CHAPTER 1

Current state of automated control systems for field artillery combat employment in condition diagnostics

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Abstract

This chapter provides a comprehensive overview of automated artillery command and control systems (ACS) for field artillery at the tactical level, emphasizing their role in condition diagnostics and adaptive fire management.

The theoretical foundations of information and control systems are analyzed, including mathematical modeling, algorithmization of military tasks, and integration of hardware-software components.

International experience in the design and implementation of field artillery ACS, including systems such as TACFIRE (Tactical Fire Direction System) (USA), ADLER (Artillery Data, Location and Evaluation/Reconnaissance system) (Germany), and BATES (Battlefield Artillery Target Engagement System) (United Kingdom), is examined.

Special attention is given to the structure, functionality, and performance metrics of ACS, highlighting the importance of real-time verification of the artillery firing cycle, Multiple Round Simultaneous Impact (MRSI), and "shoot and scoot" tactics.

The chapter also discusses the principles of modern information and communication infrastructure, operational efficiency, and resilience of ACS under complex combat conditions, providing a methodological basis for future development of high-performance automated artillery systems.

Keywords

Automated command and control systems, field artillery, fire control, tactical-level operations, information and communication infrastructure, multiple round simultaneous impact.

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1.1 Introduction

Modern research in technical and engineering systems increasingly relies on the integration of heterogeneous measurement channels, advanced data analysis methods, and computational modeling approaches. Across various domains, such as energy systems, robotics, materials science, and process engineering, the combination of empirical measurements with analytical and numerical models has proven effective in describing nonlinear dynamic phenomena under conditions of uncertainty and incomplete information [1, 2]. Techniques such as parameter identification, inverse problem solving, approximation models, and library-based process simulations are widely applied to ensure accurate assessment of system states, real-time monitoring, and predictive control [3–5].

Recent studies emphasize the universality of these approaches: methods originally developed for modeling combustion, energy transformations, or reactive material processes have been successfully adapted to contexts ranging from industrial automation to sensor-driven diagnostics [6, 7]. The use of multiple measurement channels – acoustic, optical, thermodynamic, and mechanical – combined with signal processing and data fusion techniques enables the extraction of informative indicators characterizing complex processes [8]. This multidisciplinary framework supports decision-making under dynamic conditions, allowing systems to respond adaptively to disturbances and maintain operational performance [9]. Moreover, practical applications in distributed and modular control systems demonstrate the importance of hierarchical architectures, automated decision algorithms, and optimization of computational resources for both real-time operation and predictive maintenance [10]. The integration of such methods across heterogeneous domains highlights their applicability for monitoring, verification, and evaluation of complex technical processes.

Within this context, the present chapter focuses on tactical-level artillery ACS. The chapter examines methods for planning, support, and control of artillery fire under dynamic combat conditions, emphasizing the verification of system states, optimization of resource allocation, and adaptation to disturbances in real time. By drawing on principles demonstrated in diverse technical fields, the approaches presented aim to enhance both the accuracy and responsiveness of artillery fire control.

1.2 Fundamentals of information and control systems for solving artillery tasks

In the U.S. military doctrine, considerable attention is devoted to the concept of achieving information superiority over a potential adversary in the twenty-first century [11]. The practical implementation of this concept involves creating conditions under which military formations at various levels gain an advantage in assessing the tactical situation and making decisions regarding the achievement of assigned objectives, the execution of fire missions, and the support of combat operations. This advantage is achieved through the rapid collection, processing, and transmission of intelligence and other operational-tactical information.

An important role in achieving such superiority is assigned to the extensive use of advanced methods and mathematical models of states and processes, technical means of information support, and artificial intelligence systems that ensure the adaptive evolution of successive generations of automated control systems at different levels [12]. Information superiority is achieved through the formation of an information space created by combining centralized and network-centric mechanisms for informing operational units, with a leading role assigned to service-oriented mechanisms for providing requested data. The network-centric and service-based principles of information access embedded in such systems transform each operational element of a military formation into an information-strike or information-fire complex [13], as well as into an information-based reconnaissance-strike element.

Thus, the U.S. Army is developing fundamentally new technologically advanced land forces through the design and deployment of weapons and military equipment that employ information and control technologies. This process, known as digitization, involves the use of digital components in the development of advanced weapons and military equipment associated with the acquisition, exchange, and optimal use of intelligence data across all domains of the battlespace operating within a unified information environment [14].

The current stage in the development of digital technologies in the military domain can therefore be considered a phase of automation of computer-integrated military technologies, which objective is the creation and application of automatic and automated control systems of varying complexity within a unified information environment.

Research on computer-integrated technologies for conducting combat operations is based on the development of mathematical methods for analyzing combat activities and on defining criteria and rules for the effective control of troops and weapons. In this context, the primary task is the formation of methods and rules for optimizing managerial decisions made by the commander.

The methodological foundation of computer-integrated military technologies is formed by several interrelated theoretical directions.

The theory of information processing for military applications develops optimal methods and models for the acquisition, transmission, collection, storage, and processing of information in order to ensure its reliability, noise immunity, and confidentiality under existing constraints.

The theory of algorithmization of military tasks and command-and-control processes is intended for the development of methods for forming relationships and interactions in the course of armed conflict, as well as for creating methods for the functioning of military organizational and technical decision-support systems.

The theory of military automated control systems aims to establish principles for the design and analysis of various types of automated systems for troop command and weapon control, as well as for their automation and optimization of operation. Due to the necessity of making decisions in combat conditions with incomplete or partially unreliable information, there emerged a need to develop special methods for generating decisions, which reliability under such conditions must be maximized [14]. Particular attention is therefore devoted to the problem of assessing the quality, timeliness, and completeness of the operational and tactical information used [15].

The information resources of computer-integrated systems are intended to ensure reliable assessment of the situation, the state of the battlefield, weapons, and personnel, as well as to reveal the operational intentions of opposing sides from the perspective of organizational and technical systems.

The application of mathematical models and methods in computer-integrated systems makes it possible to integrate developed functional and information models into automated control systems, thereby enabling command personnel to make decisions within the services of the information environment associated with military-technical, operational-tactical, and military-logistical components [16].

The successful application of mathematical methods and models is closely related to the development of technical means of automation, computational mathematics, and programming for automated weapon control. The tasks of weapon control include the development of fundamental principles of automation, the creation and implementation of specialized devices for the collection, transmission, processing, storage, and visualization of information, as well as the determination of the optimal distribution of functions among operators, automated control systems, and weapons (control objects). The practical achievements of automation and military computer-integrated technologies in the control of tactical-level artillery units have been manifested in the creation of automated fire control complexes [17].

Practical experience in implementing ACS and computer-integrated control systems for military purposes in the armed forces of countries outside NATO has revealed a range of technological, technical, and organizational-economic contradictions [18–20].

First, there are organizational inconsistencies associated with the absence of a unified technical policy for the informatization of the armed forces, as well as with software and information incompatibility between existing systems and those currently under development. Second, economic inconsistencies arise in the form of duplicated developments and unjustified urgent procurements of imported equipment that require additional specialized studies. Third, technological inconsistencies are related to the limited capabilities of available computing equipment and the relatively low level of the accessible component base.

To understand these contradictions, it is advisable to consider how the informatization and automation of artillery units in non-NATO countries are expected to be implemented. It is necessary to develop a methodology for implementing this complex multi-stage process, which should encompass all levels – from individual samples of weapons and military equipment and personal computing devices to full-scale automated control systems. In the practice of developing large automated control systems, it is generally accepted that the transition to the next, higher level of automated control should occur through the integration of all means of the previous level into a unified system (the "bottom-up" strategy).

The concept of an information and communication infrastructure is proposed as the basis for this approach, although the term is widely used today without a precise definition [21]. The information and communication infrastructure of a military formation can be defined as the set of technical and software means, organizational units, and service facilities that perform all information, telecommunications, and supporting processes required to ensure the functioning of headquarters, services, and operational units.

Particular attention is given to the concept of information technologies, which reflects the contemporary tendency toward the convergence of the notions of automation and informatization in the context of tactical-level artillery. This tendency is explained by the large volume of information that must be collected and processed in order to effectively accomplish the tasks of informatizing the control of artillery combat operations at the tactical level. Using general definitions [22], an information and control technology for special purposes may be defined as a technology organized as a structured set of computing hardware, communication facilities, software tools, and the databases employed. The specific characteristics of such technologies include the need for data and software protection, strict time constraints, and operation by users under conditions of high workload.

At each level of informatization and automation of tactical-level artillery, interaction occurs during the execution of relevant combat tasks under the following conditions:

– reconnaissance activities aimed at collecting information about the enemy, involving the acquisition and synthesis of intelligence data on the state of opposing forces in order to support decisions on their fire engagement;

– decision-making processes that reduce uncertainty and influence the conduct of combat operations;

– control and assessment of the results of fire engagements.

The concept of an information and communication infrastructure for a military formation, intended to support the informatization and automation of tactical-level artillery, is based on the results of research and development in the following areas [14]:

– acquisition of information about friendly forces, atmospheric conditions, and topogeodetic parameters;

– selection of information processing means for each level of command and decision-making;

– selection of high-speed and secure information transmission means;

– organization of reliable information storage and retrieval in relevant databases;

– development of methods for extracting information from reconnaissance results, including the timely detection of the enemy, determination of the coordinates of detected enemy objects, procedures for additional reconnaissance of targets, and control of the results of their engagement;

– development of decision-support methods for optimal planning of the employment of guided artillery projectiles;

– development of automated control systems for various tactical-level artillery units;

– development of methods and means for integration with higher- and lower-level information and control systems.

The concept of an information and communication infrastructure of a military formation, or information environment, has made it possible to reconsider the previously used notions of automation and integrated automation. These concepts may therefore be formulated as follows.

Automation is the process of applying a set of technical, software, and other tools and methods in order to fully or partially relieve the operator from direct participation in the processes of acquisition, transmission, storage, processing, and use of materials, resources, and information in the execution of control tasks. These tools include devices, installations, complexes, and systems [12].

Integrated automation is the process of creating and widely implementing practical automation tools combined into integrated control systems. At the stage of combat operations within organizational and technical systems, integrated automation is understood as the broad and comprehensive introduction of informatization methods and tools into the process of solving command-and-control tasks.

The experience of local wars and armed conflicts has shown that the requirements for achieving information superiority in modern armed forces cannot be fulfilled without the implementation of advanced information and control technologies. Therefore, attention must be directed toward solving a dual task: the development of intelligent automated control systems for troops and weapons, and the training of specialists capable of effectively operating such systems. The operation of these systems requires personnel who are well versed in operational art, tactics, and the combat employment of different branches of the armed forces, who possess skills in mathematical modeling, and who are familiar with the fundamentals of automatic control theory, systems theory, systems analysis, operations research, and decision-making theory. In addition, such specialists must have deep knowledge in the field of information technologies and be able to apply these competencies in combat operations.

From the presented material on the fundamentals of information and communication infrastructure and information and control infrastructure, it follows that automated control systems designed for solving artillery tasks are based on the concept of an operation, understood as an interrelated and ordered set of methods implemented over time and distributed in space, combined within a unified technological (combat) algorithm. The sequence of actions depends on the available resources and is aimed at engaging detected targets according to their operational significance. Any automated control system, including those for troop and weapon control, implies that the achievement of the operation's objective is ensured through a set of technical means consisting of control objects, control systems, and operating personnel (operators and service specialists) integrated into a unified organizational and technical system. Hereafter, the organization of an operation will be understood as the selection, from the considered set, of such values of parameters and elements of the organizational and technical system that determine the resulting outcome. An organizational and technical system will be defined as a hierarchical human-machine complex that purposefully functions to realize its inherent capabilities in accordance with its intended purpose.

1.3 Special-purpose automated control systems for tactical-level artillery

The main objectives of research on ACS are the analysis and synthesis of automation tools at all hierarchical levels associated with the planning, support, and control of artillery fire. The relevance of addressing these tasks is due to the fact that artillery combat operations are characterized by exceptionally complex conditions under which the control of fire engagement between opposing forces is carried out [23]. A fire control system represents an organized set of functionally interconnected command posts, communication systems, automation facilities, and specialized systems that ensure the collection, processing, storage, and transmission of information. In a number of existing fire control systems, significant shortcomings have been identified, including excessive centralization of control and low efficiency in generating well-grounded recommendations for operational decisions concerning the execution of fire missions within automated fire control complexes.

It should be noted that automated fire control complexes used in countries outside NATO do not comply with NATO standards. The fire potential of such units is supported by automated fire control complexes at only about 60% of their capabilities, and this level can be achieved only under the condition of reliable functioning of reconnaissance assets, electronic warfare systems, and comprehensive support of combat operations [18].

With the advancement of automation tools for controlling fire engagement, it becomes necessary to expand the capabilities of specialized mathematical and software support of automated fire control complexes, both in solving planning and support tasks and in controlling fire engagement during combat operations. A benchmark in this regard may be the level of automation achieved in the AFATDS system (Advanced Field Artillery Tactical Data System) (USA), which reaches approximately 90–95%. At present, the following directions for further development and improvement of automated control systems can be identified:

– the use of computer technologies at all levels of command to ensure that the majority of tasks are solved in real time;

– the installation on self-propelled artillery systems of individual automated systems for topogeodetic positioning, orientation, restoration of horizontal aiming, and automation of firing processes;

– the expansion of artillery reconnaissance capabilities through the use of unmanned aerial vehicles for fire correction and millimeter-wave radar systems;

– ensuring interaction with real-time reconnaissance assets through communication channels based on different physical principles of signal transmission.

The issue of optimally designing control complexes to ensure their maximum operational effectiveness remains highly relevant and requires continued research at an advanced level in this field. One of the primary objectives in constructing such complexes is to ensure the necessary message exchange speed and the required reliability of data transmission under conditions of enemy interference. Modeling the execution of fire missions imposes a set of requirements on the organizational and technical reconnaissance assets and fire control automated systems, including:

– the ability to perform fire missions across the full range of artillery systems;

– automated fire adjustment from the divisional fire control post based on data received not only from technical reconnaissance assets but also from other sources;

– automated transmission of processed data from reconnaissance systems to end-users via the fire control system;

– automated recording by the ACS of fire results, including the identification of projectile bursts from artillery systems against targets;

– ensuring, during simultaneous firing by multiple artillery systems, that the ratio of registered projectile bursts corresponds to the number of guns.

These requirements can be simultaneously implemented through the following computer-integrated technology chain: reconnaissance assets – fire control ACS – automated artillery system. The foundation of such a system must be specialized mathematical and software support covering all potential data preparation methods and fire control features. This set of operations necessitates the development of new information and control technologies to support the activities of tactical-level artillery units.

By definition, automated control systems comprise personnel and a set of tools to automate their activities, implementing an information and control technology to fulfill the assigned functions [14, 15]. The Fourth Industrial Revolution has expanded the scope of automation across various aspects of human activity, altering the composition, properties, and component base of software-technical automation complexes, as well as the methods for their application in solving practical tasks. ACS developed and implemented in the era of the Fourth Industrial Revolution are hierarchical, geographically distributed computer systems that integrate software-technical complexes, telecommunications equipment, information resources, and a large number of interacting users, all working together to ensure controllability of technological installations and objects.

At the onset of the Fourth Industrial Revolution, special-purpose ACS – systems that provide various types of security affecting the vital functions of the state – have assumed particular importance. Foremost among these are military-purpose systems [14]. This category also includes critical-state management systems, environmentally hazardous facility control systems, emergency response management systems for large-scale disasters, and similar applications. In general, special-purpose systems are employed to manage diverse resources and control equipment, typically under non-standard and critical conditions, where both external and internal disturbances may significantly impact operations.

The specificity of special-purpose ACS lies in the fact that, continuously or at specified intervals, different information and control systems can be generated based on single- or multi-level systems to address diverse tasks aimed at ensuring security.

Typically, special-purpose ACS feature dedicated information and control channels that form loops composed of software-technical resources, automating the relevant processes and tasks based on models and methods for solving control problems. The information-processing channel is responsible for collecting and initially processing all data necessary for decision-making, including syntactic analysis, aggregation, and computation of performance indicators. The analytical channel, using the obtained data, performs semantic analysis of the current situation, defines control objectives, and generates potential courses of action to achieve them. The control channel coordinates and implements the selected decisions, including the operational management of resources and equipment. In some special-purpose ACS, additional information-analytical channels may also be established.

The primary goal of any special-purpose ACS is the effective control of objects, achievable through the availability of appropriate methods and models for making optimal decisions regarding the management of these objects. These methods and models are developed and adopted to ensure the foundational principles of the ACS, which should also be economically feasible [13].

Maximum objectivity in control is attained through the highest possible formalization of the functions (tasks) performed by personnel, as well as through the completeness and consistency of the information used in decision-making.

Maximum reliability is determined by requirements for reliability indicators, including readiness coefficients for task execution, ensured through "cold" and "hot" redundancy of system elements and equipment, along with systems for the preservation and restoration of information and control resources. It is essential that, when interacting with integrated systems, the ACS readiness coefficients exceed those of the control objects at each task execution cycle.

Real-time interaction between the ACS and the controlled objects, necessary for making and implementing effective decisions, is achieved through the selection of high-performance computing systems, high-speed communication networks, and the organization of information processes using rapid-response software tools.

Maximum survivability of the ACS – defined as the ability to perform assigned functions even when some system elements are deliberately disabled – is ensured by redundancy in resources, allowing operational execution of parts of the information-control technology on functioning system components despite some degradation in accuracy and information consistency.

Maximum operational resilience of the ACS refers to its ability to reliably and coherently transmit data volumes across the information-processing, analytical, and control channels under conditions of external and internal disturbances.

The highest level of information security in the ACS is ensured through a balanced protection of data confidentiality, integrity, and availability, taking into account operational needs and without compromising organizational objectives.

In addition to these principles, the design and operation of special-purpose ACS must adhere to generally accepted principles for the development of complex information systems: openness, modularity, functional independence from hardware-software platforms, and optimization of system development and operational costs.

Analysis of existing foreign ACS for tactical-level artillery demonstrates their compliance with the previously described structure and design principles of special-purpose ACS. Automated systems have been developed and are in the process of implementation to support artillery fire and control operations, addressing tasks such as artillery fire planning, target reconnaissance and analysis, preparation of firing data, and the collection and assessment of information regarding the status, condition, and staffing of one's own units. Notable examples of such systems include the TACFIRE ACS (USA), ADLER (Germany), and BATES (United Kingdom). These systems are based on mobile computing complexes deployed at the command posts of formations and units, as well as in artillery reconnaissance units equipped with specialized hardware. Direct control of weapon systems is carried out by dedicated ACS, such as BCS (Battery Computer System) (USA), IFAB (Integrated Fire Control Artillery Battery system) (Germany), and FACE (Field Artillery Control Equipment) (United Kingdom).

Field artillery ACS, including TACFIRE, ADLER, and BATES, have been adopted and deployed within NATO formations stationed in Europe. The further development of field artillery ACS is closely linked to their integration with artillery reconnaissance systems, as conducted under programs such as AFATDS (USA) and AFFS (Advanced Field Fire Support system) (Germany). Currently, field artillery ACS have achieved widespread adoption within NATO [20]. Their capabilities have been extended to include tasks related to logistics management and equipment maintenance. To evaluate the effectiveness of input-output devices, communications, and computing capabilities of these ACS, a system response time criterion has been introduced. This criterion measures the elapsed time from the entry of target information into the forward observer station or higher-level ACS until the display of the corresponding firing units on gun displays. A classification of field artillery ACS has been established, reflecting both their hierarchical structure and the scope of artillery unit management tasks they address.

The BCS computing system, in service with U.S. field artillery, is designed to control the fire of a battery of 12 guns, and it can operate independently or in conjunction with ACS at all levels. The COMBAT ACS forms the core of the battery-to-battalion level ACS for Israeli field artillery. Its configuration and capabilities are similar to the BCS system, but it manages the fire of 8 guns. Comparable characteristics are found in ACS such as IFAB, ARES (Artillery Reconnaissance and Engagement System), ABACUS (Artillery Battlefield Automated Control and Utility System) (Germany), ATIBA (Automated Tactical Information for Battlefield Artillery) (France), and SEDAB (Système d'Échange de Données d'Artillerie de Bataille) (Italy).

Battery-to-battalion level ACS enable not only fire control but also the planning of material and logistical support, including ammunition resupply. A representative system of this class is the QUICKFIRE (QuickFire automated artillery fire control system) ACS (United Kingdom), designed to manage the fire of a 24-gun divisional artillery unit as well as other fire assets, including Multiple Launch Rocket System (MLRS). A distinctive feature of this system is its use of a set of predefined commands for automated problem-solving – capabilities that even some higher-level ACS, such as TACFIRE, do not provide. The system simultaneously performs dual computational tasks. Enhanced firing data accuracy is achieved through computational methods that account for four degrees of freedom of the projectile. Corps-level ACS elements support the planning and management of other support assets, including aviation and naval artillery, assess the effects of chemical and nuclear weapons, and handle all aspects of logistical planning.

The TACFIRE ACS, employed in the field artillery of heavy infantry divisions, exemplifies such systems. Its primary structural element is the divisional fire control center, a mobile computing complex incorporating the AN/GYK-12 computer, data input-output equipment, and display devices. The divisional fire control center manages the planning and execution of fire for 100 artillery units, coordinates additional aviation support, stores data on approximately 1,500 targets, and processes up to 60 fire missions per hour based on detected targets.

Within the TACFIRE system, tasks such as target analysis, selection of appropriate equipment for engagement, and computation of firing solutions are carried out. The results are transmitted to the battalion-level ACS fire complexes and supporting attack helicopters. Similarly, the French ATILA (Automated Tactical Information and Logistics Artillery system) ACS, at the unit level, stores in its Iris-35M computer memory the coordinates of up to 36 forward air controllers, 500 targets, 40 no-fire zones, 20 reference points, and data from four artillery support plans.

The LTACFIRE (Light Tactical Fire Direction System) ACS is employed in the field artillery of the U.S. light infantry divisions. At the battery level, the BCS system is utilized, with the divisional fire control center forming its core. The same configuration is applied at higher ACS echelons, as well as in fire support sections within units and formations. The equipment of the LTACFIRE ACS is ten times lighter than that of the TACFIRE ACS. Specifically, it allows for the control of mortar units and gunfire directly from fire control centers without the involvement of BCS systems. Experience with various field artillery ACSs has informed the development of the next generation of systems.

The next-generation systems are designed to include computing units on the guns capable of performing all necessary calculations, including the use of mobile transmission protocols within a secure messaging framework. Increasing the autonomy of fire control assets reduces ACS response times and enhances system survivability. In addition, this allows equipping all system levels with uniform and simpler hardware. Systems of this new generation include the field artillery ACS AFATDS (USA), BATES (UK), ATLAS (France), and ADLER (Germany).

The principles underlying the U.S. Army's prospective ACSs, which also inform the development of baseline ACSs in NATO countries, include: maintaining subordination of different control subsystem levels, ensuring organizational-technical and functional connections between critical system components, employing widely available commercial components, and software standardization. Examples of such special-purpose ACSs are the tactical-level Army Tactical Command and Control System (ATCCS) and the Staff Planning and Decision Support System (SPADSS).

From the presented material, it follows that only next-generation ACSs can significantly increase operational management efficiency, enabling effective conduct of combat operations in modern conditions. In the ATCCS comprehensive system, the primary component is the troop maneuver ACS, with the battery level serving as the initial point for acquiring automated information. German experts' perspective on ACS development differs from that of the U.S. Army. In Germany, the commissioned systems HEROS (Higher Echelon Reconnaissance and Operational System) and ACCS (Artillery Command and Control System) are intended primarily for use at the headquarters level of formations and higher commands. This leads to the main development focus for advanced ACSs: decentralization of combat management. It presupposes that unit commanders, without awaiting orders from higher authorities, should receive information directly from primary sources operating within their area of responsibility – data concerning the enemy, terrain, weather, composition and tactics of friendly forces, and control assets.

It is noted that combat management based on personal observation and issued orders is outdated. To fundamentally improve automation of unit command, the German Army is developing the Integrated Field Information System (IFIS), intended for mechanized infantry, armor, and anti-tank forces. This system allows precise determination of a combat vehicle's location (BMP, tank, ATGM system), movement direction, observation and firing sector, using laser gyroscope-based navigation equipment. The tactical situation, terrain, target coordinates, and textual and graphical messages are displayed on the system interface.

Analysis of open sources identifies two ACS types. The first type, for missile and artillery forces, provides automated collection and processing of information required to optimize command and control, ensuring the most effective employment of units, subunits, and formations of missile and artillery troops. The second type, for artillery fire, is an automated system integrating sensor complexes and technical means to detect, identify, and recognize targets, prepare artillery pieces for firing, aim, and accomplish target engagement. Some artillery ACSs support MRSI, enabling a target to be struck by multiple projectiles (three to five) so that all reach it simultaneously. This effect is achieved through automatic adjustment of elevation with pre-selected propellant charges, an evolution of the Time on Target firing method.

1.4 Special-purpose command and control systems for tactical-level artillery

At present, reconnaissance assets for topogeodetic, meteorological, and ballistic support employed by tactical-level artillery units and subunits are supplied by various manufacturers. These systems meet modern requirements and provide the necessary conditions for operational use. When determining the architecture of a prospective automated artillery fire control system at the tactical level, primary attention should be focused on communication capabilities that ensure the automation of interaction processes among the forces and assets employed according to the concept of operations defined by the higher commander.

Currently, a wide range of technical equipment with embedded and universal software is available. By applying computer-integrated technology approaches, these components can be combined to create automated artillery fire control systems. The diversity of such components, the need to account for their characteristics, and the significant number and inconsistency of requirements imposed on the systems being developed necessitate the use of specialized mathematical models and methods. In some cases, it becomes necessary to develop new models that enable the determination of optimal characteristics for synthesizing automated control systems from available components.

A distinctive feature of the conducted analysis is the search for system characteristics that allow comparison of different system solutions to the problems under consideration. It should be noted that each system generally has its own connection architecture, which includes several components connected in parallel and in series and therefore possesses specific indicators that characterize its operational properties. At the initial stage, however, it is not advisable to analyze such indicators in detail. In addition, each decision regarding the application of particular equipment is associated with specific features of mathematical, software, information, organizational, and methodological support required for integrating the field artillery automated control system into higher-level command and control systems.

For the analyzed field artillery automated control systems with different degrees of automation, it is necessary to consider the specific features of their operational use. A common characteristic is that each technical solution includes a base computer and a portable computer located near the gun crew. However, the capabilities of these systems and the tasks assigned to them may differ.

Data were collected on various information and control systems representing the time intervals required to perform a number of typical tasks of artillery units at the battery and battalion levels using different configurations of field artillery automated control systems. **Table 1.1** presents the average time required to perform artillery fire control tasks depending on the level of automation of fire control. The data were sorted and presented for the execution of the same group of tasks under four conditions: a non-automated mode, a mode using an automated forward observer, a fully automated mode, and an automated mode with diagnostic and service capabilities.

Table 1.1 Average time required to perform artillery fire control tasks

No.	Name of the task algorithm	Average time required to perform artillery fire control tasks (s), depending on the level of fire control automation			
		I	II	III	IV
1	Complete preparation for determining firing data	80	25	15	10
2	Target adjustment using a rangefinder and coordinated observation in mountainous terrain with the use of plain-mountain firing tables	115	50	16	11
3	Determination of firing data for a guided artillery projectile	160	75	40	20
4	Determination of firing data and illumination of the area to ensure the required operating range of night vision devices and night sights	220	110	50	25
5	Determination of data for establishing light reference points and alignment lines	260	140	60	30
6	Determination of coordinates by the resection method using measured distances, elevations, and direction angles of reference directions in mountainous terrain	270	150	75	40
7	Determination of coordinates by the resection method using measured angles with a non-oriented instrument, elevations, and direction angles of reference directions in mountainous terrain	280	160	100	50

Note: I – non-automated mode; II – automated mode with the use of an observer (spotter); III – automated mode; IV – automated mode with diagnostics and service support

The tasks were considered only in terms of information and analytical support capabilities, without the possibility of direct control of gun-laying mechanisms.

Analysis of the results of **Table 1.1** shows that calculation errors for firing setups, as well as the determination of corrections during ranging and fire-for-effect, are approximately equal and minor in all modes, except for the non-automated one. The fully automated mode with service support reduces the execution time of individual fire task elements by nearly an order of magnitude.

The conclusions drawn from **Table 1.1** confirmed the validity of the adopted analysis method for applied tasks of an artillery unit at the "battery – battalion" level. For further analysis, it was necessary to obtain data that would reflect the operation of the previously analyzed automation methods of fire control through various information and control systems, integrated with the controlled objects (artillery systems), taking into account the effects on actuator drives. **Table 1.2** [14, 15] presents the average execution time of fire tasks during field firing exercises with artillery units.

Table 1.2 Average execution time of fire tasks

No.	Name of the type of task performed in fire control	Average time required to perform artillery fire control tasks (s), depending on the level of fire control automation			
		I	II	III	IV
1	Reconnaissance and target coordinate determination	750	400	200	150
2	Topogeodetic preparation	1100	500	300	250
3	Meteorological preparation	1200	500	300	250
4	Ballistic preparation	1250	500	300	250
5	Full and abbreviated preparation	1260	500	300	250
6	Fire transfer by visual aiming	1270	500	300	250
7	Target ranging	1400	600	400	380
8	Engagement of targets at night	1480	700	500	400
9	Engagement of targets in mountainous terrain	1500	750	550	450
10	Tasks of the artillery fire observer	1510	800	600	500
11	Engagement of targets with a guided artillery projectile	1520	800	600	500
12	Engagement of targets with a multiple launch rocket system (MLRS)	1750	950	750	700
13	Fire adjustment from a reference point (target) using data from the ranging gun	1760	950	750	700
14	Preparation of barrage and accompanying fires, engagement of moving targets	3200	1600	1200	1100

Note: I – non-automated mode; II – automated mode with the use of an observer (spotter); III – automated mode; IV – automated mode with diagnostics and service support

Processing the data obtained during the artillery exercises showed that the variant of the automated control system with diagnostics and service-analytical calculations reduces the task execution time by almost three times compared to the preparation and fire task execution time in the non-automated mode.

The reduction in execution time compared to the automated mode with a spotter is one and a half times, and compared to the automated mode without diagnostics – only by 20%. It should be noted that in all modes where an automated spotter was integrated, the accuracy of coordinate determination increased. All integrated equipment of the information and control complex in the field artillery ACS for any automated mode ensures the same accuracy in determining the directional angles of reference bearings.

The methods for calculating firing data, embedded in the applied software, allow increasing accuracy by a factor of three.

The accuracy of calculated data at the current level can be improved through the development of additional methods for determining the elevations of artillery formations. The precision of determining the computed deflection from the primary firing direction is approximately the same for all artillery positions.

Regardless of the technical components used, all automated fire adjusters provide roughly the same accuracy in determining corrections during ranging and engagement, where the defining characteristics are atmospheric conditions and the actual initial velocity of the projectile at the moment it exits the gun barrel.

A detailed analysis of **Table 1.2** shows that some fire control tasks are limited by physical time parameters. These include the time for a projectile to travel from the gun barrel to the target and the time required to determine the coordinates of its impact point on the surface. Consequently, the reduction of the total execution time for such tasks is inherently limited. This conclusion is based not on the analysis of absolute time, but on the accumulated duration of completing the fire mission.

One approach to reducing the time required for fire missions is the integration of two types of mathematical models into the fire control system. The first type is a distributed-parameter model of atmospheric conditions and projectile trajectory, which determines all corrections associated with the influence of atmospheric conditions on projectile motion. The second type is a model based on the current state of the gun system and the characteristics of the charge, which determines the initial velocity of the projectile at the moment it leaves the barrel. Thus, two independent directions for modernizing field artillery fire control systems can be distinguished.

The first direction involves integrating additional mathematical models into the field artillery system to reduce the time needed to determine the coordinates of the projectile impact point. At a new level, this allows the calculation of firing data, significantly shortening preparation and execution times for fire missions. Furthermore, this enables the implementation of different firing modes. The first is MRSI, which allows a target to be struck by several projectiles fired sequentially from a single weapon, all reaching the target simultaneously. The second is "shoot and scoot," a tactic associated with the rapid firing and repositioning of artillery units. The "shoot and scoot" approach is linked to the intensive development of precise automated diagnostic and technical reconnaissance tools in the artillery forces of high-tech militaries. These two modern approaches justify the need to analyze mathematical models of internal and external ballistics to determine the projectile velocity at barrel exit for diagnostic purposes.

The second direction for modernizing field artillery fire control systems results from the rapid pace of combat operations between opposing forces, characterized by a significant increase in the intensity and distributed nature of troop employment, as observed in the modern Russo-Ukrainian war. The use of numerous and diverse fire assets, in terms of equipment and ammunition provisioning, has overcome first- and second-degree information barriers according to Glushko's classification. The only feasible way to maintain control over such a process is the extensive implementation of automation across all stages of artillery unit operations (**Fig. 1.1**).

For this purpose, it is necessary to continuously verify the execution quality of each firing element by every link in order to track possible disturbances in real time and to instantly adjust control.

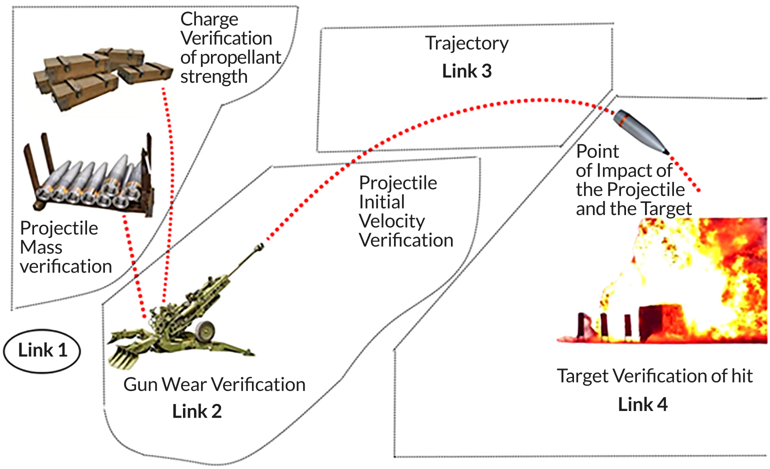

Fig. 1.1 Chain of states of the artillery round life cycle

During the execution of an artillery shot, disturbances are always present. To compensate for them, methods for verifying each link in the artillery firing process are required. Verification is understood as the confirmation of the performance of declared characteristics that directly affect overall effectiveness immediately after each link completes its assigned function for the shot.

An artillery shot consists of sequential links that form the chain of states of the life cycle, which can be represented by the following sequence: "charge – breech – barrel – projectile trajectory – target". To implement such an ACS, it is necessary to synthesize an object-oriented integrated model of the automated system for diagnostics and control of artillery units, which realizes the principles of adaptability, responsiveness, and efficiency through formalized methods of signal analysis and resource management (**Fig. 1.2**).

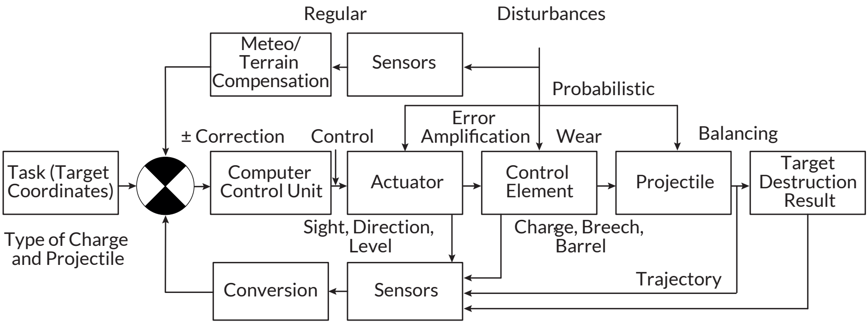

Fig. 1.2 Structural model of the information-analytical system for verification and adaptive artillery fire control

Such an ACS will make it possible to perform verification of the life cycle of each artillery round. This will allow continuous verification of each link in the chain of states to be considered a key condition for effective fire control of an artillery unit within a computer-integrated management system.

1.5 Conclusions

The analysis of ACS for tactical-level artillery allows the following conclusions to be drawn. The main tasks of ACS include planning, support, and control of artillery fire under complex and dynamic combat conditions, ensuring information superiority and timely decision-making. The life cycle of an artillery shot has been identified as a sequence of linked states: "charge – breech – barrel – projectile trajectory – target". Each state requires continuous verification to maintain operational effectiveness. Methods for verifying the performance of each link in the firing process have been proposed, allows for adaptability and responsiveness of the ACS to disturbances in real time. The integration of object-oriented models of ACS enables optimization of resource management, signal analysis, and automated decision-making, reducing execution times for fire missions while maintaining accuracy. Practical experience with field artillery ACS, including TACFIRE, ADLER, and BATES, demonstrates the importance of hierarchical, distributed, and modular systems for efficient control of artillery units and fire support assets. The implementation of next-generation ACSs enhances fire control efficiency, enables advanced firing modes such as Multiple Rounds Simultaneous Impact and "shoot and scoot", and provides real-time interaction with reconnaissance and sensor systems.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Use of artificial intelligence statement

Artificial intelligence technology was used in the preparation of this chapter. Specifically, the authors used OpenAI ChatGPT (model GPT-5.2) to assist in editing and structuring introductory text sections and in formulating generalized descriptions of research methodologies for integrating mandatory literature sources into the chapter introduction.

The authors bear full responsibility for the final manuscript. Generative AI tools are not credited and are not responsible for the final results.

Authors' contributions

Maksym Maksymov: Conceptualization, Methodology, Formal analysis, Writing – original draft.

Pavlo Gultsov: Methodology, Investigation, System analysis, Writing – review & editing.

Oleksandr Toshev: Formal analysis, Visualization, Data curation, Interpretation of results, Writing – review & editing.

Ruslan Riaboshapka: Supervision, Validation, Theoretical framework, Writing – review & editing.

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