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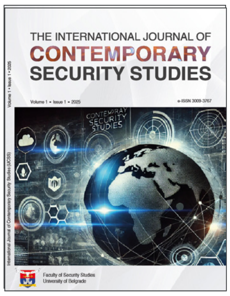

Research article

The Use of Simulation Models in Security Studies: An Example of Basketball Games as Mass Sports Events

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ABSTRACT

Within the framework of security studies, the use of software in education about dealing with and solving crises has become an increasingly relevant methodological approach. The use of the software should enable a better understanding of decision-making mechanisms and evaluate security measures in conditions that replicate real operational environments. The aim of this paper is to demonstrate how simulation models contribute to improving the design of a security subsystem by enabling the testing and optimization of procedures. A basketball game was selected as a representative mass sports event due to the predictable presence of large crowds and the potential for security-related incidents. Through scenario manipulation, trainees can modify variables such as the number of security personnel, the placement of barriers, or the number of evacuation routes, and immediately observe how these changes affect the defined performance indicators. XVR simulation software was used to design and evaluate the security subsystem for the event. The results confirm that the software enables the controlled testing of security procedures without risk to people or property, with the possibility of providing quantifiable feedback that improves training efficiency and decision-making accuracy.

KEYWORDS

Simulation model; XVR software; security risks; public gatherings; sports event; basketball game.

1. Introduction

This paper presents a systems-oriented approach to designing security subsystems, emphasizing both structural hierarchy and quality control. Central to this process is the use of a virtual environment through the XVR simulation platform, which enables simulation-based decision-making by modeling crowd dynamics and testing security interventions. By integrating systems theory with practical simulation, the approach facilitates evidence-based strategies for managing public safety in complex event scenarios.

This study investigates how simulation tools such as XVR, can improve crowd safety and emergency response efficiency during indoor basketball events. By combining concepts from security studies with advanced

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information and communication technologies, the research investigates how virtual simulations can model realistic crowd behaviors, identify potential security risks, and evaluate the effectiveness of various intervention strategies. The study further considers the role of such simulation-based approaches in training security personnel, informing the design of event-specific safety protocols, and supporting decision-making for the management of public gatherings.

2. Simulation-based modeling with the XVR platform

The theoretical foundation of this research is based on the systems-theoretic security approach developed by Nancy Leveson and William Young. Their systems-theoretic process analysis for security expands traditional hazard and security analysis by emphasizing control of system vulnerabilities instead of threat avoidance (Young & Leveson, 2013; Leveson, 2012). In this approach, system safety and security are achieved by introducing constraints that prevent the system from entering vulnerable states that may lead to losses. As the authors state, “the key question facing security analysts should be how to control vulnerabilities, not how to avoid threats” (Young & Leveson, 2014, p. 35). This makes the method suitable for complex socio-technical environments, such as securing large public events.

To translate this conceptual framework into practice, a simulation-based model was created using the XVR platform. Unlike traditional training methods, XVR enables controlled experimentation, allowing researchers to observe how different decisions influence safety outcomes in real time. Rather than describing the software from a technical standpoint, its selection and use in this study are tied directly to research needs. Specifically, XVR supports: multi-user participation, enabling several roles to act simultaneously (security officer, security shift manager, control room operator); three-dimensional animation, positional sound effects, audio and video streaming, and user interaction (Carrozzino *et al.*, 2005, p. 270); scenario branching and real-time modification, allowing the operator to inject unexpected events (e.g., crowd surge, blocked exit); integrated communication recording, making it possible to analyze communication flow and decision sequencing throughout the exercise (Barta *et al.*, 2016, p. 79); and spatial and resource manipulation (avatars, vehicles, access routes), which supports evaluation of resource allocation efficiency during crowd management.

In 2015, it was estimated that over 150 emergency services in the UK and worldwide were using this software. Also, during the six years preceding this year, the competence of the candidates improved thanks to the work in this software (Lamb *et al.*, 2015, p. 237). It is suitable for civil-military use, for training employees in emergency response and rescue units, but it could also be used to access knowledge and training, check procedures, lines of communication, and evaluate new tools. In the field of disaster management, software could be effectively applied in the Integrated Disaster Management model (Milenković, 2025, p. 178), in the preparation phase when measures to mitigate the consequences of disasters are developed, or the Integrated Disaster Risk Reduction System model (Cvetković, 2015). Technological innovations, such as (risk) simulation software, contribute to improvements in areas such as risk mapping, damage assessment, and resource utilization optimization (Dada *et al.*, 2025, p. 4).

3. A basketball game as a type of mass sports events

Gatherings therefore represent a group of people who deliberately and temporarily gather in a private or public space, for a specific purpose, that is, to express values, attitudes or opinions that are common to all members of the group (UN General Assembly, 2012; Boyle & Vullierme, 2021, p. 11). Gathering means the arrival of a certain or indefinite number of people at a certain place, for the purpose of public presentation or pointing out a problem and presenting an opinion on the possibilities for overcoming it. The moment when an (un)determined number of people arrive at a certain place and form a group in order to realize the goal of the gathering, we can say that a gathering is formed (Misić, 2016, pp. 35-36). From these definitions, it follows that gatherings are called public when they are held in a public space. Public space in the context of this work does not mean open space in the physical sense, nor space that is publicly owned and available anytime, to anyone and without compensation (see more in: Marković, 2021; Marković, 2022). These spaces are often only available during a certain part of the day and are generally publicly owned, which may not always be the case (UN-Habitat, 2018,

p. 10). The last-mentioned feature is important if you take into consideration the fact that many facilities where public gatherings are held, including sports facilities, can be both publicly and privately owned.

As public gatherings can be held in open and closed places, we can distinguish public gatherings in open spaces and public gatherings in closed spaces. An open space would be any space that is accessible for the gathering of persons whose number and identity are not predetermined. A closed space would be a space, or in this case, a facility or room that is fenced off or marked, and thus the number of people who can access it is limited. Bearing in mind that the paper deals with the issue of security risks at basketball games, the focus remains on the closed space where they are most often held. The closed space, together with other factors, conditions certain dangers, which will be discussed later.

Sports events as a type of public gathering were selected taking into account their frequency, the greatest comprehensive security risk that they carry with them with potentially the most serious consequences, and the degree of demanding security (Misić, 2016, p. 158). Sports events, as well as musical events and all other events held indoors, as a rule, involve the gathering of a large number of participants. With the increase in the number of people gathered at these events, the need for planning and undertaking effective safety and security measures increases. The most popular sports around the world are certainly football and basketball. A basketball game was chosen as the subject of the work as a type of sports event. The choice made regarding the type of sports event that will be covered in this work is supported by the following: football is more popular in the United States of America, but basketball is more popular globally (Omar, 2022).

3.1. Security risks at basketball games

Threats at sports events can be viewed through security issues or risks. Since they are related to a specific group of individuals, organization, or, in our case, a type of event, we could also call specialized security risks (Metić, 2025, p. 19). Basically, all these risks can be divided into three groups: natural character, technical character, and social character (Marković, 2022, p. 36).

Risks of a natural nature arise from natural disasters, and although they are partly limited given that basketball games are most often played indoors, they should not be neglected. We are witnessing increasingly frequent natural disasters in the form of storms accompanied by thunder, strong winds and heavy rainfall, both in the world and on the territory of our country.

When it comes to risks of a technical nature, these primarily refer to problems associated with any technical (mechanical and electronic) equipment that is an integral part of the hall for holding this type of sports event. Such problems may lead to incidents such as electric shock, fires and explosions. To this day, the worst fire in football history is the fire at the stadium known as Bradford University Stadium in 1985, which killed 56 and injured more than 250 spectators (Event Insurance Services, n.d.).

The third group of risks is caused by human behaviour. At the highest level of generality, these risks include criminal acts, misdemeanors and deviant behaviour, primarily violent behaviour. They also encompass the use and abuse of psychoactive substances and property crimes such as theft. Most often, it is about vandalism and fights. Just one example is an incident at a stadium in Egypt where fans of one team started attacking fans of another team with knives, stones, bottles and other objects, causing a total of 79 deaths (News Desk, 2022). However, a serious threat to all those present at sports events, which we have had the opportunity to witness several times, is the placement of explosive devices and terrorism. It is enough to mention the terrorist attack in Munich in 1972.

Finally, there are also potential safety problems that have a combined character, for example, fires or explosions caused by lightning strikes in electrical installations. As an example, a combination of natural disaster and uncontrolled mass movement can be cited. In Nepal, in 1988, 93 people died and another 100 were injured when they tried to escape a hailstorm inside the national stadium. Serious consequences for health and life occurred when, due to a hail storm, a crowd of visitors who intended to escape from it, but remained inside the stadium because the exit was locked (News Desk, 2022).

A significant risk that we single out here is the capacity of the sports event venue. This risk comes to the fore when the number of places for visitors is limited, and due to the nature of the event, there is a great interest in watching it live from the stands or another place intended for the audience. At the concert of rock band 'Fish

Stew' in Zagreb in 1982, Željka Marjanović, who was 14 years old at the time, lost her life due to the crowd that prevailed at the concert organized in a closed facility (S.R., 2022). During the 1988-89 FA Cup semi-final event between Liverpool and Nottingham Forest, as many as 96 people died, and 766 injured due to overcrowding at Hillsborough football stadium. Disaster struck when an estimated 2,000 people ran onto the standing terraces when the gate was opened with the intention of easing congestion at the entrance turnstiles (Event Insurance Services, n.d.). Falls and going over the face can sometimes be the main risk in a sports event.

Table 1. Classification of risks at basketball events (Source: Authors)[1]

Type of risk	Example of hazard	Probability of occurrence	Impact on safety	Possible consequence	How the risk is modeled in the simulation
Natural	storm, lightning, heavy rain, hail	Low – Medium	High	suspension of the event, evacuation, and injuries due to panic	environmental changes (sound effects, reduced visibility), activation of the evacuation scenario
Technical	fire, electrical failure, equipment malfunction, structural collapse	Medium	High	fire, injuries, evacuation delays	blocked exits, fire source, alarm activation, and lighting failure
Behavioral (Social)	crowd violence, vandalism, bringing weapons, panic movement	High	High	injuries, stampede, property damage	crowd density increase, aggressive actor behavior, trigger-based escalation
Combined risks	fire caused by a lightning strike, panic + technical failure	Low	Extremely high	mass injuries, difficult evacuation	simultaneous multi-incident scenario (e.g., power outage + panic)
Capacity-related	overcrowding, insufficient exits, bottlenecks	High	Extremely high	stampede, blocked escape routes	pedestrian flow simulation, crowd density metrics (persons/m^2)

Security risks can also be viewed from a temporal perspective: *pre-event risks*, *risks during the event,* and *risks after the event*. Risks during the event can be further divided into three subgroups. The **first subgroup** includes risks immediately before the start of the event (time from 5 hours before the start of the event to the first minute of the event), such as those that may arise during the transfer of players from their accommodation to the sports venue, within the premises where players are situated before the event, or in relation to traffic and crowd control. The **second subgroup** covers risks present throughout the duration of the event (time from the first to the last minute of the event), including risks to players or teams, spectators and other attendees, as well as issues related to parking and crowd management. The **third subgroup** pertains to risks that emerge immediately after the end of the event (time from the last minute of the event to the moment of complete emptying/leaving the hall or facility where the event took place) such as thosethat occur on the way between the sports facility and the accommodation of the players, how to pick up the players, i.e. Teams, as well as spectators (organized fan groups), as well as risks linked to crowd control during exit and dispersal.

Like the form of endangerment (Mandić & Stanojević, 2020, pp. 91-92), security risks at sports events largely depend on the activity and location. Activity is the type of sport for which the event is organized and the (nar-

1 The listed risks are prioritized using a risk matrix (probability × impact). In XVR, simulation parameters are then assigned to the selected risks, which may include Scenario Parameters (time of event, number of people in the space, number and capacity of evacuation routes); Incident triggers (appearance of aggressive crowd, blocking of exits) and Measurable Outcomes (evacuation time, crowd density, number of injured in the simulation, required number of people to respond).

rower and wider) location is where the sports event is held. A sports facility can be defined as a facility intended for holding sports events, which, in addition to the sports field, has an area for the audience and which may also have an accompanying area (sanitary, wardrobe, storage, etc.), as well as an area to which the entrance and the movement of natural persons conditioned by the possession of a ticket or a permit issued by the organizer of the sports event.

When it comes to the activity, that is, in this case, the type of sport for which the event is organized, there are no security risks that could be singled out only for this type of sport and sports event. What can be noted at this point is that, in addition to football events, basketball events represent the biggest challenge from the aspect of security and their provision is a challenging undertaking for the persons assigned that task. When it comes to location, several parameters are important. First, depending on the competition in which the sports event is held, a distinction can be made between rural and urban areas. Then, the roads that are located in the immediate vicinity of the sports facility, that is, the location of the event, as well as those that are used for the transportation of teams and spectators/fans are important. It should be taken into account whether they are main or minor roads, what their capacity is, as well as the degree of use and eventual congestion. In addition to roads, buildings in the immediate vicinity are also important, primarily their purpose. In the context of security risks, the roads used for the transport of teams and the organized transport of spectators/fans, as well as their gathering places near the sports facility itself and the places where buses and other means of transport used for the aforementioned transport are parked, stand out.

Indirectly related to both activity and location, as one of the elements on which security risks depend, is the type of facility in terms of "degree of openness". Most often, basketball games are held indoors. The closedness of the space can make it difficult to evacuate people if it was not adequately planned beforehand. The closedness of the space can increase panic among those present in the sports facility or worsen the consequences of certain harmful events such as fire or any act involving an explosion or the use of toxic substances.

4. Simulation methodology

STEP 1: WHO IS THE TARGET GROUP? – Whose training is the simulation designed for? In the case of this simulation, based on which it was designed, it was prepared for the training of security officers (security officer, manager of the security officers and security manager in the control room). At this point, it is determined which competencies the participants must have in order to access the simulation.

STEP 2: WHAT ARE THE TARGETED RESULTS OF THE TRAINING? – It is necessary to define the objectives/outcomes of the training or the criteria for evaluating the results.

STEP 3: HOW WILL THE TRAINING/EXERCISE/ASSESSMENT BE CONDUCTED? – Choose a teaching/training methodology (e.g., self-study, classroom, 1-on-1, team training, etc.), a method for data collection, evaluation and/or assessment; the way the virtual incident is presented (e.g., via XVR Expo, plenary, in different rooms or on VR HMDs). Define the schedule during the session, which hardware and which participants, and where.

STEP 4: DEFINE THE SCENARIO – 1) What happened? Adjust for each scenario: type (incident, weather, hazards, damage, number and severity of casualties, etc.); 2) Where did it happen? (exact location, entry and exit routes); 3) Who is involved? (Emergency services, firefighters, police and other interested parties). This place should include all training participants and all non-playable characters - automation and behavioral algorithms; 4) What is the flow of the story? Include all dilemmas and choices. Record information/communication sources (e.g., SITREPS following METHANE structure).

STEP 5: WORK PLAN OR ELABORATE (DETAILED INSTRUCTIONS/MANUAL) FOR CONDUCTING THE TRAINING/EXERCISE – Develop a work plan for conducting the training or exercise. Use your organization's template for a plan or handbook, or create your own. Include at least the following: Introduction, target group and teaching/training objectives/outcomes, evaluation method; A brief description of the incidents and the overall time frame for (each) incident; Real-time training session timeline and practice time (including setup, start, breaks, evaluation); Points of attention during the session, such as: checklists, evaluation form, evaluation plans, etc.; Scenario injection list and details related to XVR scenarios and Practical issues (location, layout, props, hardware, etc.).

STEP 6: CREATE XVR SCENARIO – Choose an empty XVR environment or use a basic existing scenario and templates; Set incident items (hide, group, lock or disable objects if applicable); Define motions and states; Place salvage items and hide/lock them if applicable. Prepare movements and states (if applicable); Set avatars of participants and vehicles; Define roles and their tools and interactions; Set weather conditions and simulation time. Add flags or vegetation to indicate wind direction; Place other objects (and movements) to make the scene more realistic and dynamic; Add sounds for additional virtual reality immersion (for example ambient sound, crowds, screams); Give important (groups) of subjects recognizable names; Rearrange groups for good findability; Create events (EVENTS), tasks (TASKS) and/or triggers (TRIGGERS) for greater automation and reduction of operator workload (Make them flexible to adapt to different participant choices and allow for improvisation); When creating XVR Expo scenes, add viewpoints and hotspots, export the scene and upload it; Write down in your lesson plan/handout/manual concise explanations for operators of how the XVR scenario can be used (e.g. a list of events/tasks (EVENTS/TASKS) and what needs to happen and when); Save and test often as you build XVR.

STEP 7: TEST/VERIFY – Perform a technical test and then a full simulation test. This will ensure that everything is working and ready for training/practice.

STEP 8: PRACTICAL QUESTIONS – For example, determine date(s), participants and room(s) for training.

STEP 9: EXECUTE THE EXERCISE – After briefing the participants on the objectives of the training/exercise, how to behave as participants and how to use the XVR software. Monitor the implementation of the plan while maintaining flexibility for participant input and creativity.

STEP 10: EVALUATION (AFTER EXERCISE REVIEW/ASSESSMENT) – Perform an evaluation based on the results obtained and the goals set.

Presented as a flowchart, the creation of the simulation methodology can be presented as follows (Figure 1):

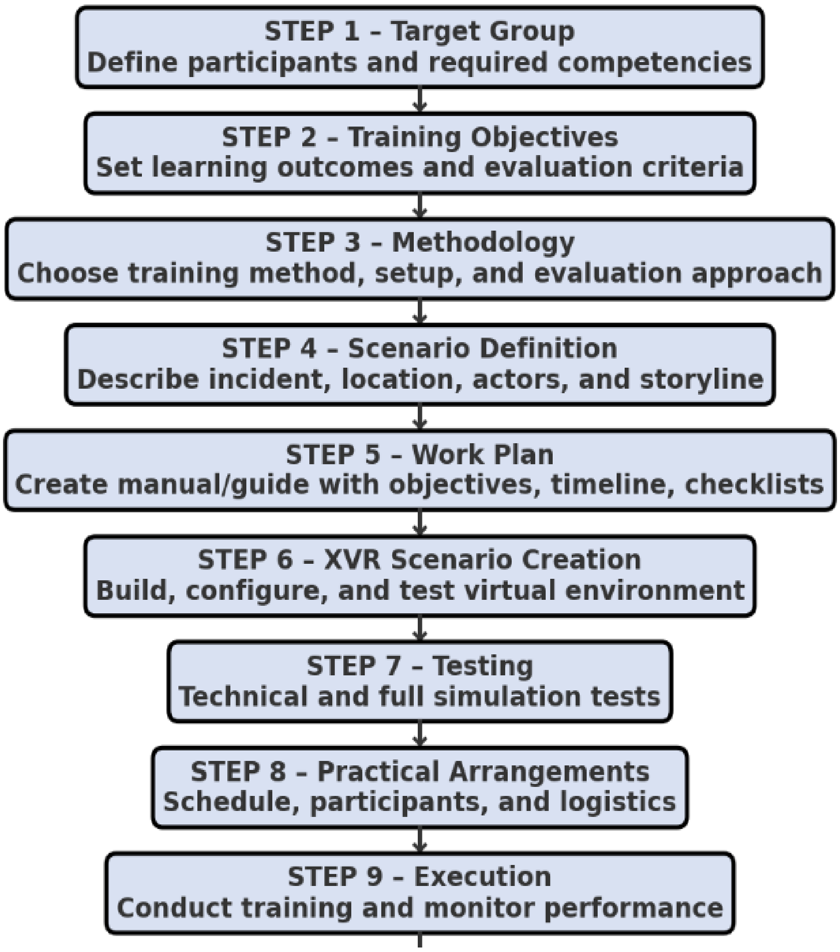


Figure 1. Simulation methodology presented as a flowchart (Source: Authors).

5. Implications of the study – Designing the Security Subsystem of a Basketball Game

As a rule, a basketball game is played indoors, in a sports hall or arena. In this regard, the first step in designing a virtual model of basketball game is designing the hall or arena. The program offers the possibility of importing an arena ('Merge' button), as well as creating an arena taking into account all internal and external elements (Empty Environment; Object Creator). For the following scenario, it was enough to form the terrain (Object Creator Cube with Proportions and Thermal properties, for example).

For example, the security system of a public gathering in a closed space – the security system of a basketball game (in the sports facility itself) consists of three roles, from the lowest hierarchical level to the highest: a security officer who is in direct contact with the audience, the manager of an official in a certain sector in the area of public gathering who is not in direct contact with the audience, but has a visual overview of the area for which he is responsible (manager of the security officer) and the security manager in the control room (desk) who, in addition to the communication system, has a visual inspection using the video security system. The simulation must include certain equipment found in any hall that has a basketball court (for example, air conditioning and ventilation systems, heating, lighting). The implementation of CCTV is significant – in this simulation, two fixed cameras in the hall and one monitor in the control room are placed (2 Fixed CCTV and Monitor (Specific properties, High resolution, 1 Monitor, No detail monitor)).

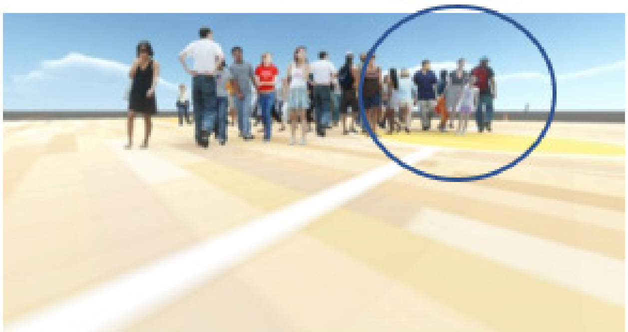
In the design, we use virtual reality so that we create three avatars for all three roles of the security system – each of the roles has its own representative in the virtual model of the public gathering space. In order to implement a quick quality check of the security subsystem, we use the capabilities of already defined objects in the XVR library. In this regard, we model the audience with the object "Crowd of people". We model the complete audience with multiple crowds (different fan groups, for example).

In this proposed scenario, we define two adjacent crowds, each with its own security officer, who has his own avatar. The crowd object itself has a number of sets of attributes: specific crowd attributes, scale, location and space, the surface on which it is defined, moving the group from one location to another, the sound heard inside the crowd, etc. We define different states for the crowd: DEPARTURE, CROWD, INJURY.

The state of the crowd "DEPARTURE" has defined parameters (Specific properties, Crowd settings: Density (40 people in a space of 10 × 10 m), Default movement speed (7 km per hour); Sound (Crowd talking, volume middle)). "CROWD" condition with the following object properties: (Specific properties, Crowd settings: Density (200 people in a space of 10 × 10 m), Default movement speed (3.4 km per hour); Sound (Crowd talking, volume max, maximum distance – crowd area)) (**Picture** 1 with indicated persons – objects that will participate in the incident). The "INJURY" condition is part of the scenario that starts the accident – a condition that requires the intervention of the safety system. The "INJURY" state is the same as the "CROWD" state, but we change the Sound property (Causality - Female - Calling for help) to a female scream that is heard once and locate the sound in the corner of the crowd space. A security officer, i.e. an avatar of a security officer located in the crowd area (Specific properties, Default movement speed (7 km per hour); Animation (Standing)), comes to the location where the sound originates and when he approaches and enters the defined sound zone, 1) a woman kneeling next to a child (Specific properties, Default movement speed (7 km per hour); Animation (Kneeling both knees)) and 2) a child lying on the ground appear (Specific properties, Default movement speed (7 km per hour); Animation (Crying; Sitting on ground)). For that, we use the Triggers logical item of the XVR simulator.

This is a pre-defined scenario of changing the state of one and the other pile, defined by a special process description Event. However, it may happen that the avatar of the security officer in the neighboring area is closer to the scene, and he leaves his area and arrives at the scene of the incident before the security officer in the area hears that the incident took place (**Picture** 2).

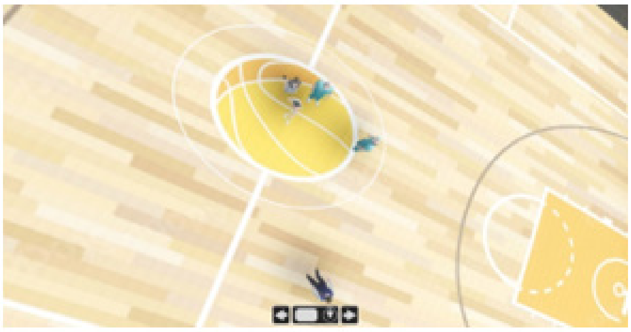
Picture 1. *The scene before the beginning of the incident (Source: Authors) – XVR Simulation*



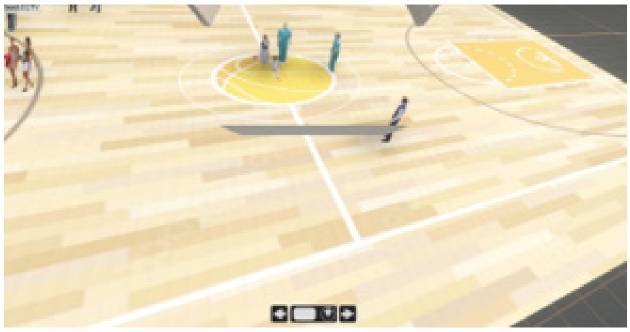
Picture 2. *The scene from the point of view of security officers (security manager, medical team, injured child next to the mother) (Source: Authors) – XVR Simulation*

Just a few moments after the security officer has left his area, another incident occurs in his area. On the other hand, the manager of the security officers through his avatar, through the design option XVR Tasks, can have the possibility to have available the programmed roles of security officers instead of real security officers and their avatars. In that case, he is the one who determines which of the programmed security officers will be assigned the task of arriving at the scene of the incident. Finally, in the command room (**Picture** 3 and **Picture** 4), they can decide whether a virtual medical team or a real medical team via an avatar should come to the scene of the incident.

Picture 3. *The scene from the control room through a camera on the ceiling (Source: Authors) – XVR Simulation*



Picture 4. *A scene from the control room through the camera on the wall (Source: Authors) – XVR Simulation*



The virtual simulation model enables measurable interoperability between security roles, as participants must exchange information, coordinate decisions, and follow reporting protocols to resolve the incident. Evaluation of the training scenario captures observable outcomes such as decision-making sequence, proving that the model improves inter-role coordination in a controlled environment.

6. Discussion

The conducted simulation demonstrated how virtual modeling can be used to design and evaluate a security subsystem for a mass event. The primary goal was to test the efficiency of decision-making and coordination between security roles during an unexpected incident within a crowded indoor space. By observing the same scenario from three different roles, each with a different level of proximity to the audience, the simulation enables analysis of situational awareness, communication flow, and command hierarchy dynamics.

Decentralized communication between on-site security personnel enabled faster information flow and quicker initial response, whereas a strictly centralized command approach introduced delays because decisions had to wait for confirmation from the command post. These findings suggest that a hybrid command hierarchy – centralized supervision combined with decentralized operational decision-making – ensures greater efficiency during time-critical situations.

The simulation model also proved valuable as a training tool for police officers, private security personnel, and event organizers. By replicating realistic scenarios such as medical emergencies or disturbances in the crowd, trainees could test strategies in a safe and controlled environment, improve their situational assessment skills, and develop more effective communication and coordination patterns. Insights generated from the simulation can directly contribute to improving standard operating procedures by identifying critical points and potential risks, optimizing resource deployment – including personnel allocation, access controls, and first-aid station placement – and providing a foundation for developing and testing crisis communication protocols.

7. Concluding remarks

In addition to highlighting the potential for designing security subsystems, this paper contributes by integrating two distinct yet complementary disciplines – security studies and information and communication technologies, specifically programming and simulation modeling. Simulation-based solutions enable the operationalization of theoretical security concepts, transforming them into functional tools for training, analysis, and decision-making in real-world scenarios. From an analytical perspective, the study demonstrates that simulation modeling can serve as a critical interface between conceptual understanding and operational readiness in the security sector. By enabling the visualization and testing of different response strategies within controlled conditions, the model provides measurable insights into the effectiveness of specific interventions and coordination mechanisms. By visualizing different response strategies under controlled conditions, the model helps identify which interventions most effectively reduce bottlenecks and response delays, and how human factors – such as decision-making under pressure – shape overall system performance. However, its broader applicability also depends on continuous refinement through empirical validation and adaptation to different operational contexts.

Future research could explore the application of this simulation model in different sports or other high-risk public events (such as concerts or festivals), as well as in broader crisis management contexts, to further validate and expand its practical utility. Additional development may include integrating sensor inputs or real-time data streams to enable dynamic adjustment of security responses while the event is in progress. Incorporating more complex behavioral patterns or environmental variables would further strengthen the model's scientific foundation and support the development of more adaptive and responsive security management systems.

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