27th ABCM International Congress of Mechanical Engineering
December 04-08, 2023, Florianópolis-SC, Brazil

COB-2023-0325 GOAL-ORIENTED REQUIREMENTS ENGINEERING APPLIED IN THE DESIGN OF A GYROSTABILIZED TURRET OF ARMORED VEHICLES

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Abstract. *The Defense sector deals with the development and acquisition of systems that have unusual requirements, which make them complex from a Systems Engineering point of view. Treating such processes without using methodologies specific to this branch of science can cause various losses, such as delays, increased costs, among others. In this way, this paper presents a simplified proposal of formal requirements for a gyrostabilized turret of armored vehicles, derived from the Goal-Oriented Requirements Engineering (GORE) methodology application, in the Systems Engineering area. Based on official public documentation of the Brazilian Army, objectives of that system are established, which support the construction of requirements using the Keep All Objectives Satisfied (KAOS) method. The requirements assessment and their formalization are done using Petri nets, to allow the design and implementation to be based on formal criteria, that is, as part of a systemic and not analytical process.*

Keywords: *gyrostabilized turret, Goal Oriented Requirements Engineering, Systems Engineering, KAOS, Petri nets*

1. INTRODUCTION

It is common in systems modeling not to consider the reasons for their development or construction. According to McManus and Wood-Harper (2008), in a research carried out by the authors in 2002, only one every eight information technology projects could be considered successful. One of the reasons for the project failure is the high cost for its continuation, usually related to some changing in requirements. Indeed, Van Lamsweerde (2009) states that it costs five times more to detect and fix requirements in the design phase, ten times more during implementation, twenty times more in the test phase and two hundred times more after the system goes into operation. Otherwise, Clouter and Hutchison (2022) state that investments in Systems Engineering result in effective, reasonable and cost-effective systems. This illustrates the importance of this branch of Science of Systems when dealing with projects with a high degree of complexity.

Particularly, complex projects are very common in Defense. The Brazilian Army (Exército Brasileiro - EB), for example, has a strategic portfolio, made up by sub-portfolios, programs and strategic projects related to some purposes, as the defense of society, force generation and the human dimension. When analyzing the scope of each strategic project, it is possible to verify that they have a complex nature. Such projects are funded by public budget, arising from the taxes payment by Brazilian citizens. Consequently, that institution must follow strict rules for contracting and maintaining such systems.

The EB has its own methodology for managing its projects. The Norms for Elaboration, Management and Monitoring of Projects in the Brazilian Army (NEGAPEB) establish foundations, guidelines and document models to prepare, manage and monitor EB projects, inspired by the Project Management Body of Knowledge - PMBOK (Brasil, 2013). In addition, it has general instructions for managing the life cycle of Systems and Materials for Military Use (SMEM), described in EB10-IG-01.018 (Brasil, 2022). It is possible to notice the systemic treatment of SMEM in this document, defining from the conceptual formulation to their deactivation, assigning responsibilities and interested parties for each phase of the life cycle. However, such norms establish a more managerial approach, without pre-established design paradigms.

Also, every four years an Army Strategic Plan (PEEx) is prepared, which describes the Army's Strategic Objectives (OEE) for the next period. The current plan covers the years 2020 to 2023 (Brasil, 2019). Annex A of the PEEx contains, in addition to the various projects to be developed and products to be acquired, the areas and lines of research applicable to short-term Defense Product (PRODE) development projects. Among them, the Systems Engineering area and the line of research on guidance and control stand out.

Article 12 of the NEGAPEB defines Strategic Army Projects (PEE) as those that have strategic impacts and that induce the process of transforming the EB (Brasil, 2013). Acquisition or development of armored vehicles are normally the subject of PEE. The gyrostabilized turret is a fundamental subsystem of an armored combat vehicle, responsible for ensuring target engagement and shot accuracy. Its project is multidisciplinary, involving dynamics, shielding, control, ballistics, optics, among other areas of engineering. Therefore, analytical treatment is not suitable for it, as other systems/subsystems influence its behavior and its domain is wide and heterogeneous, deserving a systemic treatment.

In this context, even though the EB has its own methodology for managing complex projects, it is still distant from the development process, making project verification and validation harder. Thus, the search for methods that establish a connection between those reference management models and the systemic design of military artifacts is justified. The purpose of this work is to propose the use of a systemic approach based on Model Based System Engineering (MBSE) and Goal Oriented Requirement Engineering (GORE) to meet such demand, using as a case of study the project of a gyrostabilized turret for armored vehicles. The academic contribution lies in the process that brings together objective-oriented requirements and managerial reference models.

2. TURRET'S COMPONENTS OF ARMORED VEHICLES

According to NASA (2007), a system is a collection of diverse elements that together produce a result that could not be achieved by them separately. Clouter and Hutchison (2022) states that the Systems Engineering is a multidisciplinary area and is aimed at the development of successful systems. Their success is related to meeting the needs of users and their stakeholders.

In this sense, understanding the composition of an armored vehicle is necessary. Figure 1 illustrates the main components of a tank, which is one type of armoured vehicles.

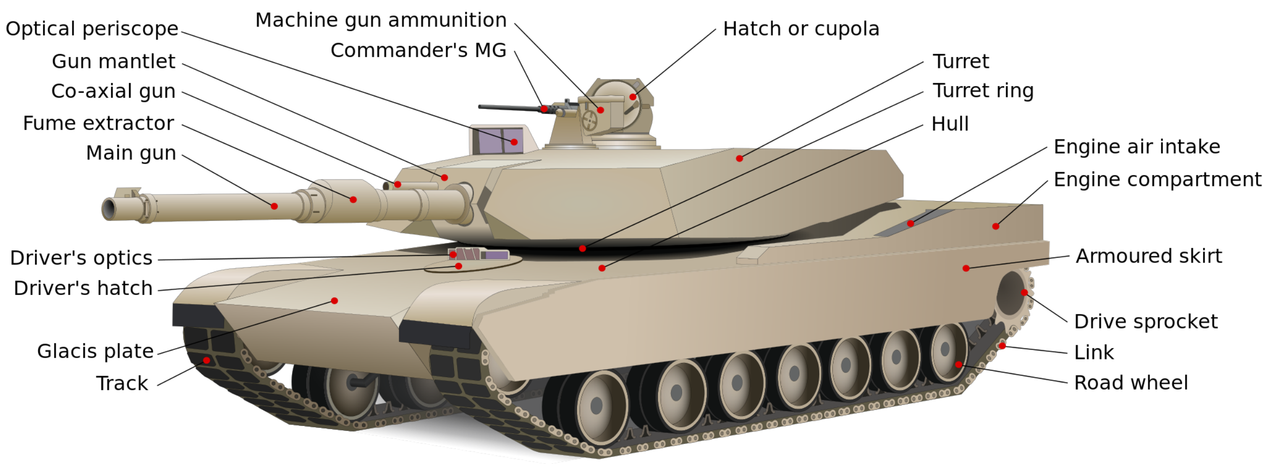

Figure 1. Tank's anatomy (Gamers, 2017)

Notice that the turret is composed of several systems/subsystems, which gives it the status of a complex system (in the sense in which NASA defines it). In fact, the turret generally involves, in addition to its own components, elements such as: primary weapon, secondary weapon, optics and communication system, as illustrated in Fig. 2. It is important to highlight that armored vehicles differ from each other based on their respective requirements. However, in general, this is a common structure.

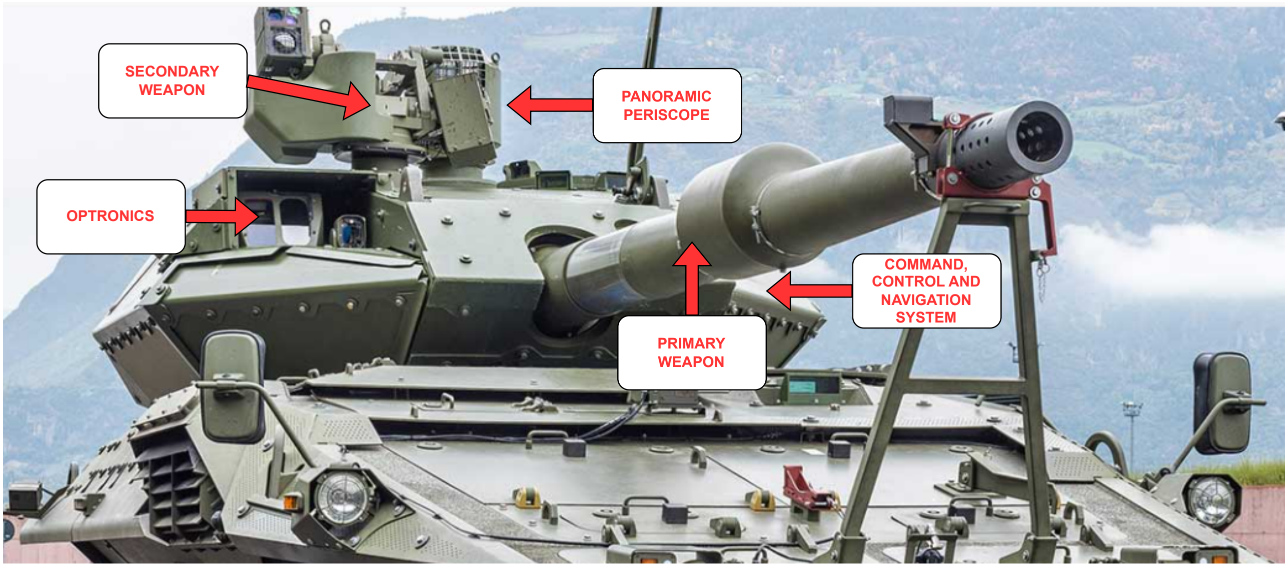

Figure 2. Centauro II turret (adapted from Consortium, 2023)

3. BRAZILIAN ARMY'S DEFENSE SYSTEMS LIFE CYCLE MANAGEMENT

The Brazilian Army follows the procedures described in the EB10-IG-01.018 (2022) to develop, buy, revitalize, modernize, repower or deactivate a SMEM. The aim of this document is to systematize the events that occur in the SMEM's life cycle and assign responsibilities to different sectors of the EB.

The document explains several specific terminologies used in it. Two concepts of interest are the operational requirements (RO) and the technical requirements (RT). Brasil (2022) defines the former as a document that presents what the user requires when employing an SMEM in an operational environment, in order to fulfill the critical missions in the possible employment scenarios. The parameters defined in the RO are restricted to operational aspects, considering the doctrinal and operational conditions and the performance parameters. The RT is defined by the same document as a document specifying the technical characteristics that the SMEM must have to meet the established operational requirements. That means define the functions, behavior (state and operating modes), performance metrics, interface requirements with other systems, environmental requirements, physical requirements, requirements for using external resources and other qualities such as reliability, maintainability, availability, interoperability, security and training.

Depending on the SMEM's category (to be developed, to be buyed, in use, in use - in process of revitalization or in use - in process of modernization, repowering or deactivation), its life cycle follows a different route. According to (Brasil, 2022), the life cycle process is represented using the Business Process Model and Notation (BPMN), containing subprocesses that bring together activities in summarized and coloured form to better understanding. The document's Annex A illustrates the whole process, detailing the subprocess and the activities in Annex B, C, D and E.

However, it does not provide a template for building the RO and RT. Nor does it make clear a systemic paradigm for its construction. Therefore, it is evident that this is a document for management purposes, making harder the connection between the SMEM's development process and their requirements.

For example, when looking at documents Brasil (2021b) and Brasil (2021a), it is clear that a technical requirement is associated with one or more operational requirements and that the requirements are classified into certain categories. However, in the way they are written, it is not possible to perceive the degree of dependence of each requirement, that is, how one affects the other. Figure 3 illustrates what a visual representation of the current model would look like. There, RTA means an Absolute Technical Requirement, which is a characteristic that the system must have. Such representation shows a horizontal categorization, when, in fact, there may be a relationship between the "requirements" (as defined by the Brazilian Army). It is at this point that an opportunity for improvement is seen, with GORE being one of the most efficient methodologies to solve this problem.

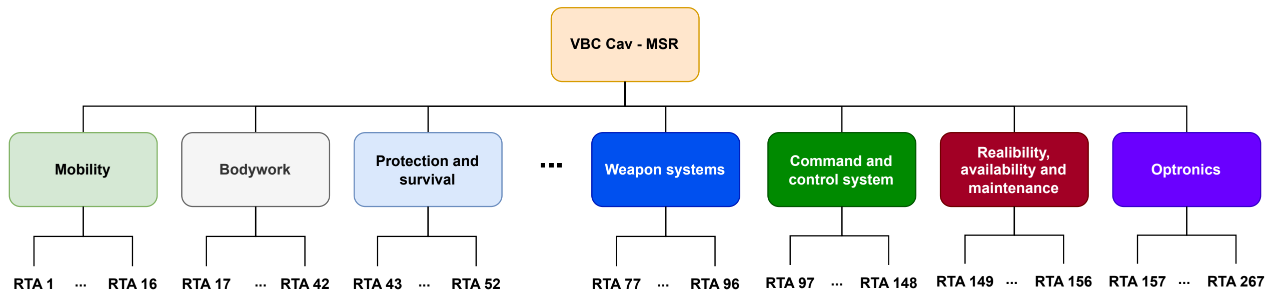

Figure 3. VBC Cav - MSR requirements as defined by the Brazilian Army (adapted from Brasil, 2021a)

4. GYROSTABILIZED TURRET'S MODELING METHODOLOGY

The Model Based System Engineering (MBSE) is a formal methodology that supports the requirements, design, analysis, verification and validation associated with the complex systems development. It should cover four domains of Systems Engineering: requirements/capabilities, behavior, architecture/structure and verification/validation. The three main types of requirements are: business requirements, user requirements, and system requirements (Shevchenko, 2021). To define them, several theories can be used. However, Heaven and Finkelstein (2004) states that one of the most important approaches to requirements engineering is Keep All Objectives Satisfied (KAOS). Such an approach is part of Goal Oriented Requirement Engineering (GORE). The focus on objectives leads to the exploration of alternative system designs, as goals are set without specifying how to achieve them. The refinement of objectives leads to system requirements.

Van Lamsweerde (2009) defines two categories of requirements: functional and non-functional. The former refers to the services that the system must provide, while the latter restricts how such services must be provided. Figure 4 illustrates the taxonomy associated to the non-functional requirements.

Within this scenario, the requirements engineering process is embodied in what the author calls the "spiral model", as illustrated in Fig. 5.

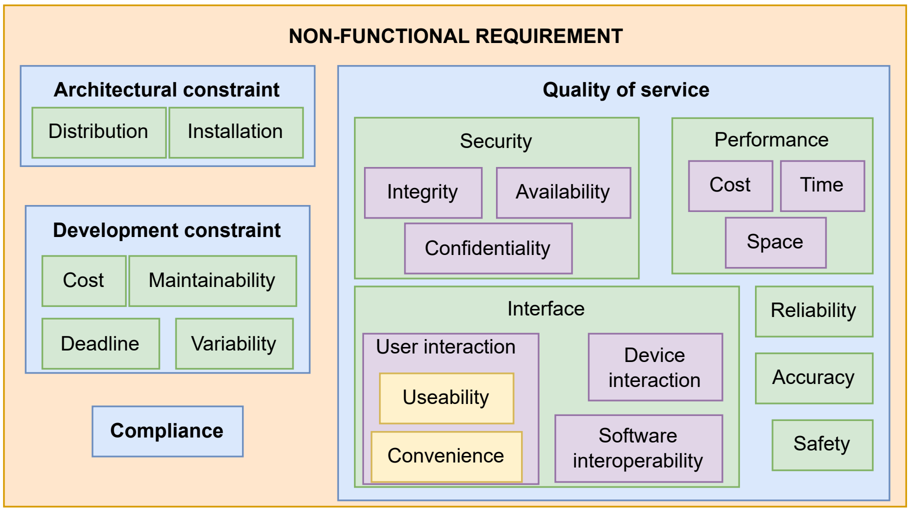

Figure 4. Non-functional requirements taxonomy (adapted from Van Lamsweerde, 2009)

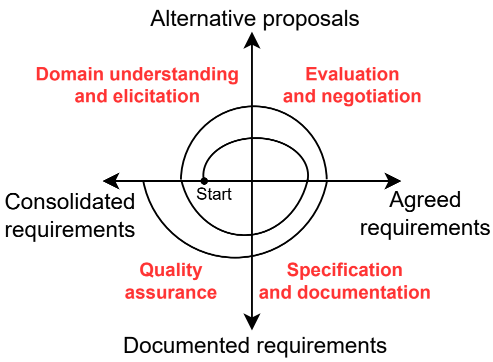

Figure 5. The Requirements Engineering process (adapted from Van Lamsweerde, 2009)

It is important to highlight some terminologies. According to Van Lamsweerde (2009), a **goal** is a prescriptive statement of intent that the system must satisfy through the agents' cooperation. An **agent** is an active component of the system performing a specific function to satisfy the goal. Thus, an objective must be formulated in terms of the phenomenon shared between agents. Different levels of abstraction can be used to define objectives. At higher levels are the strategic objectives, while at the lowest are the technical ones.

In this way, Van Lamsweerde (2009) defines **requirement** as an objective under the responsibility of a single system's agent. The author also defines **expectation** as an objective under the responsibility of a single agent in the environment. The **hypothesis** is defined as a descriptive statement satisfied by the environment and subject to change. Figure 6 presents the statements' typology.

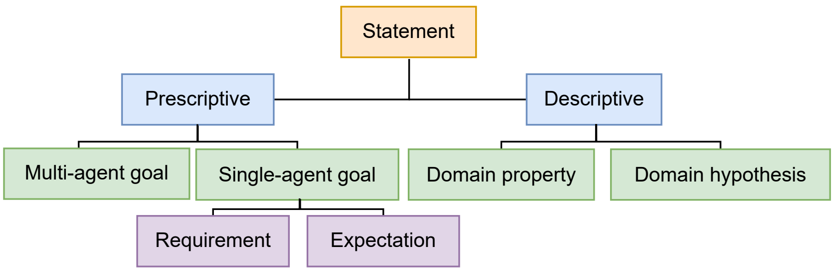

Figure 6. Statement's typology (adapted from Van Lamsweerde, 2009)

There are two types of goals: behavioural or soft. The soft goals establish preferences between alternatives for the system's behavior. They are used as criteria for selecting a system option among multiple alternatives (Van Lamsweerde, 2009).

The KAOS method can be considered as a multiparadigm framework that allows combining different levels of expression and reasoning: **semiformal** for modeling and structuring objectives, **qualitative** for selection between alternatives, and **formal** when necessary for more accurate logic (Lapouchnian, 2005).

This method proposes four visions of the problem that are treated by the following models: Goal model, Object model, Operation model and Responsibility model (Werneck *et al.*, 2009). Figure 7 briefly illustrates the four diagrams used in KAOS.

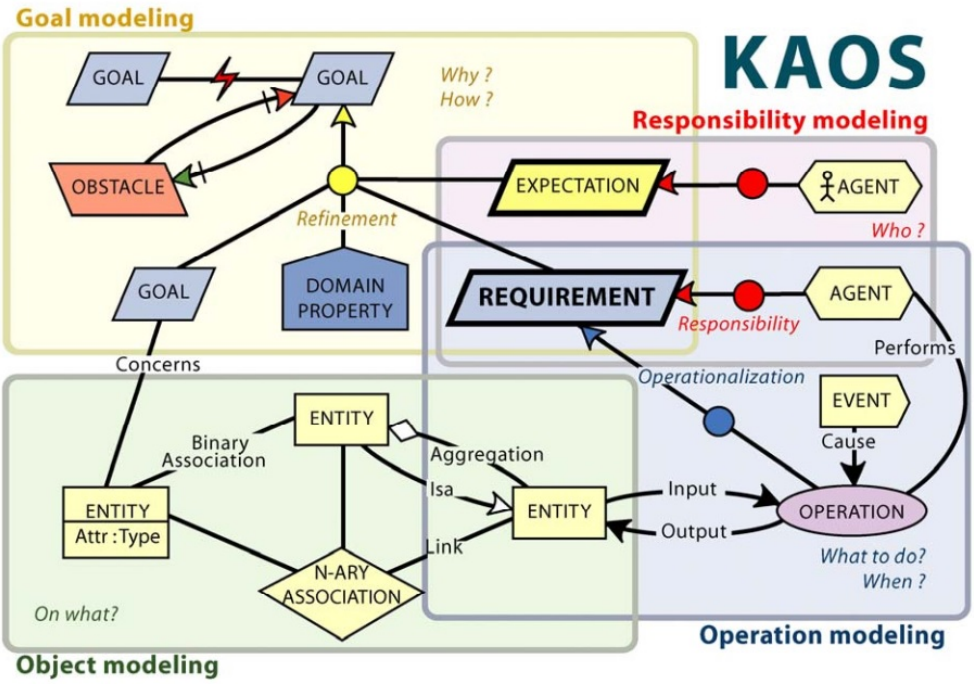

Figure 7. KAOS (Respect-IT, 2007)

The goal modeling diagram is build by establishing objectives and refining them into other sub-objectives (so that the lowest level justifies the highest level). The refinement process shows **how** the refined goal can be achieved. At the top of the diagram are the strategic or business objectives, which answer the **why** of that system. At the bottom are the system requirements. The links between objectives can be "AND" or "OR". The former merges two or more arrows into a single yellow circle, while the latter is represented by individual arrows with a yellow circle. Both type of links go from the lower-level to the higher-level objective (Respect-IT, 2007).

After building these diagrams, there is a need to review and validate the requirements to obtain a formal documentation to support the system's design. For that, Petri nets can be used.

According to Salmon (2017), "the Petri net can be seen as a visual formalism that can explain the physical behavior of a system and its components", allowing its application in Systems Engineering. Furthermore, its algebraic representation is perfectly adherent to the graphical representation, which enables the alternation between formal and semi-formal methods. Its solid mathematical base facilitates the analysis and verification of a large number of properties present in the systems, allowing the identification of possible errors and their correction before the beginning of the implementation. Consequently, such a feature adheres to model-oriented design techniques and virtual prototyping.

A formal mathematical definition of Petri nets can be found in Murata's work (1989). According to him, the behavior of many systems can be described in terms of their states and their changes by firing rules.

Murata (1989) provides a simple example to understand the systematics of the firing rule, through the chemical reaction of the water molecule ($2H_2 + O_2 \rightarrow 2H_2O$), illustrated in Fig. 8. Two tokens in each input place show that two units of H_2 and O_2 are available, so transition t is enabled. After firing t, the markup changes to the representation contained in Fig. 8 (b), in which the transition t is no longer enabled.

Murata (1989) also shows several examples of Petri nets applied in modeling systems, such as: finite state machine, parallel activities, computational data flow, synchronized control, producer-consumer type systems, among others.

According to Salmon (2017), there is an effort to standardize Petri nets worldwide. The ISO/IEC 15.909 standard collaborates with this objective. This document was conceived in three stages, containing definitions, interchange format for Petri net models (PNML - Petri Net Markup Language - based on XML), standardization of Petri net extensions, among other items.

Given the theory presented, two public documents from the Brazilian Army were considered for the purpose of eliciting the objectives of the system: the Operational Requirements of the Armored Combat Cavalry Vehicle - Medium On Wheels (VBC Cav-MSR) - (Brasil, 2021b) - and the Technical, Logistical and Industrial Requirements of the VBC Cav-MSR (Brasil, 2021a).

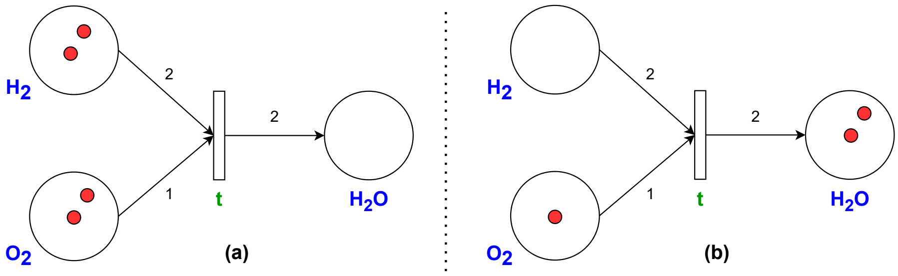

Figure 8. Marks before (a) and after (b) firing the enabled transition *t* (adapted from Murata, 1989)

To simplify the results, only the elements associated with the tower's dynamics were considered, with the following subsystems/collaborative systems: primary and secondary weapon; optronics and optics; command and control (C2); ballistic computer; rotation system; elevation system; and sensors.

To make the system's goal model, the Objectiver V3.0 software was used. The Petri net was build using the software Platform Independent Petri net Editor 2 (PIPE 2) to formalize some requirements chosen.

Some agents associated with non-functional objectives were also included in the modeling, such as the Preparation and Employment System and the Logistics System. Both are existing Brazilian Army specific systems.

For model verification purposes, elements associated with system disturbances (elicited from those documents) were incorporated into the Petri net. Only one part of the system's operation was chosen, to show how Petri nets make easier its development.

5. RESULTS

Table 1 presents the social goal of the system and the objectives that contribute to it, as well as the responsible agents, depending on the case.

Table 1. First level objectives

Level	Goal (objective)	Agent
1	Individual and collective defense (Social Goal)	-
1.1	Engage Target	Primary Weapon System
1.2	Perform self-defense	Secondary Weapon system
1.3	Perform communication	Command and Control System (C2)
1.4	Training users	Training and Employment System
1.5	System Maintenance	Logistic System

A breakdown of level 1.1 (Engage target) was carried out in order to model that system in terms of its dynamics. With that, the Table 2 presents the refinement of this objective.

Table 2. Refinement of the goal 1.1 "Engage target"

Level	Goal (objective)	Agent
1.1.1	Accurate target tracking	-
1.1.2	Have stationary or moving shooting capability	-
1.1.3	Observe, recognize and identify	Optronics and Optics
1.1.4	Have at least one safety device capable of preventing accidental triggering	-
1.1.5	Possess the ability to be operated manually in degraded mode, i.e. without using energy from the automotive platform	-

The dynamics of the gyrostabilized tower is directly associated with objective 1.1.1. Thus, it was refined, resulting in the goals set out in Table 3.

Continuing the refinement, Table 4 presents the results.

Finally, the last refinement was reached, which defined the system requirements associated with its dynamics, shown in Table 5.

Objectives 1.2, 1.3, 1.4, 1.5 and 1.1.3 were also considered as system requirements, since, for simplification, they were not refined, but associated with the respective agents responsible for their fulfillment. A visual representation of what was exposed in these tables is shown in Fig. 9.

Table 3. Objective 1.1.1 "Accurately track target" refinement

Level	Goal (objective)	Agent
1.1.1.1	Indicate, within the mission management system, the position (graphic symbol) of the azimuth and elevation of the weapon in relation to the longitudinal axis of the vehicle	-
1.1.1.2	Correct the aim in the direction and elevation of the main armament in relation to the target, considering at least the following parameters: distance from the target, type of ammunition, muzzle velocity, ambient temperature and humidity	Ballistic computer

Table 4. Fourth level refinement

Level	Goal (objective)	Agent
1.1.1.1.1	Have horizontal firing range	-
1.1.1.1.1.1	Have drift adjustment N x 360º	-
1.1.1.1.2	Have vertical firing range	-
1.1.1.1.2.1	Have elevation adjustment in the minimum range of -7º to +16º	-
1.1.1.2.1	Have gyrostabilization	-

Table 5. Requirements of the gyrostabilized tower - dynamic part

Level	Requirements	Agent
1.1.5.1	Possess the ability to change the operation to degraded mode, either due to power failure or system failure, within 10 s (ten seconds)	Backup System
1.1.1.1.1.1.1	Have an amplitude equal to N x 360º	Rotation system
1.1.1.1.2.1.1	Have a minimum amplitude equal to -7º to +16º	Elevation system
1.1.1.2.1.1	Possess sensing for automatic correction of the cannon's superelevation and precession angles when it is inclined in relation to its transverse plane	Sensors
1.1.1.2.1.2	Have an independent inertial system	Inertial System

Based on established requirements, one Petri net was built to represent part of the system's operation. The result is in Fig. 10, with the description of the system's states in Tab. 6 and their transitions in Tab. 7.

Table 6. Description of Petri net places (systems' states)

Place	State
P0	Turret energized
P1	Turret positioned at set azimuth
P2	Primary weapon system positioned at set elevation
P3	Turret aiming the target
P4	Turret following the target (locked)
P5	Turret out of position (deviation)
P6	Turret following the target (ready to fire)
P7	Turret out of position (disturbance)

Using the automatic classification of the PIPE 2 software, the resulting network could be classified as: free-choice / extended free-choice network; and simple network/extended simple network.

As for the functional properties, an analysis of the state space of the network on screen was carried out, resulting in a safe, live network (without deadlocks or blocks) and reversible (that is, with the possibility of returning to the state initial). Markings in black and red were used in order to distinguish the two assisted operations (turning and lifting of the primary weapon system).

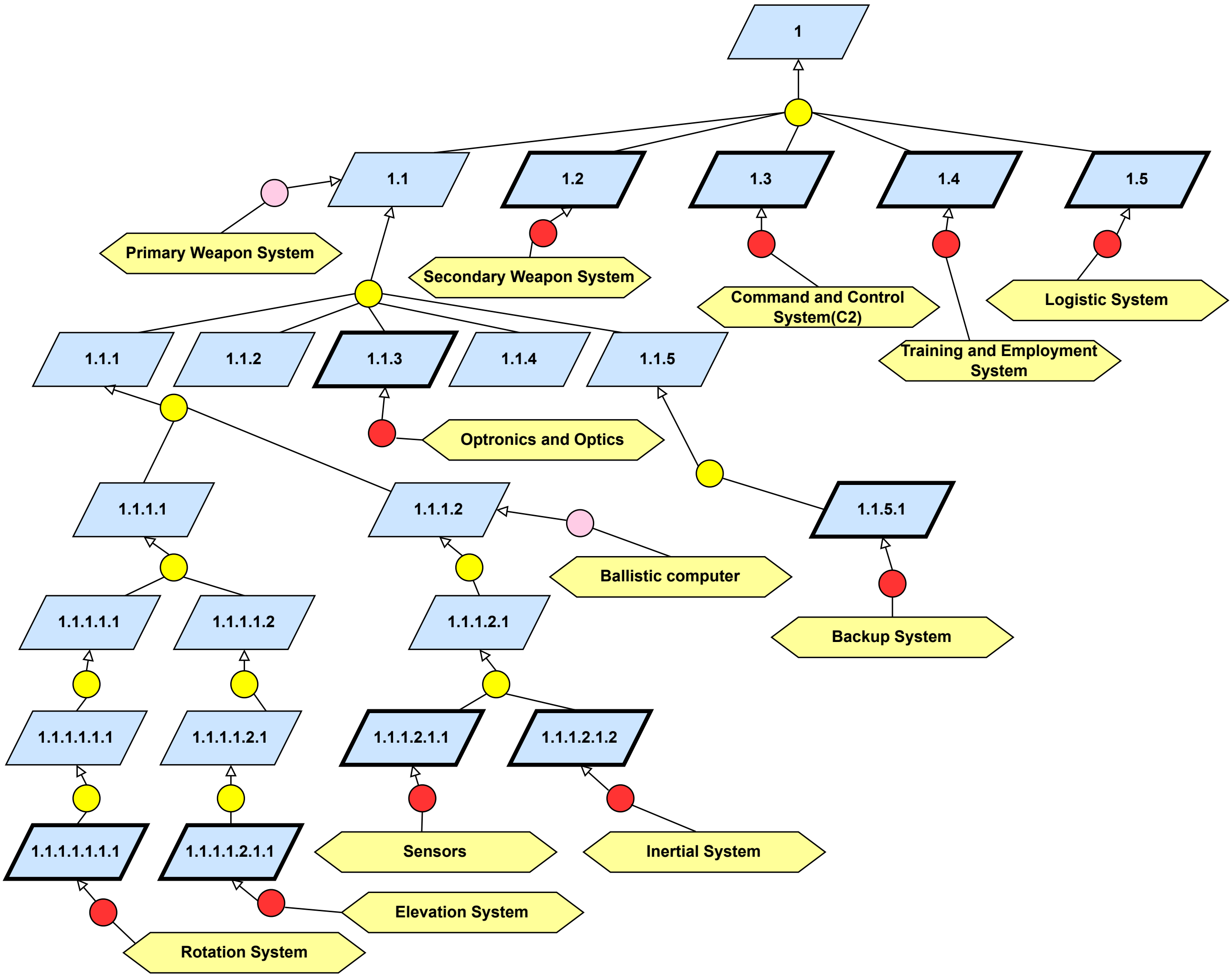

Figure 9. Gyrostabilized turret goal model

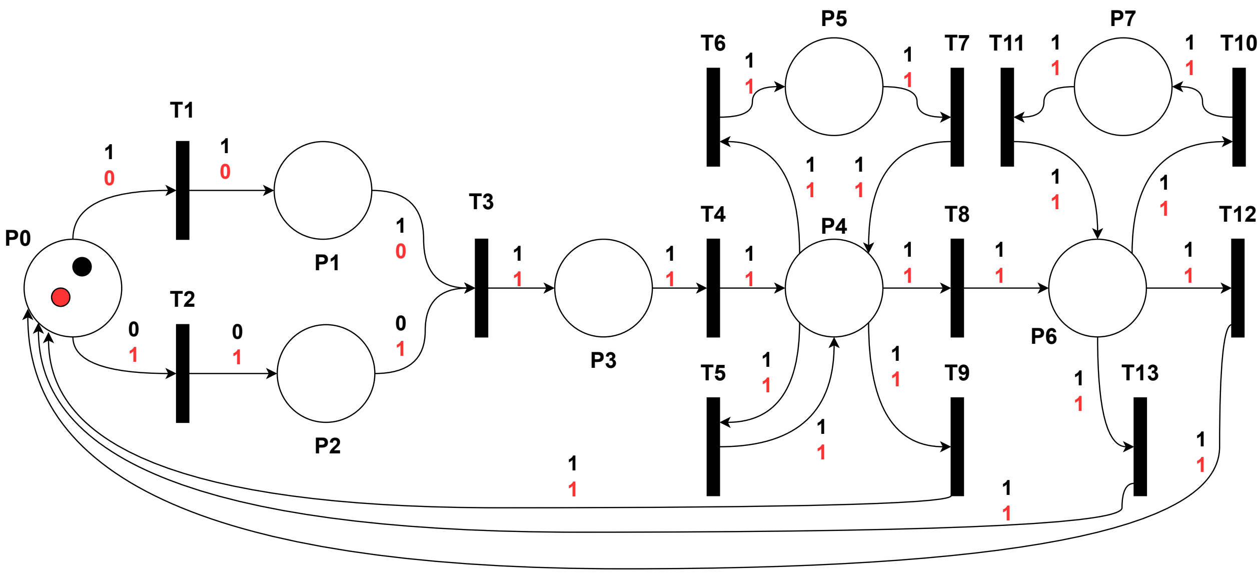

Figure 10. Gyrostabilized turret's petri net sample

Table 7. Description of Petri net transitions (events)

Transition	**Event**
T1	Activate rotation
T2	Activate elevation
T3	Confirm position
T4	Identifies and collects data from the target/environment
T5	Accidentally pressing the fire key
T6	External disturbances/vehicle dynamics
T7	AutoCorrect
T8	Allow shot
T9	Allow target
T10	External disturbance/vehicle dynamics
T11	Autotuning
T12	Abort target
T13	Trigger

6. CONCLUSION

This paper described a general composition of an armored vehicle and, in particular, the description of its turret.

The complex nature of the tower's composition was highlighted, consisting of several systems that together serve a common purpose.

The way in which the Brazilian Army deals with SMEM requirements is not adequate from a Systems Engineering's perspective. Based on the public documents related to the VBC Cav - MSR, it was possible to notice the horizontal categorization of the "requirements" (in the way it is defined by the Brazilian Army). Thus, it is not possible to notice how one requirement affects another or its relationship with the system's social goal. This makes harder to see the possible conflicts between the specifications. Furthermore, it makes the system design process more difficult, in addition to being able to delay it, as any conflicts will only be seen during this phase.

Otherwise, the use of KAOS allowed a logical visualization between the specifications contained in those documents, resulting in the true requirements (from the perspective of Systems Engineering). Other objectives were added in order to put the considered system in its real context and those problems were mitigated with such an approach.

A Petri net was elaborated to formalize the operation of the gyrostabilized tower of the VBC Cav - MSR, based on the system's requirements defined in the goal model. This approach approximates the phase of elaborating the system requirements with the phase of its design, since the solid mathematical basis of Petri nets allows them to be used, for example, to formalizing requirements and for modeling control systems.

Finally, new studies can be carried out with the aim of generating standards for the Brazilian Army based on the proposal presented in this paper, adopting KAOS to generate requirements and Petri nets to formalize and validate them. Another possibility for future research is the evaluation of the use of the theory of Discrete Event Systems (SED) for the improvement of possible previous norms, in the sense of building the system's control logic based on the validated Petri Nets.

7. REFERENCES

Brasil, 2013. *Portaria nº 176 - EME, de 29 de agosto de 2013. Aprova as Normas para Elaboração, Gerenciamento e Acompanhamento de Projetos no Exército Brasileiro (EB20-N-08.001), 2ª Edição, 2013 e dá outras providências.*

Brasil, 2019. "Plano estratégico do exército 2020-2023". URL `http://www.ceadex.eb.mil.br/images/legislacao/XI/plano`$_{e}strategico_{d}o_{e}xercito_{2}020-2023.pdf$.

Brasil, 2021a. *Portaria-EME/C Ex nº 454, de 20 de julho de 2021. Aprova os Requisitos Técnicos, Logísticos e Industriais da Viatura Blindada de Combate de Cavalaria – Média Sobre Rodas (VBC Cav - MSR) (EB20-RTLI-04.076), 1ªEdição, 2021.*

Brasil, 2021b. *Portaria-EME/C Ex nº 455, de 20 de julho de 2021. Aprova os Requisitos Operacionais da Viatura Blindada de Combate de Cavalaria – Média Sobre Rodas (VBC Cav - MSR) (EB20-RO-04.067), 1ªEdição, 2021.*

Brasil, 2022. *Portaria - C Ex nº 1.885, de 5 de dezembro de 2022. Aprova as Instruções Gerais para a Gestão do Ciclo de Vida dos Sistemas e Materiais de Emprego Militar (EB10-IG-01.018), 2ª Edição, 2022, e dá outras providências.*

Clouter, R. and Hutchison, N., 2022. "The guide to the systems engineering body of knowledge (sebok)". *The Trustees of the Stevens Institute of Technology*, Vol. 2.6. URL `www.sebokwiki.org`.

Consortium, I.O.M., 2023. "Centauro ii". URL `https://www.iveco-otomelara.com/wheeled/centauro8x8.php`.

Gamers, A., 2017. "Anatomy of a tank in world of tanks". URL https://ag.hyperxgaming.com/article/5256/anatomy-of-a-tank-in-world-of-tanks.

Heaven, W. and Finkelstein, A., 2004. "A uml profile to support requirements engineering with kaos". Vol. 151, pp. 10–27.

Lapouchnian, A., 2005. "Goal-oriented requirements engineering: An overview of the current research". *University of Toronto*, Vol. 32.

McManus, J. and Wood-Harper, T., 2008. "Understanding the sources of information systems project failure (see bcs www.bcs.org/content/conwebdoc/19584)". *ITNOW*, Vol. 51, pp. 38–43.

Murata, T., 1989. "Petri nets: Properties, analysis and applications". *Proceedings of the IEEE*, Vol. 77, No. 4, pp. 541–580.

NASA, 2007. *Systems Engineering Handbook (e-book)*. 1st edition.

Respect-IT, 2007. "A kaos tutorial". URL http://www.objectiver.com/fileadmin/download/documents/KaosTutorial.pdf.

Salmon, A.Z.O., 2017. *Modelagem e análise de requisitos de sistemas automatizados usando UML e Redes de Petri.* Ph.D. thesis, Universidade de São Paulo.

Shevchenko, N., 2021. "Requirements in model-based systems engineering (mbse)". URL https://insights.sei.cmu.edu/blog/requirements-in-model-based-systems-engineering-mbse/.

Van Lamsweerde, A., 2009. *Requirements engineering: From system goals to UML models to software*, Vol. 10. Chichester, UK: John Wiley & Sons.

Werneck, V.M.B., Oliveira, A.d.P.A. and do Prado Leite, J.C.S., 2009. "Comparing gore frameworks: i-star and kaos." In *WER*.

8. RESPONSIBILITY NOTICE

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