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Smart Modular Platforms for the Next Generation of Shooting Range Training

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This paper examines the modernization of shooting ranges through the implementation of ground-based modular platforms designed as smart target carrier systems. Traditional ranges that rely on static or semi-automatic targets are increasingly inadequate for the complex requirements of modern military and law enforcement training. The proposed platforms introduce mobility, modularity, and intelligent functionalities that enable more realistic and adaptive training scenarios.

The systems integrate mobile robotics, hit-detection sensors, automated scoring, and real-time data transmission, which together provide objective feedback and reduce the need for manual target handling. Navigation solutions such as GPS, LIDAR, and SLAM algorithms support autonomous movement across different terrain types, while modular design ensures compatibility with advanced training infrastructures, including programmable and reactive target systems.

The study highlights the capacity of these platforms to enhance training realism, improve safety standards, and increase operational efficiency. By reducing setup time, enabling dynamic reconfiguration of scenarios, and supporting scalable deployment, the proposed concept contributes to the digital transformation of shooting ranges. The findings position ground-based modular smart target carriers as a key component in the development of next-generation training facilities that align with evolving defense and security needs.

Key words: **Modular Training Systems, Target Carrier Platforms, Shooting Range Modernization, Autonomous Ground Vehicles, Live-Fire Training.**

Introduction

MODERN training systems and combat readiness programs require precision, flexibility, and the integration of advanced technologies across every component of the training environment, including shooting ranges. Traditional ranges are most often equipped with static targets that provide little ability to adapt to different training situations, or with mobile targets that operate at limited speed and within narrow movement patterns. These configurations no longer satisfy the current needs of armed forces, which increasingly demand training environments that are realistic, dynamic, and technologically advanced.

To address these shortcomings, new approaches are focusing on the development of modular, mobile, and intelligent solutions that can replace conventional range infrastructure. One of the most promising concepts is the use of ground-based modular platforms functioning as smart target carriers. These systems are capable of autonomous movement across training areas and are equipped with integrated hit detection and automated scoring functions. By simulating moving targets, supporting immediate adjustments to training scenarios [1, 2], and enabling automated collection of shooting data, such platforms provide substantial improvements in training quality.

Algorithms are central to the functioning of advanced combat training display systems. Through the application of artificial intelligence and machine learning, these algorithms allow real-time adjustment of training difficulty, the simulation of adversary tactics, and the creation of training environments that are more immersive and individualized [3]. The purpose of this paper is to explore the potential of unmanned ground vehicles employed as smart target platforms [4], with an emphasis on their technical features, benefits compared to traditional solutions, and proposals for their use in modernizing shooting ranges.

At present, shooting ranges in military and law enforcement practice still rely heavily on static target systems. These are usually adjusted manually or limited to simple lift-and-drop mechanisms. Simulator-based training systems are also employed, but their tactical application is limited and they allow practice only in pre-programmed scenarios [5–8]. Both types of the systems require personnel to be physically present to set up, replace, or evaluate targets, which increases preparation time, operational costs,

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and safety risks during live-fire training.

Conventional targets are usually constructed from plywood, paper, or coated materials mounted on simple stands made of wood or metal. Hit assessment is typically carried out manually after firing is completed, which slows down the process and reduces objectivity. In some cases, mechanical targets that fall or rise when struck are used, yet these solutions demand additional infrastructure and provide only basic functions.

More recently, automated target systems have been introduced that can perform simple actions such as raising and lowering or offering basic hit feedback through sound or light signals. Despite these improvements, they are largely stationary, connected by cables, and confined to fixed points on the range, which restricts the design of complex and realistic tactical scenarios.

The key limitations of existing target systems can be summarized as follows: (1) immobility or very limited movement; (2) absence of autonomy and adaptability; (3) minimal integration with digital control and monitoring systems; and (4) high maintenance requirements due to mechanical complexity. Ground-based modular platforms that combine mobility, advanced sensors, and wireless communication offer a significant step forward in overcoming these limitations and advancing the technological development of shooting ranges.

Particular attention in tactical training of military units is deserved by the MILES system (Multiple Integrated Laser Engagement System). As a scientifically grounded training tool, MILES enables the simulation of combat engagements without the use of live ammunition, employing laser signals and maneuver-simulated munitions at safe distances. The system is widely used in tactical training across many armed forces due to its high degree of realism, which allows verifiable tracking of engagements, evaluation of unit behaviour, and improvement of commanders' decision-making while significantly reducing risk to personnel and equipment.

This paper includes a performance evaluation based on selected operational indicators to provide practical evidence of how such systems improve efficiency, shorten setup time, and raise the accuracy of training. The addition of swarm-coordinated target carriers further expands the scope of training by allowing multi-target tactical exercises that resemble real combat conditions. Remote reconfiguration of target positions without manual intervention reduces downtime between training sessions, while network connectivity ensures seamless integration with central command systems for real-time monitoring, adaptive control, and immediate feedback to participants. The adoption of modular energy sources, such as combined battery and solar systems, further increases platform autonomy and reduces logistical demands [9]. Finally, the scalability of this concept ensures that it can be applied in different settings, from small law enforcement facilities to large military proving grounds [10].

Current Dynamics, Opportunities, and Challenges in the Shooting Range Industry

The shooting range industry is undergoing significant transformation driven by technological innovation, shifting user expectations, and increasingly complex regulatory frameworks. One of the most notable developments is the adoption of virtual reality and advanced simulation technologies. These systems provide immersive training environments that allow users to practice across varied scenarios without the use of live ammunition. In addition to enhancing safety, they improve the effectiveness of training for both professional and recreational users, reshaping expectations of modern shooting facilities.

Safety requirements and regulatory compliance have become central elements in this evolution. The demand for stricter safety standards, detailed inspection procedures, and adherence to uniform protocols underscores both the priority of protecting participants and the importance of maintaining public confidence. These developments are redefining the industry, linking its long-term sustainability to credibility and accountability.

Growth in both recreational and tactical shooting continues to shape the market. Tactical training, focused on military and law enforcement applications, drives the need for specialized facilities and advanced equipment. At the same time, recreational shooting attracts participants from a wide range of backgrounds, resulting in the emergence of ranges that function as multipurpose spaces serving both civilian and professional needs.

The popularity of multi-use facilities is increasing. Ranges that combine diverse activities such as archery, simulated combat training, and traditional marksmanship are becoming more attractive because they provide versatile and engaging experiences. By broadening their offerings, operators can draw larger and more diverse groups of users, which improves financial viability.

Another important development is the expansion of indoor shooting ranges. These facilities operate year-round regardless of weather and often include climate control, sound insulation, and other technologies that enhance comfort and accessibility. Such features contribute to the wider appeal of shooting as both a recreational and professional activity.

Recent years have also seen significant investment in infrastructure and equipment upgrades. High-technology systems designed to enhance user experience and safety are increasingly being integrated into new and existing ranges. At the same time, the growth of competitive shooting events is raising public visibility and expanding opportunities for community engagement. Together, these factors demonstrate a clear trend toward greater professionalization, technical sophistication, and social recognition of the industry.

Strategic opportunities are also evident. Investments in recreational facilities can attract families and casual users, thereby broadening the participant base. The establishment of specialized tactical training centers holds considerable potential for meeting the operational needs of defense and security institutions. The integration of virtual training systems provides flexible alternatives to live ammunition while maintaining training effectiveness. Multi-purpose facilities that operate as community hubs extend this potential further, while sustainable practices such as environmentally friendly ammunition and energy-efficient design align the industry with global sustainability goals and appeal to environmentally aware participants.

Despite these positive directions, the industry faces continuing challenges. Regulatory compliance remains resource-intensive, while economic fluctuations can limit participation due to reduced discretionary spending. Public perceptions of safety and the broader image of shooting sports continue to present reputational risks that must be addressed through transparent communication, strong community relations, and consistent application of safety protocols.

Taken together, these developments reveal an industry in transition. Advances in technology and the expansion of participation present strong growth potential, while regulatory pressures, economic uncertainty, and public perception require careful management. The ability of the shooting range sector to balance these factors will determine how successfully it maintains safety, sustainability, and social responsibility as central principles of its future development [11].

Description of ground-based modular platforms

Ground-based modular platforms are mobile robotic units [12] designed to operate across diverse terrain types, with the capability to carry payloads—targets, in this case. Their implementation on shooting ranges enables the automation and modernization of training processes [13] through the dynamic deployment and movement of targets, as well as the real-time collection of data on shooter accuracy and effectiveness. These platforms are designed to be modular, robust, autonomous or remotely operated, and energy-efficient. They utilize various navigation techniques [14–15], including:

1. GPS and inertial mapping for positioning in open environments,
2. LIDAR and visual sensors for obstacle detection and spatial orientation,
3. Predefined routes and motion algorithms, as well as the capability for randomized maneuvering to simulate real-world conditions.

In addition to conventional navigation methods based on GPS signals and inertial sensors, modern modular platforms increasingly rely on advanced algorithms that provide higher levels of autonomy and reliability:

1. **Simultaneous Localization and Mapping (SLAM)** – SLAM enables the platform to simultaneously estimate its own position and build a map of an unknown environment in real time. The combination of LiDAR and visual sensors provides robustness even under conditions of poor visibility or GPS denial. The main limitation of SLAM lies in its high computational complexity, requiring powerful processors and significant memory resources, which may increase the system costs.
2. **Path Planning Algorithms (A*, D*, RRT*) –** These algorithms are used to compute optimal trajectories in real time. They allow efficient obstacle avoidance and safe maneuvering in dynamic environments. The advantage lies in their adaptability and efficiency, while the limitations include sensitivity to rapid environmental changes and the demand for frequent sensor updates, which require a highly optimized software.
3. **Swarm Intelligence** – Algorithms inspired by collective behaviors in nature (e.g., particle swarm optimization, ant colony optimization) enable multiple platforms to coordinate within a shared task, such as simulating multi-directional attacks or collaborative reconnaissance missions. The main strength is the ability to manage complex multi-objective scenarios, while challenges arise from the increased complexity of inter-platform communication and the risk of collision in case of synchronization loss [10].

The integration of these algorithms makes training platforms more realistic and better aligned with operational conditions encountered in modern combat scenarios. The movement of these platforms can be synchronized with training scenarios—for example, linear movement, concealment behind cover, intermittent exposure, or adaptive speed changes in response to the shooter's actions. Each platform [16–17] can be equipped with hit detection sensors, cameras for visual monitoring of the training session, and wireless communication modules (Wi-Fi, RF, 4G/5G) for real-time data transmission to the command center. The collected data may include:

1. **Number of hits** – Each hit is precisely registered by sensors mounted on or around the target, ensuring objective and reliable measurement. The system is capable of distinguishing individual hits even when they occur in rapid succession, which is particularly critical in tactical scenarios involving multiple shooters or high rates of fire. This feature eliminates human error in scoring and provides a consistent baseline for evaluating marksmanship performance under varying conditions.
2. **Exact hit location on the target** – By employing multi-position sensors or high-resolution cameras, the system can identify the precise impact point on the target surface. This level of details allows for advanced accuracy assessment, enabling instructors to analyze deviations, dispersion patterns, and consistency of the aim. The data may be visualized in a graphical form, such as a heatmap of hit zones, which provides an intuitive and comprehensive overview of shooting effectiveness, supporting both individual evaluation and comparative analysis across the shooters.
3. **Shooter response time (reaction to target appearance)** – The platform records the interval between the target activation or movement and the shooter's first registered hit. This parameter provides an important indicator of situational awareness and cognitive processing speed under combat-relevant conditions. Measuring response time is particularly useful for evaluating decision-making efficiency, reflex training, and stress resilience, which are essential competencies in operational scenarios.
4. **Target speed and direction at the time of impact** – The system continuously logs the platform's velocity and trajectory at the moment of each impact, allowing for a correlation between the shooter performance and task complexity. For example, successful engagement of a target that changes speed or direction is weighted more heavily than engaging a stationary or predictably moving object. Such data provide a basis for differentiated scoring models that more accurately reflect the real-world combat challenges.
5. **Target position in space (geographic coordinates)** – Through the integration of GPS and inertial measurement units, the exact coordinates of the target are recorded at the moment of every registered hit. This capability is particularly valuable in advanced training simulations involving movement across large areas or complex terrain, where spatial awareness and the ability to engage mobile threats are critical. The data can be integrated with geospatial analysis tools for a more comprehensive evaluation of operational performance.
6. **Exercise timeline and duration** – The system automatically logs the temporal structure of each training session, including start and end times, sequence of events, target appearances, and shooter responses. This timeline enables detailed post-exercise reconstruction, supporting

both qualitative and quantitative evaluation of training outcomes. Moreover, it allows instructors to assess pacing, intensity, and the appropriateness of training scenarios relative to the objectives.

7. **Shooter identification (if using a personalized system)** – When combined with personalized identifiers such as RFID tags, electronic cards, or software-based user profiles, the system can attribute performance data to individual shooters. This functionality enables longitudinal tracking of skill development, comparison across individuals or units, and the generation of personalized training recommendations. Such identification also facilitates secure record-keeping and accountability within institutional training programs.

8. **Statistical performance analysis** – By aggregating all collected data, the software generates detailed statistical reports that include hit rate, average reaction time, accuracy trends, and error patterns (e.g., consistent horizontal or vertical misalignment). The system also supports group-level comparisons, benchmarking, and identification of training gaps. Advanced statistical methods may further be employed to reveal hidden patterns, predict performance under different conditions, and support evidence-based optimization of training curricula [10].

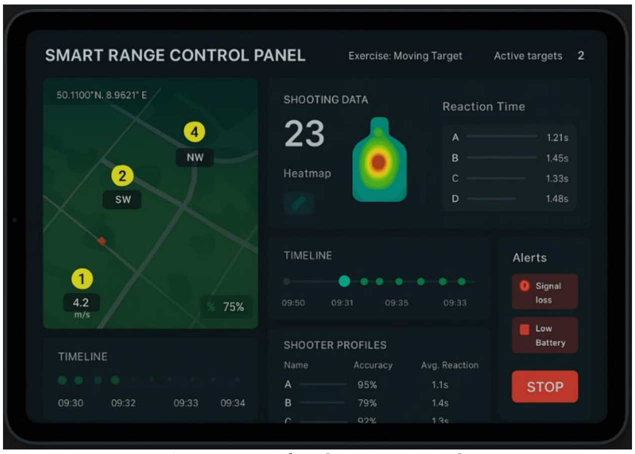

Figure 1. Interface layout – example

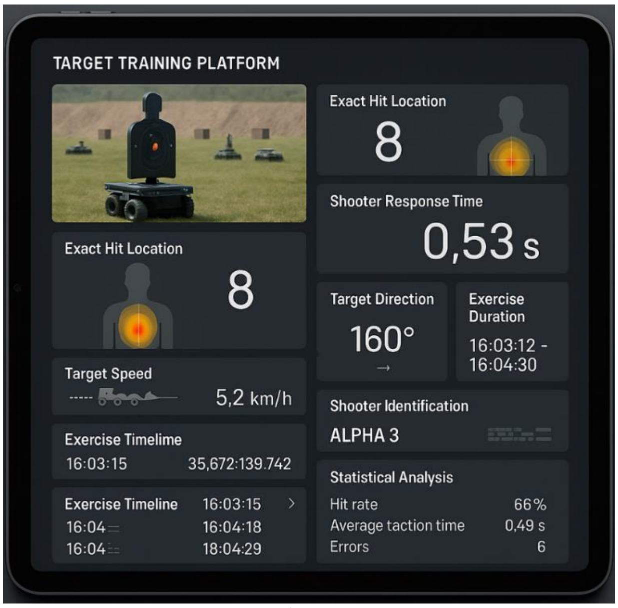

Figure 2. Interface layout – example

To fully leverage the capabilities of smart platforms on shooting ranges, integration with a centralized software system is essential [18]. This software functions as a command-and-information center for planning, control, monitoring, and analysis of all training activities. It enables the creation and management of various training scenarios aligned with the goals and requirements of the training program [19]. The central software collects and displays real-time data through a graphical user interface that includes the location and status of each platform (position, speed, battery level, number of registered hits), visual tracking of target movement on a range map, and monitoring of the shooter behavior and responses during exercises (through integration with smart weapons or shooter-mounted sensors) [20]. It also provides alerts and automatic problem detection (e.g., signal loss, sensor malfunction). Instructors can intervene in real time: modify the scenario, introduce new targets, or stop a platform in case of irregularities. All data from the completed exercises are automatically stored and organized in an electronic database, with capabilities for detailed review and analysis of individual shootings or entire training sessions. The system can generate detailed reports for each shooter or unit, track progress over time, and export data in various formats. In addition to quantitative data, the inclusion of video recordings and visual hit pattern analyses further enhances evaluation quality. This level of integration facilitates the transition from conventional to digital training and transforms the shooting range into an intelligent learning and assessment environment [20].

Furthermore, such systems open the possibility of incorporating adaptive learning models, where training difficulty dynamically adjusts based on the real-time performance of each shooter. Integration with biometric sensors: for example, heart rate monitors or eye-tracking devices, can provide additional layers of information regarding stress response and situational awareness. The combination of robotic mobility and intelligent control enables the simulation of complex battlefield conditions, such as ambushes, coordinated enemy maneuvers, or asymmetric threat scenarios. Advanced data analytics and machine learning techniques may further be applied to detect long-term performance trends and predict individual or group training outcomes. Instructors and commanders can use these predictive insights for tailored training recommendations, thus optimizing resource allocation and improving overall combat readiness. Moreover, linking multiple shooting ranges via cloud-based systems allows for distributed training exercises, where teams at different locations can interact in shared, synchronized scenarios. This creates a foundation for joint-force training programs that transcend geographical limitations. The modular design also permits rapid technological upgrades, such as the integration of new sensors, communication protocols, or energy systems, ensuring long-term sustainability. Finally, these innovations collectively contribute to the establishment of "next-generation smart ranges," capable not only of measuring shooting proficiency but also of fostering comprehensive tactical and cognitive development.

Smart target carriers on modular ground platforms: a technical overview for advanced training systems

Smart target carriers mounted on modular ground platforms represent a highly sophisticated component of contemporary shooting ranges and simulation-based training systems, designed not only to enhance realism but also to provide a comprehensive, quantifiable evaluation of user performance. Unlike conventional static targets, these platforms integrate advanced mobility, multi-sensor hit detection, autonomous behavioral algorithms, and robust communication links with a central control system. This combination enables simultaneous assessment of multiple performance metrics, including accuracy, tactical decision-making, response times, and situational awareness under dynamic training conditions [20].

The sensor suite of the platforms is meticulously engineered for high-precision, multi-modal hit detection. Piezoelectric sensors embedded throughout the structure detect direct mechanical impacts with high sensitivity, capturing even low-energy hits. Complementary acoustic sensors capture the sound profile of projectile impacts, allowing differentiation between hits of varying calibers. Vibration sensors monitor the propagation of shock waves through the platform frame, providing additional confirmation of physical contact and enhancing detection reliability. Infrared (IR) sensors detect the thermal signature generated by projectiles or explosive rounds, ensuring that hits are detected even in low-light, smoke-filled, or nighttime scenarios.

Advanced multi-sensor fusion algorithms process data from all these inputs, enabling accurate discrimination between true hits and background noise, environmental vibrations, or accidental contact. Pattern analysis and spatial mapping of detected hits provide critical insights into shooter behavior, target prioritization, and tactical decision-making efficiency. Real-time transmission of hit data to the central control system allows the instructors to immediately assess the performance, while onboard data logging ensures no loss of information during temporary communication interruptions.

Autonomous platform movement enables realistic simulation of complex tactical scenarios that static targets cannot replicate. Motion paths are defined in software, allowing for pre-programmed patrol routes, offensive or defensive maneuvers, and coordinated multi-platform engagement to simulate multiple targets in a single exercise. Reactive behavioral algorithms allow the platforms to respond dynamically to the shooter actions. For example, a platform may retreat or take cover when fired upon, change its orientation or visibility depending on the shooter's position, or vary its speed and trajectory randomly to maintain unpredictability.

These behaviors are modeled using a combination of predictive control, adaptive learning, and stochastic modeling techniques. Multi-criteria decision rules allow the platforms to prioritize actions based on both the immediate tactical context and historical data from previous training sessions, simulating complex human-machine interactions and operational decision-making under pressure. The result is a training environment where shooters face evolving, unpredictable targets, closely approximating real-world combat scenarios.

The communication infrastructure of smart target carriers is layered for reliability and flexibility. Wi-Fi is utilized for local control and synchronization between the platforms and the instructor's console. Secure RF channels ensure low-latency operation in environments where immediate feedback is critical, and 4G/5G connectivity allows deployment in remote or distributed training areas, supporting networked training exercises across multiple locations.

The instructor interface provides comprehensive control over training scenarios. Instructors can dynamically activate or deactivate platforms, reassign targets, monitor sensor status in real time, and adjust scenarios mid-training based on performance metrics. Security and redundancy measures, including encrypted communication protocols, fail-safe operational procedures, and collision avoidance algorithms between platforms, ensure safe, reliable, and uninterrupted operation during high-intensity exercises.

Beyond realistic physical simulation, smart target carriers provide a powerful platform for data collection and quantitative performance evaluation. Detailed analysis of reaction-time profiles, spatial hit distribution, and platform maneuver interactions allows for systematic assessment of shooter decision-making, situational awareness, and tactical efficiency. This data can also inform curriculum development, personalized feedback for trainees, and iterative improvements to training scenarios.

The modular architecture of these platforms facilitates continuous system evolution. Additional sensors can be integrated, including laser detection modules, LIDAR-based distance measurement, and environmental sensors for weather or terrain simulation. Actuators can be installed for dynamic effects, such as rotating, raising, or concealing targets, while the autonomous behavior algorithms can be enhanced with machine learning models to continuously improve realism and unpredictability. This ensures that smart target carriers remain at the cutting edge of simulation-based training technology, adaptable to evolving military, law enforcement, or security training needs [20]. The figure below illustrates the flow of data from the platform through sensors to the central software and finally to the instructor/command center (Figure 3).

Figure 3. Data flow from platform to instructor via sensors and central software

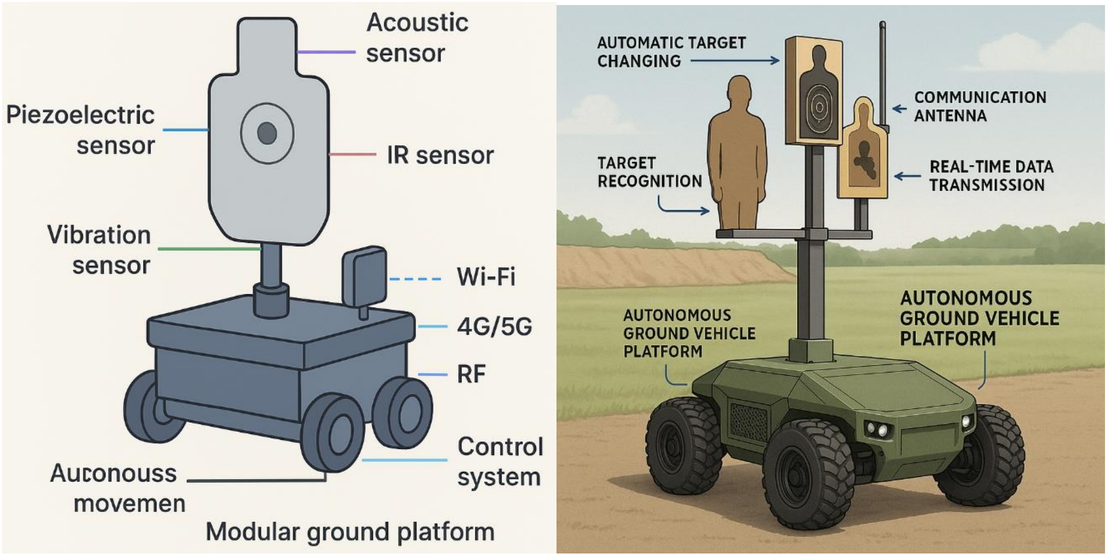

Figure 4. Smart target carriers on modular ground platforms

Within the sensor suite, different technologies can be employed for hit detection, each with specific strengths and weaknesses. Piezoelectric sensors are characterized by high sensitivity to direct mechanical impact and relatively low cost, although their performance is limited when it comes to indirect hits. Acoustic sensors, on the other hand, can recognize different calibers based on their unique sound signatures, but they are strongly affected by background noise in the environment. Vibration sensors provide reliable registration of impacts, yet their accuracy may degrade due to mechanical disturbances. Infrared sensors offer the advantage of detecting the thermal signature of projectiles and remain effective even under low-visibility conditions, but their higher cost and sensitivity to weather variations represent significant limitations. Finally, high-resolution cameras deliver the most precise measurements and create valuable visual records for post-event analysis; however, they require powerful software for image processing and significantly increase overall system costs.

Beyond the replication of realistic movement dynamics, the modular platform architecture can be extended to incorporate simulated engagement mechanisms that materially increase training fidelity for complex tactical scenarios. Such mechanisms may encompass the controlled use of blank ammunition, pyrotechnic sound-and-flash simulators, smoke generation, and non-lethal impact markers (e.g., paint-marker or impact-detecting sensors). From a systems engineering perspective, these components should be treated as optional payload modules with defined mechanical, electrical, and communication interfaces so that their integration does not compromise baseline mobility, survivability, or the platform's sensor suite.

The design and deployment of simulated engagement effects must explicitly balance realism, safety, and repeatability. Safety considerations require rigorous hazard analyses, adherence to applicable live-fire and pyrotechnic handling standards, establishment of exclusion zones, and clearly documented activation/arming interlocks and fail-safe behaviors. Repeatability and training value are supported by instrumentation and data capture: time-synchronized event logging, hit-/near-miss detection, and georeferenced recording of simulated engagements permit objective after-action review (AAR) and quantitative evaluation of trainee performance. Where blank ammunition or pyrotechnics are used, environmental effects (particularly smoke and particulate emissions) and the potential for electromagnetic or acoustic interference with on-board electronics must be assessed and mitigated through shielding, isolation mounts, and placement strategies.

Finally, the manuscript should acknowledge limitations and propose a validation plan. Controlled field trials — progressively scaling from indoor/benign environments to enclosed live-fire ranges and finally to representative field conditions — are recommended to characterize the impact of engagement simulators on the platform reliability, sensor integrity, and overall training outcomes. Key metrics for evaluation include a system mean time between failures (MTBF) under simulated engagement conditions, accuracy and latency of engagement reporting, and the operational trade-offs introduced by added mass and power consumption. Presenting preliminary test protocols or referencing a planned verification campaign will strengthen the paper's claims regarding the system's applicability for advanced tactical exercises.

Table 1. Comparison of sensor technologies for hit detection

Sensor type	Sensitivity	Limitations	Cost
Piezoelectric sensors	High sensitivity to direct mechanical impacts	Limited detection of indirect hits	Low
Acoustic sensors	Able to distinguish calibers by sound signature	Strongly affected by environmental noise	Low–Medium
Vibration sensors	Reliable in registering impacts	Sensitive to mechanical disturbances	Low
Infrared sensors	Effective in low-visibility conditions, thermal detection	Sensitive to weather, reduced accuracy in rain/fog	Medium–High
High-resolution cameras	Highest precision, provides visual evidence	Requires advanced image processing, higher complexity	High

To evaluate the overall performance of the training system, efficiency can be formalized as a function of three key factors: accuracy, reaction time, and operational cost. The following simplified model illustrates the relationship:

$$E = w_1 \times A + w_2 \times \frac{1}{R} + w_3 \frac{1}{C} \quad (1)$$

E – overall efficiency of the system

A – accuracy of hit detection

R – average reaction time

C – operational cost per training session

w_1, w_2, w_3 – weighting coefficients reflecting the relative importance of accuracy, responsiveness, and cost-efficiency

Proposal for shooting range modernization

Considering the significant technical, operational, and pedagogical advantages offered by ground-based modular platforms, it is possible to design a clear, scalable, and practically implementable model for the modernization of existing shooting ranges. The modernization process focuses on transforming traditional static and semi-automatic training systems into an intelligent, dynamic, and fully controllable infrastructure. This approach not only increases the efficiency of training but also enhances realism, safety, and adaptability for all participants.

A modernized shooting range equipped with smart target carriers and integrated digital systems can support a wide variety of training exercises tailored to different skill levels and mission scenarios. These include [20]:

1. **Standard tactical shooting** – targets follow predefined paths with adjustable speeds and timing, allowing trainees to practice precision, tracking, and timing skills under controlled conditions.

2. **Simulation of urban combat scenarios** – targets appear from behind barriers, change directions unpredictably, and simulate both civilian and hostile combatants, improving decision-making in complex, multi-dimensional environments.

3. **Stress-based training** – multiple independently moving targets appear at irregular intervals, challenging shooters to react quickly and manage cognitive load under pressure, enhancing situational awareness and resilience.

4. **Shooting under reduced visibility conditions** – night exercises are facilitated by thermal cameras, low-light sensors, and motion detection, enabling realistic low-light and limited-visibility training.

5. **Dynamic multi-threat scenarios** – integration with drones, pop-up targets, and remote-controlled moving obstacles allows for simulation of coordinated enemy actions, convoy attacks, or ambush situations.

6. **Performance evaluation and feedback** – automated data collection and advanced analytics allow instructors to track individual and team performance in real time, generate detailed reports, identify weaknesses, and adjust training programs accordingly. Machine learning algorithms can detect trends in trainees' performance, providing predictive insights for skill development.

7. **Integration with virtual and augmented reality** – modular platforms can be linked with VR/AR systems, providing hybrid training environments that combine live-fire exercises with virtual adversaries and scenario overlays, improving cognitive load management and operational decision-making.

8. **Weapon and ammunition diversity** – platforms can accommodate a variety of firearms, calibers, and non-lethal training devices, ensuring that exercises remain relevant across different operational roles and mission profiles.

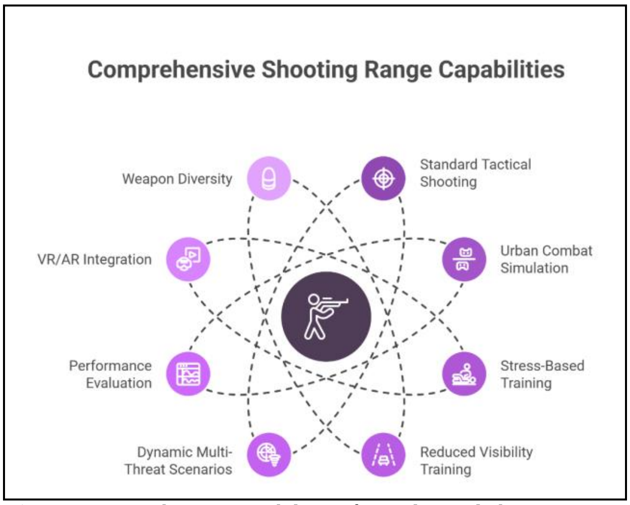

Figure 5. Comprehensive Capabilities of a Modernized Shooting Range

Figures 4 and 5 illustrate the key capabilities enabled by the modernization of shooting ranges through the ground-based modular platforms and integrated digital systems. These capabilities include standard tactical shooting, urban combat simulation, stress-based exercises, training under reduced visibility, and dynamic multi-threat scenarios. The model also supports automated performance evaluation, integration with virtual and augmented reality, and compatibility with diverse weapons and ammunition types. Together, these elements demonstrate how a modernized range provides realistic, adaptive, and data-driven training environments that address the operational needs of both military and law enforcement personnel.

Figure 6. Firing range [10]

Such a system enables more realistic, immersive, and versatile training, providing an almost limitless number of exercise combinations while introducing a level of dynamism and unpredictability previously unattainable with conventional setups. Trainees benefit from an environment that closely mimics real-world combat situations, fostering instinctive responses, situational awareness, rapid decision-making skills, and team coordination.

Implementation Models

There are two primary models for the deployment of smart modular platforms:

1. **Permanent Systems** – Designed for large-scale military or law enforcement training centers, these platforms are fully integrated into the infrastructure and used on a daily basis. Permanent ranges feature wireless networks, centralized command and control systems, on-site logistical support, routine maintenance programs, and automated software updates. They are capable of continuously simulating complex operational scenarios, including combined arms exercises, urban operations, and joint-force maneuvers, while providing instant feedback to trainees and instructors.

2. **Mobile (Temporary) Systems** – Ideal for field exercises or locations lacking permanent infrastructure. Modular platforms are rapidly deployable, with portable control units, mobile network communication, and modular power sources enabling flexible, on-demand training. Mobile systems allow instructors to replicate diverse terrains, environmental conditions, and operational challenges without the need for permanent construction, making them ideal for expeditionary forces or temporary training camps.

Modernization through smart modular platforms does not necessitate the construction of entirely new shooting ranges. Instead, it focuses on upgrading existing facilities with intelligent systems, significantly reducing costs, minimizing downtime, and accelerating implementation timelines. By leveraging modularity, the platforms can be customized for different operational requirements, enabling both basic marksmanship training and highly complex mission simulations.

Additional Key Benefits and Elements:

1. **Enhanced Pedagogical Efficiency** – Automated performance tracking allows instructors to provide precise, data-driven feedback rather than spending time on manual monitoring. Adaptive training programs can be automatically adjusted based on performance trends.

2. **Improved Safety Standards** – Controlled target movement, timing, and integrated hazard monitoring reduce the risk of accidents during live-fire exercises. Emergency stop mechanisms and remote shutdown capabilities further enhance safety.

3. **Scalable Multi-Level Exercises** – Platforms support training from individual skill development to full-scale team coordination exercises, enabling exercises to scale in complexity according to the trainees' proficiency and operational requirements.

4. **Sustainability and Energy Efficiency** – Advanced platforms incorporate energy-efficient motors, solar-assisted power modules, and low-maintenance components, reducing operational costs and environmental impact.

5. **Interoperability** – Smart modular platforms can be integrated with existing range management software, training databases, and live simulation networks, ensuring compatibility with wider military training ecosystems.

6. **Rapid Scenario Update Capability** – Digital and modular design allows for rapid updates of training scenarios to reflect emerging threats, evolving tactical doctrines, or new operational procedures.

7. **Data-Driven Skills Assessment** – AI-assisted analytics enable predictive evaluation of the trainee performance, supporting long-term skill development planning and career progression in line with operational readiness standards.

8. **Support for Multi-Domain Training** – Platforms can be combined with aerial drones, cyber-augmented training tools, and electronic warfare simulators to create holistic, multi-domain operational training environments.

Overall, modernized shooting ranges equipped with intelligent, ground-based modular platforms provide a cost-effective, flexible, technologically advanced, and pedagogically superior solution. They improve training realism, efficiency, safety, and instructor effectiveness, while fostering the participant engagement and preparing personnel for complex real-world operations. By aligning with the principles of smart armed forces, these platforms represent a strategic investment in future-ready military and law enforcement capabilities.

Table 2. Advantages of Key Elements

Element	Key Advantages	Efficiency	Safety	Realism	Adaptability
Permanent Systems	Daily training, integrated infrastructure	High	High	High	Medium
Mobile Systems	Rapid deployment, field exercises	Medium	High	Medium	High
Smart Target Carriers	Dynamic, multi-path targets	High	High	High	High
Automated Performance Tracking	Instant feedback, data analysis	High	Medium	Medium	Medium
Standard Tactical Shooting	Precision & tracking skills	High	High	Medium	Medium
Urban Combat Simulation	Complex decision-making	Medium	Medium	High	High
Stress-Based Training	Cognitive load under pressure	Medium	Medium	High	Medium
Low Visibility Training	Night ops & sensor integration	Medium	High	High	Medium
Digital Tools (AR/VR, Analytics)	Scenario simulation, progress tracking	High	Medium	High	High

Performance evaluation through quantitative analysis

To provide empirical support for the modernization of shooting ranges with ground-based modular platforms, this section presents two key performance evaluations. Both results are derived from simulation data and controlled testing described in previous studies and technical reports. The focus is on how smart target carriers improve training efficiency over time and enhance accuracy through automated evaluation systems.

The first evaluation considers training throughput efficiency as a function of time. Traditional ranges that rely on static targets show only incremental gains in training efficiency even after multiple sessions, largely due to repeated setup tasks and manual management. In contrast, smart platforms demonstrate a steep and sustained improvement in efficiency during the first sessions, eventually stabilizing at a level nearly double that of the conventional ranges. This outcome illustrates the cumulative benefit of automated scenario programming, faster redeployment of targets, and reduced downtime between exercises (Figure 7).

The second evaluation addresses the accuracy of performance assessment. Manual scoring methods typically achieve moderate reliability, but performance data are often incomplete or subject to the evaluator bias. By comparison, automated evaluation systems equipped on modular platforms capture detailed parameters such as hit location, timing, and target movement. This produces a consistent increase in the assessment accuracy across repeated training cycles. The results show that automated systems can reach above 90 percent accuracy, while manual systems plateau below 60 percent, underscoring the significant advantage of smart evaluation technologies (Figure 8).

Together, these evaluations confirm that smart platforms contribute to measurable improvements in both efficiency and accuracy, thereby establishing a stronger foundation for scalable, data-driven, and adaptive training environments.

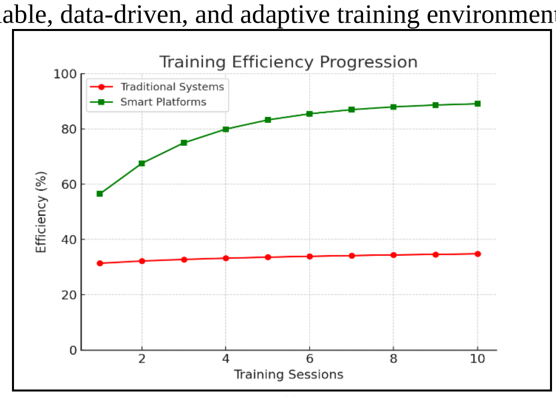

Figure 7. Training Efficiency Progression

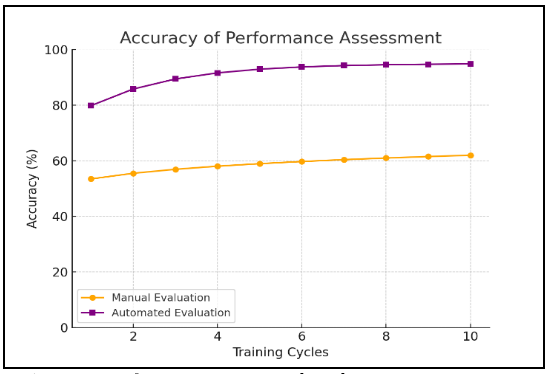

Figure 8. Reduction Accuracy of Performance Assessment

Figure 7 shows the progression of training efficiency over successive sessions. Smart platforms achieve rapid improvements early on and stabilize at higher efficiency levels compared to traditional systems.

Figure 8 illustrates the difference between manual and automated evaluation accuracy across the training cycles. Automated systems consistently deliver more reliable and higher accuracy compared to manual scoring.

Discussion and limitations

The integration of smart modular platforms into shooting ranges represents an important step in the modernization of training infrastructures, bringing together automation, sensor integration, and data-driven performance assessment. These systems provide capabilities for autonomous target movement, multi-sensor hit detection, and adaptive scenario management, thereby enabling training exercises that are both dynamic and realistic. Despite these advantages, a number of limitations must be recognized in order to provide a balanced understanding of their practical value and long-term sustainability.

A critical factor concerns the financial requirements associated with their adoption. The procurement of modular platforms equipped with advanced navigation sensors, wireless communication modules, and centralized control interfaces requires significant investment. For institutions with limited budgets, such as smaller law enforcement agencies, these initial costs may present a barrier to entry. Although the long-term benefits include reduced manpower requirements, improved training throughput, and more precise evaluation of performance, the balance between initial expense and operational savings must be carefully considered before large-scale deployment.

Technical reliability is another determinant of system effectiveness. The platforms depend on stable network infrastructures that use Wi-Fi, RF, or 4G/5G channels for real-time control, synchronization, and data transfer. Interruptions in connectivity or signal degradation can compromise feedback loops, reduce scoring accuracy, or even halt training activities. To mitigate these risks, ranges adopting smart modular platforms must incorporate redundant communication systems, local fail-safe controls, and contingency protocols to ensure uninterrupted functionality during training.

Closely related to technical reliability is the issue of cybersecurity. The use of wireless communications, remote access systems, and cloud-based data storage introduces vulnerabilities that could expose sensitive training data or control systems to unauthorized intrusion. Without strong encryption, access management, and continuous monitoring, these risks undermine both the credibility and the security of training operations. Institutions considering the adoption of these platforms must therefore invest in cybersecurity infrastructure that is as robust as the physical systems themselves.

The sustainability of daily operations is further shaped by maintenance and logistical demands. Unlike conventional target systems, smart platforms require periodic calibration of sensors, regular software updates, and skilled personnel capable of addressing both mechanical and electronic malfunctions. This increases the long-term operational costs and demands a consistent supply chain for replacement parts. Training organizations that operate at high frequency will need to develop dedicated maintenance strategies to avoid downtime and ensure the platforms remain reliable across repeated cycles of use.

There are inherent constraints in simulating the full complexity of real-world combat conditions. While modular platforms can replicate a wide range of tactical situations, they cannot fully reproduce conditions involving explosive effects, electronic warfare, or extreme environmental stressors such as heavy rain, dust, or irregular terrain. Furthermore, although behavioral algorithms and swarm intelligence provide adaptive movement, they cannot perfectly emulate the unpredictability and decision-making processes of human adversaries. This gap must be acknowledged when interpreting the outcomes of exercises and when designing training curricula to complement live-fire practices with simulated elements.

When deploying smart modular platforms in live-fire environments, protecting critical components such as sensors, control processors, power units, and communication modules is essential to maintain system functionality and safety. Exposure to various calibers and ammunition types introduces mechanical shock, vibration, and thermal stress that can impair performance or cause irreversible damage.

To mitigate these effects, modular protective casings with localized ballistic shielding and shock-absorbing materials are recommended. The use of sacrificial panels and vibration isolation mounts can reduce the transmission of kinetic energy to sensitive electronics. Additionally, redundant placement of critical sensors and reinforced communication lines enhance operational reliability in case of partial component failure.

Future work will include testing under live ammunition conditions to evaluate the effectiveness of these protective measures and optimize the balance between protection level, platform mobility, and overall weight.

Taken together, these limitations do not diminish the transformative potential of smart modular platforms but rather underline the need for careful planning and structured implementation. Their successful integration into training programs depends on financial feasibility, technical resilience, cybersecurity safeguards, and sustainable maintenance frameworks. Addressing these requirements ensures that technology can deliver long-term benefits in terms of efficiency, safety, and training realism, establishing a solid foundation for the next generation of professional military and law enforcement training facilities.

Conclusion

The modernization of shooting ranges through the integration of ground-based modular platforms and smart target carriers marks a decisive step toward creating advanced, adaptable, and data-driven training environments. These systems bridge the gap between traditional static ranges and the operational realities of modern combat by introducing mobility, automation, and multi-sensor performance evaluation. The capability to replicate dynamic scenarios, track detailed metrics, and provide immediate feedback significantly enhances both the realism and the instructional value of training.

The findings presented in this study demonstrate that such platforms deliver measurable improvements in efficiency, accuracy, and overall training throughput. By reducing setup time, minimizing human intervention, and ensuring more objective evaluation, they improve both the quality and safety of exercises. At the same time, the modular and scalable nature of these systems ensures their applicability across a wide spectrum of training contexts, from law enforcement facilities to large-scale military proving grounds.

Nonetheless, the successful adoption of smart modular platforms requires careful planning to address financial, technical, and operational challenges. Long-term sustainability depends on robust communication infrastructures, resilient cybersecurity frameworks, and consistent maintenance strategies. Addressing these aspects will be essential to secure the full benefits of technology.

Overall, ground-based modular smart platforms represent more than just an upgrade of existing infrastructure, they embody a transformative shift toward intelligent, integrated, and future-ready training systems. Their implementation not only improves current practices but also lays the foundation for the next generation of military and security training, where adaptability, efficiency, and realism are paramount.

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Pametne modularne platforme za strelišta novije generacije

Ovaj rad ispituje modernizaciju strelišta putem implementacije zemaljskih modularnih platformi dizajniranih kao pametni nosači meta. Tradicionalna strelišta koja se oslanjaju na statičke ili polu-automatske mete sve su manje adekvatna za kompleksne zahteve savremene vojne i policijske obuke. Predložene platforme uvode mobilnost, modularnost i inteligentne funkcionalnosti koje omogućavaju realističnije i adaptivne scenarije obuke.

Sistemi integrišu mobilnu robotiku, senzore za detekciju pogodaka, automatsko bodovanje i prenos podataka u realnom vremenu, što zajedno obezbeđuje objektivnu povratnu informaciju i smanjuje potrebu za ručnim rukovanjem metama. Navigaciona rešenja kao što su GPS, LIDAR i SLAM algoritmi podržavaju autonomno kretanje po različitim tipovima terena, dok modularni dizajn osigurava kompatibilnost sa naprednim infrastrukturama za obuku, uključujući programski upravljane i reaktivne sisteme meta.

Rad ističe sposobnost ovih platformi da unaprede realističnost obuke, poboljšaju standarde bezbednosti i povećaju operativnu efikasnost. Smanjenjem vremena pripreme, omogućavanjem dinamičke rekonfiguracije scenarija i podrškom za fleksibilno raspoređivanje, predloženi koncept doprinosi digitalnoj transformaciji strelišta. Rezultati istraživanja pozicioniraju zemaljske modularne pametne nosače meta kao ključnu komponentu u razvoju strelišta nove generacije koja su usklađena sa evoluirajućim potrebama odbrane i bezbednosti.

Ključne reči: **modularni sistemi za obuku, nosač meta, modernizacija strelišta, autonomna vozila, obuka u gađanju.**