2023 NDIA MICHIGAN CHAPTER
GROUND VEHICLE SYSTEMS ENGINEERING
AND TECHNOLOGY SYMPOSIUM
MODELING SIMULATION AND SOFTWARE TECHNICAL SESSION
AUGUST 15-17, 2023 - NOVI, MICHIGAN

A PERSPECTIVE ON GVSC CREWSTATION DEVELOPMENT AND ADDRESSING FUTURE GROUND COMBAT VEHICLE NEEDS

Terrance M. Tierney

U.S. Army DEVCOM GVSC, Warren, MI

ABSTRACT

The U.S. Army Combat Capabilities Development Command (DEVCOM) Ground Vehicle Systems Center (GVSC) has been developing next generation crew stations over the last several decades. In this paper, the problem space that impacts design development and decisions is discussed. This is followed by a historical overview of crewstation development activities that have evolved over the last 30 years, as well as key lessons learned that must be considered for successful ground vehicle Soldier-vehicle interactions. Lastly, the direction and critical technological focus areas are identified to exploit advancements and meet future combat vehicle system needs.

Citation: T. Tierney, "A Perspective on GVSC Crewstation Development and Addressing Future Ground Combat Vehicle Needs," In *Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium* (GVSETS), NDIA, Novi, MI, Aug. 15-17, 2023.

1. INTRODUCTION

The interaction of Soldiers with advanced combat vehicle systems grows more complex with: 1) Advancements and adaptation to emerging technology; 2) Increased sharing and proliferation of data and information; 3) Changing tactics and requirements of where and how these systems are to be used to gain battlefield dominance; 4) The goal to standardize software and hardware components to reduce costs/maintainability and enable more rapid integration into existing and emerging vehicle systems; 5) The unique shock and vibration experienced by ground combat systems; 6) Weight of the vehicle must be considered for transportability, which drives the vehicle size, that in turn impacts the crewstation volume, or the space Soldiers occupy to operate the platform; 7) Survivability and safety of the crew is also essential, so it is desirable to bring the crew under armor instead of head out of hatch.

The potential for a smaller crew size to accommodate reduced vehicle weight is a difficult challenge in itself; a reduced vehicle crew must achieve the same level of performance as its predecessor larger crew, which implies existing tasks must be allocated across team members to successfully accomplish the mission. Now add that these tasks must be performed under armor, which requires vision systems be utilized that take 360 degrees of sensor input and present the visuals on a two-dimensional display within a reduced crewstation volume…we begin to appreciate some of the difficulties that drive successful Soldier interactions with proposed vehicle systems. Reduced volume, under-hatch operations are only one consideration. When we contemplate the additional complexities identified above, the challenge becomes significant. Let's look at each identified challenge and its impact.

New technologies bring great opportunity to increase Soldier-system performance, but they also bring complications. First this new system or service must be properly integrated into a crewstation to maximize useability and increase task efficiency. Secondly, a Soldier must learn how to properly use a new system or service, as well as trust that the technology provides the desired level of capability. An example here would be a new target recognition system that provides the user with a list of battlespace objects that it detects and recognizes. If an object is not what is expected (i.e., a false positive), the Soldier must manually validate this object and then correct, which reduces trust in this new technology as well as creating more work for this crewman.

Secondly, there are enormous volumes of data available to be used for decision making. Sources include network communications, sensor data, systems data, and verbal interactions with team members to name a few. Greater information is critical to making better and faster decisions, but only if the data is useful and relevant to the decision maker. With advancements in computing, machine learning and artificial intelligence, there are promising tools that can be applied to sort, prioritize, and automate data delivery, but again the user must trust these tools to provide the information in a timely, accurate and helpful manner.

Thirdly, changing tactics and requirements of where and how these systems are to be used also drive Soldier-system design. An example is maneuverability in small villages or towns. Bridges have weight limits and street widths are narrower, so the vehicle must be smaller to successfully operate and maneuvering in various formations is difficult. Also, there is the potential for top attack from multi-storied buildings as well as improvised explosive devices and distinguishing enemy combatants from the civilian population. Contrast this with open and rolling terrain. Also, the future Multi Domain Operations focus will have a significant impact on distribution of forces and concepts for organization. Traditional Army operational concepts must change to address this, which will impact individual combat vehicle designs.

Fourthly, vehicle modernization will impact Soldier-system design. To aid in reducing cost, shorten upgrade timelines, simplify maintenance, increase modularity and interoperability, and standardize data definitions and interfaces, vehicles of tomorrow with utilize a common infrastructure architecture [1]. This modernization is very helpful in the long run but will require time for both hardware and software suppliers to comply, which currently limits available design options.

Lastly, ground combat vehicles experience unique environmental factors due to traversing severe off-road terrain, weather conditions, and exposure to biohazards to name just a few. Also, vehicle induced aspects such as shock from weapon firing, and vibration from engine and track operations impact how Soldiers must interact with crewstation systems and influence design considerations to optimize Soldier-system performance. Many of the complexities outlined above have been addressed by GVSC in past activities that will be outlined in the next section. Many more must still be developed to take advantage of technological advances and meet emerging vehicle requirements…they will be discussed later in this paper.

2. PAST CREWSTATION ACTIVITIES

In this section, a brief look at many of the science and technology programs that have shaped GVSC crewstation design over the past 30 years will be highlighted.

2.1. Crewman's Associate (CA), 1994

GVSC was charged with developing multiple crew stations to explore crew strength for baseline, near future and far future tank concepts. To address this challenge, three designs were explored:

1. Baseline Abrams M1A2 (1994, 4-man crew)
2. M1A2 System Enhance Program (1998, 3-man crew)
3. Future Main Battle Tank (2005, 2-man crew)

All designs were implemented in a simulated environment and informed by the Rotocraft Pilot's Associate [2] Advanced Technology Demonstration program; workload comparisons were conducted comparing the three variants. The hypothesis of this virtual experiment was that a ground combat vehicle with an integrated crew station and Force XXI Battle Command will decrease crew workload and increase crew performance. An example of crewstation design is shown in Figure 1.

Figure 1: Crewman's Associate project.

The crewstation was composed of flat panel displays providing indirect vision to the operator, and programmable bezel buttons were utilized to interact with multi-functional displays (touchscreens were not utilized) to provide mission function. Additionally, menus on the multi-functional displays could be accessed via a bump cursor on the yoke. The design principles for crew design were as follows [3]:

- Hands on primary controller
- All critical information in primary vision zone
- One step functions
- Consistent Mental Model
- Intelligent placement of cursor (bump cursor)
- Minimize "drag and click" (difficult on the move)
- Automated data entry (reduced use of keyboard)

This implementation served as the foundation for many of the future crewstation projects, with many of the lessons learned still being incorporated in today's designs.

2.2. Vetronics Technology Testbed (VTT), 2001

The VTT project enhanced our previous laboratory crewstation designs and integrated it into a prototype combat vehicle (Bradley platform with turret removed) as seen in Figure 2. The primary focus of this effort was indirect vision driving (cameras providing visuals to flat panel displays) with the crewstation located under armor for greater Soldier survivability. This implementation of a scout mission utilized two identical crew stations with dedicated visual driving displays, as well as 3 multifunctional displays that included tactile feedback programmable bezel buttons. On-board simulation was utilized for weapon and sensor functions, while driving was performed using drive-by-wire and near-unity vision (essentially providing out of the vehicle view from existing eyepoint, to reduce motion sickness) [4] with ideally placed sensors on the vehicle for ~135-degree field of view unity vision driving, maximize maneuverability and optimizing situational awareness.

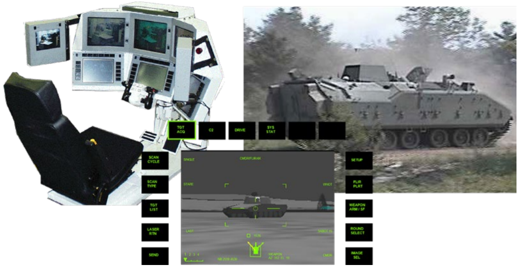

Figure 2: VTT project.

Other technologies were also integrated to include speech recognition, 3D Audio, graphic overlays, and a bump cursor for redundancy of touchscreens (permitted fixed hand position during operations). Experimentation was conducted at Camp Grayling, Michigan, supported by the DEVCOM Army Research Laboratory (ARL) and the Mounted Maneuver Battle Lab, and was composed of the following segments:

- Slow & close maneuver
- Vehicle following
- Cross country driving
- Road obstacle negotiation
- 2-man workload assessment conducting scout maneuvers

Much was learned during this excursion that validated previous crewstation designs and drove future design implementations. Through on-the-move operations we gained a better understanding of hand anchoring for display engagement, vibration impacts on equipment, the effect of high noise environment on speech recognition and improving indirect vision driving.

2.3. Crew integration & Automation Testbed (CAT), 2004

The Crew integration and Automation Testbed as shown in figure 3, was the manned element (Stryker platform with no turret) of the Vetronics Technology Integration (VTI) program. VTI also included the Robotic Follower project, which was an unmanned semi-autonomous prototype vehicle (also a Stryker with remote turret), that performed mobility and lethality functions. The robotic operator was stationed within the CAT testbed vehicle, and the two platforms moved in formation.

Figure 3: CAT project.

CAT utilized much of the functionality from VTT but required the additional robotic control mission. The platform changed from a larger tracked Bradley to a narrower wheeled Stryker, and as a result, interior volume was reduced. The crewstation was redesigned with these constraints, as well as taking advantage of advanced touchscreen display technology, where displays changed from 12.1” landscape to 20” portrait. Touchscreen capability permitted removal of bezel buttons and narrower bezel widths, which allowed for reduced distances between display area.

Again, identical multi-functional crew stations were utilized that accommodated fight, scout, carrier and robotic control missions of unmanned air vehicles, ground vehicles (large and small), and unattended ground sensors. The CAT prototype also had semi-autonomous driving capability that utilized waypoint following from a mission planning screen. Controlled handoff of functionality could be performed between crew members. Embedded simulation was also implemented for lethality and C2 functions for mission execution. Speech recognition was again explored in this effort, as well as use of a Helmet Mounted Display (HMD) with overlay content for head out of hatch commander awareness. Project experimentation was conducted at Fort Knox, KY in coordination with ARL and the Unit of Action Maneuver Battle Lab (UAMBL).

Results from this experimentation has provided advancements in Warfighter Machine Interface design [5] as well as initial development of unmanned systems planning and control concepts.

2.4. Robotics Collaboration (RC), 2008

Robotics Collaboration Army Technology Objective (ATO) (see figure 4 below) began as the Human Robotic Interaction Science and Technology Objective (STO) and changed over the course of its execution to be merged with an unmanned air activity called the Unmanned Autonomous Collaborative Operations STO.

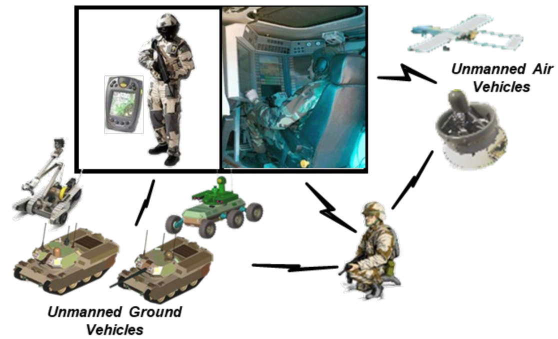

Figure 4: RC project.

This project had multiple objectives: 1) provide intuitive, consistent interactions through common Warfighter Machine Interface functionality scaling from small, dismounted controllers to crewstation-level implementations, with a focus on interoperability, extensibility, and portability; 2) Modeling and simulation to predict and validate soldier-robot control workload levels and associated training burden; 3) Development of intelligent agent software to adaptively automate and/or minimize soldier control tasks.

There were many significant discoveries realized in this project. 1) A greater understanding of tele-operational control of unmanned systems was gained through rigorous field experimentation [6]. 2) Multiple intelligent agents/aids were developed and employment that provided: a) Greater Soldier understanding of autonomous systems actions and behaviors, such as mobility cost maps (maps showing locations where the unmanned system deemed most fit for traversing) and Laser Detection and Ranging (LADAR) path projections showing potential paths the unmanned systems proposed to traverse; b) Driving aids like steerable waypoint, figure 5, which permitted greater control of the unmanned asset (provided operator the ability to control the vehicle’s mobility by manipulating an interim waypoint) without manually overriding the system;

Figure 5: Steerable Waypoint Driving Aid.

c) Behavior levels of unmanned systems could be altered based on desire for more aggressive mobility, such as pushing the vehicle to traverse a grass field that the operator knows to be safe but the unmanned system perceives as obstacle-laden. 3) Rearchitecting the software allowed for implementation on multiple operating systems, rapid and seamless discovery and integration of services, and the ability to change the look and feel of the Warfighter Machine Interface (WMI) presentation. 4) Dismounted control effectiveness was explored utilizing multiple modes of communication to include tactor belt and radio, to assess varying methods to increase the performance level between Soldier and small unmanned vehicles [7].

2.5. Improved Mobility and Operational Performance though Autonomous Technologies (IMOPAT), 2014

The IMOPAT project primarily explored improved indirect vision driving and providing 360 by 90-degree local situational awareness, see figure 6. GVSC partnered with DEVCOM Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance and Reconnaissance (C5ISR) Center's Night Vision and Electronics Sensors Directorate (NVESD) and ARL to provide a secure mobility capability through maturation of visual sensor suites, human integration, and assisted mobility technologies.

Figure 6: IMOPAT project.

The visual sensor suite was composed of motion-based threat cueing and image capture, slew to cue from 360-degree vision system to high resolution imager, target handoff via a virtual pointer, a commander's gimbal with non-lethal suppression and improved driving and threat detection via a distributed aperture vision capability utilizing high-definition color and Short-Wave Infrared (SWIR) Imaging cameras on a gigabit ethernet architecture to support fast data transfer. Lastly, the suite also employed a digital video recording function that allowed for near real-time evaluation of visual data.

The overall indirect vision and local situational awareness capability [8] developed under IMOPAT served as the baseline for the follow-on ground Degraded Visual Environments (gDVE) project below.

2.6. Ground Degraded Visual Environments (gDVE), 2018

The goal of the goal of the ground Degraded Visual Environments program (see figure 7) is to increase situational awareness (SA) for ground vehicle systems in degraded visual environments including day, night, dust, or smoke, using scalable sensors and augmented visual enhanced with computer graphics and fused navigational data.

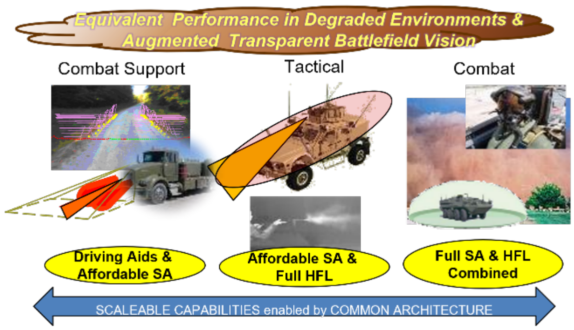

Figure 7: gDVE project.

Seeing through obscurants was a high priority for the rotorcraft community, especially when landing. In the ground domain, the question was how could these costly high resolution infrared sensors be employed for local situational awareness on ground vehicles? The sensors would need to be scaled for uncooled operations and have a significantly lower cost. Additionally, the ground environment had other significant challenges to overcome, such as dynamic obstacle detection/avoidance, shock and vibration, different crewstation configurations.

The metrics established for this project had to meet or exceed current baseline capability. The measures are as follows:

1. 70% probability of NATO man size target detection
2. Increased operational tempo for degraded driving (>16 KPH in dust)
3. Reduce total visual latency from sensor to glass (< 120ms)
4. Convoy safety in degraded visual environment (blackout drive markers - distant reduction)

To achieve these goals, gDVE utilized the following technical approach: 1) High resolution uncooled infrared sensors developed at the C5ISR Center's NVESD; 2) Common sensor processing to include DVE image processing, collision warning and road following cueing; 3) Low cost RADAR for forward looking, collision warning and road following cueing; 4) Standardized interfaces that provided system scalability, common interfaces, multiple displays, ability to adopt emerging sensors; 5) Driving aids such as optic flow enhancer, lane departure warning system, friendly force position, go/no go overlays, obstacle detection/collision avoidance and image enhancement processing of sensor input, see figure 8.

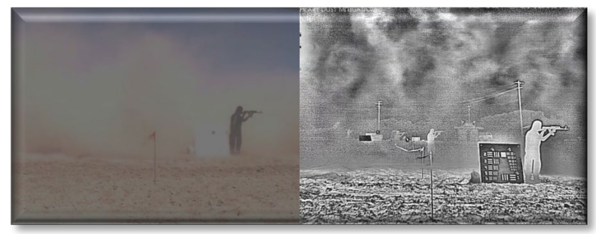
Figure 8: Sensor Image Enhancement.

This project utilized the strengths of GVSC and our NVESD and ARL partners to meet/exceeded all metric objectives and had great interest from Program Manager customers. Many of the lessons learned here have been carried on into future design efforts.

2.7. Crew Optimization and Augmentation Technologies (COAT), 2018 - current

The COAT (see figure 9) project looks to overcome barriers and address the question of how do mounted combat vehicle Soldiers still successfully conduct their mission while: 1) Incorporating the ever-expanding volume of battlespace information; 2) Dealing with the complexity of advanced technologies (to include integration and interactions); 3) Adjusting for the demand for reduced crew sizes to support transportability, mobility and other operational challenges; 4) Interacting with team members as well as section and platoon members (to include unmanned ground and air systems) to address MDO operations?

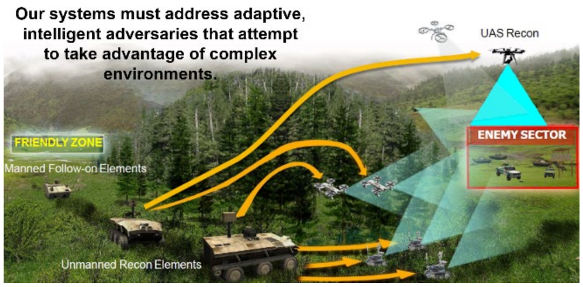

Figure 9: COAT project.

GVSC and ARL are teaming with the DEVCOM Soldier Center (SC) to optimize Soldier team operations in manned systems though: 1) the use of intelligent agents that transform the vehicle system into an additional crew member; 2) Employing dynamic tasking/re-tasking, task autonomies and learning to properly distribute the collective workload across crew members; 3) Exploring other novel concepts such as HMD's, embedded training, after-action reports, and advanced planning tools that support a reduced crew size and interactions with unmanned systems.

To date, COAT has evaluated indirect vision driving compared to a HMD version utilizing stereo vision cameras. HMD's show great promise, but still much work needs to be done in the areas of motion effects, interactions with visuals and optimizing resolution and form factor of the device.

Other key products that have been developed by the COAT project to date are:

- Transparent Route Planner
- Commander's interface
- Embedded Training
- Project Vitreous

The Transparent Route Planner [9] provides humans with the ability to understand intelligent agent actions, intentions, goals, and general reasoning. This capability provides transparent interaction between humans and agents; the baseline capability addressed off-road teleoperations and permitted a rapid ability to change vehicle formations, see figure 10.

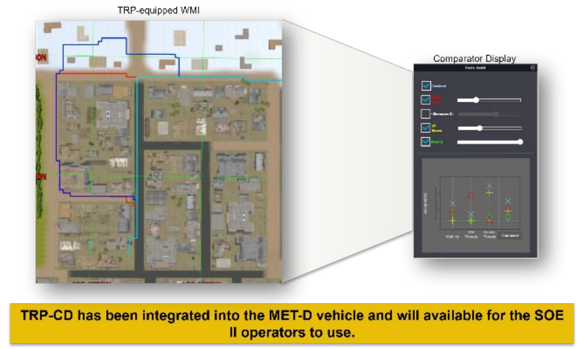

Figure 10: Transparent Route Planner.

The Commander's Interface provides information about vehicle state, crew state and play-calling capability, providing the commander with command-and-control capabilities through tools to coordinate execution of team responses to evolving situational needs, see figure 11.

Figure 11: Commander's Interface.

The embedded training capability, developed by Soldier Center, enables individual-to-platoon training both inside a ground combat platform and on mobile, tabletop, or testbed environments. It provides the capability to adapt to the on-demand training requirements of the Warfighter Machine Interface (WMI) product line, crew tasks, and fully lifecycle training, see figure 12.

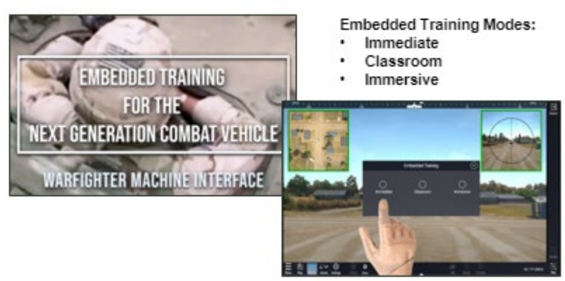

Figure 12: Embedded Training.

Project Vitreous, a joint project under COAT between ARL and GVSC, is a next generation HMD interface concept that provides the potential to significantly enhance situational awareness, improve driving, gunner and commander functionality and revolutionize crewstation interactions, see figure 13.

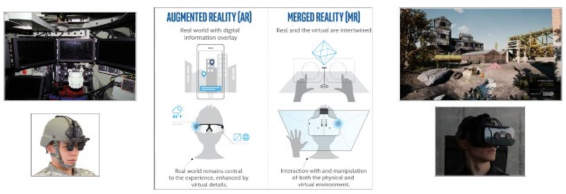

Figure 13: Project Vitreous.

Project Vitreous utilizes a greater than HD resolution HMD, head tracking, and high-resolution stereo sensors or simulated input to provide a full view of the outside environment while maintaining a partial view of interior controls. It also presents crew, vehicle, and mission information without impairing awareness of the outside environment.

The COAT project is on-going and has recently restructured to provide additional focus on manned combat platform issues such as reduced crew size and optimized crew interfaces.

3. FUTURE DIRECTION AND NEEDS

As future combat vehicle demands evolve and change science and technology focus and priorities, crewstation development will continue to pivot to provide greater Soldier-system performance enhancements. A few of the current demands influencing direction are as follows: 1) Reduced crew size; 2) Focus on greater lethality capability; 3) Commonality across platforms, to include hardware, software, and architecture; 4) Greater use of artificial intelligence (AI), machine learning (ML) and autonomy; 5) Multi-Domain Operations.

To operate proficiently in a reduced crew environment, fewer Soldiers must be able to perform the existing mission at the same performance level. This implies that each must accomplish more to still be effective. This is not necessarily true; with the application of advanced technologies, algorithms, more efficient task execution, and changes to the existing paradigms for how the mission is achieved (ex. split squad, task organizing operations), equivalent levels of performance may be achieved with a reduced crew.

Examples of advanced technologies that can provide extended capability outside of direct crew-system interactions include intelligent target recognition systems that recognize, identify, and pair and then load the correct munition for the right target. Advancements are being made in this arena, but these systems still require Soldier validation prior to executing the target. Driving autonomy is another area that can make a big impact on Soldier workload, potentially freeing them to perform other critical vehicle functions. Great strides have been and are being made in this area as well, but these systems still make mistakes in highly structured environments; continued development is necessary to gain the necessary trust and performance level for off-road unstructured and unconnected environments.

Crew-related technologies that offer a great deal of promise are:

- Soldier monitoring to include eye tracking, biometrics – greater understanding of user state to bring more tightly into decision loop
- Modalities such as tactile/haptic (think rumble strips, force-feedback on input devices), 3D audio and speech recognition
- Individualization – customization of environment to individual

Soldier (think preferences, handedness
- Augmented reality, virtual reality (greater informational content on visuals)
- Dynamic task allocation
- Task agents (like Jarvis in Ironman movies that serve as extra crew person), AI, and ML
- Advanced training aids like embedded training and AAR's
- Use of apriori data to provide baseline object locations to augment real-time systems data
- Helmet Mounted Displays and other visual methods for transmitting images to the user

At GVSC, a dedicated Crewstation Laboratory, as shown in figure 14, has been constructed to explore and rapidly evaluate emerging technologies in a virtual simulation environment.

Figure 14: Crewstation Laboratory at GVSC.

This laboratory will also provide and environment for customer program support and is tied to other experimentation facilities such as 6 degree of freedom motion-based simulation and multi-player virtual experimentation laboratories.

Commonality of architecture, hardware and software across platforms will provide efficiencies, increase the rate of transition, and reduce costs for customers as well as have a great impact on WMI development. Shared repositories of reusable, validated code will be available to developers, reducing the time to speed innovation.

In addition to in-house development, GVSC looks to our academic, industrial and Government partners for solutions and collaboration, so we can provide the best product to our Warfighters.

4. CONCLUSION

Advancements in technology will continue to enable greater battlefield capability, but the crewstation community must work with vehicle developers to ensure the Soldier is included as part of the integrated solution. Joining applicable technologies with timely and relevant information as well as greater understanding of Soldier and environmental state will serve to increase speed of decision and provide Warfighters with an overmatch capability for future conflicts. GVSC is ready to leverage years of design and development and work with our partners to create the crew stations of tomorrow that our Soldiers and our Nation demand.

5. REFERENCES

[1]MOSA Objective Architecture Working Group, "GCS Common Infrastructure Architecture (GCIA) v2.0," 25 February 2022.

[2]Miller, C., & Hannen, M., "The Rotocraft Pilot's Associate: Design and Evaluation of an Intelligent User Interface for Cockpit Information Manager," Knowledge Based Systems, 12, 443-456, 1999.

[3]Micro Analysis & Design, Inc, "Advanced Abrams (AA) Technology Crew Station Evaluation Report," Contract # DAAE07-95-C-R045, 30 April 1997.

[4] Smyth, C., (2001) "Mental Workload and Task Performance for Indirect Vision Driving with Fixed Flat Panel Displays", Driving Assessment Conference 1(2001), 1-6.

[5]Franks, E., "Advanced Warfighter Machine Interface," Proc. SPIE 5801, Cockpit and Future Displays for Defense Security, 25 May 2005.

[6]Metcalfe, J., Alban, J., Cosenzo, K., Johnson, T., Capstick, E., "Field Testing of Tele-operation Versus Shared and Traded Control for Military Assets: An Evaluation Involving Real-time Embedded Simulation and Soldier Assessment," Proc. SPIE 7692, May 2010.

[7]Hutchins, S., Cosenzo, K., Barnes, M., Feng, T., Pillalamarri, K., "Soldier-Robot Teaming: Effects of Multimodal Collaboration on Team Communication for Robot Reconnaissance," ARL-TR-5385, October 2010.

[8]Mateuffel, C., Metcalfe, J., Johnson, T., Jaswa, M., Nham, X., Brumm, B., "A methodology for the assessment of 360° Local Area Awareness Displays," Proc. SPIE 8042, SPIE Defense, Security, and Sensing, 2011.

[9]Perelman, B., Lakhmani, S., Wright, J., "Human-Autonomy Teaming Essential Research Project 2: Transparent Multimodal Crew Interface Designs. Technical Note 1: General Overview," ARL-TN-1003, January 2020.