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RApid Data Integration and Visualization (RADIV) in Subsurface Operations

Complex subsurface operations are characterized by a life-threatening environment, a skilled and initiative opponent, and the absence of predictability of the events due to a high level of interdependencies. The reduction of complexity by provision of essential information is crucial for decision-making and rapid integration and visualization of heterogeneous data is essential for successful mission accomplishment. Currently, only standalone applications are available for the underground operational environment, and collaborative planning and working spaces in command and control are missing. The RApid Data Integration and Visualization (RADIV) process addresses exactly this challenge and ensures the lateral continuity of visualization systems across the entire reality-virtuality continuum (2D ⇔ 3D ⇔ mixed reality). It provides a comprehensive command and control system for subterranean operations by processing and visualizing data in different views for different purposes. Integration of these data within the Subsurface Operations Mission Tool (SOMT) will increase the decision quality by improved perception and collaboration. Close cooperation and information exchange between operators and action forces is a prerequisite for success by displaying the relevant information within the truly comprehensive common operational picture, thereby enabling more accurate and precise action reducing own losses and collateral damage.

Keywords complex subsurface/subterranean operations; reality-virtuality-continuum; command & control; RApid Data Integration and Visualization; Subsurface Operations Mission Tool

RAsche DatenIntegration und Visualisierung in Untertage-Einsätzen

Komplexe unterirdische Operationen sind gekennzeichnet durch eine lebensbedrohliche Umgebung, einen geschickten und initiativen Gegner und die fehlende Vorhersehbarkeit der Ereignisse aufgrund eines hohen Maßes an gegenseitigen Abhängigkeiten. Die Reduktion der Komplexität durch die Bereitstellung wesentlicher Informationen ist für die Entscheidungsfindung von entscheidender Bedeutung, und die schnelle Integration und Visualisierung heterogener Daten ist für die erfolgreiche Durchführung von Missionen unerlässlich. Derzeit stehen für das Einsatzumfeld unter Tage nur Einzelanwendungen zur Verfügung, kollaborative Planungs- und Arbeitsumgebungen in der Einsatzleitung fehlen. Der Prozess der RAschen DatenIntegration und Visualisierung (RADIV) adressiert genau diese Herausforderung und gewährleistet die laterale Durchgängigkeit von Visualisierungssystemen über das gesamte Realitäts – Virtualitäts – Kontinuum (2D⇔3D⇔Mixed Reality). Er bietet ein umfassendes Steuerungs- und Kontrollsystem für unterirdische Einsätze durch die Verarbeitung und Visualisierung von Daten in verschiedenen Ansichten für unterschiedliche Zwecke. Die Integration dieser Daten in das Subsurface Operations Mission Tool (SOMT) wird die Entscheidungsqualität durch verbesserte Wahrnehmung und Zusammenarbeit erhöhen. Die enge Zusammenarbeit und der Informationsaustausch zwischen Betreibern und Einsatzkräften ist eine Voraussetzung für den Erfolg, indem die relevanten Informationen innerhalb eines umfassenden Common Operational Picture angezeigt werden, wodurch ein genaueres und präziseres Vorgehen ermöglicht wird, das eigene Verluste und Kollateralschäden verringert.

Keywords Komplexe Einsätze unter Tage; Realitäts – Virtualitäts – Kontinuum; Führung; RAsche DatenIntegration und Visualisierung; Subsurface Operations Mission Tool

1 Complex subterranean/subsurface operations

Complex subterranean operations[1] are characterized by the presence of a life-threatening environment, a skilled and initiative opponent, and the absence of any kind of predictability of the events due to an extremely high degree of interdependencies. Therefore, the reduction of this complexity by provision of essential information is crucial for decision-making, the rapid integration and visualization of permanently growing and heterogeneous data an essential prerequisite, as perceiving a complex situation appropriately is the first step to cope with it. Currently only standalone applications are available for the underground operational environment and collaborative working spaces are missing. A complex subsurface scenario is characterized by the [...] simultaneous breakdown of essential functions (lighting, ventilation, sensoring) due to a cyber-attack and ubiquitous threats from armed opponents thereby causing multiple cascading effects, extreme increases in mission duration and logistic demands. Mission accomplishment can be optimized using military techniques, tactics and procedures [1]. To

[1] Within our research group and this document, the terms subterranean, subsurface, and underground are used synonymously to address the operational environment below the Earth's surface.

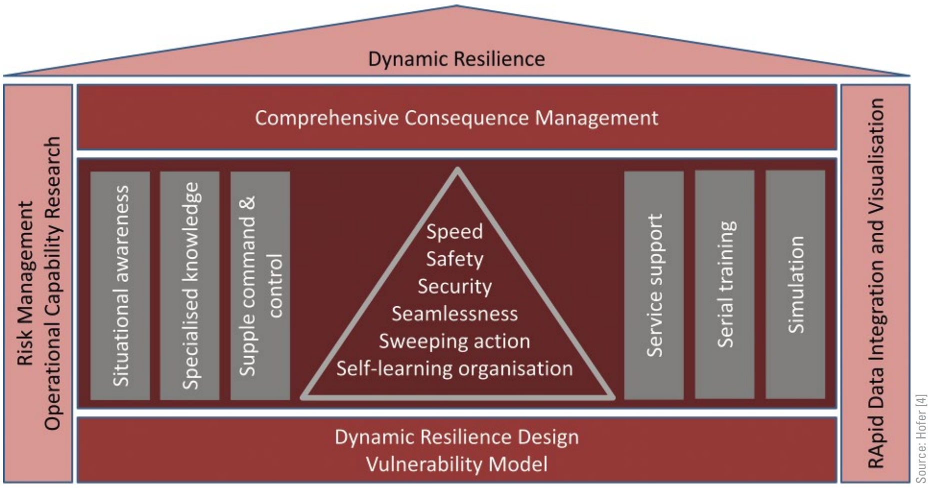


Fig. 1 The S^6 model: Safety and security strategies for subsurface service structures.

initiate research and development, a reference scenario has been developed after evaluation of past incidents constituting a major challenge for action forces due to environment and opponent as well as the limited capabilities of the involved stakeholders [2]. To deal with such scenarios requires an operational procedure based on three zones, dividing complex situations with different threats into contiguous spaces with changing requirements, allowing the operational command to adapt to these circumstances, and enabling the reduction of complexity [3].

2 Stakeholders' interests and responsibilities

Safe and secure operation of subsurface service structures require the efficient interaction of a group of stakeholders [2] with different interests and responsibilities. The S^6-Model (Figure 1) frames the common responsibility of keeping the infrastructure operational, safe, and secure [4]. The continuous application of the principles (triangle) and the activities (columns) will improve efficiency of operations in general and especially in case of emergencies. A special process must support the implementation during all phases in the life cycle of an underground structure – from the initial idea on the drawing board to decommissioning by rapid integration and visualization of data.

Initial considerations in the preproject phase can be supported by visualizations, the facility can thus be better planned, and stakeholders and the public can be better and more specifically informed about the project intention [5]. During the construction phase, the emergency plans can be adapted to the constantly changing needs as construction progresses and allow emergency personnel to deal with the situation on a permanent basis without always having to enter the facility. The development of the final emergency plans is possible much earlier with the inclusion of visual impressions, thus enabling a smooth start of operations, which can also be supported much better. In case of an emergency, up-to-date data and the preparation of the process allow a quick and efficient deployment of the emergency forces and thus help to minimize the resulting damage significantly – with the help of visualization a much better understanding of the operational environment is possible. All use cases, which have been elaborated within the so-called ETU ZaB project [6], are ideally supported by combining safety and security in an unprecedented interaction. Training for operational situations will be much better and cheaper using extended reality, augmentation of real training scenarios by virtual elements, or completely virtual training. This will result in a more cost-effective scenario design and training as well as offering maximum realism at reduced limitations to the relevant subsurface structure.

Data integration and visualization must be designed in accordance with the S^6 model (Figure 1), which was developed to improve the resilience of subsurface service structures by an inter-actor framework for preparation and action. It can be understood as a guide for creating standard operating procedures, setting up training lectures, and provides arguments for investments in smart personnel, hardware, software, and data.

3 RApid Data Integration and Visualization (RADIV)

Within a Digital Headquarters, the RApid Data Integration and Visualization (RADIV) process ensures the lateral continuity of different visualization systems across the entire reality-virtuality continuum (2D⬄3D⬄mixed reality), [7] thereby creating an immersive planning and training environment. Integration of these data within the Subsurface Operations Mission Tool (SOMT) will massively increase the decision quality by improved perception as well as optimized collaboration by providing a more comprehensive command and control system for subterranean operations.

RADIV can be defined as a core support process in assisting focused networking within the stakeholder group, rapid integration of heterogeneous data, and fostering interoperability between applications and visualization across the whole reality-virtuality continuum to provide a truly comprehensive common operational picture

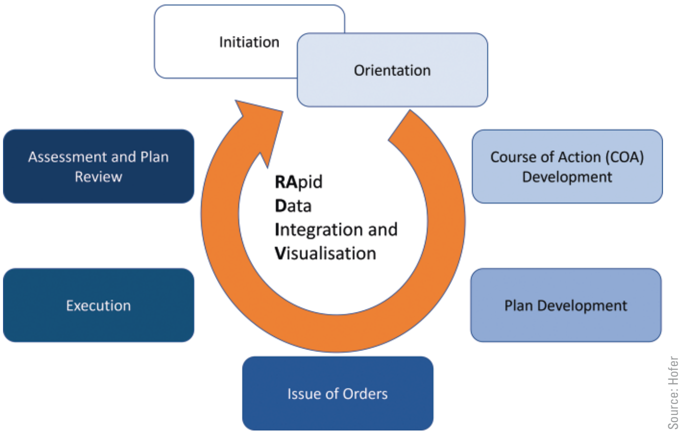


Fig. 2 The stages of the command-and-control cycle (C^2 cycle).

(tcCOP). It bridges the needs of dynamic resilience design and comprehensive consequence management [8]. To bring the best possible understanding of the situation, visualization is crucial and various forms of media can be used. While analogue maps can be the best solution for action forces, staff members can be more efficient using digital tools. Digital 2D software is easy to work with and can provide a comprehensible situational overview. Using 3D software, especially if perceived in a virtual reality (VR) environment, with a stereoscopic 3D vision is the only way of comprehending the spatial complexity of subterranean structures before entering it.

RADIV enables a digital workflow through all applications assisting the command and control cycle (Figure 2). A core feature is to transfer captured ideas, thoughts, and objects to other RADIV components, allowing every contributor to add input, hand it over to others easily, and produce fail-safe products (e.g., prints) at any stage.

Smooth data integration is crucial as various data sources are brought together, some through standardized interfaces and other manually prepared and added. The digital workflow without media breaks is realized using standardized exchange files between all RADIV components: ODIN[2], Subsurface Operations Mission Tool[3] (SOMIT), Browser-based ORientation In Space (BORIS), Geo Information System (GIS), BIM/TIM, and the whole range of on-premises cyber-physical systems. Designed as an open-process architecture able to integrate and visualize a great variety of heterogeneous data, every piece of information can be assigned explicitly using its position and properties, enabling a transfer across all applications by comma-separated value files with spatial data description in text format for point, line, and polygon features – open to all coordinate and projection systems.

4 Applications within RADIV

BORIS is a simple 3D visualization tool for use with a web browser primarily addressing the requirements during the initiation and orientation phase of the C^2 cycle by provision of an instant, easy-to-use (e.g., on a tablet) 3D view on the operational environment extended with sketching, labeling, and measuring functionalities [9]; drawn sketches and labels are exportable to other RADIV components.

SOMT is a software for visualizing and planning complex subterranean operations complementing conventional, surface-focused, Command and Control Information Systems (C^2IS) (ODIN within the DHQ RADIV project). It provides a virtual reality (VR) environment to give a genuinely comprehensive 3D insight into the terrain and subterranean structures (Figure 3). In addition, it provides tools for planning and allows to work simultaneously with multiple VR users. Collaboration is possible inside a shared virtual environment via a network connection without both users being present at the same location. Every VR user is supported by an additional operator combining the best user experience principles from VR and quick input. Shared data can be exchanged through a software interface (REST-API) to provide interoperability between SOMT and other C^2IS, creating a shared Common Operational Picture (COP).

SOMT enables virtual reconnaissance of the area of operations, the development of courses of action (Course of Action and Plan Development) including the synchronization of own actions, and their presentation (Issue of Orders). SOMT uses standard military symbology, pro-

2 ODIN is the C^2IS within RADIV: https://odin.syncpoint.io/
3 https://www.laabmayr.at/tunnel-plus/rd/ftmt-fast-tunnel-modeling-tool

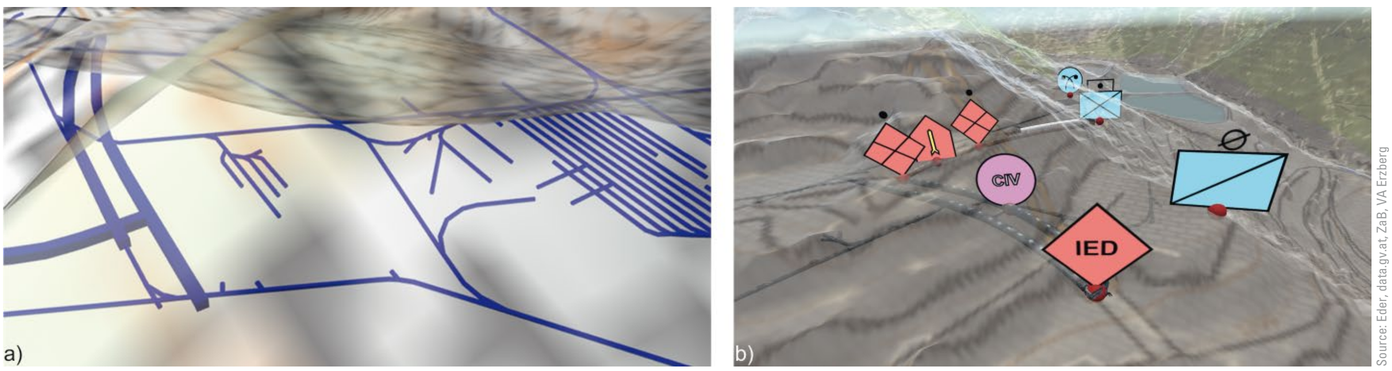
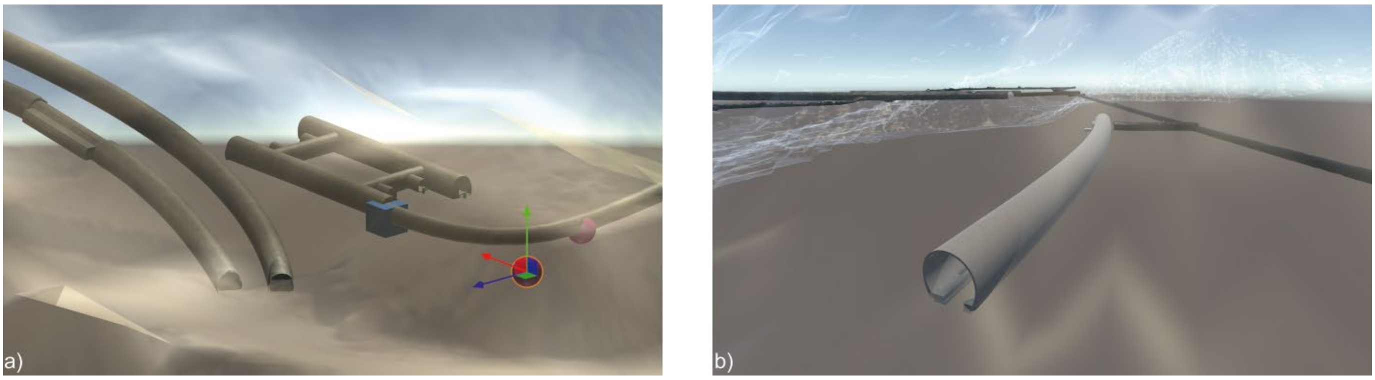


Fig. 3 BORIS provides a quick available but very rough first view a), whereas SOMT enables sophisticated planning in an XR-capable environment b).



Source: Eder, data.gv.at, ZaB

Fig. 4 Comparison between a) FTMT model and b) BIM model.

vides the functionalities of viewing, interacting, and analyzing the digital model incorporating in first person and bird view, and comes along with measuring tools for distances and diameters but also the possibility of drawing freehand, placing symbol markers, or taking virtual photos.

The Fast Tunnel Modelling Tool (FTMT) can be used to quickly (re-)create a VR-enabled subsurface environment. Technical drawings and plans of infrastructure can be seen as the most accurate and detailed background information available. In some situations, they are accessible via an interface to a Building Information Modeling/Tunnel Information Modeling (BIM/TIM) and in other situations they are available in archives as analogue construction or emergency plans, which must be scanned, georeferenced, and the content digitally modeled in a proper way. To provide 3D insight into the subterranean area of operation as fast as possible, converting the available 2D plans into 3D models is often required. FTMT allows to create 3D models of complex subsurface structures in a short period of time (less than an hour) based on the tunnel axis and the standard cross sections of the tunnel. Additional elements, like breakdown bays, shafts, or crosspassages, can be inserted as standardized blocks, and the created 3D models can be exported to other applications including SOMT. FTMT is meant to be used if no other higher-quality 3D models, like laser scans or BIM models, are available [10] and is helpful in those cases, where digital data is missing.

Figure 4 shows a comparison between an FTMT model and a BIM model. While the FTMT model lacks the technical accuracy of a precisely planned BIM model, it gives almost the same visual understanding of the area of operation, especially within a VR environment.

BIM/TIM are currently being established for planning subterranean structures in the industry. It is expected to be utilized for planning in most future tunneling projects and can therefore contribute to the RADIV process with highly detailed 3D models, including different construction attributes. This information can be incorporated into 3D applications like SOMT to provide high-quality visualizations of the subterranean environment (Figure 5).

Source: Eder, Laabmayr&Partner, data.gv.at

Fig. 5 BIM-model, portal building Karawankentunnel, visualized in SOMT.

To provide better situational awareness during an operation, a variety of cyber-physical systems must also be integrated and visualized. In the best case, parts of the subterranean infrastructure are still accessible and systems like surveillance cameras and ventilation devices can still be used. In the worst case, information related to infrastructure must be gathered by the action forces. The integration of on-premises and deployable sensor systems and their interoperability is a key task of RADIV.

The communication and data transfer between action forces and operators is a vital part of the RADIV. Only a stable data link can ensure transfer of speech and data in both directions. Conventional VHF communication devices are only suitable in structures with large diameters. With decreasing cross sections, radiowave attenuation decreases the reach drastically. In addition, data transfer and bandwidth are very limited. Subterranean operations can borrow from already existent technologies introduced in mining and tunneling. Communication devices on wireless mesh network basis with frequencies well above 1 GHz create both a stable link with an acceptable reach and the necessary bandwidth to support the needs of RADIV. Mobile mesh-network nodes with battery packs can be set up easily and automatically route the information in the desired direction.

5 Conclusion and outlook

A close cooperation and information exchange with operators of subsurface structures and action forces is a prerequisite for success and will enhance the common perspective by displaying the relevant information within the truly comprehensive COP, thereby enabling more accurate and precise action and reducing own losses and collateral damage. The operator's responsibility of ensuring safe and secure operations within their subsurface service structure can be assisted by the application of the S^6 model and early implementation of a RADIV to achieve a maximum of dynamic resilience through smoother operation and improved emergency preparedness.

The training, research, and development facility Zentrum am Berg (ZaB)[4] will support these developments by the creation of a digital twin, offering a completely changed approach for further training, research, and development activities. Built and operated by the Montanuniversität Leoben, it provides a unique environment in highway and railway tunnels equipped with the latest technology and many kilometers of former mining galleries offering a unique environment. The ZaB represents a real-world baseline to which virtual elements like special pieces of equipment, additional supersurface, surface, and subsurface infrastructure could be added. With different types of training scenarios and varying settings, backed by XR devices, a fully hybrid training, research, and development environment will come into existence second to none to hone the skills for subterranean combat, firefighting, explosive ordnance disposal, medical treatment, handling radioactive substances, and dealing with a panicking mass of people and many others.

All the projects within the NIKE research and development program[5] stand ready for interaction with the DHQ-RADIV project to provide a maximum of synergies and achieve full operational capability for complex subsurface operations in due time.

4 www.zab.at

5 www.milak.at/nike

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