent Message', while its output is the 'Processed Message'. Each 'Processed Message' is composed of 'Annotations', which are also represented as a `Relator` that materializes the relationship between an 'Entity Category' and the corresponding 'Tagged Expression' of the original sent message.

The 'Entity Category' element characterized by the `Kind` construct represents the pre-defined categories for the C2 domain, which may be used in the NLP processing of the exchanged messages. The 'Tag' element is a specialization of the 'Entity Category' element, assuming the role of a 'Tag' in an annotation context and it is characterized by the `Role` construct.

Figure 2 shows the entity categories identified so far: 'Place', 'Action', 'Military Unit', 'Agent', 'Direction', and 'Equipment'. The 'Place' category was based on [33], and it is divided into two new subcategories called 'Geographic Accident' and 'Territorial Division'. The 'Territorial Division' is divided into seven new categories: 'Public Place', 'Neighborhood', 'City', 'State', 'Country', 'Continent', and 'Part of Division'. The 'Equipment' category was chosen based on [32], while the 'Military Unit' and 'Action' categories were based on [30].

The model has been partially implemented and tested using the Protégé tool. Additionally, we built and analyzed an initial dataset to gain a better understanding, ensuring more consistent testing. To further enhance message comprehension, it is essential to analyze more messages in the dataset, while evaluating the importance of incorporating new entities.

V. Conclusion

Technological advances related to information technology have influenced how messages are exchanged in a C2 scenario.

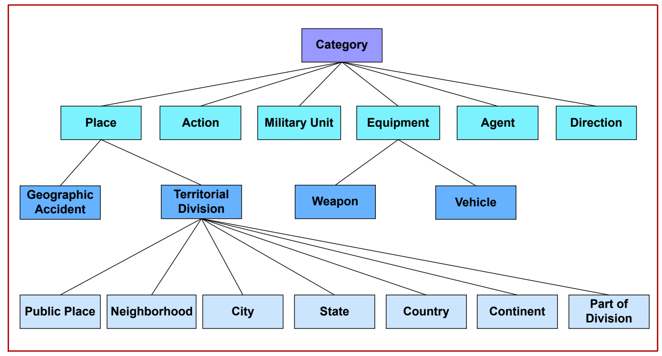

Fig. 2. Taxonomy of C2 named entities.

The ever-increasing volume of received messages forces us to choose which ones we should prioritize. Environmental variables, such as climate conditions and vegetation, add another layer of complexity, directly impacting communication efficiency. Furthermore, the effectiveness of decision-making in a C2 scenario is directly tied to semantic interoperability, where the shared understanding of messages exchanged plays an important role in guiding actions and choices.

In many cases, message interpretation is limited to the expertise of OC3s, who have the significant responsibility of conveying to the commander the intended message. This can introduce a risk to a mission, as the correct interpretation depends on their experience level and interpretative capabilities. To contribute and mitigate subjectivity in message interpretation in a C2 scenario, this work proposes an ontological model that assists OC3s in achieving a more profound and standardized understanding, reducing reliance on their interpretation abilities.

The proposed ontology describes the operational knowledge of messages exchanged in C2, considering both semantic and ontological commitments. The primary objectives of this model are three-fold. First, it enhances the comprehension of messages exchanged within C2, enabling a clearer and more standardized understanding. Second, it empowers individuals engaged in joint operations across the Armed Forces, equipping them with an enriched knowledge of the domain-specific vocabulary and the interrelations among its elements. Finally, it lays the foundation for data persistence within a database, ensuring the enduring preservation of operational knowledge.

To contribute and try to mitigate subjectivity in the interpretation of messages exchanged in a C2 scenario, the MAISC^2 model is founded upon a robust foundational ontology that enables the identification of the main components of a message exchange, as well as the application of artificial intelligence to enrich semantic understanding. In addition to building an ontology to assist the entire message exchange process in C2, a taxonomy has been developed to categorize named entities, further enhancing the system's capabilities. This model also contributes to creating a process for classifying messages as either priority or non-priority.

In future work, we intend to deepen the studies of messages exchanged in C2 to identify newly named entities and how they relate to each other to improve their classification. It is also intended to verify new artificial intelligence techniques, mainly those related to machine learning, to improve the semantic understanding of exchanged messages. This model can also be persisted in a database and there are plans to implement it as an Application Programming Interface, allowing other software to extend its capabilities. Although initially designed for use by the Armed Forces, $MAISC^2$ has the potential to be applied in other domains that require vocabulary alignment and improved message understanding, such as disaster relief and emergency first response services.

ACKNOWLEDGMENT

This work was supported by national funds through FINEP, Financiadora de Estudos e Projetos and FAPEB, Fundação de Apoio à Pesquisa, Desenvolvimento e Inovação do Exército Brasileiro, under project "Sistema de Sistemas de Comando e Controle" with reference nº 2904/20 under contract nº 01.20.0272.00. Additionally, this material is based upon work supported by the Air Force Office of Scientific Research under award number FA9550-22-1-0475.

REFERENCES

[1] Gao, K., Wang, H., Nazarko, J., and Jarocka, M. (2022). "Adaptive decision method in c3i system". Computational Intelligence and Neuroscience, 2022. DOI: 10.1155/2022/6967223.

[2] Rydmark, J., Kuylenstierna, J., and Tehler, H. (2021). "Communicating uncertainty in risk descriptions: the consequences of presenting imprecise probabilities in time critical decision-making situations". Journal of Risk Research, 24(5):629–644. DOI: 10.1080/13669877.2020.1801807.

[3] Brasil. Portaria normativa nº 1.691./EMCFA/MD, P. N. no (Ed.). "Dispõe sobre a doutrina da comando e controle - MD31-M- 03". [S.l.]: Brasília, DF: Ministério da Justiça., 2015. 1—48 p.

[4] Perez, F. J.; Zambrano, M.; Esteve, M.; Palau, C. "A solution for interoperability in crisis management". International Journal of Computers Communications and Control, v. 12, n. 4, p. 550–561, 2017.

[5] Geng, H.; Dong, B. "The topic model of voice interactive dialogue based on the localized command and control system". In: Proceedings of the 4th International Conference on Computer Science and Software Engineering. [S.l.: s.n.], 2021. p. 38–42.

[6] McMaster, R. "Sensemaking in emergency response command and control". University of Birmingham, 2014. Disponível em: https://books.google.com.br/books?id=hx7noAEACAAJ.

[7] Kostin, S. "Modelo para gerenciamento de dados em um ambiente de comando e controle". PUC/RJ, 2001.

[8] Bello, L. L.; Akerberg, J.; Gidlund, M.; Uhlemann, E. "Guest editorial special section on new perspectives on wireless communications in automation: From industrial monitoring and control to cyber-physical systems". IEEE Transactions on Industrial Informatics, v. 13, n. 3, p. 1393–1397, 2017.

[9] Brasil. "Caderno de Instrução CI 21-75-1 Patrulhas". 1. ed. Brasília, DF, 2004. [S.l.]: Brasília, DF: Exército. Estado-Maior., 2005. 4-8/4-10 p.

[10] Orellana, M.; Lima, J.-F.; Game, D. C.; Leon, P. M.; Cedillo, P.; Prado, D. "Application of the LSA technique to determine the priority of alerts from a command and control center". In: IEEE. 2021 Eighth International Conference on eDemocracy and eGovernment (ICEDEG). [S.l.], 2021. p. 210–214.

[11] Tambouris, E., Tarabanis, K., Peristeras, V. and Liotas, N., 2007. "Study on Interoperability at Local and Regional Level". Final Version. 20 April 2007.

[12] Gaurino, N.; Oberle, D.; Staab, S. "What is an ontology?" In: Handbook on ontologies. [S.l.]: Springer, 2009. p. 1–17.

[13] Haberlin Jr, Richard J., Paulo CG da Costa, and Kathryn B. Laskey."A Probabilistic Ontology Development Methodology". In: Proceedings of the 19th International Command and Control Research and Technology Symposium. 2014.

[14] Bunge, M. "Treatise on basic philosophy: Ontology I: the furniture of the world". [S.l.]: Springer Science and Business Media, 1977. v. 3.

[15] Borst, W. N. "Construction of engineering ontologies for knowledge sharing and reuse". 1999.

[16] Guarino, N.; Giaretta, P. "Ontologies, and knowledge bases". Towards very large knowledge bases, IOS press Clifton, VA, USA, p. 1–2, 1995.

[17] Guarino, N.; Welty, C. A." An overview of ontoclean". Handbook on ontologies, Springer, p. 201–220, 2009.

[18] Guizzardi, G.; Falbo, R.; Guizzardi, R. S. "A importância de ontologias de fundamentação para a engenharia de ontologias de domínio: o caso do domínio de processos de software". IEEE Latin America Transactions, v. 6, n. 3, p. 244–251, 2008.

[19] Guizzardi, G.; Lopes, M.; Baião, F.; Falbo, R. "On the importance of truly ontological distinctions for ontology representation languages". In: Enterprise, Business-Process, and Information Systems Modeling. [S.l.]: Springer, 2010. p. 224–236.

[20] Almeida, J. P. A.; Guizzardi, G. "A semantic foundation for role-related concepts in enterprise modelling". In: IEEE. 2008 12th International IEEE Enterprise Distributed Object Computing Conference. [S.l.], 2008. p. 31–40.

[21] Guizzardi, G.; Benevides, A. B.; Fonseca, C. M.; Porello, D.; Almeida, J. P. A.; Sales, T. P. "UFO: Unified Foundational Ontology". Applied ontology, IOS Press, v. 17, n. 1, p. 167–210, 2022.

[22] Guarino, N.; Guizzardi, G. "We need to discuss the relationship: revisiting relationships as modeling constructs". In: Springer. Advanced Information Systems Engineering: 27th International Conference, CAiSE 2015, Stockholm, Sweden, June 8-12, 2015, Proceedings 27. [S.l.], 2015. p. 279–294.

[23] Helmke, H.; Slotty, M.; Poiger, M.; Herrer, D. F.; Ohneiser, O.; Vink, N.; Cerna, A.; Hartikainen, P.; Josefsson, B.; Langr, D.; Lasheras, R. G.; Marin, G.; Mevatne, O. G.; Moos, S.; Nilsson, M. N.; Pérez, M. B. "Ontology for transcription of atc speech commands of SESAR 2020 Solution PJ.16-04". In: 2018 IEEE/AIAA 37th Digital Avionics Systems Conference (DASC). [S.l.: s.n.], 2018. p. 1–10.

[24] Kasmier, D.; Merrell, E.; Kelly, R.; Smith, B.; Heisey, C.; Maki, D. E.; Brittain, M.; Ankner, R.; Bush, K. "Ontology of plays for autonomous teaming and collaboration". 2021.

[25] Zhu, W.; Wang, Z.; Hou, G.; Yu, M. "Capability-based context ontology modeling and reasoning for C4ISR communication". Journal of Systems Engineering and Electronics, BIAI, v. 27, n. 4, p. 845–857, 2016.

[26] Khantong, S. and Ahmad, M.N., 2020. "An ontology for sharing and managing information in disaster response: In flood response usage scenarios". Journal on Data Semantics, 9, pp.39-52.

[27] Ji, J.; Zhou, W.; Yu, M.; Xu, Y.; Sun, X.; Zhu, K. "Ontology construction and reasoning of air defense and anti-missile assistant decision based on distributed operation". In: IEEE. 2021 7th International Conference on Big Data and Information Analytics (BigDIA). [S.l.], 2021. p. 157–165.

[28] Falbo, R. de A. "Sabio: Systematic approach for building ontologies". In: Onto. Com/odise@ Fois. [S.l.: s.n.], 2014.

[29] Richetti, P. H. P.; Gonçalves, J. C. de A.; Baião, F. A.; Santoro, F. M. "Analysis of knowledge-intensive processes focused on the communication perspective". In: Springer. Business Process Management: 15th International Conference, BPM 2017, Barcelona, Spain, September 10–15, 2017, Proceedings. [S.l.], 2017. p. 269–285.

[30] Estado-Maior, B. E. "Glossário de termos e expressões para uso no exército". Estado-Maior do Exército, 2018.

[31] Griffo, C.; Almeida, J. P. A.; Guizzardi, G. "Towards a legal core ontology based on Alexy´s theory of fundamental rights". In: Multilingual workshop on artificial intelligence and law, ICAIL. [S.l.: s.n.], 2015.

[32] Souza, L. C. C. de; Pinheiro, W. A. "An approach to data correlation using JC3IEDM Model". In: IEEE. MILCOM 2015-2015 IEEE Military Communications Conference. [S.l.], 2015. p. 1099–1102.

[33] Rocha, L. B. L. d. et al. "Ontologia de notícias: um modelo para classificação do conteúdo dos jornais on-line brasileiros, segundo a lógica da web semântica". Universidade do Estado do Rio de Janeiro, 2012.