MILITARY SIMULATION METHODOLOGIES IN CIVIL CRISIS MANAGEMENT

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Abstract - The paper analyzes the significance and application of Modeling and Simulation (M&S) as pivotal tools in modern crisis management. It focuses on the transition of these technologies from the military to the civilian sector, with emphasis on their role in prediction, preparedness, and operational planning during disasters.

The methodology employs a descriptive and comparative approach, defining the concepts of modeling and simulation through key literature (Angelevski, Banks). Three primary categories of simulations are analyzed: Live, Virtual, and Constructive (LVC). Key findings include the concept of "safe failure," the digitalization of crisis management through the Next-Generation Incident Command System (NICS) in North Macedonia, and practical verification through simulation exercises. The integration of advanced simulation systems (JCATS, OneSAF) and modern command-and-control platforms (NICS) is an effective response to natural and technological threats.

Keywords - modeling and simulation, crisis management, military simulation systems, next-generation incident command system, evacuation and civil protection.

Introduction

Contemporary crisis management is increasingly challenged by the complexity of modern threats, ranging from natural disasters to technological accidents and hybrid emergencies. Traditional response methods often prove insufficient in such dynamic environments, highlighting the need for advanced analytical tools that can anticipate consequences and support rapid, evidence-based decision-making.

At the core of this transformation are modeling and simulation (M&S) methodologies. A model represents the abstraction of essential system characteristics (Banks and Sokolowski, 2009, p. 5), while simulation is the controlled imitation of real-world processes over time (Banks, 1998, p. 3). Together, they provide a methodological framework for experimentation, enabling decision-makers to test strategies and operational plans without exposing people or resources to risk. This approach introduces the concept of "safe failure," where mistakes can be studied in a controlled environment and transformed into lessons for future preparedness.

Although M&S technologies were initially developed for military purposes, such as training, operational planning, and tactical decision-making, their adaptation to civilian sectors has become a defining trend. They are now widely applied in civil protection, logistics, and evacuation planning to strengthen institutional resilience and improve coordination among various agencies and organizations involved in crisis response.

This paper examines the role of M&S in crisis management through a comparative analysis of military simulation systems such as JCATS and OneSAF, alongside civilian platforms such as the Next-Generation Incident Command System (NICS). It explores their application in preparedness, logistics, and evacuation, emphasizing how military-grade methodologies can be leveraged to enhance civilian protection. The central focus is on whether universal models of crisis management exist, or whether their application is inevitably conditioned by specific contexts and institutional frameworks.

The Role of Modeling and Simulation in Crisis Management

Crisis management is a complex process encompassing prevention, preparedness, response, and recovery, where timely and high-quality decision-making is crucial for minimizing consequences to people, infrastructure, and the environment. To establish the conceptual foundation, Banks (1998, p. 3, para. 1) defines simulation as "the imitation of the operation of a real-world process or system over time", emphasizing its role as a methodological framework for experimentation and analysis. Similarly, Banks and Sokolowski (2009, p. 5, para. 2) describe a model as "a representation of an event and/or things that is real (a case study) or contrived (a use-case). It can be a representation of an actual system. It can be something used in lieu of the real thing to better understand a certain aspect about that thing. Creating an effective model requires abstracting a description of a dynamic system from reality. The model can depict the system at some point of abstraction or at multiple levels of abstraction with the goal of representing the system in a mathematically reliable fashion."

According to Slavko Angelevski, PhD, "a model can be defined as a representation of some or all characteristics of a resource, system, or object" (Angelevski, 2022, p. 9, para. 2). He further explains that a model may serve as a relative substitute for the original object, a depiction of its essential characteristics, or a logical representation expressed through mathematical, physical, or procedural means (Angelevski, 2022, pp. 9-10, paras. 3-4). Modeling, therefore, is the process of replacing an original object with a substitute to obtain information about its essential properties, establishing logical connections between real systems and their abstractions, and enabling experimentation through the model (Angelevski, 2022, pp. 9-10).

In this sense, simulation is the operationalization of models in the time domain. Angelevski (2022, p. 11, para. 4) defines simulation as "an indispensable method for solving real-world problems by describing and analyzing system behaviour." He further describes it as "the imitation of processes or system functioning in the real world over time" (Angelevski, 2022, p. 11, para. 2) and, in technical terms, "the implementation of the model in the time domain, where the model presents how the system functions during a given period" (Angelevski, 2022, p. 11, para. 3).

Modeling in crisis management falls into three primary classes (Angelevski, 2022). Mathematical models use equations and algorithms to simulate events like forest fire spread or flood flow. Physical models offer material representations, such as scale models or topographic maps for analyzing terrain and evacuation routes. Most significant are procedural (conceptual) models, which establish logical event sequences over mathematical equations. These serve as the operational framework, representing the Standard Operating Procedures (SOPs) executed immediately upon an alarm (Mustafovski & Petrovski, 2025a).

In the context of protection and rescue, modeling is not merely a theoretical tool but an essential process of creating a relative substitute for a real-world hazard (such as a flood, fire, or earthquake). Rather than waiting for an actual disaster to occur to observe the system's reaction, a model is created containing only the essential characteristics of the terrain and resources (Mustafovski, 2025a). This enables the study of potential scenarios without risking human lives or expensive equipment. Depending on the level of realism and the method of user interaction, simulations are most commonly classified as Live, Virtual, and Constructive (LVC) (van den Berg, de Reus and Voogd, 2011, p. 3):

1. Live Simulations: These involve real people operating real systems in controlled conditions. They are primarily used for practical training and the verification of procedures. While they provide a high degree of realism, their application is limited due to high costs and complex logistical requirements.
2. Virtual Simulations: These occur when real people operate simulated systems. This category bridges the gap between reality and digital environments, allowing participants to interact with computer-generated interfaces. It is particularly effective for behavioral analysis and scenario testing where using real equipment would be too dangerous or expensive.

3. Constructive Simulations: Constructive simulations feature simulated people operating simulated systems. Human participants do not act as players, but as directors setting initial parameters and scenarios. By rapidly processing complex, large-scale variables such as logistics or mass evacuations, these models are essential for high-level decision-making and strategic planning.

Military Simulation Systems

Modern military simulations reduce resource costs and real-world risks inherent in traditional exercises (Mustafovski, 2025b; Mustafovski, 2025c). They enable safe scenario testing, consequence analysis, and operational capability advancement for better training, planning, and decision-making. Prominent examples include JCATS and OneSAF, which serve as key constructive simulations at tactical and operational levels.

JCATS (Joint Conflict and Tactical Simulation)

JCATS, a constructive simulation system developed to support joint and combined military operations, accurately replicates entity-level operational scenarios for military tactical training and analysis, involving land, air, and maritime forces, as well as civilian actors (Lawrence Livermore National Laboratory, 2024). The system enables detailed modeling of terrain, units, assets, and their interactions in real time.

The system offers flexible scenario creation for diverse operational conditions and training objectives. Operators role-play friendly and enemy forces via a graphical interface, reporting results to commanders through actual command-and-control systems. Highly scalable and featuring human-in-the-loop control for "what-if" simulations, it is globally deployed across hundreds of U.S. military, civilian, NATO, and international organizations (Lawrence Livermore National Laboratory, 2024).

OneSAF (One Semi-Automated Forces)

OneSAF is an advanced simulation system designed to reduce the duplication of Army Modeling and Simulation (M&S) investments and to foster interoperability across M&S communities. It represents a full range of operations, systems, and control processes in support of applications across six domains: Acquisition, Analysis, Experimentation, Intelligence, Training, and Test and Evaluation (U.S. Army PEO STRI, 2024).

Featuring variable fidelity, OneSAF models both individual entities and full formations. Its autonomous forces react to events using predefined rules and doctrines for realistic operational dynamics.

Distributed to diverse organizations for widespread reuse, this source code supports U.S. Army training, concept analysis, capability assessment, and high-level command decision-making (U.S. Army PEO STRI, 2024).

Table 1. Comparative Overview of JCATS and OneSAF Simulation Systems

Criterion	JCATS	OneSAF	Similarity	Primary Focus
Simulation Type	Constructive, entity-level	Constructive, entity & formation-level	Both are constructive simulations	Tactical & operational environments
Main Purpose	Tactical training and scenario analysis	Multi-domain M&S support (training, analysis, experimentation)	Support military decision-making	Broader enterprise-level integration (OneSAF)
User Interaction	Human-in-the-loop control	Semi-automated behavior with rule-based AI	Interactive operational modeling	Higher autonomy in OneSAF
Interoperability	Integrates with C2 systems	Designed for interoperability across M&S communities	Supports joint operations	Stronger architecture integration in OneSAF
Flexibility	High scenario customization	Variable fidelity modeling	Scenario adaptability	Greater scalability in OneSAF
Deployment	Used by NATO, US and 30+ countries	Widely used within US Army and partner institutions	International application	Institutional Army integration (OneSAF)

Table 1 presents a comparative overview of the JCATS and OneSAF military simulation systems, highlighting their core characteristics, operational focus, and interoperability features. The comparison shows that both systems belong to the category of constructive simulations and are designed to support tactical and operational decision-making in complex security environments. While JCATS emphasizes entity-level control with strong human-in-the-loop interaction and scenario flexibility, OneSAF offers broader multi-domain applicability with variable fidelity modeling and higher levels of semi-automated behavior. The table illustrates that both platforms enhance military preparedness and analytical capability, while differing in architectural scope and integration depth within modeling and simulation communities.

Next-Generation Incident Command System (NICS)

The NICS system (Next-Generation Incident Command System) was developed in 2010 by MIT Lincoln Laboratory in cooperation with the Science and Technology Directorate of the U.S. Department of Homeland Security (DHS S&T), with the aim of improving the coordination and response of emergency services during large-scale wildfires in California (MIT Lincoln Laboratory, 2024). It is a web-based communication platform that enables centralized incident management through a shared incident map, real-time information exchange, and coordination among different services and organizations.

The image illustrates a constructive military simulation environment in which operational activities are visualized over a geospatial terrain model. The interface displays a digitized map with multiple divisions (Div A, Div B, Div E, Div F, Div Z, and Div Y) positioned within a defined operational area. The red-marked boundary represents a designated area of operations, maneuver corridor, or control perimeter, while unit markers indicate the spatial distribution of forces and points of interest.

The system integrates terrain modeling, force disposition, and command-and-control reporting within a unified graphical interface. On the right side, a structured reporting panel enables the input and monitoring of operational data, such as incident type, location, weather conditions, and structural damage. This demonstrates the integration of simulation tools with real-time situational reporting and decision-support mechanisms (Mustafovski, 2025d).

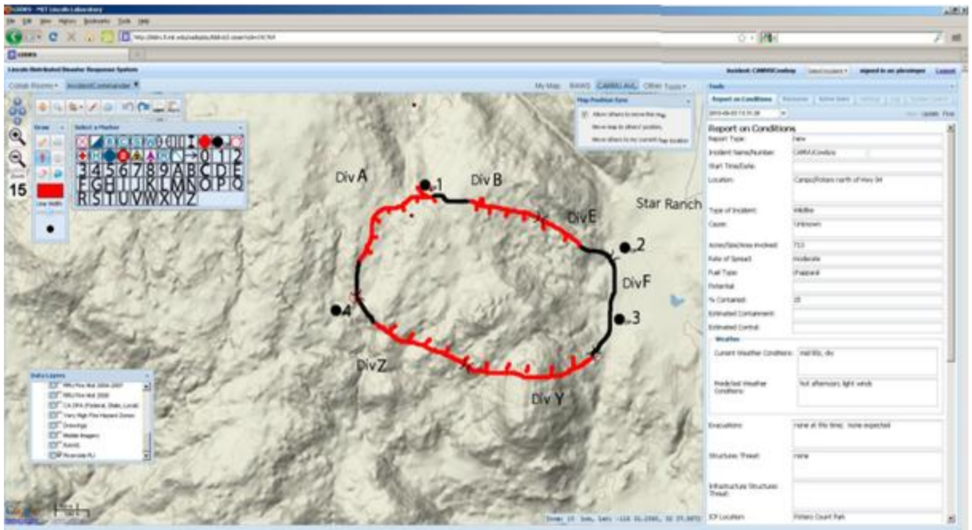

Figure 1. Example of NICS interface during a wildfire in Southern California, where emergency services shared real-time information such as fire size, unit locations, and fire spread rate. Source: MIT Lincoln Laboratory, Tech Notes, 2011.

Such visualization supports tactical planning, scenario testing, and the evaluation of operational outcomes without exposure to real-world risk. The representation highlights how simulation platforms enhance situational awareness, coordination among units, and the analytical assessment of maneuver strategies in complex environments (Mustafovski, 2025e).

The illustration presents a network-centric emergency management architecture that integrates aerial EO/IR sensing, geospatial positioning, and mobile command interfaces into a unified operational environment. An airborne platform captures real-time imagery and transmits situational data to ground units and command centers, enabling synchronized coordination among emergency vehicles and response teams. The system supports collaborative decision-making through shared visualization platforms, thereby enhancing situational awareness during large-scale incidents such as wildfires, earthquakes, and floods (Mustafovski et al., 2025).

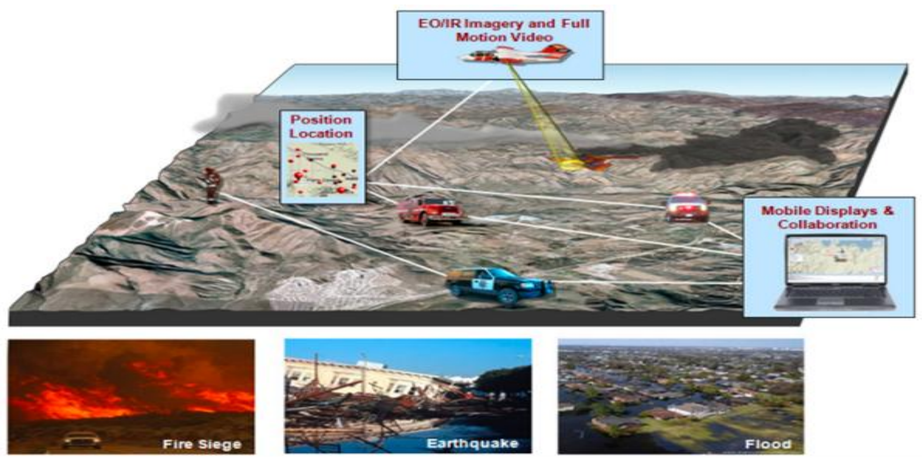

Figure 2. Integrated Aerial Surveillance and Command Coordination Architecture for Emergency Response. Source: MIT Lincoln Laboratory, Tech Notes, 2011.

NATO SPS Involvement

In 2016, NATO, through the "Science for Peace and Security" (SPS) program, initiated cooperation with MIT Lincoln Laboratory and DHS S&T to adapt and implement NICS in Southeast European countries. This collaboration was carried out within the framework of the Advanced Regional Civil Emergency Coordination Project (ARCECP), aimed at enhancing regional coordination and interoperability in the management of civil crises and disasters (U.S. Department of Homeland Security, 2021).

Adoption and Institutionalization in the Republic of North Macedonia

The Republic of North Macedonia was the first country in the region to formally adopt NICS as a national crisis management system. The adoption was officially announced in 2019 during a NATO SPS conference held in Skopje, emphasizing the role of MIT Lincoln Laboratory and the support of NATO and DHS in the implementation process (MIT Lincoln Laboratory, n.d.). The process received full institutional support through a decision of the Government of the Republic of North Macedonia, adopted at its 141st session, which reviewed information on the digitalization of the Crisis Management System through NICS. This decision mandated that all state administration bodies and relevant institutions actively participate in the integration and use of the system (Radio Slobodna Evropa, 2019).

Functionalities and Role of NICS in Crisis Management

NICS enables command over engaged resources, inter-agency coordination, and real-time data exchange (text, images, and video content) among institutions involved in incident and crisis response. Through a shared digital incident map, the system allows visualization of incident boundaries, evacuation zones, weather conditions, and GPS locations of personnel, significantly increasing situational awareness and facilitating coordination.

Practical Application, Training, and International Exercises

Within the ARCECP project, NICS was used in real incidents in the Western Balkans, and in North Macedonia more than 500 users from different institutions were trained. As part of the final phase of testing and evaluation, NATO employed NICS as the main communication technology during the Euro-Atlantic Disaster Response Capability Exercise held in Ohrid, based on a hypothetical scenario involving a strong earthquake followed by a tsunami (U.S. Department of Homeland Security, 2021).

Comparative Analysis and Integration

Simulation systems such as JCATS, OneSAF, and NICS illustrate different but complementary roles of modeling and simulation in crisis management. JCATS and OneSAF are primarily designed for planning and preparedness, enabling the testing of scenarios, evaluation of strategies, and improvement of operational readiness. In contrast, NICS is focused on real-time crisis response, providing situational awareness and coordination among emergency services.

A key difference is the stage of the crisis at which they are applied. Military simulation systems operate before events occur, reducing uncertainty through prediction and experimentation. NICS operates during crises, reducing uncertainty through real-time information sharing and coordination. This distinction highlights their complementary nature rather than direct competition.

In terms of the modeling approach, JCATS emphasizes detailed, human-controlled simulations at the tactical level, while OneSAF extends this with broader, multi-level modeling and greater scalability. NICS does not simulate future scenarios but instead integrates and visualizes real-world data, supporting decision-making in ongoing operations.

Despite their differences, all three systems emphasize interoperability and information sharing. JCATS and OneSAF integrate with command-and-control structures, while NICS connects civilian institutions through a unified platform, highlighting the importance of shared information environments. Overall, the comparative analysis reveals that military simulation systems and civilian crisis management platforms share common objectives: improving preparedness, reducing risks, and supporting better decision-making. Future development points toward greater integration of these systems, combining simulation-based planning tools with real-time coordination platforms to strengthen resilience and improve responses to complex crises.

Application of Simulations in Civil Protection and Rescue Systems

Simulations play an increasingly significant role in modern protection and rescue systems, especially under conditions of heightened frequency and complexity of natural and anthropogenic disasters. Unlike the military context, where simulations are primarily used for planning and conducting operations, in civil protection their application is directed toward risk reduction, population protection, and improving institutional preparedness for response in crisis situations.

Simulations in the Preparedness and Training Phase

In the preparedness phase, simulations are used as a fundamental tool for personnel training and for testing existing plans and procedures. Through scenario-based simulations, the reactions of institutions to different types of disasters, such as fires, floods, earthquakes, or industrial accidents, are tested. These simulations allow the identification of weaknesses in coordination, communication, and resource allocation, without exposing participants to real risks.

A particular advantage of simulations is the possibility of repeating and modifying scenarios, which enables the gradual improvement of the knowledge and skills of the involved personnel. In this way, simulations complement theoretical training and contribute to the development of practical competencies among protection and rescue services.

Simulations in the Operational Planning Process

In the operational planning process, simulations are used to analyze possible scenarios and assess the effects of different decisions. By modeling the spread of fires, the movement of water masses during floods, or the impact of earthquakes on infrastructure, the responsible institutions can determine critical points and intervention priorities in advance. These simulations enable more efficient planning of resource use, such as human capacities, equipment, and logistical support. The application of such an approach reduces reaction time and increases the likelihood of successfully managing the crisis, especially in the initial phases when decisions are made under pressure.

Simulations as a Tool for Coordination and Decision-Making

One of the greatest challenges in the protection and rescue system is coordination among different institutions and actors (as well as their interoperability). Simulations, especially when integrated into command and information systems, enable a shared understanding of the situation and alignment of activities among all involved parties. By using simulation scenarios, decision-makers can assess the effectiveness of different strategies and select solutions that provide the best balance between risk, time, and available resources. In this way, simulations do not replace the role of human decision-making but provide analytical support that increases the objectivity and quality of decisions.

Logistics and Evacuation Modeling

Effective crisis management is not limited only to decision-making, it also encompasses the optimal use of resources and the planning of population movement. Simulations and models enable the prediction of potential problems, allocation of capacities, and organization of assembly and evacuation points. Logistics models are used to analyze available resources, such as rescue teams, medical equipment, transportation means, and other infrastructural capacities. Through simulations, the optimal distribution of resources can be determined, with the aim of maximizing coverage of risk areas and reducing intervention time.

Beyond resource allocation, contemporary modeling emphasizes the integration of Geographic Information Systems (GIS) to provide spatial intelligence. Hui, Yu and Peng (2024) demonstrate that data-driven simulations allow for more accurate predictions of evacuation times in complex urban environments, particularly within "smart" infrastructure. Their study shows how bottleneck analysis and spatial decision support systems enable planners to identify flood-prone zones and determine shortest paths to medical facilities, thereby significantly reducing response times compared to traditional static routing.

Furthermore, logistics models must address the complexities of Transit-Based Evacuation. Khalili, Mojtahedi, Steinmetz-Weiss and Sanderson (2024) highlight that modern strategies increasingly focus on transit-dependent populations. By treating evacuation as a variation of the Vehicle Routing Problem (VRP), models can incorporate constraints such as shelter capacity and road network integrity to ensure an equitable response. This perspective underscores the importance of integrating public transportation networks into evacuation strategies to enhance operational efficiency and ensure safety for vulnerable groups.

In parallel, Ershadi and Shemirani (2022) show that multi-objective optimization frameworks are essential in the crisis response phase. Their model demonstrates how managers can minimize unsatisfied injured populations while simultaneously optimizing transportation activities. This hierarchical approach ensures that priority needs are met while maintaining efficiency in logistical operations, making it particularly relevant for large-scale disaster scenarios.

Finally, the shift toward Agent-Based Modeling (ABM) has allowed for a deeper understanding of human behavior during crises. Rather than viewing crowds as a uniform flow, ABM simulates individual decision-making processes, such as leader behavior or route choice. Hui, Yu and Peng (2024) note that integrating these behavioral insights into logistics planning ensures that evacuation points and resource distribution centers are located where people are most likely to naturally congregate. This reduces chaos and increases the overall survival rate, making ABM a valuable complement to GIS and optimization approaches.

Simulation Exercises and Evacuation

Simulation exercises for evacuation represent a key tool for testing the preparedness and functionality of protection and rescue systems. Through realistic scenarios, such exercises enable the practical application of plans, improvement of coordination among institutions, and the development of skills among participants. At the same time, they serve to identify weaknesses in organization, communication, and access to critical locations. Their role is particularly significant in raising awareness and preparedness among students, employees, and the wider community. Below are specific examples of evacuation simulation exercises conducted in educational institutions and industrial facilities.

Simulated Fire Evacuation – OEMUC "St. Naum of Ohrid"

On November 3, 2023, at OEMUC "St. Naum Ohridski," a simulation exercise for fire evacuation was conducted (Figure 3). The exercise was intended for first- and third-year students and was successfully implemented in cooperation with the Red Cross Ohrid (TVM Ohrid, 2023).

Members of the Local Youth Organization actively participated as stewards, actors, and responsible persons for the successful evacuation of students and teachers. "The simulation began with the evacuation of students by teachers and members of the youth community, after which they had the opportunity to follow the procedures for providing first aid for the three most common injuries. Participants included the Red Cross Ohrid first aid team, as well as the team for psychological first aid," informed the Red Cross Ohrid (TVM Ohrid, 2023).

After the exercise, students attended a lecture on first aid delivered by trained demonstrators. This marked the beginning of the Red Cross Ohrid First Aid Campaign, scheduled to run for the next two months.

Figure 3. Simulated evacuation during fire – OEMUC "St. Naum Ohridski."

Simulation Exercise for Earthquake and Fire Evacuation – SOSU "St. Cyril and Methodius," Ohrid

The Territorial Firefighting Unit Ohrid, in cooperation with SVR Ohrid, Red Cross Ohrid, and the Crisis Management Center, conducted a simulation exercise for earthquake and fire evacuation at SOSU "St. Cyril and Methodius" (Figure 4).

The exercise demonstrated a high level of professionalism, coordination, and efficiency. Teams from the Territorial Firefighting Unit, SVR Ohrid, first aid and psychological support teams, as well as the Crisis Management Center and the Directorate for Protection and Rescue, were actively involved.

Representatives from the UNDP Office in Macedonia, the Head of SVR Ohrid, and officials from CMC and DPR attended and evaluated the exercise as highly successful. The Red Cross Ohrid expressed gratitude to all institutions and participants for their support and professional engagement (TVM Ohrid, 2024a).

Figure 4. Simulation exercise for earthquake and fire evacuation – SOSU "St. Cyril and Methodius," Ohrid.

Simulated Evacuation and Rescue Exercise – Magna Company, Struga

In the industrial zone of Struga, Magna Company carried out a simulation exercise to practice and verify operational rescue and evacuation plans (Figure 5). At the sound of the alarm, employees stopped work and evacuated according to the operational plans.

The scenario included a fire, to which the Territorial Firefighting Unit Ohrid responded in real time. The exercise also simulated injured and shocked individuals, who received medical and psychological assistance from the Struga Health Center and Red Cross Ohrid teams. Other institutions were present: the Directorate for Protection and Rescue, Crisis Management Center, Territorial Firefighting Units, and SVR Ohrid.

The President of the Red Cross Ohrid, Sasho Tochkov, emphasized that prevention during accidents is crucial, and such exercises enable coordination among institutions and verification of operational plans. The first observation from the exercise was the difficult access for services to the location, which will be corrected in future activities (Savić, 2024).

Figure 5. Simulated evacuation and rescue exercise – Magna Company, Struga.

Importance of Training and Prevention in Emergencies

Simulation exercises for evacuation and rescue, such as those conducted at OEMUC "St. Naum Ohridski," SOSU "St. Cyril and Methodius," and Magna Company, emphasize the necessity of systematic training for students, employees, and institutional teams in dealing with disasters and emergencies.

Training and practical exercises enable:

1. Improvement of coordination among different services (fire department, Red Cross, police, and crisis management centers).
2. Evaluation of operational plans, identifying potential weaknesses in access, evacuation routes, or reaction time.
3. Development of awareness and composure among participants, as emphasized by Sasho Tochkov, President of the Red Cross Ohrid: "Prevention in acting during accidents and disasters is the most important segment; we must be prepared, know how to react, and understand our responsibilities." (Savić, 2024).

Additionally, regular training increases the efficiency of decision-making in real crisis situations. The integration of simulation systems and command-information platforms such as NICS provides practical experience in resource management, coordination, and communication. In this way, participants acquire practical skills for:

4. Rapid and accurate reporting to competent services.
5. Risk assessment and prioritization of decisions.
6. Coordinating evacuation and resource allocation in real time.

Conclusion

Modern crisis management is inconceivable without the integration of models, simulations, and digital command-information systems. Models enable systematic representation of complex situations and prediction of possible consequences, while simulations allow testing of strategies, personnel training, and resource optimization without exposure to real risk. At the same time, their application creates the concept of "safe failure," which enables learning from mistakes in a controlled environment.

The military development of simulation systems, such as JCATS and OneSAF, and their wargaming methodology, serve as a foundation for adapting civilian crisis management systems, allowing better planning, coordination, and timely decision-making. The implementation of the NICS system in the Republic of North Macedonia demonstrates the practical application of these technologies, providing centralized incident management, real-time information exchange, and coordination among institutions.

Simulation exercises for evacuation and rescue, conducted in schools and companies, confirm the importance of practical training and prevention, enabling the development of competencies, evaluation of operational plans, and raising awareness among participants. The combination of theoretical knowledge, simulations, and digital platforms ensures preparedness and confidence among all participants, which is critical for effective responses in real crisis situations and for minimizing consequences for human life and resources.

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