

DEVELOPMENT OF THE TECHNICAL CONDITIONS FOR CBRN TRAINING IN HUNGARY

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ABSTRACT

The aim of the study is to develop a conceptual architecture for integrating risk and consequence analysis, monitoring, geospatial visualization and constructive simulation systems into hazardous materials incident management training in Hungarian higher education. The research applies literature review, comparative functional analysis and scenario-based system assessment. The examined components include DNV PhastRisk, ALOHA, MARPLOT, RODOS, MoLaRi, radiological monitoring services, the MARCUS constructive simulation environment and the Hazmat/CBRN tool system. The study identifies the educational role, principal inputs and outputs, and potential data-transfer relationships of these systems. The proposed architecture uses consequence-model outputs, monitoring information and geospatial data as structured inputs for dynamic simulation exercises. Its principal contribution is a platform-independent workflow connecting scenario generation, hazard assessment, operational decision-making and post-exercise evaluation. The framework provides a basis for establishing a hazardous materials incident management specialist cabinet, while its practical effectiveness requires subsequent validation through pilot exercises.

KEYWORDS:

industrial safety; disaster management; decision support systems; simulation training; hazmat, CBRN, DMML response

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1. Introduction

The industrial safety field of the Hungarian disaster management organization plays a key role in protecting the population, maintaining the safe operation of critical infrastructures, and preventing and managing incidents involving hazardous materials. With the increasing complexity of modern industrial and transport systems, increasing emphasis is being placed on technical tools and decision support systems that are capable of predicting risks, modeling the course of events, and underpinning intervention decisions. However, the effective application of these systems is not only a technological issue, but is also closely related to the preparedness of the user base.

Currently, higher education is dominated by theoretical knowledge transfer, while the development of practical competencies – especially in the field of complex industrial safety systems – has limited opportunities. In many cases, the use of real operational systems for educational purposes is not possible, as their continuous availability is a fundamental requirement. Consequently, it becomes justified to create a training environment that reflects reality at a high level, but can be operated independently, and that is capable of ensuring that students gain the necessary practical experience.

The aim of the study is to examine how the practical nature of higher education in industrial safety can be improved by establishing an incident management and hazardous materials damage prevention specialist cabinet. In this context, the research explores the applicability of risk and consequence analysis, monitoring and simulation systems for training purposes, as well as the possibilities of their integration in a complex educational environment. The study also covers the areas of dangerous establishments, dangerous goods transport, nuclear accident prevention and the protection of critical infrastructures.

The scientific contribution of the study is the development of a functional training architecture that connects risk and consequence analysis, geospatial visualization, monitoring systems and constructive simulation within a unified educational workflow. The proposed framework defines the educational role of each technical component and identifies the principal data-transfer steps between analytical software, monitoring services and the simulation environment. The novelty therefore does not lie in the individual software applications themselves, but in their coordinated use for scenario generation, operational decision-making, dynamic exercise management and post-exercise evaluation in Hungarian disaster management higher education.

2. Research Methodology

The methodology of the study is based on a qualitative research approach combining a comprehensive literature review, comparative system analysis, and functional assessment. The research included the evaluation of international and Hungarian scientific publications, technical guidelines, regulatory documents, and professional reports related to hazardous materials incident management, industrial safety, disaster management education, and decision-support technologies. Particular attention was given to identifying the educational potential of existing software applications, monitoring systems, and simulation environments used in industrial safety and CBRN emergency management. The examined systems were evaluated according to their operational characteristics, educational applicability, functional capabilities, and potential integration into a unified training environment. The analysis focused not only on the individual technical capabilities of the selected software and monitoring systems but also on their possible interoperability and complementary application within a practice-oriented educational framework. The functional assessment considered the role of these systems in supporting risk analysis, consequence modelling, emergency planning, situational awareness, and decision-making during hazardous materials incidents.

In addition, representative industrial safety and hazardous materials incident scenarios were used to assess the practical value of risk analysis, monitoring, and simulation tools under realistic operational conditions. The examined scenarios represented the principal areas of industrial safety, including dangerous establishments, dangerous goods transport, nuclear accident response, and the protection of critical infrastructures. The findings obtained from the comparative and

functional analyses were synthesized into a conceptual framework supporting the development of a hazardous materials incident management specialist cabinet intended for higher education and professional training purposes.

The research question of this study is whether the integration of risk analysis, monitoring, simulation, and decision-support systems can effectively support the development of a practice-oriented hazardous materials incident management training environment within higher education. Based on this research question, the study examines whether the combined educational application of these technologies can contribute to strengthening practical competencies, improving decision-making skills, and enhancing the preparedness of future disaster management professionals.

3. Procedural, Methodological and Technical Conditions for Hazardous Materials Incident Management

The main goal of the industrial safety field of the Hungarian disaster protection system is to protect the population, ensure basic services for citizens, and protect the state and local government tools, systems, infrastructures, and facilities necessary for this, and to maintain their operation at a reliable safety level throughout the entire operation, both in normal times and under emergency conditions.

To this end, in order to prepare for the use of the systems and tools of disaster management event management centers that are undergoing further modernization or newly established as a result of existing and future technical developments, it is considered appropriate to incorporate the use of these systems from a practical perspective into the training system of future employees (Cséplő et al., 2016).

Since the existing systems of the disaster management bodies do not primarily serve educational and training purposes, and their temporary withdrawal from the protection system for educational purposes may adversely affect their availability, the establishment of an industrial safety incident management (hazardous material damage prevention) specialist cabinet (hereinafter: cabinet) is considered justified (Cséplő et al., 2016). The cabinet can also be a natural part of the ability to manage various events falling under the scope of disaster management or safety and security administrative regulations.

An important aspect in the formation of the cabinet is the implementation of training and further training tasks within the framework of higher education. Forecasting the course of events, event chains, their consequences and impacts is an important operator and regulatory task in all fields of disaster management, including industrial safety.

In the field of industrial safety, forecasts of the spread of harmful effects are necessary and can be used as part of prevention, preparedness and emergency response measures:

1. In the area of preventive measures, the quantification of risks associated with industrial safety incidents is applied. Complex risk and consequence analysis software is used for dangerous establishments, primarily for operator process safety and industrial safety regulatory purposes. The industrial safety authority uses the DNV PhastRisk software for this purpose (DNV, n.d.).

2. Preparedness measures for managing permanent (non-elimination) risks are provided by emergency management, protection, resilience, damage control, evacuation, firefighting and rescue plans of various security disciplines at both the operator and settlement levels.

The consequences of event chains and their effects, for example in the case of dangerous establishments and their surroundings, are forecasted using consequence analysis software. In all planning procedures, the basis for forecasting is sample event sequences determined by physical impact modeling for the given activity.

3. *Accident prevention measures* serve to prevent or reduce the harmful effects of events during the events that have already occurred. This latter system of measures means the real-time implementation and application of the plans prepared in accordance with the previous point for emergency purposes.

These forecasts form the basis for the decision-making activities necessary for the application of hazardous material damage prevention and related potential public protection measures.

The technical equipment used for industrial safety incident management provides the technical basis for prevention, preparedness and emergency response activities. According to Zsitnyányi (2022), the equipment used for hazardous materials incident management can be divided into the following main categories: command and control equipment; CBRN reconnaissance and monitoring equipment; hazardous materials response equipment; personal protective equipment; mobile and on-site response equipment; logistical support equipment; and mobile or installed public warning systems.

Based on the findings of the present study, it is necessary to use the most important decision-support systems and hazardous material damage prevention equipment and instruments for training and education purposes, even at the higher education level.

The following section outlines some ideas for the development of the technical and training background of practice-oriented training.

4. Implementation of the Risk and Consequence Analysis Application Function

The forecasting procedures and methods used for industrial safety events can be examined separately for each industrial safety field.

1. *Dangerous establishments area.* The economic organization entrusted with the preparation of the safety report, safety analysis and the serious damage incident response plan is obliged to use the software used in generally recognized international practice and accepted by the authority to assess the risk of a serious accident involving hazardous materials. The key application requirement imposed by the industrial safety authority on the software used is that the physical models, procedures and databases used by the programs must be accepted and used at an international level. Risk and consequence analysis software is widely used in industrial safety practice. Earlier software environments frequently treated consequence modelling and quantitative risk assessment as separate analytical stages. However, this should not be considered a general limitation of contemporary software, since current integrated platforms can combine consequence calculations, event frequencies, vulnerability data and risk assessment within a unified workflow. The rationale for combining several tools in the proposed training environment is therefore not a presumed lack of modern software capability, but the different analytical, operational, monitoring and educational functions of the selected systems (Cséplő et al., 2016).

From the examination of the applicability of risk and consequence analysis software for the purpose of prevention and preparation in dangerous establishments (Kátai-Urbán, 2025), it can be stated that the DNV PhastRisk software used and “systematized” by the industrial safety authority is suitable for all risk and consequence

analyses. It follows that when assessing the safety documentation and protection plans of dangerous establishments dealing with hazardous materials and below the threshold value, as well as when preparing the external protection plan, it is essential for disaster management staff to have a deeper expert knowledge and smooth use of the aforementioned risk and consequence analysis software. Preparing for the skill-level use of the applied software is of paramount importance, however, acquiring the knowledge at an appropriate level during the performance of official work after graduation is not smooth, and in the first period it may also take part of the official administrative time report (Cséplő et al., 2016).

The hazardous substance release, spread and impact analysis procedures and methods used in dangerous establishments have already been analyzed in detail in a previous study (Kátai-Urbán, 2006).

2. Dangerous goods transport field. During dangerous goods transport incidents, the serious accident sequence may depend on the specific transport activity, dangerous goods class and substance involved. The present study focuses on public safety planning issues as a representative example.

It is important to highlight that the primary response staff of the professional disaster management organization are mostly provided with descriptive procedures and documents related to the management of certain industrial emergencies.

Of these, the Emergency Response Guidebook (ERG, 2024) is a fundamental reference for first responders during the initial phase of hazardous materials transportation incidents. However, due to its general guidance-oriented purpose, the ERG alone is insufficient for facility-specific consequence modelling, detailed tactical planning and complex scenario-based training.

It can be determined what training methodology and what technical tools can be used in the management of situations related to each sample series of events. Furthermore, what additional conditions may be needed to increase the effectiveness of prevention and accident response measures. Here, the use of risk and consequence analysis software and simulation tools for the management of various accident events can be highlighted.

The educational application of information technology developments, including virtual reality (VR) tools, should also be considered.

In this case, the identification of serious accident sequences resulting from intentional damage is done by assigning the so-called reference material, which is assigned to the four main point and line facilities (sites) according to the transport modes. These operational facilities are specifically related to road, rail and inland waterway transport operations.

The classification of intentional acts occurring in operational facilities and in situations specifically characteristic of certain transport sectors is always carried out according to a methodology based on events involving containment damage, during which the largest amount of hazardous material is expected to be released in proportion to time (Kátai-Urbán, 2025). These devices are tank containers, mobile tanks, road and rail tank vehicles, and tankers.

In the prevention and management of serious accidents involving the transport of dangerous goods, the previously mentioned risk and consequence analysis software is of particular importance, as it can also facilitate the public safety intervention and task planning of the intervening units with map display. Such tools include ALOHA, MARPLOT, or DNV PhastRisk, which can be used to calculate and model the exact harmful effects of a dangerous goods incident involving a high public safety risk, and

the level of risk it would pose to people, the environment, and neighboring facilities, both in the case of linear and point-like facilities.

The ALOHA hazardous material consequence analysis software (ALOHA, 2016) provides rapid modelling of hazardous substance releases. The generated hazard zones can be transferred to MARPLOT for geospatial visualization and subsequently used in scenario-based training and operational decision-making exercises.

3. *Nuclear accident response field.* The identified sample event sequences in the case of nuclear accidents can be predicted using the previously presented, but specifically radioactive material release, propagation and impact models, for which we use the measurement results of real-time meteorological and radiation sensor monitoring systems. To run the propagation models of radioactive materials, we use the so-called RODOS system, which is a real-time on-line international nuclear accident response decision support system developed with the support of the European Union. The name of the system comes from the English term Real-time, On-line, Decision SuppOrt System (NDGDM, n.d.).

RODOS is a real-time radiological decision-support system that combines meteorological, environmental and radiation-monitoring information to estimate dispersion, contamination and radiation doses. Within the proposed training architecture, its outputs support scenario development and decision-making exercises related to nuclear and radiological emergencies (RODOS, n.d.).

4. *Critical organizations field of expertise.* Critical infrastructure dealing with hazardous materials can be classified into one of the previous groups, as a result of which the prognoses of events are prepared according to the principles already described. It is also necessary to identify events in sectors and sub-sectors affecting critical organizations, which is not the objective of this research.

It can be stated that the DNV PhastRisk software used by the industrial safety authority is suitable for all industrial safety risk and consequence analyses. It follows from this that when assessing the safety documentation and protection plans of hazardous substances and below-threshold dangerous establishments, as well as when preparing the external protection plan, it is essential for disaster management staff to have a deeper knowledge of the aforementioned risk and consequence analysis software and to use it smoothly. It is therefore important that the practical use of the implementation of risk and consequence analysis is mastered by students of the Ludovika University of Public Service, Faculty of Law Enforcement, Disaster Management Institute, to varying degrees depending on the major. From an educational perspective, the primary value of the software lies in supporting the practical understanding of industrial risk assessment and consequence modelling.

Table no. 1
Functional comparison of the selected systems within the proposed integrated training environment

System	Primary function	Main input	Main output	Temporal character	Educational role	Potential interface
Phast	Consequence modelling	Substance, source term, process and weather data	Dispersion, fire, explosion and toxic-effect results	Primarily scenario-based	Detailed accident modelling	Reports, structured result sets, spatial outputs

System	Primary function	Main input	Main output	Temporal character	Educational role	Potential interface
Safeti/ PhastRisk	QRA and consequence-based risk assessment	Frequencies, consequence results, population and vulnerability data	Individual and societal risk results	Primarily static/probabilistic	Risk-informed planning	Data export and mapped risk results
ALOHA	Rapid consequence modelling	Release and meteorological data	Threat zones	Static or repeatedly updated	Initial assessment and tactical decision training	MARPLOT and GIS-compatible display
MARPLOT	Geospatial visualization	Locations and threat-zone data	Operational map layers	Updateable	Common operational picture	Map and GIS data
RODOS	Radiological decision support	Source term, meteorological and monitoring data	Dispersion, dose and countermeasure information	Dynamic/real-time capable	Nuclear emergency decision training	Monitoring and forecast data
MoLaRi	Chemical and meteorological monitoring	Sensor measurements	Measured concentrations and weather data	Real time	Sensor-based situational assessment	Monitoring data service
RTN	Radiological monitoring	Gamma dose-rate measurements	National radiological situation data	Real time	Radiation situation assessment	Telemetry data
MARCUS	Constructive simulation and exercise control	Scenario and entity data	Dynamic exercise state and response effects	Dynamic	Multi-agency command training	HLA-compatible or custom middleware, subject to implementation
DMML tools	Mobile detection and sampling	Field measurements and samples	Identification and measurement results	Real time	Field reconnaissance training	Manual or digital reporting

(Source: Authors' own work)

Table no. 1 demonstrates that the selected systems perform complementary rather than overlapping functions within the proposed training environment. Risk and consequence analysis software supports scenario preparation, mapping applications provide spatial visualization, monitoring systems supply real-time information, while the MARCUS simulation environment integrates these outputs into dynamic command and decision-making exercises.

5. Development of Industrial Safety Incident Management Functions

From the perspective of hazardous material damage prevention and the introduction of related public protection measures, it is of utmost importance to identify serious accident model event sequences (reference event sequences), the use of which must be implemented both in theory and in practice. The identification of model event sequences may vary by industrial safety field, as they may be dangerous activity specific, hazardous material and goods class specific, or event specific. When examining the latter issue, the causes causing the event must also be taken into account, such as human error, technological failures or intentional damage known among external causes, or the effects of serious accidents caused by natural disasters. From the perspective of hazardous material damage prevention - which is considered primary among preparedness measures - the consequences of serious accident model event sequences used in protection or hazard prevention planning and their harmful effects can also be identified using consequence analysis procedures and methods. The industrial safety risk and consequence analysis function can also be developed as part of the incident management function.

In order to prepare future employees for the use of the systems and tools of disaster management incident management centers, it is advisable to include the practical use of these systems in the training of future employees (Cséplő et al., 2016).

Of course, the primary purpose of the cabinet is to perform hazardous material damage prevention education and training tasks related to the prevention of serious accidents, where the prevention and preparation-type serious accident model event sequences are used on the one hand to model the consequences and harmful effects of the model event sequences, which serves as a basis for damage prevention and public protection management decision-making. During the prevention of hazardous material damage, the so-called simulation software can be used to position certain aspects of accident prevention, to implement accident prevention measures by various primary intervention organizations, and to implement emergency management management and organizational measures and to model their effects. The chemical and radiation situation modeling (prognostication) and emergency management simulation applications can be used in particular to conduct various core management exercises.

The practical benefits of industrial safety simulation applications can include:

1. The development of basic data on the chemical and radiation situation and event occurrence data enables the setting of an objective and diverse practical environment.
2. The impacts of the emergency management practice of leadership decision-making on the safety of the population and logistics can be measured and modeled separately, taking advantage of the possibilities of situational awareness.
3. The different sequences of events (scenarios) can be modeled in advance by the exercise designers, thanks to which a diverse training, communication and modeling environment can be created (Petrányi et al., 2023).

Simulation systems can be divided into live simulators, virtual simulators or trainers, and constructive simulation systems. Real-time simulation can model all practical activities according to the actually available resources of the organizations participating in the exercise and the capabilities of their technical equipment (Cayirci et al., 2009). Various simulation systems have been used for national defense purposes in Hungary for a long time, which can be used for all public safety events or disaster situations with minor modifications.

The MARCUS simulation system was developed in Várpalota, at the National Modeling and Simulation Center of the Hungarian Armed Forces, which also operates at the Faculty of Military Science and Defense Officer Training of the Hungarian University of Technology (Zsitnyányi, 2021a).

The simulation system's so-called Crisis Management Training Simulator subsystem consists of the following elements that can be used for disaster management purposes:

1. Chemical and radiation monitoring networks, replicas of installed measurement systems, such as the MoLaRi educational environment, RTN and AMAR monitoring data services, radiation gate systems (Paksi Nuclear Power Plant, border stations).
2. Virtual simulators of mobile chemical and radiation detection systems, such as Disaster Management Mobile Laboratories (DMMLs), CBRN, IFR and IFM (Emergency Police), Komondor RSV (Paks Nuclear Power Plant), are able to provide current data on the chemical and radiation situation.
3. The deployment control (PAJZS, DÖME) and communication systems (Maraton terra) ensure the conditions for emergency communication (Zsitnyányi, 2021b).

The system's complex data exchange center can model, among other things, dangerous operational and traffic accidents, events involving the failure of critical infrastructure, nuclear accidents, and CBRN events arising from public safety reasons.

From a technical perspective, the proposed integration is based on the transfer of structured scenario data from the analytical and monitoring components to the constructive simulation environment. Consequence-analysis software may provide hazard-zone geometry, threshold distances, concentration or radiation-dose values, source coordinates, release duration and time-dependent impact data. Before these results are used in MARCUS, a transformation layer is required to harmonize measurement units, coordinate systems, time stamps and the semantic definition of hazard levels. The processed information can then be represented in the simulation as affected-area polygons, exposure conditions, access restrictions, population-protection zones, resource requirements and constraints on responder movement.

The architecture does not necessarily require direct native integration between every software application. In an initial implementation, data exchange may be performed through structured files, GIS layers or a dedicated import interface. A more advanced implementation could use custom application programming interfaces or middleware, while standards such as the High-Level Architecture or Distributed Interactive Simulation may provide a basis for runtime interoperability if supported by the connected simulation systems. The present study therefore proposes a platform-independent interoperability concept rather than claiming that all identified interfaces are already implemented in MARCUS.

Thus, the proposed architecture should not be interpreted as a collection of independent software applications, but as a functionally integrated educational workflow in which the output of one component becomes the input of the next training stage.

The system also tracks the health status of the responding personnel, the presence of the population, and the health and logistical background situation. The system can be used, among other things, to develop scenarios for complex or sectoral safety and security management and disaster protection exercises; to plan, conduct and support emergency and protection plan exercises affecting industrial

safety specialties, especially to support the internal protection plan and serious damage incident response plan exercises of dangerous establishments, and to integrate XR (VR, AR, MR) and AI solutions. The system can be installed in a training center or used as a mobile simulation training group. The system is excellently applicable as an event management function of the Ludovika University of Public Service, Disaster Management Training Center.

The integrated application of the selected analytical, monitoring and simulation systems forms a unified educational framework for hazardous materials incident management. Figure no. 1 illustrates the proposed architecture, the flow of information between its main components and the expected educational outcomes.

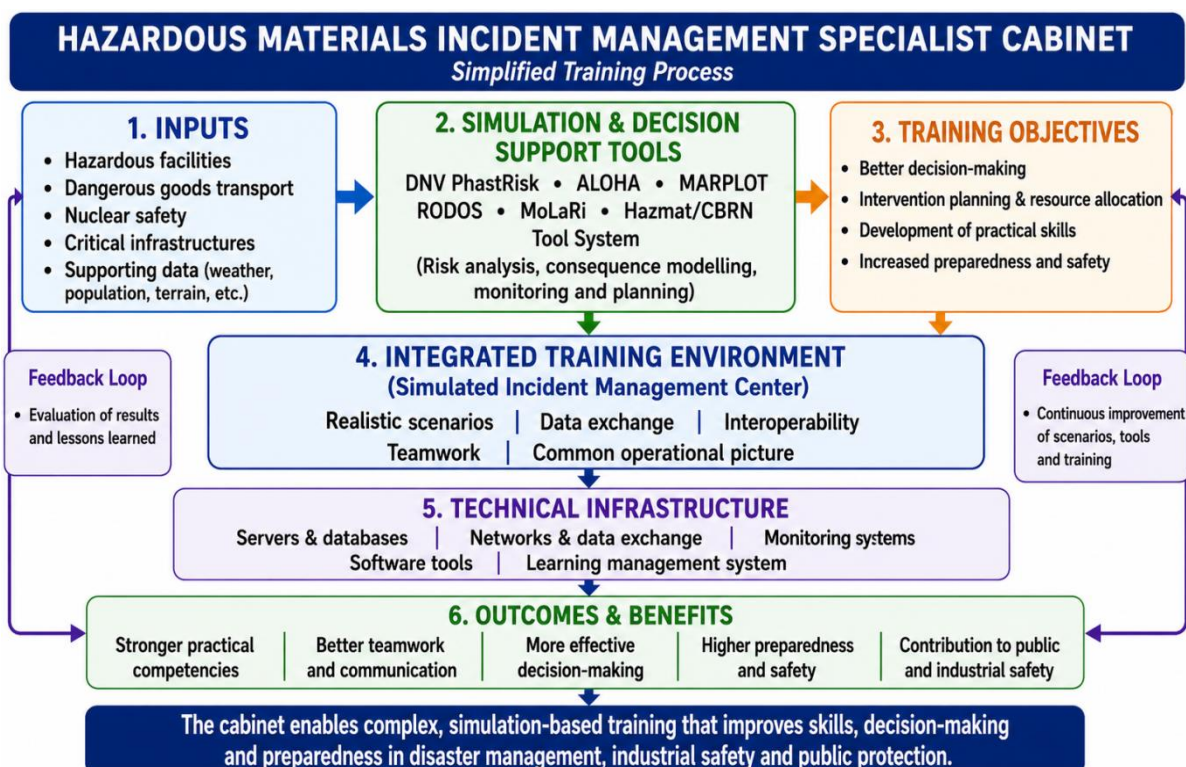


Figure no. 1: Conceptual structure and operational framework of the hazardous materials incident management training cabinet

(Source: Authors' own work. The graphical visualisation was prepared with the assistance of OpenAI ChatGPT (GPT-5.5 image generation) based on the authors' original concept)

The outputs of each analytical component provide structured inputs for the subsequent stage of the training process, thereby creating an integrated educational workflow rather than a collection of independent software applications.

6. Creating the Installed Hazardous Material Monitoring Application Function

The hazardous material monitoring systems installed by the disaster management serve public protection purposes. Hazardous material monitoring data support emergency decision-making, which form the basis for alerting the public and introducing individual and social distancing measures. Two nationwide systems have been built and operated, which are presented below.

In the period between 2006 and 2020, the Ministry of the Environment, Forestry and Climate Change (MOEC) installed a monitoring and public alert system (hereinafter referred to as the MoLaRi System) in the vicinity of certain dangerous establishments in order to ensure a high level of protection of the population against serious industrial accidents and to implement EU obligations. The system ensures the timely notification of hazardous substances released during a possible serious accident, the determination of dispersion data, the display of data for decision-makers, as well as the early warning of the population and the activation of the external protection plan. The MoLaRi System is composed of three main system components: meteorological and chemical monitoring system, public alert system and data transmission system (Cimer et al., 2021). The MoLaRi System has currently been implemented in the vicinity of 30 dangerous establishments. The system covers 12 counties (Békés, Borsod-Abaúj-Zemplén, Csongrád-Csanád, Fejér, Hajdú-Bihar, Heves, Komárom-Esztergom, Pest, Tolna, Vas, Veszprém, Zala) and the capital. A total of 768 public alarm information points and 419 monitoring endpoints have been installed (NDGDM, n.d.). Probes measuring data necessary for calculating atmospheric spread will be installed at the meteorological measuring points, while gas detection probes will be suitable for measuring data specific to the dangerous establishment. The MoLaRi System will also be integrated into the internal protection plans of dangerous establishments and the external protection plans of settlements, where it supports public protection decision-making in the area of emergency management (Cimer et al., 2021). The MoLaRi System allows disaster management agencies to have immediate measurement and spread calculation data during incidents occurring in the area of dangerous establishments. Through the alarm systems built as part of the system, it is possible to immediately inform the affected population about the situation and the behavior to be followed by means of acoustic signals, pre-programmed text panels, and also online live speech (Cséplő et al., 2016).

There is currently a training system for applying the MoLaRi System.

The Radiological Telemetry Network (hereinafter: RTN) subsystem of the National Radiation Monitoring, Signaling and Control System (NRMS) serving to support the nuclear accident response tasks of the Ministry of the Interior (MOI) may also be suitable for educational use, to which the radiological data exchange system and the nuclear accident response decision support system are also connected.

The installed automatic monitoring telemetry stations of the RTN Radiological Telemetry Network, consisting of 132 measuring stations covering 6 sectors - as the national early warning system for nuclear accident response - continuously monitor changes in the national gamma background radiation and measure the results of the gamma dose rate of environmental radiation (NDGDM, n.d.).

Both systems have regional and national professional management and decision-making centers. Training in the management of the systems can provide an important theoretical and practical basis for professionals in various positions involved in hazardous material damage control, who can significantly increase their skills by learning about the procedures, evaluation, and management decision-making methodologies associated with the systems.

7. Establish a Practical Disaster Management Mobile Laboratory Training Function

Recent civilisational and natural disasters have proven that the use of specially equipped radiological, biological and chemical reconnaissance teams, and from 2012

onwards, CMLs, has become essential in the vast majority of interventions in the presence of hazardous substances. Accidents involving vehicles transporting hazardous substances, incidents and accidents in dangerous establishments, hospitals, waste storage facilities and similar facilities and dangerous establishments producing, handling and using hazardous substances can result in the release of hazardous substances into the environment that can seriously harm people's lives and health (Cséplő et al., 2016).

In the event of accidents involving the presence or release of hazardous materials into the environment, and in the event of natural and civilisational disasters, the DMMLs were established to create safe working conditions for the primary responders (firefighters, ambulance workers, and police), to detect and identify hazardous materials, and to protect the population and the environment. These groups provide the data necessary for the collection, systematization, and processing of initial data for the assessment of the emergency situation, as well as for the on-site and laboratory determination of toxic or radioactive materials, and, if necessary, they contribute to the coordination of relief tasks thanks to their professional training in industrial safety (Cséplő et al., 2016). The protection of Hungary is currently provided by 19 county DMMLs, as well as the Budapest DMML, which maintains continuous operational readiness and also participates in official inspections in the fields of dangerous goods transport and dangerous establishments.

In addition, a DMML is also on duty at Ferihegy Airport, and a vehicle has been assigned to the Disaster Management Education Center for training purposes (Kátai-Urbán, 2025). Currently, a significant portion of the practical training of DMML personnel is carried out as part of the course-based training conducted by the Disaster Management Training Center, focusing on local practice of handling specialized technical equipment within the framework of a 6-day practical training spent at the DMML services of the regional disaster management bodies. During the 6-day practical period, the primary task of those serving at the regional bodies (mentors) is not education, but the provision of the given DMML service, which does not always promote the effectiveness of the practical training. It would therefore be advisable to place a basic DMML vehicle equipped with tools and instruments more frequently used in everyday industrial safety activities at the Ludovika University of Public Service and during the practical training there, students may have the opportunity to regularly practice the handling and elimination of simulated damage events with various sources of danger and hazardous effects in several cases, without depending on other external bodies. The continuous assurance of the operability of the chemical, radiation and biological, water analytical detection, evaluation and analysis instruments and devices installed or equipped in the DMML vehicles, and the accuracy of the information obtained from their data are of decisive importance during the application (Cséplő et al., 2016).

Within the proposed architecture, MoLaRi data may be used as dynamic exercise input. Simulated changes in measured concentration, wind direction or wind speed can modify the hazard-zone parameters during the exercise, requiring students to reassess cordons, public-protection measures and responder deployment.

8. Conclusions

The analysis shows that the effective operation of the industrial safety field of the Hungarian disaster management system is closely related to the availability of appropriate technical equipment and the preparedness of the professionals who use

it. Public protection, the safe operation of critical infrastructures, and the response to emergency situations can only be ensured at an appropriate level if the use of systems supporting decision-making processes is demonstrated at a skill level among professionals. The study clearly demonstrates that the current training structures are primarily theoretical in nature, while the complexity of the systems used in practice justifies the more intensive development of practical competencies.

The findings support the conceptual feasibility of integrating risk analysis, monitoring and simulation systems into a practice-oriented industrial safety training environment. However, the educational effectiveness of the proposed architecture should be validated in future pilot exercises using predefined performance indicators and feedback from students and instructors.

One of the most important conclusions of the research is that the direct application of real systems for educational purposes is limited, as they primarily serve operational tasks, and their extraction for training purposes may jeopardize the availability of the system. Consequently, it is justified to create an industrial safety incident management cabinet that models real operations at a high level, but can be operated independently, and which provides students with the opportunity to gain practical experience. The cabinet may be suitable for teaching the complex, integrated management of various industrial safety fields – such as dangerous establishments, dangerous goods transport, nuclear accident prevention and the protection of critical infrastructures.

It can be stated that risk and consequence analysis software – in particular DNV PhastRisk, as well as ALOHA and MARPLOT – play a key role in both the prevention, preparedness and response phases. Their application allows for the modelling of the spread of dangerous substances, their impacts and the risks to the population, which is essential for informed decision-making. Systems used in the field of nuclear accident response are of similar importance, especially RODOS, which supports official measures based on real-time data. Installed monitoring systems, such as MoLaRi and RTN, further strengthen the reliability of decision-making, as they provide a continuous data supply for emergency situation assessment.

The use of simulation systems – including constructive, virtual and live simulations – opens up a new dimension in training. These provide the opportunity to model complex sequences of events, examine the consequences of decisions, and compare different intervention strategies. Exercises carried out in a simulation environment significantly contribute to the development of leadership and management skills and to making cooperation between multiple organizations more effective. Of particular importance is the integration of virtual and augmented reality (VR/AR) technologies, which can make training even more realistic and interactive.

The principal contribution of the study is the definition of a functional architecture in which consequence analysis, risk assessment, geospatial visualization, monitoring and constructive simulation support successive stages of the same training process. The proposed data workflow enables analytical outputs, such as hazard zones, threshold values and time-dependent impact information, to be transformed into dynamic exercise parameters affecting population-protection measures, responder deployment and resource management.

The current study presents a conceptual architecture rather than a fully implemented software integration. Its next development stage should include the specification of a common scenario-data model, the testing of file-based or API-based data exchange with MARCUS, and the validation of the training process through

representative hazardous materials incident exercises. Nevertheless, the proposed framework provides a technically and pedagogically structured basis for establishing a hazardous materials incident management specialist cabinet in Hungarian higher education.

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Conceptualization, M.K.-U. and Cs.A.; methodology, M.K.-U. and Cs.A.; investigation, M.K.-U. and Cs.A.; formal analysis, M.K.-U. and Cs.A.; writing—original draft preparation, M.K.-U. and Cs.A.; writing—review and editing, M.K.-U. and Cs.A. All authors have read and agreed to the published version of the manuscript.

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