

Conceptualizing an Urban Operations Vehicle within a Comprehensive Research and Development Program

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Abstract

In the last decades we have witnessed an increasing number of military operations in urban environments. Complex urban operations require high standards of training, equipment, and personnel. Emergency forces on the ground will need specialized vehicles to support them in all parts and levels of this extremely demanding environment including the subterranean and interior of infrastructure. The development of vehicles for this environment has lagged but offers a high payoff. This article describes the method for developing a concept for an urban operations vehicle by characterization of the urban environment, deduction of key issues, evaluation of related prototyping, science fiction story-typing of the requirements for such a vehicle, and comparison with field-proven and scalable solutions. Embedding these thoughts into a comprehensive research and development program provides lines of development, setting the stage for further research.

History

Received: 22 Jan 2023
Revised: 23 May 2023
Accepted: 17 Aug 2023
e-Available: 07 Sep 2023

Keywords

Urban operations, Complex operations, Subterranean, Subsurface, Narrative prototyping, NIKE research and development

Citation

Hofer, P. and Knight, C., "Conceptualizing an Urban Operations Vehicle within a Comprehensive Research and Development Program," *SAE Int. J. of CAV* 7(1):53–67, 2024, doi:10.4271/12-07-01-0005.

ISSN: 2574-0741
e-ISSN: 2574-075X

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1. Introduction

Throughout history cities have been violently contested for politico-strategic or logistic objectives, although major urban fighting faded from Western public consciousness during the Cold War. A resurgence in recent decades can be expected to continue, driven by rapid worldwide urbanization, conflict among crowding populations, and the desire to use structures to shelter from sensors and weapons. The built environment confounds. It obstructs movement and visibility so that forces are channeled, divided by streets, and unable to concentrate direct fires. It conceals, offering innumerable firing positions among buildings while hidden movement may be possible behind or through them. Yet, it also acutely exposes movement on open streets to overwatch and fire from surrounding buildings. It is an environment of limited approaches where lurking snipers, mines, and improvised explosive devices wreak havoc. Leading experts argue that the compounding challenges in the urban environment represent “*the hardest form of warfare*” [1].

New technologies may assist. Development foci for the urban fight include the utility of multi-mission platforms and modularity, the scope for joint effects using COTS (commercial off-the-shelf) equipment especially drones, integration of digital soldier systems, the issue of reducing the humanitarian catastrophe of collateral damage, and employing optionally crewed or uncrewed “robotic” platforms to reduce risk to humans [2]. There is a potential constructive relationship between these last two. Destructive levels of firepower are often employed in the urban battle to reduce the risk to dismounted troops and robotic platforms might reduce that risk in other ways.

The potential of uncrewed ground vehicles (UGV) to perform tasks that are dangerous, dirty, or tedious is reflected in the scale and scope of their development worldwide. However, while they have provided revolutionary capability in niche tasks such as bomb disposal, their tactical employment has encountered setbacks since they were first used in battle in World War II. This suggests that development efforts such as the US Army’s family of “broad mission” combat robots [3] strives to overcome multiple challenges such as assured control in a contested electromagnetic spectrum, and there are promising opportunities in other niches. A prime example would be the development of an urban operations vehicle (UOV) intended to operate within confined urban spaces in all levels of movement (triple-S: supersurface–surface–subsurface). Since until recently armies have neglected the urban fight, such specialist capabilities have been overlooked. However, they may offer a high moral and financial cost payoff for development investment if they provide capabilities beyond the current approaches.

Western militaries have largely neglected training and equipping to fight a peer enemy in cities, despite the likelihood of urban combat being acknowledged and documented. There is a “[...] *phenomenon of nearly a century of cognitive disconnect between the foreseeable demands of urban battle and military preferences and policies*” [4]. The popular resistance that

followed US-led invasions in the Middle East, created an imperative for developing and refining urban counterinsurgency techniques; however, combined arms urban war fighting was neglected for 20 years. Unlike the restraint required in counterinsurgency, the urban combined arms fight concurrently applies the battlefield effects from different types of units to overwhelm. For example, artillery suppresses the area where the enemy might be located, engineers clear pathways for both tanks and infantry, and tanks destroy any enemy positions that engaged own advancing infantry while in turn those infantry protect the tanks from enemy infantry and antitank teams.

In recent urban battles the primary overwhelming effect has come from air and artillery bombardment. This has caused catastrophic levels of civilian harm from immediate casualties and the reverberative consequences from the loss of infrastructure and resources: disease, displacement, and starvation [5]. Consequently, limiting the employment of “wide-area-effect” weapons has become a priority issue for the ICRC and humanitarian NGO, and this is likely to lead to political constraints. This is not a new challenge. During World War II all armies employed air and artillery area bombardment to overwhelm enemies in urban areas, but they discovered that this created massive obstacles. They reduced the need for such bombardments by fielding platforms that could physically reshape the battlefield and deliver pinpoint destruction: armored self-propelled guns and engineering vehicles. These systems are no longer in service. A crucial question is whether UGV can underpin concepts of urban combat that reduce the need for area bombardment by delivery of high explosives?

All emergency forces operating in an urban environment need specialized vehicles to support them, but they are indispensable for conducting military combined arms operations. However, most vehicles have reduced mobility on urban terrain and few can move within the cover and concealment of buildings, much less enter subterranean systems. The current optimization of military platforms for rural use constrains total capabilities within urban terrain, increasing risk and limiting what forces can achieve. This situation does, however, provide an opportunity for a suitable platform to positively transform urban operations.

2. Purpose

This article describes the development of both a concept of employment for an UOV and definition of the parameters for a prototype. The document is systematically laid out, beginning with the working assumptions and then following the steps described under “working assumptions and method.” This provides the reader the rationale and approach to the project, locates it within the IRON NIKE research and development program [6], and anticipates associated research projects.

The UOV development occurs in the context of complexity, requiring particular and unfamiliar approaches. Military operations have always been dramatically shaped

and constrained by an urban environment. Factors include the character and size of the urban system, the number and nature of subsystems, the scale and ratio of opposing forces, the fighting skills of an opponent, the susceptibility of the urban system to degradation, and the extent of the operational area (in all three dimensions!) [7]. However, in recent decades information war enabled by ubiquitous access to overhead imagery, real-time communication, and algorithm-based messaging has compounded the military-political problems of civilian casualties, misinformation, and disinformation. Kilcullen labeled the fight in cities resulting from the interaction of the complexities of terrain, population, and informational factors “complex warfighting.” Such conflict is emergent, meaning it resists conventional analysis, defies linear predictions about responses to a given stimulus, and requires a systems approach: a big picture view that can apply varied tactical stimuli and observe for emergent trends to reinforce [8].

When dealing with conflict in a complex system such as a city it is necessary to start with comprehensive tools for understanding the initial “steady-state” of urban stability and resilience [9]. The better the understanding of actors and activity within the city the better commanders can respond and shape the behavior of the system. It follows that communication, cooperation, coordination, and learning by all relevant actors and systems operating in the urban system is vital. Responding to complexity demands not only high and defined standards for organizing, training, and equipping the human forces within a framework of efficient civil-military cooperation, but maximum integration of platforms as intelligent sensors, nodes, relays, and processors. The UOV should not only offer this, but also be modular in order to be the basis of applying a wide range of effects on the urban combat system.

3. Working Assumptions and Method

To frame the development of an UOV, the following basic assumptions have been made (italics for key points):

- **Subterranean Focus**—*The most-demanding and confined environment—the subterranean—must be taken as a benchmark for the UOV development.* Taking this into account enables the development of an UAV capable of operating under any circumstances in an urban environment.
- **Interior Operation**—Technological superiority will force an inferior opponent into the interior of infrastructure (supersurface and subsurface). *Forces must be prepared to operate about and within urban infrastructure.*
- **Rubbled Environment**—Our understanding of urban operations is *distorted by the clinical environments* represented by tidy and clean *training areas*. Rather, the underlying environmental conditions must be characterized by rubble and ash.
- **Minimum size**—Operational experience with UGV has frequently seen minor obstacles deny progress of smaller platforms such as the Wehrmacht *Goliath* [10], while crewed tankettes and similarly sized *Springer* demolition vehicles [11] proved significantly more agile. As a broad initial principle, the development platform should be either small and light enough to be moved by persons or have the step and gap crossing characteristics of a *Springer*. This also represents approximately the *minimum size to provide an armored envelope* able to accommodate an operator and a payload (troops, combat supplies, machinery, etc.).
- **Human Control—Limited Autonomy**—War is about applying violence to force the opponent to do one’s own will [12], and military necessity may demand all measures that are not prohibited. Theoretically, within a fully autonomous robotic war there might be no limit to destruction as swarming systems destroy all resistance and perceived threat—be it robotic or human. There is political and civil society effort to use prohibition to avoid such a dystopic future. Therefore, for both pragmatic and ethical reasons *we assume that urban operations will not be fully autonomous*, noting the challenge of defining the relevant limitations [13].
- **Human Relevance**—Joint operations with a high proportion of infantry (infantry-centric) combined with relevant stakeholders and operators [14] will remain dominant. *Human soldiers will remain essential* on the urban battlefield for functions that cannot be executed by machines, including interacting with populations.
- **Human-Machine Teaming**—Given the human-in-the-loop requirement *efficient human-machine teaming will be key*, especially for authorizing lethal force. This will drive technological development including varied electromagnetic spectrum links, signal compression or efficiency, novel sensors and feedback mechanisms, and decision support machine learning.
- **Workforce Not Reduced**—The use of autonomous systems can reduce the number of personnel needed and shift force ratios only to a limited extent. For the foreseeable future, especially given human-in-the-loop specifications, *a significant workforce* of platform operators, logistic, and maintenance personnel will be required.
- **Interdisciplinary capability development and training** must be *framed by the three aforementioned main factors* of urban operations namely size, triple-S (supersurface—surface—subsurface), and complexity [7, 15].
- **Quality not Speed**—Automation will not necessarily accelerate decision making, as the responsibility will always lie with the human being—*it will improve quality-wise.*

The working assumptions discussed earlier led us to focus on an UOV suitable for operating in the most-demanding and human life-threatening of the urban environments: the

FIGURE 1 Inside view of the confined space within the subterranean operational environment.



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subterranean (Figure 1). The process of developing the base concept followed these steps:

- Characterization of the urban operational environment
- Identification of key issues
- Development of an initial (opportunistic) reference scenario
- Employing AI as an additional input
- Evaluation of related prototyping
- Deduction of “straw man” requirements for an UOV
- Research on existing solutions
- Definition of basic construction features

4. Characterization of the Urban Operational Environment

The urban operational environment in which the UOV will operate can be characterized as follows:

- **Dimension:** Urban environments are big. The area of Tokyo for example—one of the greatest megacities around the world—is home to nearly 40 million people and covers an area of 8200 square kilometers [17], Europe’s sixth largest city Vienna has an area of 415 square kilometers and houses 2.9 million inhabitants [18]. Fighting a peer, even the largest armies can only dominate a small part of such a city, dictating that forces will often fight in isolated groupings with tenuous logistics. The large number of civilians affected will typically place an additional burden on emergency forces. The obligation of the military to provide protection and assistance to civilians is a particular problem for modern military forces, which are small and have austere logistic support [19].
- **Spatial complication:** Urban terrain is three-dimensional and complicated. There are different zones with varying categories of building type and infrastructure development by most of which must also be understood on at least three levels of movement (triple-S: supersurface—surface—subsurface). The subterranean environment is still particularly misunderstood. Operating there is not only a matter of applying close quarter battle drills in an enclosure without daylight. With increasing penetration depth, forces become extremely isolated from all kinds of

support while the subterranean environment itself presents acute risks and requires true technical and tactical mastery [20].

- **Shaping and exposure:** urban terrain channels movement, while concurrently creating extreme exposure in open places which, unlike in most open terrain, may be subject to multiple threats from all directions, including from above and below. The consequent vulnerability continues in depth along the lines of communication making combat service support particularly challenging. Autonomous resupply may therefore offer special advantages in this environment.
- **Compartmentalization:** Urban environments change constantly with development and can be dramatically reshaped by bombardment. The urban fabric restricts and confines the effects of communications, sensors, and weapons. While this compartmentalization may dilute the effects of firepower overall, locally the effects of explosive blast may be reinforced by confinement, possibly causing mass casualty incidents with specific injury patterns [21]. Communication means are severely degraded by the effects of infrastructure on electromagnetic radiation compared to open terrain [22].

While we must design and develop our UOV to operate in the above environment, it can be difficult to find terrain to conduct urban training and research activities. It is rarely

possible to do so within functioning cities for obvious practical reasons. While Austria does not currently have dedicated urban training facilities at scale, our project is fortunate to have access to a site that suitably represents the interface between the surface structures of a contemporary city and an extensive subsurface system. As discussed, this may be considered among the most-demanding operating environments. [Figure 2](#) depicts the semi-virtual urban commuter hub “THREE KINGS” created by the virtual supersurface extension of the existing subsurface “Zentrum am Berg” research and training facility in Eisenerz [23]. This digital half-brother gives an idea of the challenges associated with urban operations and has been the playing ground for research and development activities within the NIKE program.

5. Key Issues

The UOV must not only be designed to function well in the urban environment described earlier, it must also be able to operate synergistically with humans. We should not attempt to specify the tactics, techniques, and procedures (TTP) it should conform with, since that might constrain us from new approaches. However, we must still consider conceptually how we will fight. We have chosen to be guided by the “leadership principles” offered within the recently published field manual

FIGURE 2 The urban commuter hub “THREE KINGS” combining the real-world subterranean research and training infrastructure “Zentrum am Berg” with a virtual urban setting provides the playing ground for the development of UOV variants (R&D Group NIKE, data taken from [24, 25, 26]).



for subterranean operations [27] and we treat these as key issues for our UAV development concept.

- Subordinate commanders must be given maximum **freedom of action** to exploit opportunities as they arise. This enables them to be more effective against an opponent and increases the safety of the forces deployed by quickly adapting to changing threats. The oscillation between command and control and mission command [28] is a delicate one in urban operations and should be kept in mind for a comprehensive UOV design. Mission command remains relevant, as it assists complexity reduction and aligns with the framework of Safety and Security Strategies for Service Structures [29].
- An operation in an urban environment requires **intensive cooperation** with other emergency organizations and infrastructure operators. The advance sharing of information, the exchange of liaison officers, a joint operational command, and standardization of equipment underpin success. Cross-actor cooperation requires a **clear goal or aim** in order to coordinate the diverse capabilities and objectives of the different organizations and deliver a comprehensive and sustainable effort [30].
- Areas of responsibility are crucial in controlling movement. Although spatial organization can result in unusual boundaries, this is essential to ensure **unity of command**. The spatial and temporal **synchronization** of forces at the different levels of movement is a major challenge and requires a very clear situational picture. The often confusing, multidimensional operational environment requires precise synchronization. This is vital to coordinate **effects and movement** and to minimize the danger to own forces or uninvolved third parties in rapidly changing situations, especially where may be necessary to frequently shift the **main effort**. The **formation of reserves** must consider that urban terrain may prevent rapid redeployment between elements. This calls for specialized command and control systems that provide a truly comprehensive Common Operational Picture (tcCOP), which also visualizes the interior of structures [31]. **Information superiority** is largely determined by the ability to rapidly integrate all available data sources and easily visualize the result (RApid Data Integration and Visualization—RADIV) [32].
- Whoever is the first to use urban space for its own purposes has an initial advantage. **Initiative must be maintained or won** by acting quickly and decisively, because in the fluid urban battlefield, changes in the situation are to be expected constantly. The prior preparation and interaction of all relevant stakeholders is essential [33, 34].
- Deployment in urban areas places a high burden on the forces deployed and requires attention to the **economy of force**. Increased force ratios at vital points are enabled by higher mobility and automated support systems. With increasing depth of penetration and duration of

deployment, resupply becomes more and more critical to survival and endurance. Sustaining the material and psychological **combat value of the force** is crucial and disengaged forces should not be immediately brought back into action without considering sustainment, especially time for and areas to rest in [35].

- Complex situations are characterized by unexpected dependencies. **Simplicity** becomes a dominant principle to achieve success. The more complex the challenges, the simpler the execution of missions should be. Mitigating the effect of complexity is the responsibility of headquarters with the involvement of experts of the SubSurface Operations Cell (SSOC) [36] or the Urban Operations Support Cell (UOSC) [7].
- Multiple movement options can increase **surprise** if exploited in a synchronized way. Protection against enemy surprise increases the importance of reconnaissance and requires a sustainable saturation of the urban space with one's own forces and sensors. **Deception** may be achieved by simple means (e.g., smoke, noise) given a lack of visibility, but it requires tight coordination with other assets and efforts.
- **Protection and safety** increase the importance of reconnaissance using all available forces, means, and sensors, securing the area of operations and adherence to safety regulations (self-protection). Mission accomplishment in the urban environment also requires the highest safety standards [33].
- An operation in urban space is an infantry-centric fight with constrained support options and requires a different kind of **mobility**, which is linked to **mobility of leadership**. The **mobility of the force** is increased by covered movement possibilities as well as the availability of the necessary protective equipment and specialized transport solutions.

6. Development of a Reference Scenario

Scenarios offer a proven and accessible means of conveying the context in which a new concept or system should function. The IRON NIKE research and development program uses a common reference scenario “THREE KINGS” [37]. It describes a situation in which a complex attack is unfolding within an urban commuter hub over all three levels of movement. This has been developed as the standard setting for all research and development projects within the program [15] by combining all challenges within one operational box. While a small-scale scenario in military terms, it poses a high degree of complexity due to the peculiarities of the subsurface environment [20] intertwined with the other levels of movement. We continue to apply the principle that coping with this challenging scenario will demonstrate the capacity to respond to many other urban operations challenges. The scenario is as follows (see Figure 3):

FIGURE 3 The commander's hand map shows the complexity of the situation with the insert providing a virtual bird-view of the triple-S environment (R&D Group NIKE; data taken from [24, 25, 38, 39]).



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A hybrid attacker causes a local power outage through a cyber-attack and simultaneously launches an attack with armed fighters in a metro station. Sudden darkness, attackers firing wildly, and explosions triggered by them affect many people who are in the mass transit hub at the time and begin to panic and move uncontrollably. The attackers take advantage of the resulting chaos and can move and shoot unhindered, exploiting night vision equipment, respiratory protection and local knowledge. Emerging fires cause enormous volumes of non-breathable, toxic atmospheres, which, due to the power failure, only follow the natural air currents. On the surface, more attackers wait for the arrival of the rescue forces to open fire into the assembly areas.

Major F.'s infantry company has been in action in the core of the city for a few hours against an opponent who has the initiative and excellent knowledge of the terrain. The access points for the underground infrastructure were quickly secured and the soldiers were able to operate immersed in the underground operational environment because of their intensive training. Nevertheless, after long hours in endless dark smoke-filled stretches, moving using breathing protection and in constant anticipation of encountering the enemy at close range, uncertainty is huge. When the outlines of armed persons dimly appear in the smoke at the end of a tunnel, an

unambiguous identification is not possible—nor can this be checked. The soldiers had received information that their own forces are moving parallel to them, but whether they are above, below, left or right, no one can tell down here anymore. Who is that there in the shadows—are they their own or the enemy? [40]

This scenario can readily be applied to describe the required capabilities of the UOV and support prototyping.

Since our project acknowledges the need to exploit AI, we consider that it might be useful to seek AI input. This recognizes that the AI will be approximating consulting a wide variety of prior inputs. To this end, the following conversation with ChatGPT was conducted:

Q: What will the future of urban operations look like?

A: "It is difficult to predict exactly what the future of urban operations will look like. However, it is likely that the use of technology, such as drones, robots, and advanced sensors, will continue to play a larger role in urban operations. These technologies can help to reduce the risk to human personnel and improve situational awareness in complex urban environments. Additionally, there may be an increased emphasis on working with local populations and addressing the root causes of conflict in urban areas, rather than simply trying to militarily defeat an adversary" [41].

Although these responses appear valid, they are only equivalent to a human "gross error check" or "environmental scan," and other approaches are needed.

7. Exploration with Narrative Prototyping

Fictional narratives can be an engaging and productive way of thinking about future requirements and can be both scenarios and a means of prototyping. As Johnson explains, “A prototype is a story or a fictional depiction of a product” [42], therefore science fiction prototyping offers a useful way of exploring and understanding the issues in developing a military system. The approach allows true interdisciplinary engagement as “The stories, movies and comics that we make can get researchers, designers, scientists, engineers, professors, politicians, philosophers and just everyday average people thinking about science in a new and creative way by using science fueled stories that capture our imaginations” [42].

For our exploration of the requirements of a UOV, there is pertinent and recently written online “future military narrative” work entitled “Der Verlorne Haufen” [43]. This describes the amphibious recapture of an island from foreign invaders, by a human force using optionally crewed and uncrewed systems. The emphasis is on the urban break-in battle, offering various technical and tactical concepts from both friendly and enemy perspectives. Within this the focus of the story is the combat and combat support role of a range of specialized UGV and UAV under remote control from both local and distant command facilities, enabled by very high degree of autonomy based on artificial intelligence. The mix of crewed and uncrewed platforms of different size (and naturally cost!) perform an attack into an urban environment making extensive use of the interior of infrastructure for vehicle and human cover and movement. This is enabled by mechanically and explosively breaching into and through buildings and using varied obscurants for concealment. The story describes the use of remote-controlled weapon stations, human-machine teaming based on suggestions from the artificial intelligence and other systems to improve situational awareness. These include the *transparent armor effect* (created by specialized visualization systems integrated into the helmet) and presenting fighters with real-time detailed virtual wire models of the urban environment around them. The narrative also explores issues of International Humanitarian Law and the Law of Armed Conflict, in portraying one force maintaining “human control of lethality” with the opponent employing lethal autonomy. The ideas provide an anchor point for our study but need refinement with regard to the subterranean operational environment, which is the benchmark for the UOV as well as service support and in-theatre communication.

At this stage we were ready to begin distilling our requirements for a UOV, and began with writing a fictional narrative to involve a conceptual “strawman”—a starting point for discussion of what the UAV might look like and operate. It is set within a large city and describes the main features of the UOV and their interfaces to other technological solutions.

UOV-1387 (see Figure 4—the hand sketch graphic is deliberately used to convey that this layout is indicative and the

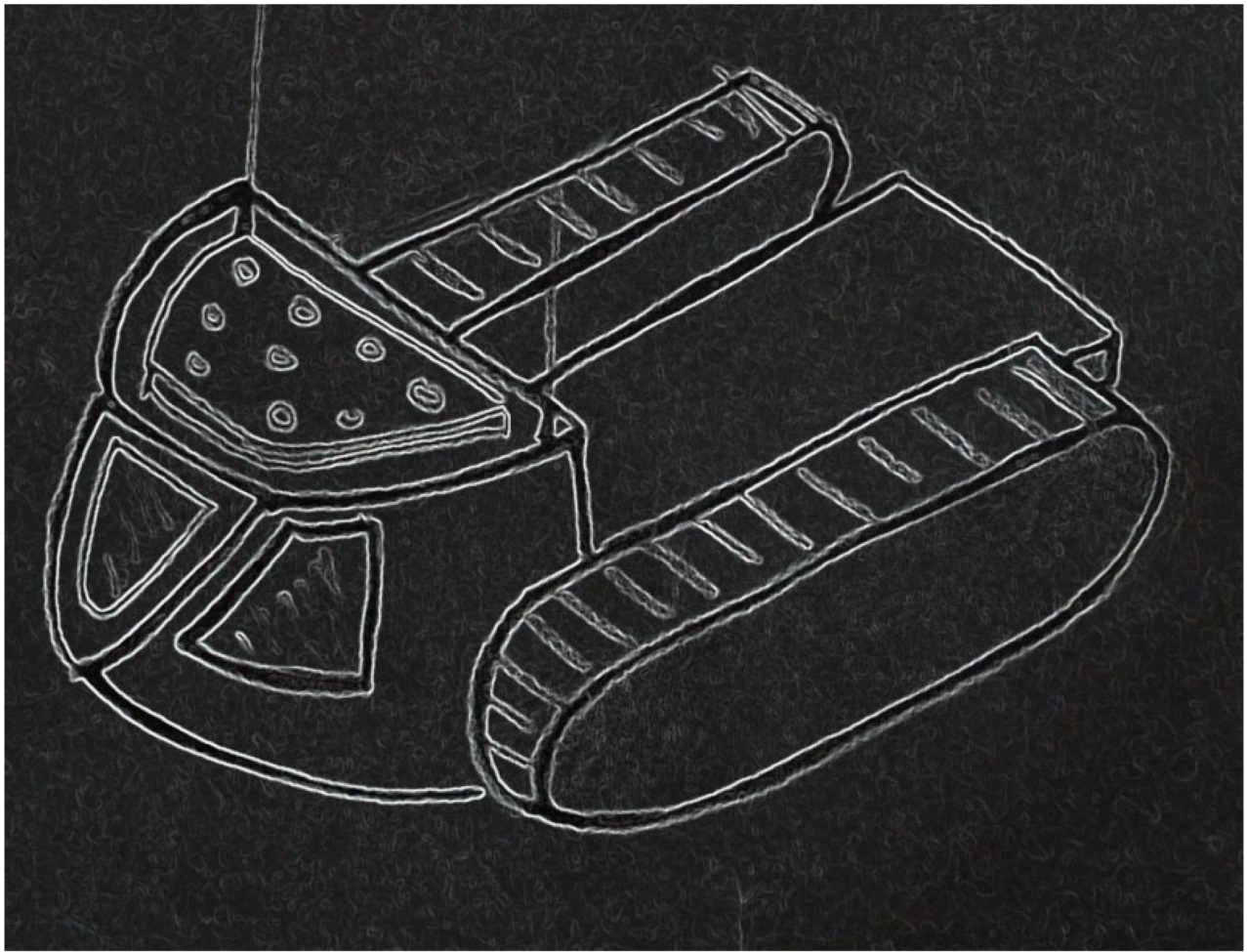
actual design will evolve iteratively) *has entered the area of operation (AOO) via the Line of Communication (LOC) TIGER. Hank is one of the most experienced operators of semi-autonomous platforms. The enterprise put a lot of research into feedback and haptics, but has not yet reproduced the experience of physically driving a machine. A significant number of assistance systems made operations easier and safer, but all the sensors and algorithms were not able to replace the driver in a rugged and hostile urban environment. Along the selected and cleared LOC Hank activates the auto-driver which is following a path of waypoints, outbound and inbound drone traffic is heavy in the corridor above him. Proximity warnings indicate troops and other vehicles around UOV-1387 and generally it will avoid all types of obstacles, but Hank always has a close look at the surrounding environment not to miss a thing requiring his intervention. He has loaded a troop transport container (TTC) carrying a squad of infantrymen to their destined location in the city—another reason why Hank is very attentive. The armor provides sufficient protection against the commonly used weapons and active onboard defense systems are very reliable but tend to cause abrupt steering maneuvers. With his experience and the observation of the battlefield Hank can override the auto-driver and provide a more predictable, smooth and comfortable path also over the ubiquitous rubble heaps, the four UOV’s carrying the rest of the platoon and the equipment follow uncrewed.*

The Tactical Operations Center (TOC) tracks the movement of the little convoy, and the huMan mAchine navigation Teaming (MATE) system provides precise navigation data of all personnel and moving platforms in GNSS-denied environments. Therefore, the TOC will also track the five vehicles on their way through the six kilometers of road tunnel lying ahead. The mission planning has been done using the triple-S Operations Mission Tool (S³OMT) and the AI-backed #SMART_COMMAND C² solution. The hologram-assisted protection helmet (HOLPRO) not only provides ballistic protection but also information about the opponent and own elements scaled down to the soldier’s needs. In total two infantry companies with six platoons and a specialized combat support company are on their way to the urban commuter hub THREE KINGS.

Before entering the tunnel, a swarm of drones hop on the exchange dock (X-DOCK) on UOV-1387’s roof top and start to load their batteries and simultaneously transmit data from their reconnaissance flight. They are small to fit through the smallest openings, and so rely on nearby moving platforms for energy and a broadband connection. On exiting the tunnel, they will leave the platform and take over another swarm’s task. The UOV’s multichannel communication device will then transmit the data to the operations cloud via available means. Together with all the sensor data gathered by UOV 1387—LIDAR, CO, CO₂, NH_x, radiation, toxic agents—this is a valuable contribution to the tcCOP.

In the staging area troops are gathering, so transfers must be quick—unloading the troop containers and loading the next containers. Hank detaches two of the UOV’s to another operator who forms a medical unit with Medical Treatment Containers (MTC) from civilian organizations—joint comprehensive

FIGURE 4 A first hand drawing of UOV-1387 characterizing some main features: tracks (with integrated power units), low hull, driver compartment with X-Change Dock and antennas on top, resectable for swap body.



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product development pays off. The emergency team has already started with the treatment of the patients in the containers—saving precious time to achieve the golden hour. In the meanwhile, Hank has been tasked with picking up one of the specialized units for subsurface operations. Due to the confined subterranean spaces Hank must fully rely on electrical power modules (EPM) to avoid exhaust fumes and be independent from oxygen. Hank looks for the next power station container (PSC) to get six modules prior to picking up the ventilation module containers (VMC) of a ventilation squad with his remaining units.

The little convoy enters the subway station via the staircase. During the past years, most of the infrastructure underwent a retrofit—new structures are already planned in line with the needs of the security forces—hidden loopholes, preparation for mobile brattices [44], provisions for UOV movement). With their low center of gravity and the tracks the UOVs reach the station level within a few minutes and enter the subway tunnel. Depressions in the profiles of the tracks provide a smooth ride on the standard European rail gauge. Even within the narrow profiles the UOVs can move due to their low hull and the slanted edges on top of the containers. At the wider profile of a crossing

the ventilation squad establishes the mobile brattice and starts the onboard fans of a VMC to activate the zone transition to supply the yellow zone with fresh air. The next task of evacuating civilians from the red zone is already waiting and Hank must move personnel evacuation containers (PEC) packed with rescued civilians to the surface and fetch subsurface fire platforms (SFP). Those are equipped with a weapon station, using thermal imaging with a pose estimation system enabling unequivocal differentiation. Integrated into the tcCOP this contributes to a comprehensive picture of emergency forces, opponents, and civilians. Also flatbed transport platforms (FTP) are needed, forces advancing in the red zone should not carry too much weight. Hank drives on—this has long day written all over it...

8. Field-Proven Solutions

Having created the strawman previously, we then reviewed both historical and contemporary vehicles to gather insights from “real-world” platform development. When looking at

locomotion we considered a wide variety of tracked and wheeled dumpers, radio-controlled crawler vehicles, snow mobiles, mini excavators and multi-loaders, civilian multi-purpose vehicles, military tracked vehicles, and specialized solutions were checked for their basic suitability [45]. Concurrently, we looked at armored fighting vehicles and considered their use in the urban environment. Although good wheeled solutions are already available or under development, we have opted for a tracked vehicle offering superior all-terrain mobility in the whole triple-S environment under the most difficult rubble and ash conditions as described previously.

After tanks overcame the stalemate of static trench warfare in World War I and restored maneuver to the battlefield, most designs were small, lightly armored, and agile. When used to support infantry, such vehicles proved invaluable in urban fights in Spain and China during the 1930s and again in the opening campaigns of World War II. However, this value was largely forgotten when they proved to be vulnerable to heavier tanks with bigger guns and better armor. This drove the evolutionary race of tanks as antitank systems leading to the heavy armored behemoths that are considered dominant today.

Concurrently, tank-based assault artillery emerged such as the German StuG III, IV, or the Russian SU-122, SU-152.

These simpler, cheaper turretless vehicles provided direct fire support for advancing infantry and had special design characteristics such as a lower hull, relatively more powerful shells [46], and they proved highly effective during urban operations. British Commonwealth forces also employed a range of armored engineering vehicles, based on Churchill tanks [47]. The most common were armed with demolition guns or flamethrowers and were used in conjunction to evict building defenders. Such specialized vehicles have now vanished from all armies, which must currently rely on main battle tanks for protected fire support in the urban fight, for which they are not designed but indispensable. Improvements have been made for the Leclerc, Leopard, or Challenger main battle tanks [48], the most recent example being the Streetfighter II upgrade for the Challenger 2. This improves the weaponry, situational awareness, and tank-personnel cooperation for urban operations [49].

While large heavy well-armored and powerfully armed tanks, and probably similarly protected armored personnel carriers will likely remain vital for the urban fight, they will remain vulnerable to overhead attack and too large and heavy to enter dense urban areas (Figure 5). Consequently, this project assumes that tanks will continue to have a niche role in the urban fight, but our focus is to

FIGURE 5 Available vehicles are too large and heavy to effectively be operated in all urban infrastructure. The picture shows the infantry fighting vehicle ULAN in a subterranean environment within an experimental capability development.



develop a platform that can provide support within the confined spaces of urban environments where bulky and heavy vehicles cannot go. Therefore, as the basis for discussion and development we chose a set of compact crewed and uncrewed vehicles.

The later replacement of the StuG III, the low-profile Hetzer tank destroyer [50, 51] offers an interesting hull type for the UOV. Among existing scalable solutions, the Milrem Robotics THeMIS medium unmanned ground vehicle [52, 53], the Highland Systems STORM [54], the Howe&Howe RIPS AW MS1 [55], the WIESEL2 [56], the CVR-T [57, 58], and the MARTEL MTT154 [59] in Quad-Track or Side-by-Side configuration [59] offer interesting concepts. Table 1 gives an overview of these platform's main features. As we have a base vehicle with a set of swap bodies in mind, solutions as the RCV Engineer also provide interesting concepts [60].

9. Design Considerations

By this stage a clear sense of the range of dimensions for the UOV was beginning to emerge so we decided to again consult AI. We asked ChatGPT questions and used this to drive reflection, noted in brackets. **Q: What are the main features of an urban operations vehicle?** A: "There are a number of features that are important for vehicles used in urban operations:

1. *Maneuverability: Urban environments often have narrow streets and tight corners, so vehicles need to be able to maneuver easily in these spaces.* (The vehicle

should be no larger than a small car and able to execute neutral turns.)

2. *Armor: Vehicles used in urban operations may need to be armored to protect against small arms fire and other threats.* (A platform not protected against small arms fire would be excessively vulnerable.)
3. *Size: Vehicles should be small enough to maneuver easily in urban environments, but large enough to carry the necessary personnel and equipment.* (The right balance between adequate interior volume and exterior dimensions cannot be determined without a better practical experience, particularly for crossing steps and gaps, however the size of small historical AFV is a good starting point for experimentation.)
4. *Power: Vehicles should have sufficient power to navigate through debris and other obstacles that may be present in urban environments.* (If electrical systems are used, power in the form of torque is unlikely to be a limit, however the traction of the tracks on different surfaces when crossing obstacles must be considered.)
5. *Communication equipment: Vehicles should be equipped with communication equipment that allows personnel to stay in contact with each other and with higher headquarters.*
6. *Sensors: Vehicles should be equipped with sensors, such as thermal imaging cameras, that can help personnel to detect threats and improve situational awareness in complex urban environments.*" [41]

These features offer grouping for further specification of the main features (see also Tables 2, 3, and 4).

TABLE 1 Selected vehicles with relevant technical features (available data taken from above mentioned sources; not available information marked as "n.a.").

Feature	Hetzer	CVR-T SCORPION 90	THeMIS	STORM	RIPS AW MS1	WIESEL 2	MTT154 one single track with 3 batteries
Length	6.27 m	4.79 m	2.4 m	5.895 m	4.78 m	4.2 m	2.24 m
Width	2.63 m	2.13 m	2 m	2.875 m	2.18 m	1825 m	0.58 m
Height	2.17 m	2102 m	1.15 m	2.455 m	1.44 m	1.7 m	0.64 m
Weight	15,750 kg	8,732 kg	1,630 kg	8,000 kg	3,175 kg	4,100 kg	290 kg
Payload	n.a.	n.a.	1,200 kg	2,500 kg	907 kg	n.a.	227 kg
Ground Clearance	38 cm	42 cm	40-60 cm	50 cm	96 cm [SIC!]	30 cm	n.a.
Power/pull force	118 kW	140 kW	15 kN	440 kW	441 kW	80 kW	14.2 kN 4.4 kN ¹
Climbing	60%	60%	60%	75%	50%	60%	45%
Transverse gradient	89%	n.a.	30%	n.a.	n.a.	30%	35%
Range ²	130-180 km	756 km	1,5-15 h	8,5-36 h	n.a.	286 km	60-105 km/12 h
Velocity	42 km/h	73 km/h	20 km/h	142 km/h	112 km/h	70 km/h	18 km/h
Armor	Yes	Yes	No	Yes	Yes	Yes	No

¹ Off-road.

² Range: terrain - road.

TABLE 2 Basic required dimensions, mobility, and steering features of the urban operations vehicle.

Maneuverability and size	
Dimensions UOV/basic	
Dimensions offering mobility in limited subterranean profiles (e.g., London Underground tube stock dimensions: 2597 m wide and 2.882 m high [61] at a profile diameter of 3.81 m [62] including even narrower access buildings.	
Width	1.8 m
Length	3.5 m
Height	1.5 m
Ground Clearance	30 cm
Mobility and steering	
<ul style="list-style-type: none"> • Two laterally located drive elements • Hybrid diesel-electric drive • Interchangeable (additional) power units • Combination of high speed and mobility in heavily restricted urban terrain • Low center of gravity • Semi-autonomous driving (primary: driver) • Machine-learning (fully autonomous driving on frequently used and secured routes) • Bidirectional driving (limited profiles without possibility for turning) • Driver assistance system (low/zero visibility) and auto-driver with override function • Accessibility with the EU standard rail gauge of 1.453 mm 	
Climbing ability	60%
Transverse gradient	80%
Velocity	up to 100 km/h
Turning radius	Turn at the stand

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TABLE 3 Urban operations vehicle protection requirements.

Protection (armor)	
<ul style="list-style-type: none"> • Shape stability in case of spillage • CBRN protection 	
Protection Level 1 (NATO AEP-55 STANAG 4569)	
Kinetic energy	7.62 × 51 mm NATO Ball at 30 m with 833 m/s 5.56 × 45 mm NATO Ball at 30 m with 900 m/s 5.56 × 45 mm NATO Ball at 30 m with 937 m/s
Grenade and mine blast	Hand grenades, unexploded artillery fragmenting submunitions, and small anti-personnel explosive devices detonated under the vehicle
Artillery	155 mm at 100 m distance
Personnel sustainability	Up to 12 h
Heat resistance	Up to 150°C

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TABLE 4 Communication, navigation, and sensor requirements.

Communication, navigation, and sensors
<ul style="list-style-type: none"> • Integration in and provision of data for the tcCOP (truly comprehensive Common Operational Picture) [36] from an on-board multisensor unit • Multiple-source-integrated (on-board and remote) navigation and positioning system in both GNSS-enabled and -denied environments integrating systems such as NIKE BLUETRACK [63] and RASPOS [64] • Threat detection and pose estimation as provided by NIKE SUBMOVECON [65] • Drone swarm landing dock • Redundancy of systems • Navigation and sensor systems working in cold and hot smoke conditions • Operations in explosive atmospheres • Multichannel, data-capable, wireless communication (HF, VHF, UWB, 5/6G according to availability) • Embedded within an all-actor positioning system • Positioning within a GNSS-denied environment

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10. Summary and Outlook

Complex urban operations require high standards of training, equipment, and personnel. The development of vehicles for this environment has lagged but offers a high payoff and is aligned with the top priority of the IRON NIKE research and development program, which is to support emergency forces. This article has described how we selected the design problem of a UOV suitable for subterranean operations such as the most challenging requirement and how we developed the concept to paper prototype stage. Our process included science fiction prototyping, a common reference scenario, and comparison with field-proven solutions and has proven effective for our needs.

This process has allowed us to develop a basic concept of an UOV, which has to be further refined, and we will validate the idea with a series of studies.

- Tabletop simulations/analyses.
 - Identification of a set of urban scenarios which challenge a combat team-sized entity in a variety of different urban environments.
 - Baseline gaming—each scenario is gamed through with a conventional/contemporary force versus a red team.
 - UOV Initial gaming—each scenario is gamed through with UOV versus the red team. Vignettes offering insight are captured/boxed for further analysis.
 - UOV adaption gaming—the UOV design/specification is modified in the light of gaming insights and relevant scenarios are played again.

- Virtual modeling—the physical characteristics of the refined platform (or platform variations) are modeled in CAD or similar.
- Virtual simulation analysis—a physical environment to correspond with selected vignettes is created and virtual simulation conducted to refine the prototype.

The scope to integrate in the IRON NIKE research and development program offers ongoing synergies as it is pursuing full operational capability for urban operations [15]. The fruitful environment provided by coordination and collaboration between diverse research and development teams working in a supportive military setting was demonstrated within the IRON NIKE Research Activities [66] and the Urban Operations Expert Talks [67]. The development of the UOV will be embedded into this program and benefit from the synergies that flow from cross-project collaboration and coordination.

Acknowledgement

Several projects of the IRON NIKE Research Activity are funded by the Austrian Ministry of Defence and the Austrian Research Promotion Agency within KIRAS and FORTE funding tenders. NIKE UOV is currently developed as a collaboration project in a community of interest.

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Abbreviations

AOO - Area of Operation
COTS - Commercial Off-the-Shelf
EPM - Electric Power Modules
FTB - Flatbed Transport Platform
HOLPRO - HOLogram-assisted PROtection
HQ - HeadQuarters
LOC - Line of Communication
MATE - human mAchine navigation TEaming
NIKE - Nachhaltige Interdisziplinarität bei Komplexen Einsätzen (sustainable interdisciplinarity in complex operations)
PEC - Personnel Evacuation Container
PSC - Power Station Container

RADIV - RAPid Data Integration and Visualization
S³OMT - triple-S Operations Mission Tool
SFP - Subsurface Fire Platforms
SSOC - SubSurface Operations Cell
tcCOP - truly comprehensive Common Operational Picture
TOC - Tactical Operations Center
TTC - Troop Transport Container
TTP - Tactics, Techniques, and Procedures
UAV - Unmanned Aerial Vehicle
UGV - Unmanned Ground Vehicle
UOSC - Urban Operations Support Cell
UOV - Urban Operations Vehicle
VMC - Ventilation Module Container
X-DOCK - eXchange DOCK

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