# Decision Support within Complex Subterranean Operations

**Peter HOFER**
Theresian Military Academy / Institute for Advanced Officer Training
AUSTRIA

peter.hofer@bmlv.gv.at

**Julian EDER**
IL - Ingenieurbüro Laabmayr & Partner ZT GmbH
AUSTRIA

julian.eder@laabmayr.at

**Clemens STRAUSS**
Austrian Armed Forces / Institute for Military Geography
AUSTRIA

clemens.strauss@bmlv.gv.at

## *ABSTRACT*

*Successful accomplishment of subterranean operations requires highly specialized capabilities and accurate planning assisted by up-to-date tools. The research group NIKE of the Austrian Military Academy aims to support decision making, planning, and training for these very special operational environments. Rapid data integration and visualization of heterogeneous sources like 3D-modells, plans, maps, or laser-scans as well as operator's information gathered from sensors and cameras inside the underground structures offers the possibility of virtually entering installations normally out of sight. Specialized tools as the BORIS (Browser-based Orientation In Space) initial HTML-Model, the Subsurface Operations Mission Tool (SOMT) or the Fast Tunnel Modelling Tool (FTMT) improve quick visualization by creating a virtual twin of the subterranean mission area. The improved spatial apprehension within Extended Reality (XR) applications significantly improves decision-making and supports synchronized mission planning and execution. As close cooperation and information exchange between operators of subsurface service structures and action forces is a prerequisite for success, the integration of all relevant factors and actors will massively increase comprehensive collaboration. The project enhances the common perspective by displaying relevant information within a truly comprehensive Common Operational Picture, thereby enabling more accurate and precise action, reducing own losses and collateral damage.*

## 1.0 COMPLEX SUBTERRANEAN[1] OPERATIONS

Future operating environments will be increasingly urbanized, a circumstance directly affecting the capability development requirements, the need to task organize a proportion of the armed forces and to prepare databases as a prerequisite for successful mission accomplishment in urban operations [1]. Being considered as a key terrain for future military engagements urban environments present the highest imaginable complexity for action forces as operations must be synchronized within three interdependent movement levels: supersurface – surface – subsurface, the latter representing an essential part of that urban area:

> *"Existing underground service facilities include road and rail tunnels, urban subways, underground parking, canalisation as well as energy recovery, transport and storage sites. But also structures out of sight as abandoned traffic systems, former air-raid shelters or nuclear waste deposits are part of the subterranean environment." [2]*

[1] The terms subsurface, subterranean and underground are used synonymously throughout the text.

The NIKE research and development program[2] strives for an integrated interdisciplinary approach as the subsurface environment holds specific challenges, namely the missing ability of comparing the map with terrain features and an extremely demanding and life-threatening operational environment. These challenges apply for subterranean operations in urban and rural areas alike. The evaluation of past scenarios and integration into a new reference scenario [3] gave direction to an understanding of complexity as being characterized by its own dynamics, irreversibility as well as a lack of transparency for the decision maker, requiring a high level of knowledge about the subsystems and the ability to reduce complexity [4].

*„The complex scenario, which has been chosen as reference within our research, can be described by a simultaneous breakdown of essential functions (lighting, ventilation, sensors) and ubiquitous threats from armed opponents causing multiple cascading effects, extreme increases in mission duration and logistic demands [...]“ [5]*

The different levels of movement need consideration and must be understood as one, forming an integrated operations environment. Conventional battlefield management systems focus on own, enemy, and civil action forces, are embedded into a GIS framework and already offer 3D in display, but content management is focused on surface and airspace, the subterranean environment is not covered accordingly. Surface-centered and specialized for the interaction between military sensors and effectors those systems do not unveil what is hidden in the underground and structures out of sight with a narrow field of view and frequently limited visibility. Accessible information about ongoing subway infrastructure projects in Vienna [6] or London [7] give an impression of the associated challenges. Currently those cutouts are the only way of having a look inside the structure before entering it.

## 1.1. SubSurface Operations

The operational concept (Ill. 1-1) was the most decisive prerequisite for defining the required capabilities by application of “complexity” to the scenario and not to the infrastructure.

*"Open and accessible by design and necessity, crowded with people, and key for the functioning of economic and daily life in the cities they serve, these systems represent both attractive and high-impact targets. Their openness and high usage also make them difficult to secure." [8]*

Security forces in the red “Contact Zone” face the most adverse and difficult circumstances and periodic replacements must be planned. With increasing penetration depth, the amber “Consolidation Zone” must follow to enable the periodic relieve and support of advancing forces by the provision of ventilation, specialized logistics and communication services. The green “Saturation Zone” bridging the operation to the outer world and denying access for the opponent into the rear area completes the underground operational concept (Ill. 1-1) [9].

[2] https://www.milak.at/nike

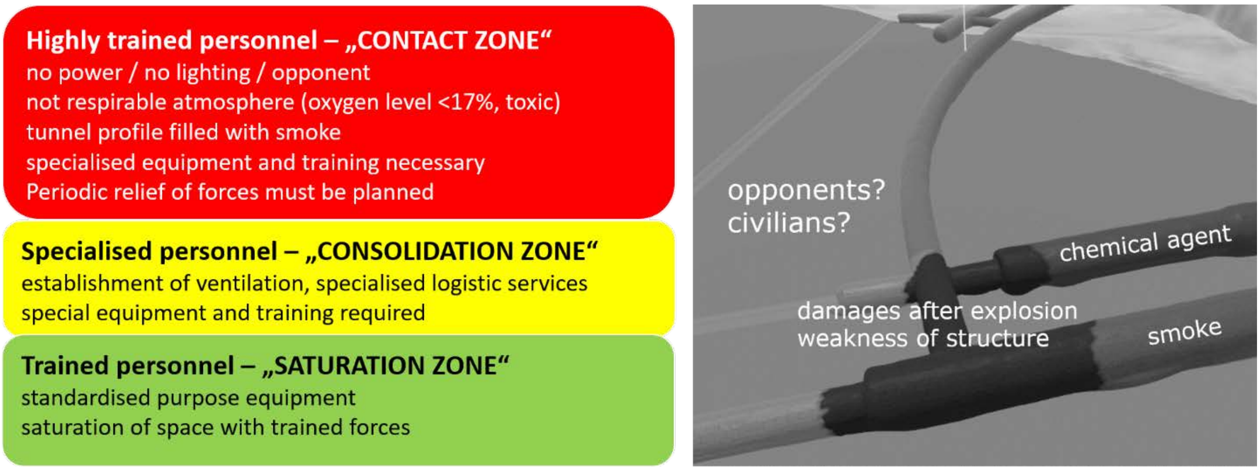



**Illustration 1-1: The Operations Concept frames the challenge into three zones (Ill: Hofer) [9].**

This concept was designed to address the associated challenges of the underground environment holding very specific risks deriving from geology, structural statics, smoke and gas, hazardous material, water, confined spaces, obstacles of different kinds, absolute darkness and failing forced ventilation, the presence of an opponent and a significant number of civilians.

As the deployment of commonly used assets as satellite or drone imagery is restricted and heterogenous data integration requires a specialized toolbox capable of visualizing accordingly to assist military forces, the availability of XR-applications in the whole spectrum of the reality-virtuality continuum [10] as a prerequisite for success will assist staffs, decision-makers and action forces entering the subterranean structures.

## 1.2. Safety & Security Strategies for Subsurface Service Structures

Significant improvements have been achieved to raise the safety to an impressive level, but there is still a lot to do concerning security, sometimes the provision of safety can also be contradictory if emphasized to much [2]. The development of coping strategies must balance stability and flexibility by integrating preventive and reactive action to achieve a maximum of resilience providing the capacity to regain own freedom of action after the occurrence of a critical event. The preparation within the stakeholder group is of uttermost importance underlining the necessity of preparedness [11]. The development of the Embracive Leadership Model [12] helped building bridges between the several disciplines and framing the $S^6$-Model of **S**afety and **S**ecurity **S**trategies for **S**ubSurface **S**ervice **S**tructures (Ill. 1-2) encompassing

*„[…]activities and principles to succeed in challenging, complex underground scenarios by observing six activities (columns) describing WHAT to do and six principles (triangle) HOW to act. Although originally designed for subsurface environments, it goes without saying, that the $S^6$ – Model is applicable to every kind of service structure of strategic interest.“ [9]*

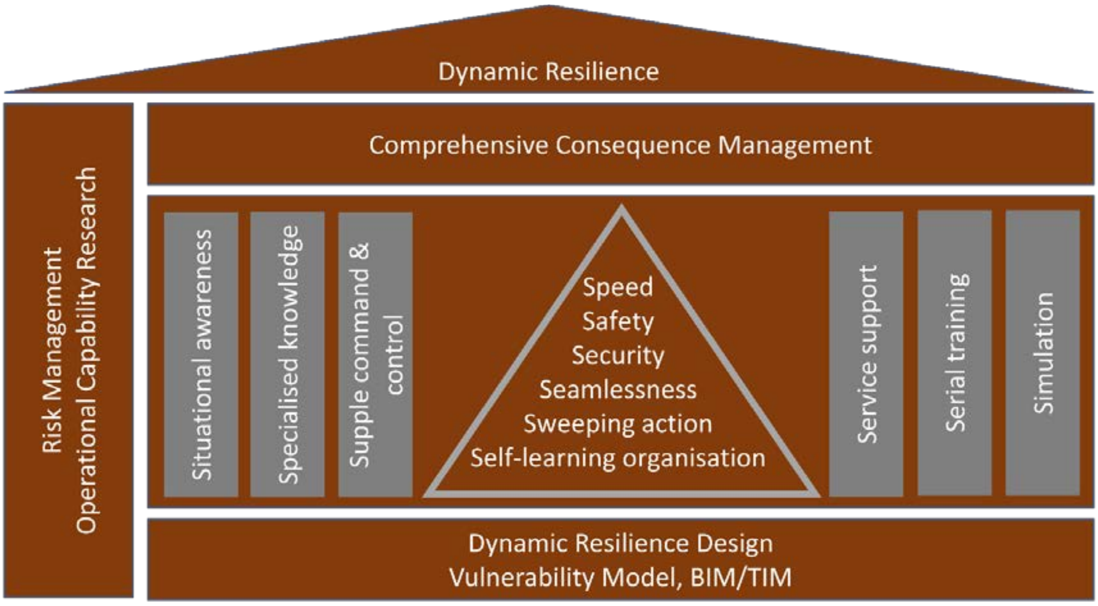



**Illustration 1-2: Activities and principles are the framework for successful mission accomplishment within an urban and especially a subterranean environment (Ill: Hofer) [9].**

The rapid integration of data and its visualization is a key to successful implementation of the $S^6$-Model. The required process has therefore to be understood as a new core process within command and control. The urban terrain across the three levels of supersurface – surface – subsurface requires a different approach to the integration of a wide range of heterogenous data, the staff work must be enabled by a process of rapidly visualizing this data. The availability of a tcCOP (a truly comprehensive Common Operational Picture) is of decisive importance for successful mission accomplishment.

## 2.0 RADIV – RAPID DATA INTEGRATION AND VISUALIZATION

RADIV constitutes a core process in staff work with the primary purpose of building a digital twin of the area of operations enabling virtual interaction in hidden infrastructure as well as an improved estimation of side-effects of effects. The virtual replication of reality is indispensable for hidden subsurface structures. Growing penetration depth into widely branched subsurface structures full of nooks and crannies require digital twinning for successful mission accomplishment – operating without a current picture of the underground will inevitably result in a mission creep.

Maps have traditionally been and will be used for command and control in military operations as they are easy to handle, do not require electricity, fit in the pockets of soldiers in the field and provide the highest level of persistence against disturbance from the electro-magnetic spectrum. In urban – and especially in subsurface – environments digital solutions yield many benefits. Digital products can be created faster, are more precise, can be copied, transferred over large distances, and modified – but first and foremost they are able to integrate and visualize content in a way which cannot be provided by a map – they are the only way to visualize the sub-terrain properly.

In line with the $S^6$-Model, the process of Rapid Data Integration and Visualization (RADIV) addresses the challenges in command and control by integration of a variety of heterogenous data sources into a truly comprehensive Common Operational Picture embracing all relevant factors and actors. This improves situational awareness for the decision makers and therefore decision quality. Apart from opposing and own forces, the data to be integrated comprises the infrastructure with associated risks and dangers, the presence of civilians including their estimated behavior in a mass and all types of sensor data. In this context we are talking not about those integrated into the sensor-effector network but infrastructure-related sensors. The Rapid Data Integration and Visualization process must enable the integration of community, governmental and operator data to provide a situation specific, automated workflow with expert interaction. Several digital solutions are being developed within in the NIKE research and development program to integrate and visualize data from heterogenous sources to provide the best decision support possible.

### 2.1. Operator Data Integration

Operator data are the foundation for a truly comprehensive Common Operational Picture of subsurface service structures comprising construction data required for the virtual reconstruction (plans, 3D-data) as well as a range of tunnel operating cyber physical systems. Subterranean structures like railway, subway, and road tunnels include different surveillance systems (cameras, sensors) providing operating states to ensure smooth and safe operation by optimized ventilation, event detection and reaction. If not damaged or dazzled during an event, these sensors can be used to gather important information about the situation inside the subsurface structure. Additional sensors can be operated by advancing forces, also deployed with autonomous vehicles giving an enormous added value for the development of a tcCOP.

The advancing digitalization in the construction industry is reflected in the trend towards Building Information Modelling.

> *"Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition." [13]*

Tunnel Information Modelling (TIM) is currently undergoing a standardization process that is not concentrated in individual places nationally or internationally. For Austria, an agreement on 3D modelling related to components is emerging. These components represent the result of excavations in which a cavity is created with a cycle of loosening of rock and the installation of support, or the concreting of individual blocks in the inner shell. This 3D modelling is carried out at different stages of the design and construction of the tunnel project and extensively reflects the construction method. The standardization of linkage points of individual blocks in TIM will accelerate the continuous update of georeferencing in model creation [14]. In the context of RADIV, BIM/TIM models can provide attributed 3D models of an urban and subterranean area of operation making available valuable insights assisting experts in their assessment of the operational environment. As the adoption of BIM in civil engineering is slow and a large amount of existing subterranean structures will not be available as 3D models soon, an additional process is required to provide 3D models of these structures.

### 2.2. Fast Tunnel Modelling Tool[3]

The process of Fast Tunnel Modelling [16] can be utilized to generate 3D models based on the 2D plans within shortest possible time after the incident. For almost all subterranean structures maps or plans can be acquired, very different in quality and ranging from old hand drawn mining maps to detailed construction plans or specialized emergency plans. In case of an incident, these plans can be obtained from the operators of the affected facilities in the form of a digital or scanned image. Therefore, a combination of standardized elements is dynamically generated into a model of the subterranean structure. The geometry of the elements can be selected from a set of standardized blocks (breakdown bay, cross passage, ventilation shaft, tunnel) combined via defined joints (Ill. 2-2). The focus of this process is to provide a Virtual Reality environment of the area of operations in a short period of time. Although accuracy of this model is limited in the beginning it improves

[3] https://www.laabmayr.at/tunnel-plus/rd/ftmt-fast-tunnel-modeling-tool/

with more detailed data available during the operation. The accuracy of fast tunnel modelling cannot compete with the accuracy generated by BIM models or laser scans of the structure, but it represents a highly valuable support to action forces to get a virtual inside view of the subsurface structure and is also sufficient for ventilation simulation purposes.

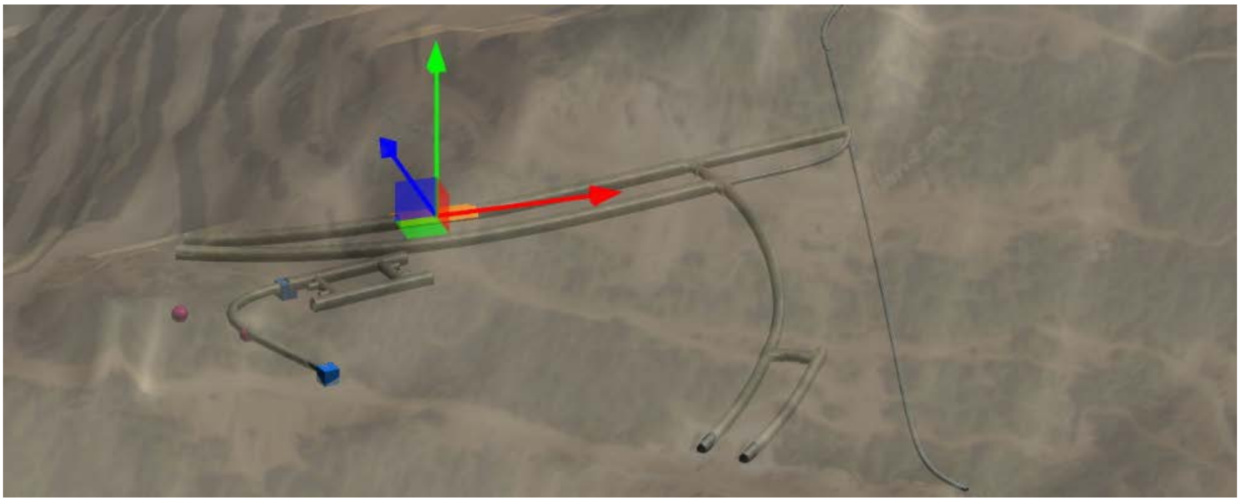


**Illustration 2-2: Model of Subterranean facility "Zentrum am Berg" created with FTMT (Ill: Eder; Data: Zentrum am Berg, data.gv.at)**

## 2.3. BORIS

BORIS (Browser-based ORinetation In Space) is the first product being available during the planning phase of a subsurface operation. It is a simple 3-dimensional visualization tool for a web browser providing a first view of the area of operations by blending GIS and infrastructure data. Because this tool can be shared quickly using mobile devices, the forces are able to familiarize themselves with local conditions already on the way to the operational area. Anchor points allow fast georeferencing of simplified structures (squared or round profiles) based on the tunnel axes. BORIS is based on the qgis2threejs plug-in for QGIS and extended to sketching, labeling and measuring functionality [15]. Regarding RADIV's digital workflow the drawn sketches and labels are already exportable to the other components and vice versa aiming at establishing a complete digital data flow without media disruptions (Ill. 2-1).

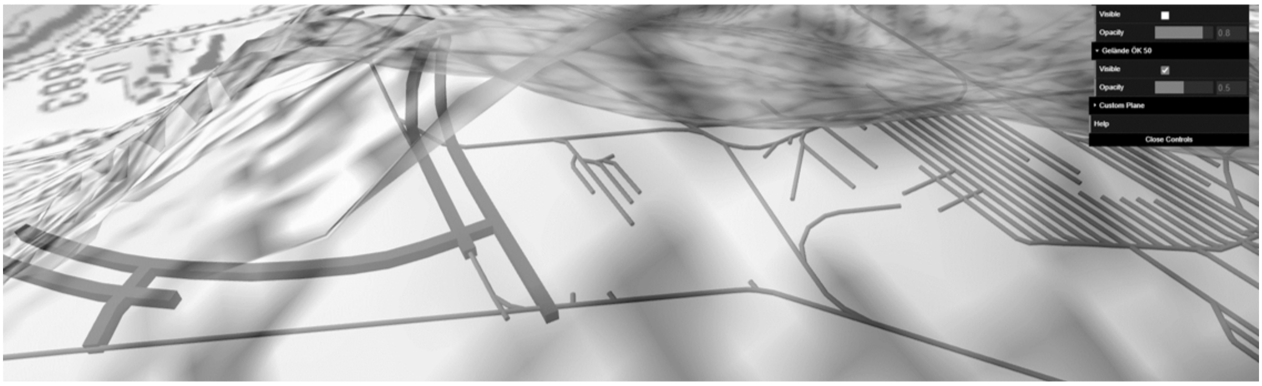


**Illustration 2-1: BORIS provides a quick overview of the subterranean area of operations embedded into the surface environment (Ill: Strauß; Data: VA Erzberg, data.gv.at)**

## 2.4. Ventilation

A major area of interest in subterranean scenarios is the ventilation of the structure. Especially smoke or CBRN incidents can cause difficulties for deployed forces. Predicting the natural or forced flow of air through the system and controlling the ventilation with installed or mobile fans as well as fixed doors and mobile brattices requires the consideration in the tcCOP as a prerequisite for the zone management. The atmospheric conditions pose a particular challenge for underground operations as the dispersion of hazardous gases of various origins poses a high safety risk for the emergency forces and civilians present. To be able to predict changes due to external influences in the underground atmosphere and to estimate the effectiveness of necessary measures, VentSim[4] (Ventilation Simulation) has been tested. This software is widely distributed in mining and is based on 3D-data or the basic structural features of tunnel axis and cross-sections. The simulation requires input parameters to describe and calculate the atmosphere. Together with control elements for targeted ventilation interventions (ventilation doors, ventilators, gas sources, fire loads, ventilation paths), modelling can be performed within minutes (Ill. 2-3). The combination of the FTMT and VentSim will provide very efficient means for rapid ventilation modelling in support of mission planning based on the specific cross-sections of the underground structure. [14]

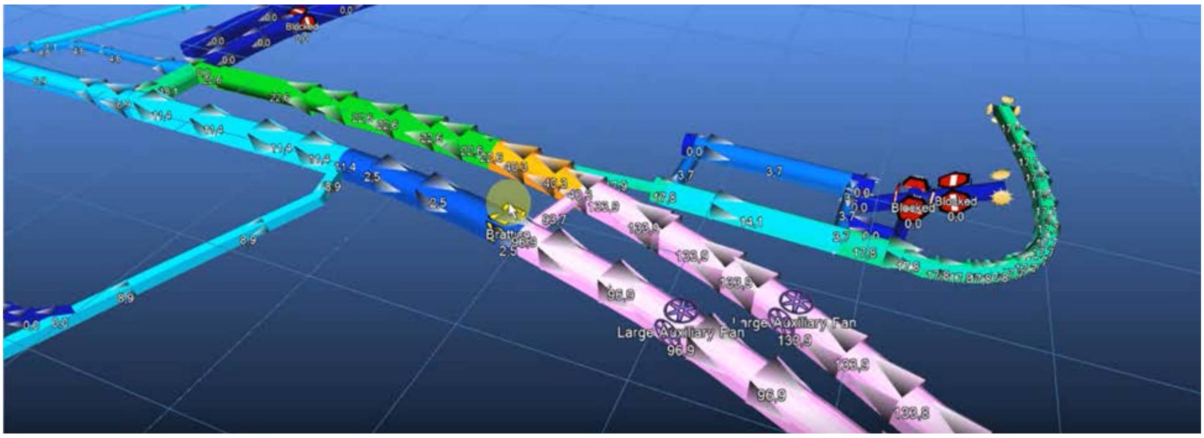


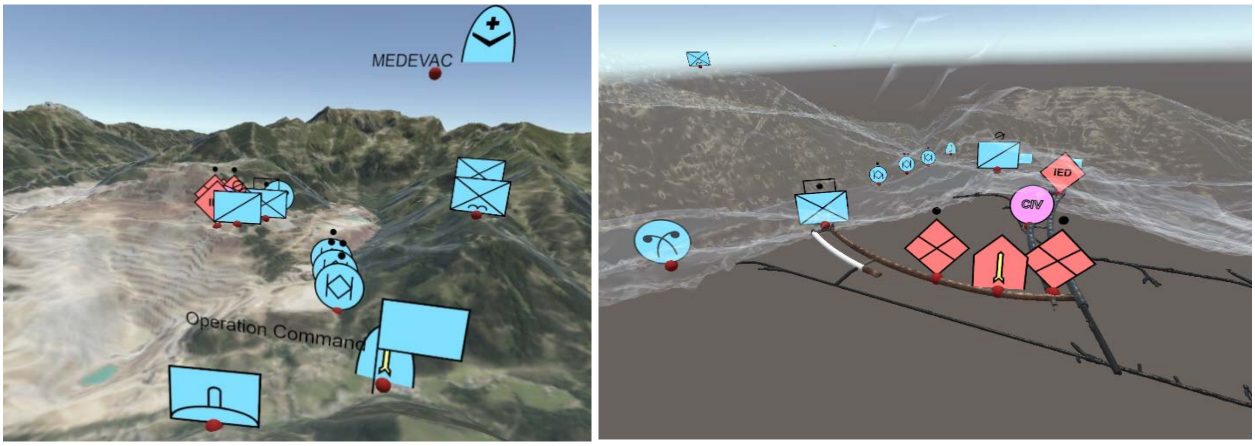

**Illustration 2-3: VentSim simulation enables an estimation of the air flow very quickly as a prerequisite for the zone management (Ill: Nöger; Data: VA Erzberg, Zentrum am Berg)**

## 2.5. SubSurface Operations Mission Tool[5]

In complex subterranean operations comprehending 2D maps is more difficult, compared to other operations because many layers of different levels stacked on each other, make it difficult to comprehend the situation on first sight. An urban traffic hub with multiple subway and railway lines, interconnections, traffic tunnels, shafts and maintenance tunnels represent an extended and sophisticated network. The Subsurface Operation Mission Tool (SOMT) is designed to visualize all relevant data within an XR-capable 3D-model as the common framework for the tcCOP. The effort of the RADIV process is to provide the required information. Mission planning and support can therefore be done digitally, in a 3D environment, significantly improving the understanding of the area of operation as SOMT enables integrated mission planning integrating all actors and factors relevant for subterranean operations (Ill. 2-4).

[4] https://ventsim.com/

[5] https://www.laabmayr.at/tunnel-plus/rd/somt-subsurface-operation-mission-tool/




**Illustrration 2-4: Mission planning in Surface and Sub-Surface environment (Ill: Eder; Data: Zentrum am Berg, data.gv.at)**

While conventional 3D Applications still require the projection onto a screen, Extended Reality (XR) applications can provide an immersive look into the mission environment, utilizing “true” stereoscopic 3D. With the support of Virtual Reality (VR) in SOMT the user can conduct mission preparation “inside” the area of operation. This drastically improves the understanding of the terrain in the area, as well as the subterranean structures, because the user can view the situation from a “bird perspective”, as well as in a 1:1-Scale inside view of the friendly and hostile perspective. SOMT offers the possibility of collaboration for multiple users in a shared environment - also from separated sites (Ill. 2-5).

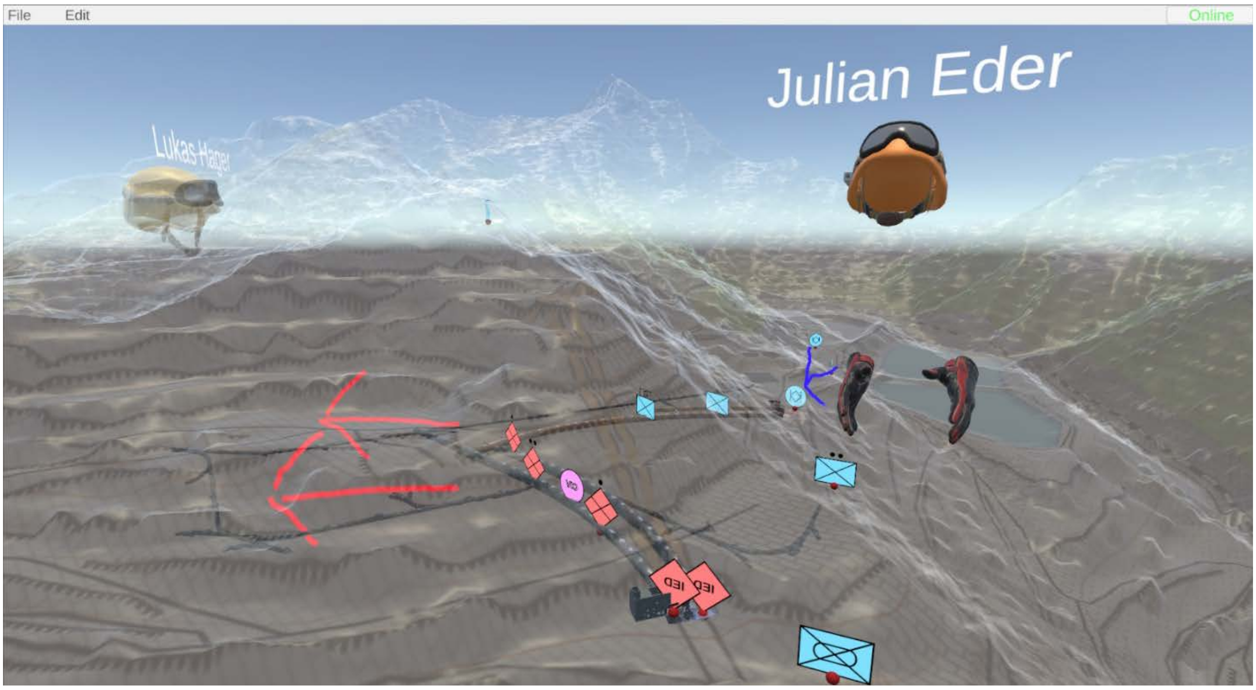



**Illustration 2-5: Planning of an Operation by multiple Virtual Reality Users (Ill: Eder; Data: Zentrum am Berg, data.gv.at)**

While comprehension of the situation is easier, some interactions, like searching for a required tactical symbol or entering textual data, are difficult to do in Virtual Reality. Therefore, the VR-user is assisted by an operator speeding up these interactions with mouse and keyboard input (Ill. 2-6).

**Illustration 2-6: Operator and VR-User Collaboration (Picture: ÖBH/Hammler)**

SOMT aims to implement the RADIV process by becoming a central hub for collecting, distributing, and visualizing all types of data. Therefore, it provides a centralized Server, which can exchange data with all current and future RADIV systems developed by the NIKE research and development group. Ill. 2-7 shows the interfaces to the systems discussed in the previous sections.

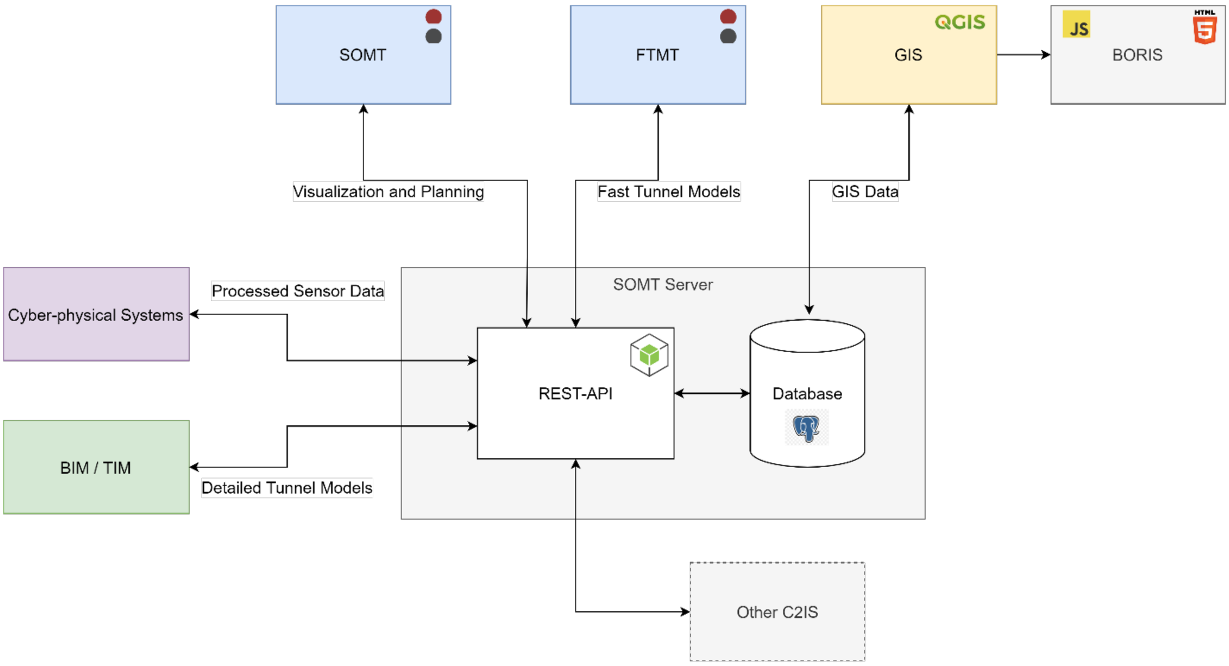



**Illustration 2-7: SOMT Architecture and Interfaces (Ill: Eder)**

## 2.6. SSOC

The CO or the civilian head of operations is generally not a subject matter expert in subterranean operations and the best digital twin is useless without expert interpretation, therefore assistance from a group of experts – the Subsurface Operations Cell (SSOC) is needed. The various aspects of the subterranean environment require specialized knowledge provided by a group of experts, data integration and visualization represents a key capability (Ill. 2-8).

> *"Mission accomplishment within complex scenarios in subsurface service structures heavily depends upon the availability of specialised knowledge to assist the decision-making process—provided by the SubSurface Operations Cell (SSOC). Without integration of this specific expertise, a subterranean operation is prone to end up in a severe mission creep causing avoidable damage and losses of personnel." [5]*

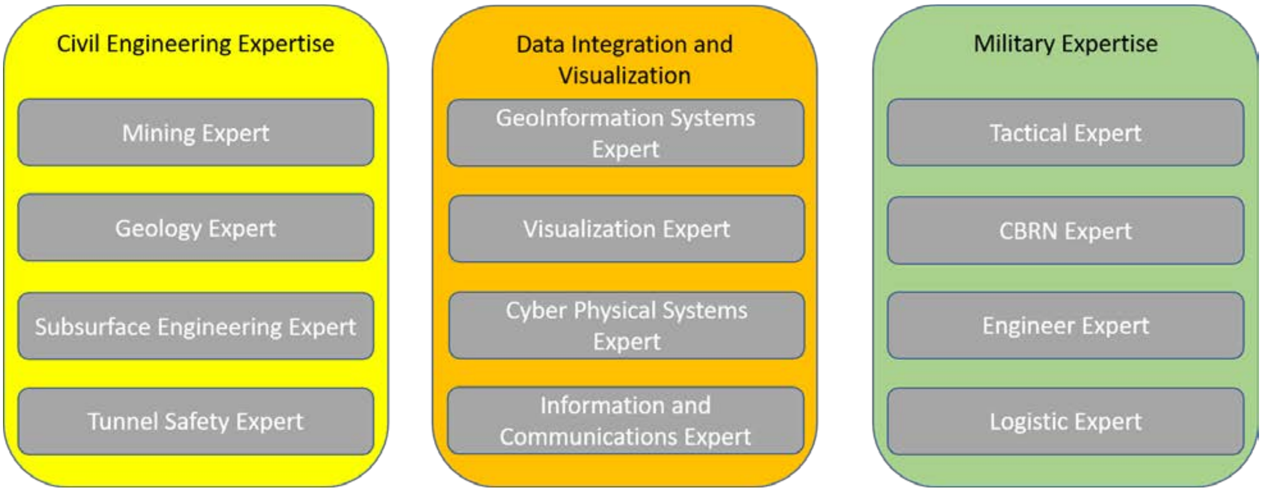



**Illustration 2-8: The SubSurface Operations Cell (SSOC) is a group of dedicated experts (Ill: Hofer [5]).**

The SubSurface Operations Cell (SSOC) is a group of hand-picked experts with military and civil background to assist military Headquarters and civilian chiefs of operation likewise. The cell is able to provide assistance in the development of emergency and crisis management plans, establishment of long-lasting comprehensive relationships, the provision of an integrated assessment for subterranean risks and dangers, the integration of all relevant data sources, the contribution of specific pieces of situational awareness and the zone management [5].

## 3.0 CONCLUSION AND OUTLOOK

Urban operations require the ability to control the subsurface environment and a subterranean combat team is a future-proof unit which can be deployed across the entire spectrum of urban operations for a wide range of tasks, but it needs specialized command and control to succeed. Rapid data integration and visualization (RADIV) of heterogeneous sources like 3D-modells, plans, maps, or laser-scans as well as operator's information gathered from sensors and cameras inside the underground structures offers the possibility of visualizing of infrastructure generally out of sight. By establishing RADIV as a core assisting process in command and control the challenges associated with urban operations can be addressed much better thereby enabling more accurate and precise action, reducing own losses and collateral damage. Close cooperation and information exchange between operators of subsurface service structures and action forces to integrate all relevant factors and actors is the foundation for processing relevant information within a truly comprehensive Common Operational Picture. An insight view of the subterranean structures for the action forces before entering this highly demanding operational environment is indispensable for mission success. Successful accomplishment of subterranean operations requires highly specialized capabilities and accurate planning assisted by up-to-date tools. Therefore, RADIV will play an essential role in the digitalization of headquarters significantly improving decision support for urban operations.

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