2010 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
ROBOTICS MINI-SYMPOSIUM
AUGUST 17-19, 2010 DEARBORN, MICHIGAN

ROBOTIC WINGMAN

Jerry Lane
Landforce Systems Operation
Science Applications
International Corp.
Sterling Heights , MI

Frank Antenori
DARPA Programs
Raytheon Corp.
Tucson, AZ

Andrew Dallas
Business Development
Soar Technology, Inc.
Ann Arbor, MI

ABSTRACT

Robotic Wingman (RW) is an advanced unmanned systems concept integrated with current operational tactics to enhance the force effectiveness of combat vehicle platoon and substantially enhance the survivability of manned vehicles in combat operations. Two approaches to RW; reconfiguring common fleet and new/unique platoon vehicles. Each approach has its advantages in wingman operations. This paper will discuss the approaches, the required technologies and program implementations. RW combat effectiveness and advances in force survivability will be assessed and discussed in both approaches.

Advanced technology including sensors, autonomy, communications and automated behaviors will enable the RW to look, move, and act like companion manned vehicle. For its optimum effectiveness, the RW wants to cause the enemy to engage it first. The automation of the manned fleet to implement and achieve unmanned system performance similar to manned operations and is required to fool the enemy to not let it pass without intervention/engagement. New hardware and software technologies are required to create the normal, manned-like operations of the RW system and its supporting unit. Inherent advantages of unmanned systems will enable RW configurations to survive multiple hits, perform degraded operations and effectively execute decoy tasks. For effective RW operation, including automation of fire control, target acquisition, armament (including autoloaders), and advanced mobility sensors are needed to perform with man-like agility and mission performance.

To be useful, the RW cannot add significant workload to its command tank, otherwise platoon effectiveness will be negatively impacted. The RW must exhibit tactical behaviors such as formation control and automated unit behaviors if its command vehicle is hit. The RW must operate on high level commands and integrate advanced robotic controls to see, understand and autonomously negotiate mobility hazards, pedestrians, and vegetation.

Supervised Autonomy is a critical technological component that alleviates operator workload. We will discuss progress made in the areas of Universal Autonomous Controllers (UAC) and autonomous behavior development in support of Supervised Autonomy. The focus of recent research will be discussed including developments and design of a technical approach for translating mission level objectives into a representation that can be communicated to the platform for use in its decision cycle.

The paper will also address advanced technologies needed too make RW a battlefield capability including SAIC's advanced robotic controls and command & control capabilities with collaborative unmanned systems behaviors; Raytheon with its advanced sensor suites, target acquisition and fire control technology; and SoarTech with advanced autonomous behaviors, team formation and supervisory control knowledge.

INTRODUCTION

The current conflict has seen the enemy exploit our capability gaps and technological advantage by using unconventional and asymmetric warfare tactics. These include the extensive use of improvised explosive devises and small arms ambushes. Most of these occur in locations that present a very limited route selection for U.S. troops, forcing them to drive or patrol into very high risk areas such as dense urban area or complex mountainous terrain. The enemy then selects a point within that area that will provide them with a tactical advantage over U.S. Forces.

In Afghanistan, box canyons and primitive roads that follow river beds are very common. This results in vehicles having to navigate roads with steep terrain on both sides, preventing the vehicle from going off road to avoid IEDs or ambushes. In Iraq, the dense urban environments such as those seen in Baghdad, Fallujah and Ramadi, coupled with the presence of a large number of non-combatants in close proximity resulted in limited route selection and provided a predictability for the enemy to plan and emplace ambushes.

The U.S. Forces are well aware of such locations and have developed a “sixth sense” to predict likely ambush locations. In such cases, the use of an unmanned vehicle to conduct reconnaissance and detect IEDs is needed. Robotic Wingman can act as the route reconnaissance, decoy, and explosive ordinance clearance vehicle in such situations, dramatically reducing exposure of humans to many potential explosive and projectile threats. However, to do so, an unmanned vehicle must be similar in appearance to those manned vehicles contained within the unit. A vehicle with visibly empty crew seats, burdened with visible antennas and sensors on the vehicle’s exterior, unarmed or unarmored or might make irregular or atypical movements (hits objects, leaves the road, etc.) that an otherwise manned vehicle would not make would tip off the enemy and result in them allowing the unmanned vehicle to pass without engaging the ambush.

In the case of route reconnaissance, the unit commander would designate a remote vehicle operator to direct the Robotic Wingman to drive a certain route in advance of the main unit. As the vehicle drives the route, small, discrete cameras and sensors would collect data and images for the unit commander, allowing him to make a more accurate assessment of conditions and enemy situation along the route. The vehicle can also be used as a “point vehicle” to drive several hundred meters in front of the main element to draw enemy fire or seek the premature detonation of IEDs that are pressure, pressure release, trip wire, or remotely detonated. With regard to those IEDs that are remotely detonated, the vehicle must present the appearance of being manned, to include the presence of mannequins (animatronics) in the crew positions. If the vehicle detects a potential enemy position, it must also be equipped with a remote weapons station capable of being operated from a significant distance and from another vehicle.

Effective integration into the current force units will be a critical step to Robotic Wingman. A current armor platoon formation is shown below in Figure 1.

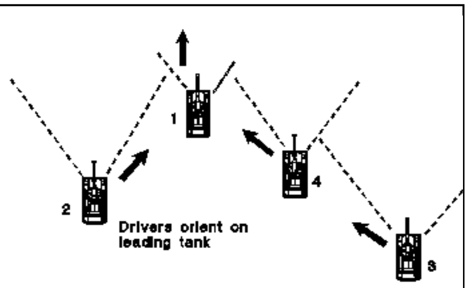

Figure 1 Current armor platoon formation with the Platoon Leader and Platoon Sergeant leading the unit

With two Robotic Wingman tanks in the platoon, both the platoon leader and platoon sergeant can remain rearward in a movement to contact mission first exposing the robotic wingman tanks as shown in figure 2.

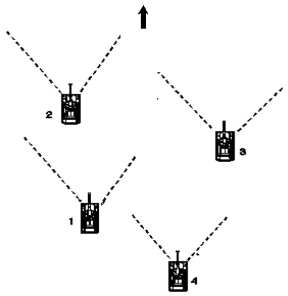

Figure 2 Two Robotic Wingman leading Platoon Leader & Platoon Sergeant Tanks

Robotics Capabilities of Robotic Wingman

Robotic Wingman will evolve as tactics and technology are integrated into the concept. Increasing levels of autonomy for mobility, fire-control, weapons, planning, C2 and other operational tasks will progress and be refined to support the Robotic Wingman needs.

Robotic Wingman should be platform independent but will be driven by automated features in current and future combat vehicles.

A Threshold Capability: robotic wingman can always lead tank sections exposing first the unmanned system to enemy fires. Platoon leaders vision will be forward through the RW. The platoon leader/sergeant will remain rearward of the formation.

Threshold capability of RW will be mostly automated with no more than 33% teleoperation from the leader tank. Autoloader and aided target trackers are required for this level of semi-autonomous operation. Coordinated route planners for RW and leader tanks will automate some movement functions.

An Objective Capability: RW control will be automated with high level commands from the leader tank. The leader's tank movement will be automated to move in coordination with RW based on leader's intent, mission and threat & friendly positions. Aided trackers will grow in capability to significantly enhance target recognition capability. Route planners will evolve to full mission planners with tactical movement embedded including anticipating enemy movements and reactions.

General Control Architecture for an Unmanned Autonomous Platform

Knowledge-rich intelligent agents capture the high level behaviors that would be used for command and control of Robotic Wingman. Though knowledge-rich intelligent agents have been successfully developed and deployed in simulation, there are significant challenges when transitioning to hardware platforms. Specifically, the following issues must be addressed when integrating robot behaviors into the robot architecture:

- Behaviors developed for real robots must handle the degree of uncertainty typically absent in simulated environments
- Reasoning in an unstructured, terrestrial environment requires a tight integration between the knowledge-based behavior model and the robotic architecture
- Transducing perceptual data to symbolic structures suitable for reasoning requires bottom-up (e.g., image processing) and top-down (e.g., contextualized reasoning) processes to achieve satisfactory performance

Incorporating autonomous behavior into the robot control stack is a key enabler towards the realization of tactical units of autonomous robots. Figure is a revised control stack supporting autonomous behavior. The blue boxes represent additions to the control stack that are required to support autonomy. Behavior consists of two elements: (1) an Intelligent Robotic Behavior Architecture that is a set of mechanisms and structures used by the robot to generate behavior, and (2) information[1] that will be used by the architecture to assist the robot in generating behavior [Laird, et al 2006]. These two elements are important while developing the autonomy required of tactical robotic units.

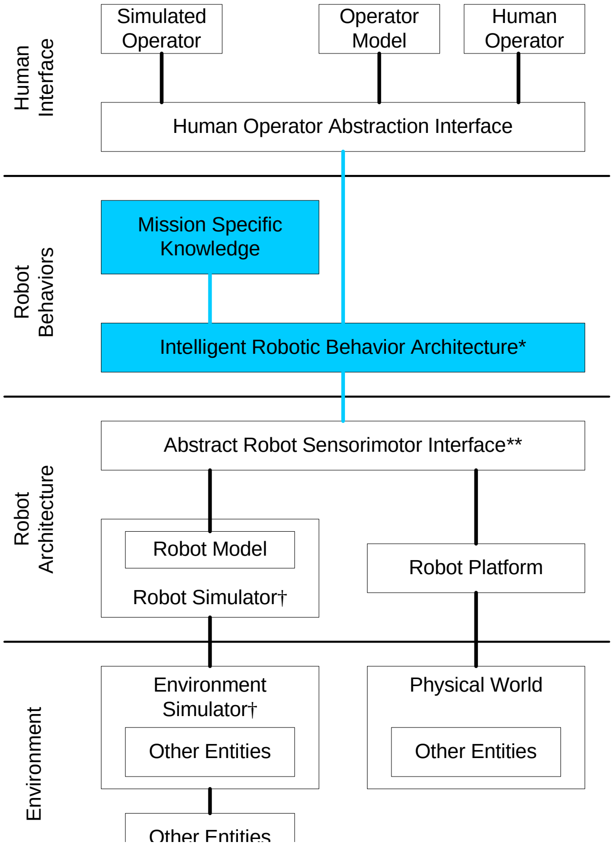

Figure 3: A revised control stack supporting autonomous robots.

Notice that behavior architecture now appears in two levels of the control stack. In general, a behavior architecture is defined as a set of fixed mechanisms and processes, to which information is added to generate behavior. In the case of the

---

[1] The informational content required to support a tactical behavior includes information on sensor and robotic platform capabilities, mission-specific knowledge, and knowledge about behaviors and the environment..

Robot Architecture level, the physical robot and its low-level control software form the architecture, and the information that is added is external control signals that drive behavior.

The Robot Behaviors level contains an Intelligent Robotic Behavior Architecture. This architecture provides the fixed mechanisms and processes that are designed to *generate the suggested actions* for the Robot Architecture to execute, given the higher level context associated with the mission specific knowledge, the information about the state of the world (situational understanding) at that particular time, and the Human Interface level. A more complex version of this architecture may provide flexible support for arbitrary information about context-driven autonomous behavior specification. What makes this architecture superior to a general-purpose programming language (like Java) is that it provides meaningful constraints that guide the development of behaviors, and is designed to provide precisely the kind of flexibility necessary to produce real-time, autonomous behavior in terrestrial environments.

Soar is a prime candidate for such behavior architecture. Soar is a cognitive architecture inspired by human cognition and is designed to support general reasoning. Soar has been used for over a decade to develop various tactical behaviors in simulation, and continues to mature and stay on the cutting edge of behavior generation (Laird, 2008). Using Soar, we have developed a range of autonomous entities that model human behavior, including simulated fixed-wing platforms (Jones et al. 2004), rotary-wing platforms (Jones et al. 2004), an automated fire direction center (Stensrud et al. 2006), and automated air traffic control (Taylor et al. 2007). Several of these models, including the fixed-wing and rotary-wing platforms include "wingman" behaviors.

Weapons and Fire Control

The Robotic Wingman must operate as a fully functional combat vehicle to include a fully integrated weapons and fire control system. Most combat vehicles are armed with a crew served weapon. To preclude a soldier from manning the weapon from an exposed turret, remote weapons systems have been developed and deployed on many combat vehicles operating in theater. These systems offer an opportunity to integrate additional fire control and sensors, to assist in target acquisition, tracking and engagement, as well as accurate target location for the purpose of providing direction for indirect fires and Close Air Support (CAS).

The system must be gyro stabilized to allow for steady image viewing by the remote operator and a stable firing platform to improve weapon accuracy and extend range. The system also needs a range finder, a GPS based target locator for indirect fire, a laser target designator (LTD) for precision guided munitions, and a Laser Pointer (LP) to assist in the application of fires from AC-130 gunships and Apache helicopters.

The CROWS II system manufactured by Kongsberg Defense Corporation already provides for on-the-move and first burst engagement of targets. This system can be improved by additional sensors to allow for simultaneous, multi-target tracking and engagement to reduce/prevent operator task overload and improve accuracy. It can also be equipped with additional targeting sensors and fire control to add a CAS and indirect fire targeting capability. The CROWS II is mounted primarily on the Stryker vehicle but can also be mounted on other wheeled and tracked vehicles.

Other combat vehicles possess similar systems, such as the IBAS systems on the Bradley Fighting Vehicle, the commander's independent viewer (CIV) on the M1 Abrams, and the LRAS3(FS3) on the Stryker and HMMWV. These systems have different degrees of visual optics acuity for target recognition and other features that may lend themselves to automation and remote operation but they would also need improvements to provide the capability needed for a Robotic Wingman application. All of these sensors and weapons stations would also need to be integrated into a command and control system, such as FBCB2 and AFATDS.

A complete system must provide variable zoom, day and night optics capable of clearly identifying and engaging an armed, man sized target at least twice the effective range of the mounted weapon system/systems. For far target location, the system will need an integrated laser range finder, GPS(SAASM), inclinometer/magnetic compass or inertial navigation unit for precise angle measurements, along with a laser target designator. The optics would have to have an I^2 and IR capability and possibly a fused image to improve target recognition. The image must be exportable via a secure, multi-channel digital optical video transmitter to a remote weapons station both by line of sight and via satellite uplink. To eliminate a potential uplink/downlink time lag, the system will need to be able to autonomously lock and track a target via cursor/track box in real time and engage upon command from a remote operator.

An operational consideration is the ability to detect IEDs and disrupt them either via the turret mounted weapon system or some other type of weapon or detonating device mounted to the front of the vehicle. Another consideration is the use on non-lethal weapons. These include directed energy weapons that may employ electromagnetic radiation, microwave radiation, acoustic and visual dazzlers. It may also include chemical weapons such as malodorants and irritants (pepper spray), non-lethal rubber projectiles, stun grenades (Flash Bang), entanglement systems. These non-lethal weapons will likely need addition integration for their control and use and possibly different targeting systems.

The robotic vehicle itself will need a variety of sensors for the purpose of its operation and navigation. The will require a 360º situational awareness capability so the remote operator can see potential threats, obstacles and optional vehicle routes. There also needs to be a two way acoustic capability whereby the operator can hear such things as weapons fire, voices, and characteristic vehicle noises (Spinning tires, grinding gears, rubbing or scraping an object, etc). The vehicle will also need a PA system to speak to non-combatants or combatants during the course of its operation. Additional sensors will be required in case visual and radio contact with the vehicle is temporarily impaired or lost due to battle damage. These sensors will assist the vehicle in autonomous operation. Some of the sensors may include a Doppler RADAR, flash LADAR, FOBEN or OBSPEN RADAR, road margin sensing, pedestrian protection sensors, and anti-collision sensors.

There are three kinds of processes related to autonomy that must be done simultaneously to allow for supervisory control: task execution, task monitoring, and dialogue management (Wood 2003). Task Execution (TE) is the online process of performing low-level actions in the environment, once a task has been clearly defined and all questions about it answered. Task Monitoring (TM) is a self-reflective process of making sure the task is being executed properly, including noticing when milestones have been met and raising alerts when something goes awry. Dialogue Management (DM) handles a number of communication processes: making sure the tasking is clear before executing, translating the task from human terms into vehicle terms, and communicating status and situational awareness information from the vehicle back to the user. More specifically:

- **Dialogue Management** using encoded knowledge about dialogue protocols required for asking clarifying questions, following up on requests for information, etc.
- **Task Execution from knowledge-based mission decomposition** into atomic actions that can be issued to the robotic platform
- **Task Monitoring to track the progress of the autonomous entity with respect to its goals**, in order to report progress or report when progress has been interrupted in some way

Any unmanned system under supervisory control must have a behavior model from which to execute its task. The behavior model is a representation of the goals and atomic actions that must be performed while executing a specific task. When constructed correctly, it also provides the grounding between the unmanned platform and the soldier. For the Robotic Wingman, with a correct behavior model controlling it, a Commander can communicate with the Wingman using the same concepts and level of detail that is associated with employing a manned vehicle to do the same task.

Numerous types of representations exist to capture such information. One useful representation is a Hierarchical Task Networks (HTN). HTNs provide a representation of a mission plan. The HTN is constructed using domain-specific knowledge that is extracted from Subject Matter Experts (SMEs) and through published literature such as Field Manuals and doctrinal publications about how commanders execute tasks and the high-level goals are pursued while accomplishing these tasks. The information gleaned is decomposed into high-level goals and fine-grained primitive actions that the RW can execute. This results in a behavior model that replicates a human decision making process. In the case of a Robotic Wingman, the behavior model would ensure that the correct tactical decision is used by the robot within the context of the task being performed.

The DM is responsible for constructing the HTN based on its understanding of the command and the established protocols for interacting with the operator. The HTN essentially represents the DM’s understanding of the task based on the dialogue with the operator. An example HTN for robotic control is given in Figure 4. The HTN is a mixed plan, consisting of both mission actions (e.g., move along road) as well as dialogue actions (e.g., report status). The TE is responsible for assigning these actions to system components. For example, the robotic platform is one component that can perform a physical action (e.g., drive to a location), the Task Monitor can watch for system states to change (e.g., UGV reached waypoint), and the DM can report status back to the user (e.g., “Achieved waypoint34”). An instantiated HTN has each leaf node assigned to a system component. A node that cannot be assigned is a trigger for more interaction with the user for clarification. The system can maintain multiple parallel HTNs, depending on the nature of the task or other commands that are issued while existing tasks are underway. Individual threads can also be suspended and reactivated later.

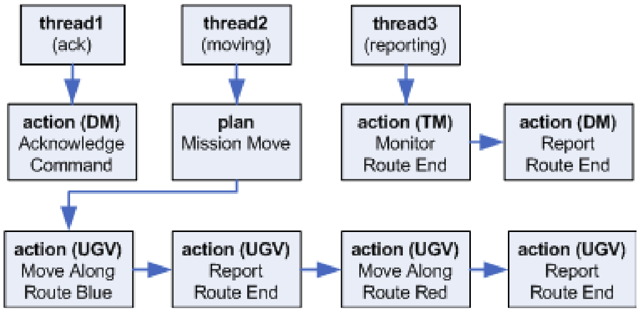

Figure 4: Example parallel Hierarchical Task Network with assigned actions (Vehicle, Dialogue Manager, Task Monitor)

The system can also naturally handle dynamic re-tasking. New tasks must be integrated with the current task, either by replacing, pausing, or interleaving. The new task may be accompanied with instructions from the operator about how to handle it relative to the old one (e.g., “Supplier1, this is TeamLead, pause ingress and wait for backup.”). In the absence of a direct instruction, domain-specific rules may also apply regarding how to treat the two tasks. Where the DM is unclear about how the new task fits with the old, it will ask for clarification. In either case, whether the system followed instructions or applied domain-specific rules, it will report to the user how it will address the new task (“Roger, pausing ingress for backup.”) This gives the operator insight into the plan, and a chance to correct if needed. As such, the Robotic Wingman’s plan can be dynamically modified without interfering with other unrelated aspects of the plan.

A number of insights have enabled us to develop Soldier Robot Interfaces supporting supervised autonomy that is required for the Robotic Wingman to execute similar to a manned vehicle. The first insight is that we can draw a distinction between the underlying navigation task and the user interactions related to that task. The autonomy required for navigation is different than the intelligence required for interaction with a user. Navigation is a perception-oriented task, dealing with routes and ensuring that obstacles are avoided. User interaction on the other hand involves categorically different kinds of knowledge about how to communicate effectively such that it is equally understood by both the manned and unmanned platform. In supervisory control in particular, there are a few different kinds of communication:

- Talk *about* the task: details of the task, subtasks, expectations
- Talk *during* task execution: status updates, alerts when things go wrong
- Meta-talk *about the interaction*: clarification, acknowledgements that tasking was clear, etc.

For the Robotic Wingman, these different kinds of talk are essential to maintaining situational assessment by both the manned and unmanned vehicles and it requires different kinds of knowledge. Talking about the task requires knowledge of how tasks are structured; knowledge about planning helps put things in the right order. Talk during the task requires knowing what information is needed to help the user maintain situational awareness; SOPs help define these protocols, as well as other agreements (e.g., to report status) that are made during task definition. Talk about the interaction itself is a kind of meta-discussion and requires general knowledge about how people clarify and give feedback while talking to each other; these are typically general rules that apply to many kinds of situations. Furthermore, any of this kind of talk can occur over multiple modalities, including speech and gesture. An effective task-oriented natural dialogue system must possess these different kinds of knowledge, and must be able to manage user interaction across multiple modes of communication.

A key enabler of this technology, and which underlies the Soldier-Robot Interface, is again the Soar cognitive architecture (Newell 1990; Laird et al. 1991). As previously mentioned, Soar has been used to create many diverse intelligent systems across a range of domains, including both autonomy and dialogue management. Soar is designed to organize information and make decisions in ways similar to how people do, specifically optimized for making goal-directed, knowledge-based decisions in complex environments. All of the systems we have created can speak with human operators and other participants using dialogue that is natural to their particular domains. We have also used Soar to generate multi-modal explanations for the behavior of intelligent agents, including text and graphical outputs (Taylor et al. 2006).

Command & Control and Communications

Information Management and Networking (IMN) manages the network between the Human Robot Interface and Autonomous Driving Architecture of the Robotic Wingman and its Control tank, particularly if there are multiple vehicles or multiple controllers, or when network nodes are near the edge of network connectivity. IMN prioritizes delivery of messages, reduces message sizes, reduces the number of non-data packets (i.e., ACKs and NACKs), and manages the connection to SOSCOE, ensuring that command information gets to the robot and that important situational awareness is delivered to the HRI. IMN is transparent to the Robotic Wingman HRI application; it abstracts the physical radio connection to any IP radio.

IMN increases the effectiveness of tactical networks to ensure the Robotic Wingman controller(s) get the information they need when they need it. Developed by NSRDEC and SAIC, IMN is government owned, and is specifically designed to address the issues of ad-hoc tactical wireless networks.

IMN transmits highly compressed Robotic Wingman images across the network as binary data, reducing transmission size; in support of interoperability, messages are converted back to the common JPEG format before the message is received by the application. Images can optionally be converted to grayscale or resized to fit the needs of the recipients and the network IMN traffic shaping manages network traffic as the network load approaches and reaches saturation. Messages will be transmitted based upon the quality of service (QoS) and control mechanism.

IMN provides a tactical message filter that helps units gain SA of elements outside of their network and prevents a resource constrained network from being overwhelmed with all of the data available from the Robotic Wingman or TOC. IMN prevents congestion by using an advanced traffic shaping algorithm and prioritizes egress network traffic so that the important data get through before lower priority data; smoothes network flows to prevent bursts and network failures by queuing transmissions when needed; drops unnecessary messages before they enter the network and restricts low priority messages from consuming too much bandwidth.

Platform Alternatives

Platform selection is critical to the effectiveness of Robotic Wingman. Unique vehicles operating in conjunction with manned combat vehicle have all the advantages afforded an unmanned system except convincing the enemy that he will engage humans if he shoots at the target. Vehicle like the Autonomous Platform Demonstrator (APD) will be an efficient demonstrator of Robotic Wingman robotic capabilities but will have a unique battlefield silhouette. Whereas the use of a platform like the Stryker or Bradley will require additional work to roboticize but will add the visual dimension of a uniform force in tactical engagements. Ultimately the measure of effectiveness will be the loss exchange ratio increase in favor of friendly blue forces using the Robotic Wingman concept. More specifically assessing a favorable decrease in blue manned systems losses, possibly at the expense of increased Wingman losses.

For the foreseeable future the target Robotic Wingman application will be the M-1 Abrams. But with no automatic loader planned it is not practical concept. Ultimately the Army Ground Combat Vehicle (GCV) will be another likely candidate but for now the decision for demonstrator platforms is between S&T testbeds like APD or fielded systems with auto-loaders such as Stryker or BFVs.