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METHODOLOGY FOR ASSESSING THE EFFECTIVENESS OF THE AIR DEFENSE SYSTEM

Abstract. This academic article introduces a pioneering methodology for the comprehensive assessment of air defense systems, addressing existing shortcomings in evaluation approaches. The **subject of this study** revolves around the development and implementation of an advanced methodology for assessing air defense systems. **The primary aim is** to rectify existing evaluation shortcomings by introducing a holistic model that significantly enhances both efficiency and effectiveness in the evaluation of air defense systems. This methodology incorporates critical elements such as system description, mission, objectives, combat environment, threat, and concept. By explicitly considering factors like system flexibility, survivability, and operational concepts, the study surpasses traditional evaluations, providing a nuanced understanding of the capabilities inherent in air defense systems. The methodology places particular emphasis on the importance of threat analysis, addressing uncertainties related to enemy forces and tactics. Additionally, the study introduces an innovative evaluation model employing tactical scenarios to assess system reliability, availability, and durability, integrating combat environment factors and potential adversary combat options. The research contributes to the academic discourse by providing a systematic and thorough approach to air defense system evaluation, tailored to the complexities of modern warfare and in alignment with the evolving military and technological landscapes. The article suggests avenues for future research to delve into nuanced criteria selection and aggregation methods, aiming to further refine the proposed evaluation methodology.

Keywords: air defense, system, effectiveness, evaluation, concept.

Introduction

Air defense systems play a pivotal role in safeguarding airspace and critical assets from an array of aerial threats including aircraft, missiles, drones, and other airborne platforms. Despite their significant evolution, these systems encounter persistent difficulties, limitations, and challenges [1]. Air defense systems demand meticulous design and management, necessitating a broad operational scope, integration of cutting-edge technologies, robust cybersecurity protocols, and ample resources to sustain continual readiness and effectiveness. This has been a consistent concern in recent literature [2]. Strategic air defense planning, accompanied by effective training programs and sound management practices, becomes imperative to mitigate vulnerabilities commonly associated with air defense systems.

Before delving into the concept of air defense system effectiveness, it is essential to elucidate the distinctions between efficiency and effectiveness. As per P. Drucker's insights, efficiency denotes "doing things right," while effectiveness signifies "doing the right things" [3]. Efficiency is quantified by the ratio of effects to costs, reflecting the precision in execution, whereas effectiveness gauges the extent to which objectives are accomplished.

Literature review. In this context, the effectiveness of an air defense system is gauged by its capability to fulfill predefined objectives and tasks within specific temporal and operational constraints. A myriad of methods exists for evaluating air defense system effectiveness, encompassing metrics like average fire

effectiveness, anti-aircraft defense effectiveness, combat activities effectiveness, interaction effectiveness, and airspace control system effectiveness found in technical and tactical literature.

One prevalent calculation method involves determining the efficiency index (E_{AD}) by comparing the average number of destroyed air targets (M_{AD}) to the expected number of targets (N_{EAV}) through the formula [4]:

$$E_{AD} = \frac{M_{AD}}{N_{EAV}} * 100\%, \quad (1)$$

where, E_{AD} is the efficiency index, M_{AD} represents air defense capability, and N_{EAV} is the number of air attack vehicles affecting protected objects.

Another method, endorsed by the US Weapons System Effectiveness Industry Advisory Committee, introduces the effectiveness as a product of availability (A), reliability (R), and capability (C), depicted by the formula [5]:

$$Effektiveness = A * R * C. \quad (2)$$

Here, availability hinges on the system's initial state, reliability mirrors the system's state during task execution, and capability outlines the system's adeptness to perform tasks under specified conditions.

Analyzing these methodologies reveals gaps in accounting for crucial air defense system features. The oversight in selecting the appropriate system, defining accurate criteria, or inadequately describing the operational conditions underscores the necessity for a systematic approach to address these aspects. The ensuing methodology is conceived in response to these considerations, aiming to offer a methodical and logical framework for a comprehensive assessment.

The analysis of these methodologies shows that some important features related to the air defense system are not taken into account during such assessment. Failure to select the appropriate system, correct criteria, or incomplete description of the conditions surrounding air defense system operations indicates the need for a systematic means of determining such aspects. The methodology proposed below arises from the need to pay attention to these considerations and is intended to provide a logical approach to them.

A new methodology for evaluating the effectiveness of the air defense system

A novel methodology is proposed to assess the effectiveness of air defense systems, utilizing system effectiveness as a criterion for comparing alternative systems. The efficacy of a military system is often measured by the degree of success anticipated in achieving its goals. However, as system effectiveness is inherently challenging to gauge qualitatively, the need arises for a quantitative expression to precisely define it. This necessitates the development of a model that encapsulates the pivotal elements influencing the system's effectiveness.

In the realm of air defense systems, critical key elements encompass "description," "mission," "target," "environment," "threat," and "concept." The clarity in defining the system for evaluation is of paramount importance, albeit occasionally challenging due to dependencies on subsystems, neighboring components, and parent systems. For instance, in evaluating an Air Defense division, the primary system may be the AD brigade, with its batteries serving as subsystems.

Systems are intricately designed to furnish interoperable functionality and often function as sub-components within larger systems. Anti-aircraft missile units, strategically positioned to ensure fire system integrity in case of unit failure, establish detection zones at varying heights, exchange vital information, and safeguard the system until readiness for subsequent firing in combat operations. Consequently, the imperative to

meticulously define the system for evaluation arises, steering clear of narrow subsystem descriptions that may lead to optimization challenges or overarching parent system descriptions that could yield misleading or impractical analyses.

The evaluation process mandates a clear definition of the system under scrutiny, accompanied by a comprehensive description of its mechanics, functionality, and operational procedures. Understanding the intricacies of how the system mechanically functions, serves its purpose, and is operated forms the foundation for a rigorous evaluation.

System description

Generally speaking, a system description is a section of a technical document or report that provides an overview of the system, its structure and components, and explains how it works [6]. It may also provide information about related systems and technologies used in conjunction with the main system. The initial phase of evaluating an air defense system involves identifying and delineating the system at the appropriate level. The selection of the system for evaluation necessitates careful consideration of whether the air defense means are deployed in localized conflicts or extensive air warfare scenarios directed towards strategic objectives.

Once the system is clearly defined and chosen, the subsequent step involves a detailed description, as exemplified in Fig. 1 for an air defense system. Factors such as vulnerability, resilience, and survival, while challenging to quantify precisely, play pivotal roles in articulating the system's characteristics. The vulnerability of the air defense system emerges as a critical element, given that enemy operations typically involve penetrating or neutralizing air defenses, necessitating countermeasures against electronic interference, damage, or destruction. Therefore, the system's vulnerability to electronic countermeasures, high-precision weaponry, anti-radar missiles, air-to-ground missiles, and conventional ammunition must be consistently considered.

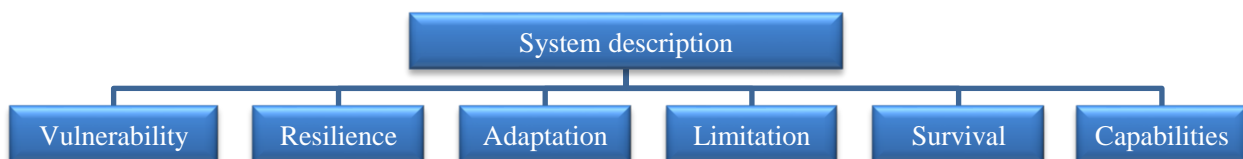


Fig. 1. System description

System flexibility is an integral aspect of its description, acknowledging that changes in tasks, locations, or operational modes have cascading effects on other factors, including capabilities and limitations.

Survivability, though subtle, constitutes a crucial component of the system description. The success or failure of a firing unit within the broader air defense system can exert a direct influence on the overall system's functionality. Key elements in system description encompass capabilities, limitation, and compatibility. In essence, these factors delineate the system's operational scope, limitations, and its integration into overall combat

operations. While combat capability stands out as a quantifiable and information-rich indicator, a comprehensive understanding requires simultaneous consideration of limitation and compatibility. System limitations, encompassing mission completion time, reload time, weather conditions, and combat resources, introduce measurability and realism into the system description. Although quantifying compatibility is more intricate than capabilities and limitation, it is a crucial factor defining the air defense system's ability to interact with ground and air combat assets effectively, emphasizing the need for efficient management, control,

and information exchange interfaces for individual firing units to fulfill assigned tasks.

Mission

A mission describes what the system will do and the purpose of doing it. The mission statement describes Kipling's "six honest serving-men" – who, what, when, where, why, and sometimes how. The mission provides the context for defining measures of effectiveness and for development of the Concept of Operations [7]. The mission of an air defense system constitutes a pivotal element in its effectiveness assessment, necessitating the translation of the system's mission into clearly defined objectives.

The complexity of multitasking can lead to an excessive number of system goals, creating challenges in decision-making processes. To discern the system's mission, it is imperative to initially establish a comprehensive concept of the system. Concept definition involves a meticulous examination of the needs and requirements within the problem area, incorporating general processes such as task analysis and consideration of stakeholder needs and requirements [8].

Task analysis, a method to distinctly identify the problem and available means to resolve it, encompasses activities such as delineating the system's goals and formulating the operational concept.

The determination of system objectives plays a crucial role in enhancing its effectiveness, demanding an analytical approach based on the best available information about warfare. The clarity and precision with which the mission is expressed directly influence the logical transformation of requirements into desired results. In the context of air defense systems, considering both air and surface combat requirements is essential to avoid the complications associated with multitasking.

Objectives, categorized in Fig. 2, are derived from various sources, including doctrine and considerations specific to the system's objectives and constraints. Doctrinal statements, such as those ensuring air defense within a unified AD system, provide a general framework applicable to air defense assessments [9]. Implicit and explicit requirements guide these objectives, ranging from explicit goals concerning enemy assets to veiled demands emerging from tactical shifts, such as terrain masking during deployment.

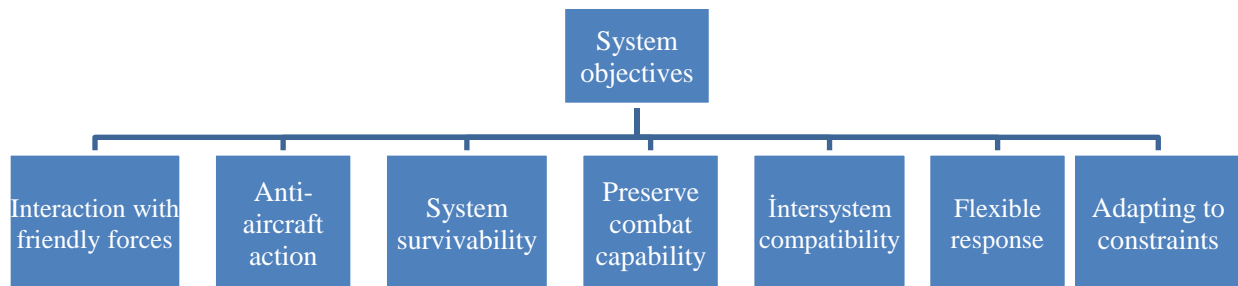


Fig. 2. Objectives of the system

Continuous combat readiness, a primary goal of system evaluation, comprises elements like system reliability, availability, and durability. The detailed analysis of combat-ready, weakened, and non-combat-ready firing units is more informative than a single figure reflecting the total number of assets.

The articulation of clearly stated objectives, coupled with a thorough definition and description of the system, establishes the foundational concept of effectiveness for evaluation. For instance, an air defense system tasked with protecting forces from enemy air attacks would evaluate its qualitative effectiveness based on the degree to which it safeguards forces and key facilities within its area of responsibility.

Considering the objectives of an air defense system underscores the requirement for its means to support both air and ground combat. The task of defending the homeland against air threats serves as a clear and precise organizational purpose, guiding the entire system development process. This requirement acts as a reference point for determining the suitability of the system's performance in fulfilling its mission.

Concept of operation

A concept of operation is a document that describes a proposed system concept and how that concept would

be operated in an intended environment [10]. The operational concept serves as a verbal and graphical representation of an organization's assumptions or intent regarding the operation of a system or a collection of related systems [11].

This concept aims to provide an overview of operations from the users' perspective, offering insights into the use of specific systems within an organization's operating environment.

In the context of the Air Defense System, the overarching goal is to defend the homeland by neutralizing the unwanted effects of enemy air attack means.

The operational concept can be visually represented in Fig. 3, where broken lines connect external objects that, while not direct components of the system, play crucial roles in its operation.

External Objects:

Air Threats: Encompassing the enemy's air and missile capabilities, this external object is pivotal in determining system requirements and directly influences task accomplishment.

Weather and Visibility Conditions: Despite sensitivity to weather, the air defense system must ensure continuous combat readiness, considering diverse weather conditions.

Operational Directives: Set at the political level, these directives dictate the capabilities required for the Air Defense System to fulfill its mission aligned with the country's political interests.

Naval Air Defense Assets: Though not direct components, these tools enhance the system's detection and destruction capabilities.

Internal Objects:

C4ISR: Concentrating command, control, management, surveillance, and intelligence functions, these tools facilitate effective coordination and decision-making among system objects.

Radars: Emphasizing the key capability of detection, these tools are crucial for tracking and neutralizing potential threats, ensuring the system fulfills its mission.

Fighter Aviation: Providing essential information about detected unknown objects, fighter aviation determines the threat level and can engage in combat activities against air targets.

SAM Systems: Highly effective in destroying both manned and unmanned aerial vehicles, including cruise missiles, these systems require strategic repositioning and have limitations in addressing unknown targets.

Air Defense Units of the Troops: Equipped with anti-aircraft artillery and portable missiles, these units protect troops from direct air threats.

The operational concept unfolds as follows: the initial step involves detecting potential air threats under any weather or visibility conditions. Upon detection, command posts are activated, referencing operational directives to counter the threat effectively. If the identified target is confirmed as an enemy, it can be neutralized using anti-aircraft missiles or artillery. If additional information is needed for target identification, fighter jets are deployed, and if necessary, the target is destroyed.

This systematic approach ensures a comprehensive response to potential air threats, aligning with the mission of defending the homeland.

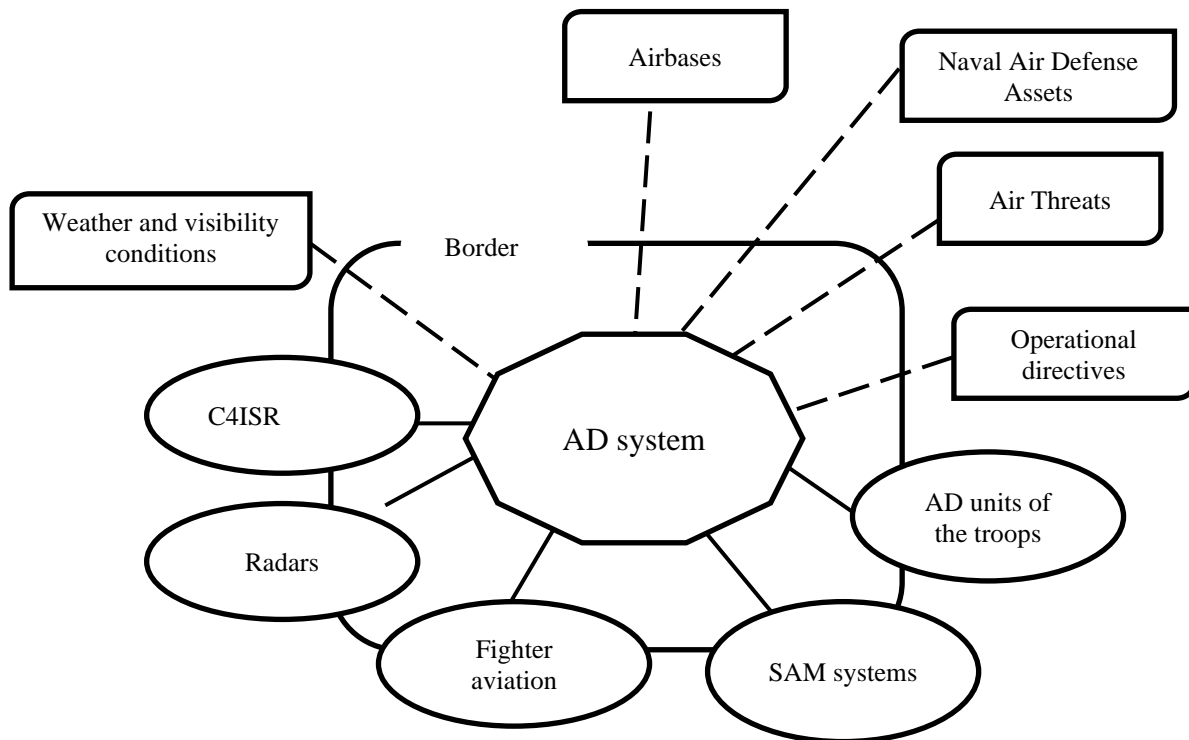


Fig. 3. Operational concept of AD system

Threat

In evaluating system effectiveness, a precise articulation of threats is pivotal. Threats are elements surrounded by uncertainty, grounded in intelligence but necessitating judgment regarding feasibility. Clear threat definition involves considering the enemy's target forces and tactics, forming the primary components of the tactical scenario essential for assessment (Figure 4).

The air defense system utilizes a threat tactical scenario to devise countermeasures, assessing its capability to safeguard protected objects. While multiple elements contribute to threat development, they can generally be classified within the components of Fig. 4.

Target Objectives:

Determining where and how to neutralize air defenses or navigate strong defense points through indirect approaches, assessing the enemy's objectives involves acquiring sufficient information. Factors such as target priority, desired damage level, maximum acceptable attrition, and the enemy's influence on operations are crucial for accurate assessment.

Force Data:

Dependent on the selected system's rating level, force data encompasses the enemy's combat capability, battle formation, and organization-staff structure. This information is vital for anticipating possible threat situations.

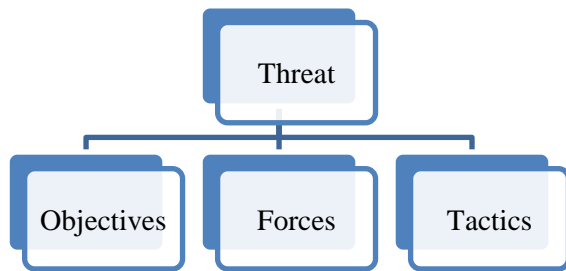


Fig. 4. Threat factors

Tactics:

Tactics play a significant role in defense assessment against air attacks, particularly concerning protected objects. Understanding the enemy's tactics and their rules of application is essential. War games can aid in determining which combat methods and tactics merit consideration.

Threat clarification for assessment combines objective, force, and tactics, translating into the enemy's flight profile, attack method, and approach directions. These elements are integrated into assessment models, transforming information into a series of combat options that the system must contend with, judge, and quantify. This process contributes to developing an operational definition of system effectiveness.

For an air defense system designed to protect objects, the enemy's intent might be air bases, headquarters, etc.

The effectiveness of the air defense system is contingent on quantifying information such as approach paths, flight profiles, aircraft types, and target priorities. When incorporated into a tactical scenario, the enemy's battle tactics emerge, providing a comprehensive evaluation of the Air Defense system.

Combat environment

In the evaluation of air defense system effectiveness, a crucial requirement is the comprehensive analysis of the combat environment. This assessment is pivotal for two primary reasons. Firstly, understanding the combat environment, coupled with the system description, enables the determination of the combat readiness state.

The environment, with its components such as weather, jamming, and terrain, exerts a profound influence on the system's condition. Secondly, the combat environment, alongside force and task considerations, serves as a fundamental element in shaping the tactical scenario that underpins the assessment process. Numerous elements contribute to the combat environment, logically falling into categories depicted in Figure 5. While military-economic factors are typically established at a level beyond direct assessment, their impact can be substantial in the evaluation.

As the focus narrows on the combat environment, weather and terrain emerge as primary considerations due to their significant effects on camouflage, mobility, and the performance degradation of systems in adverse weather conditions. Evaluating electronic countermeasures (ECM) and anti-radiolocation missiles

(ARM) necessitates distinguishing whether they originate from air or surface means.

In a scenario where adversaries capable of mounting effective air attacks are present, it is implausible for them to risk expensive and modern aircraft in an environment lacking tactical efficiency.

Therefore, if Air Defense systems are engaged in combat, it must be assumed that the adversary will employ electronic countermeasures and anti-radar missiles extensively. The evaluation of the Air Defense system must align with this assumption, intricately incorporating it into the development of the combat environment.

Evaluation process

In evaluating the effectiveness of an air defense system, a robust evaluation model is essential, employing a tactical scenario to operationally ascertain the system's capabilities. This scenario delineates what should be observed, the conditions under which observations occur, and the requisite operations. The assessment of system effectiveness must encompass how observations are made, measured, and managed. By amalgamating the results of the assessed tactical scenario with selected effectiveness criteria, a comprehensive evaluation of the system's effectiveness is achieved. The tactical scenario results can be derived through parametric analysis, system indices, deterministic or stochastic models, as well as analyst or user judgment.

Fig. 6 visually outlines the integral elements of the assessment process, where the system description, operational concept, and combat environment collectively shape potential combat readiness situations.

The combat environment, coupled with threat information, generates a spectrum of adversary combat options for system testing. Parameters like reliability, availability, and durability are derived from states of combat readiness, influenced by the enemy's warfare methods to determine the system's reliability.

As an illustrative example, consider a combat operation involving air defense, ground forces, and fighter aircraft countering enemy air strikes. The tactical scenario unfolds with ground troops in a defensive zone, air defenses in combat positions, and fighter aircraft ready on the runway. The objective is to protect objects, while the enemy aims to destroy selected targets using a low flight profile.

The combat environment is simplified (no electronic countermeasures/anti-radar missile application). Assuming all systems are combat-ready, the tactical scenario progresses, evaluating combat operations using various assessment models. These models assess target detection, tracking, identification, decoy, and other elements. The evaluation includes reports detailing subsystems neutralized or destroyed, surviving assets, system damage, enemy air attack assets' status, and other criteria describing combat operations.

Returning to the example, if the enemy shifts tactics due to pressure from air defenses, achieving medium-altitude profiles, and coordination with fighter aircraft results in successful interaction, the air defense system's effectiveness is demonstrated.

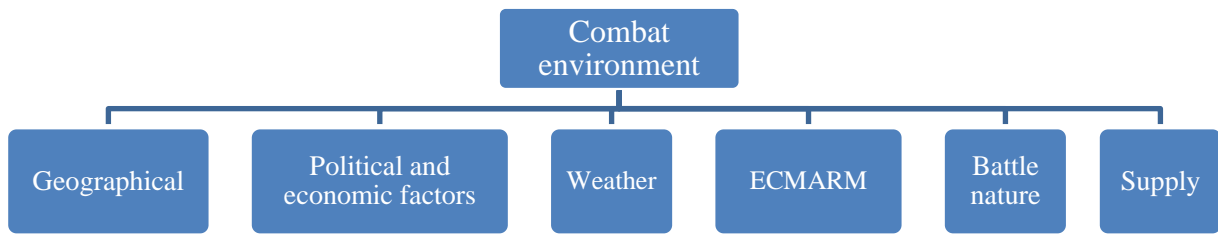


Fig. 5. Combat environment

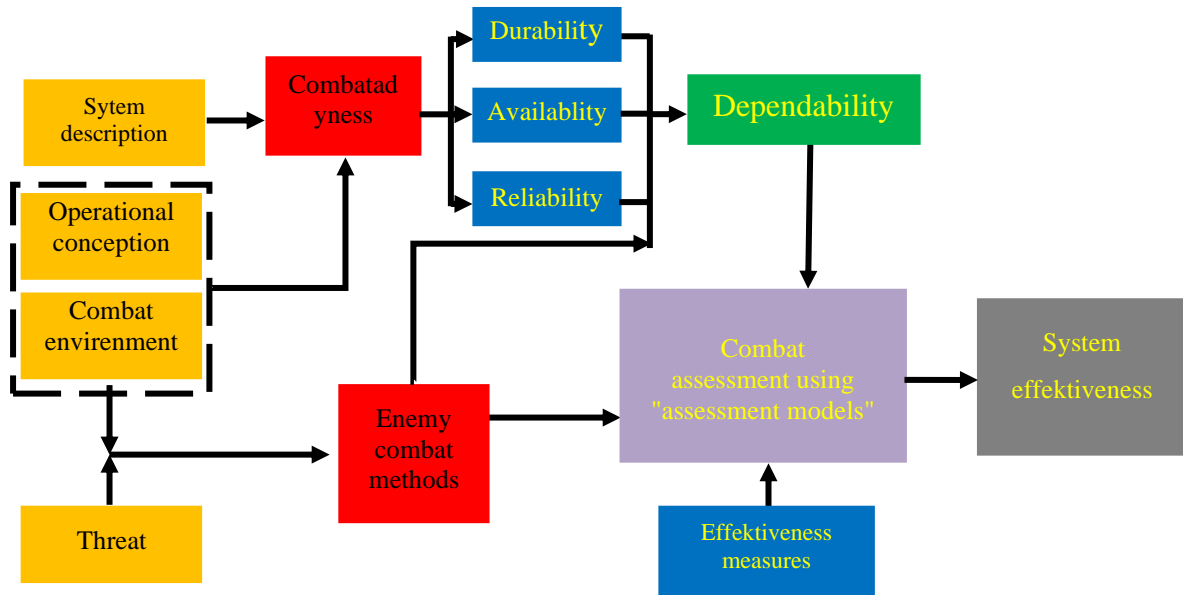


Fig.6. Evaluation model

The combat assessment yields quantitative information supporting the system's evaluation objectives.

Effectiveness criteria selection is pivotal in the evaluation, reflecting the degree of goal achievement. Choosing measures that accurately depict the system's effectiveness is particularly crucial in evaluating air defense systems, considering the potential for multiple effectiveness criteria.

Therefore, a careful selection of measures is imperative to accurately gauge the evaluated system's effectiveness accurately depict the system's effectiveness is particularly crucial in evaluating air defense systems, considering the potential for multiple effectiveness criteria. Therefore, a careful selection of measures is imperative to accurately gauge the evaluated system's effectiveness.

Combat assessment can include a number of assessment models that assess target detection, tracking, identification, decoy, and other elements of combat operations [13-15]. These models might be Monte Carlo Simulation Models, Mathematical Models for Sensor Performance, Recognition Models, Electronic Warfare Models, Battlefield Simulation Models, Operational Analysis Models, C4ISR Models [16-18].

Conclusion

In the contemporary landscape of air defense systems, measuring effectiveness solely through the destruction of the enemy's air attack means for mission

accomplishment is deemed inadequate. Alternative approaches include dissuading the enemy from executing the task, compelling the utilization of unfavorable attack profiles, or prompting fewer impact strikes.

Another avenue for establishing performance criteria involves summarizing or weighting them based on their significance.

While a single criterion poses no challenge, the presence of multiple efficiency criteria necessitates determining the most crucial ones for gauging system effectiveness. This decision, often made by assessors, can benefit from expert opinions, consultation with decision-makers on prioritized actions, or the application of a decision matrix.

In determining the overall system effectiveness, it is prudent to devise an efficiency function offering a measure of system effectiveness for comparison among alternatives.

Formula 2 could yield the desired outcome if the system is defined as a unit of fire. However, if the system encompasses an Air Defense combination or operates at the operational level, assessing effectiveness involves considering the defense in the combat environment, the adversary, and their interactions through comprehensive effectiveness criteria.

Evaluations at general levels tend to be intricate, requiring the careful selection, aggregation, and combination of key performance criteria with combat evaluation data to furnish a reliable indication of system effectiveness.

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Методика оцінки ефективності системи протиповітряної оборони

Ельшан Гашимов, Ельнур Худейнатов

Анотація. Ця наукова стаття представляє новаторську методологію всебічної оцінки систем протиповітряної оборони, усуваючи наявні недоліки в підходах до оцінки. **Предметом цього дослідження** є розробка та впровадження вдосконаленої методології оцінки систем протиповітряної оборони. **Основною метою** є усунення існуючих недоліків оцінки шляхом впровадження цілісної моделі, яка значно підвищує як ефективність, так і результативність оцінки систем протиповітряної оборони. Ця **методологія** включає важливі елементи, такі як опис системи, місія, цілі, бойове середовище, загроза та концепція. Завдяки чіткому розгляду таких факторів, як гнучкість системи, живучість і експлуатаційні концепції, дослідження перевершує традиційні оцінки, забезпечуючи детальне розуміння можливостей, притаманних системам ППО. Методологія приділяє особливу увагу важливості аналізу загроз, розглядаючи невизначеності, пов'язані з силами та тактикою противника. Крім того, у дослідженні представлена інноваційна модель оцінки, яка використовує тактичні сценарії для оцінки надійності, доступності та довговічності системи, інтегруючи фактори бойового середовища та потенційні бойові варіанти супротивника. **Дослідження сприяє** науковому дискурсу, забезпечуючи систематичний і ретельний підхід до оцінки системи протиповітряної оборони, пристосований до складнощів сучасної війни та у відповідності до еволюції військових і технологічних ландшафтів. У статті **пропонуються шляхи для майбутніх досліджень**, спрямованих на вивчення нюансів вибору критеріїв і методів агрегування, з метою подальшого вдосконалення запропонованої методології оцінювання.

Ключові слова: ППО, система, ефективність, оцінка, концепція.