

The Future of Autonomous Ground Logistics: Convoys in the Department of Defense

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Abstract

The Future of Autonomous Ground Logistics Convoys in the Department of Defense by MAJ Damian A. Green, U.S. Army, 55 pages.

The military needs an autonomous ground convoy capability because the speed and complexity of the environment in which it operates has begun to exceed the abilities of its members to operate within it. U.S. Army doctrine requires the logistics forces to be able to provide continuous and uninterrupted distribution of supplies. Human frailty, high volumes of supplies, fast paced and offensive operations all hinder the ground transportation system from being able to keep pace. Operational commanders continue to hold back their operations and look back for the required supplies to sustain them. Robotics technology has reached a point where the technology is ready to support some military operations but funding priorities, planning horizons and organizational reluctance towards the new technology are hindering this evolution in transportation operations.

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Acronyms

BCT	Brigade Combat Team
BSB	Brigade Support Battalion
CALL	Center for Army Lessons Learned
CASCOM	Combined Arms Support Command
CAST	Convoy Active Safety Technology
COTS	Commercial Off The Shelf
DOD	Department of Defense
DARPA	Defense Advanced Research Projects Agency
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities
EOD	Explosive Ordnance Disposal
FAQ	Frequently Asked Questions
FM	Field Manual
FY	Fiscal Year
GEN	General
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IED	Improvised Explosive Device
JGRE	Joint Ground Robotics Enterprise
JROC	Joint Requirements Oversight Committee
KPH	Kilometers Per Hour
LHS	Load Handling System
LTG	Lieutenant General
MDMP	Military Decision Making Process
MOS	Military Occupational Specialty
MPH	Miles Per Hour

ONS	Operational Needs Statement
PATH	Partners for Advanced Transit and Highways
PPBE	Planning, Programming, Budget and Execution
TRADOC	Training and Doctrine Command
U.S.	United States

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Introduction

The military needs an autonomous ground logistics convoy capability because the speed and complexity of the environment in which it operates has begun to exceed the abilities of its members to function within such an environment. The challenge that the military is facing is how to effectively use automation technology to reduce soldier exposure to threats and increase the operational tempo of the force, while conducting dull, dirty and dangerous operations.¹ Combat operations during Operations Desert Shield/Storm (1990–1991) and Iraqi Freedom (2003) demonstrate the importance of continuous and uninterrupted distribution of supplies to military forces. During each of these operations, logistics hindered the ground combatant commander. An autonomous convoy capability could be one tool of many to provide the operational commander with increased operational flexibility in future military operations.

Those interested in this capability include Congress, the Department of Defense, Defense Advanced Research Projects Agency (DARPA) and many civilian companies who have joined the military as partners in industry.² The current state of robotics has arrived at a point where Lieutenant General Rick Lynch, the former 3rd Infantry Division (Mechanized) commander and III Corps commander, has advocated employing the current technology on the present battlefields of Iraq and Afghanistan. Unfortunately, LTG Lynch, in the course of career progression, has lost his positional authority to influence robotics development to support the warfighters, as the U.S. Army's senior garrison commander. Without senior generals, outside of the research and development organizations, advocating the potential of robotics to the rest of the operating force will be difficult.

¹The use of the word soldier includes U.S. Marine Corps Marines. The technology described in this paper could easily be adapted into either service with ease.

²Jim Overholt, "JGRE Update: NDIA Quarterly Meeting" (Presentation, Robotics Division Quarterly Meeting, December 15, 2009).

One piece of the technology that has matured to the point of employment is Lockheed Martin's Convoy Active Safety Technology (CAST). A vehicle, when equipped with over approximately \$150,000 worth of sensors and controls, autonomously follows a similarly equipped lead vehicle. Currently the technology has not reached the point of full autonomy; however, this system begins the evolution towards autonomy. The benefits of building this capability are twofold; a reduction of the effects of human frailty in sustainment of combat operations and a reduction in the public costs associated with deploying humans.

Programmed to operate independent of direct human intervention, eventually these autonomous convoys will help reduce injuries and death associated with the highest percentage killer on the modern battlefield, the improvised explosive device or IED. Lives are directly saved by removing personnel from each convoy. The challenge for the technology to overcome is how to ensure that the lives saved during the convoy do not translate to lives lost within the supported unit's formation.

A military analyst noted, during the initial stages of Operation Iraqi Freedom, "The biggest killer is fatigue, and right now we have a whole Army running toward Baghdad on zippo hours of sleep."³ Currently, driver availability determines the military's ability to move cargo. With autonomous vehicles, convoys would not be constrained by physical concerns of rest but rather constrained by the size of the fuel tank and maintenance readiness of the system. Once loaded, convoys can depart (individually or in groups with security, depending on the situation) more quickly, increasing turn-around times. Fog, blowing dust, nighttime operations and other

³N. L. Matsangas, P. Miller, L. G. Shattuck, "Fatigue and its Effect on Performance in Military Environments" (Report, Naval Postgraduate School Operations Research Department, Monterey, CA, 2007), 231.

weather conditions that would have prevented or at least hindered a manned convoy could become drivable within.⁴

An increased convoy capability, with less force structure, through an autonomous convoy system, provides many opportunities for strategic level military planners. In an era of expected budget cuts, it could provide a means to reduce costs for the Department of Defense's structure by removing unnecessary personnel.⁵ In current conflicts, the cost to deploy a single soldier has risen to over \$750,000 per year, which does not include the financial responsibilities of the military should death or injuries occur. Autonomous vehicles can reduce the total cost by decreasing the number of personnel required to perform non-automated tasks in support of the vehicle's operations.

The initial introduction of robotics in the military force structure to support convoy operations is not likely to have a drastic impact on the doctrine of how the military organizes and conducts operations. Over time, with the development of user trust and increased capability of the technology's ability to understand the complex environment, the dynamics of military sustainment will change. Moreover, while any prediction about a future capability is highly speculative, the operational commander will likely gain increased flexibility to win our nation's wars.

⁴There are other military technologies that enable vehicle operations in poor visibility conditions, such as Drivers Vision Enhancer (DVE) and individual night vision goggles. DVE provides incredible visibility for the driver through its thermal imaging system allowing manned vehicles to conduct convoy operations in suboptimal conditions. However, these systems are not connected with control of the vehicle. The lowest common denominator remains the human looking through them and constantly paying attention to their environment.

⁵CNN Wire Staff, "Gates: Pentagon Must Cut Overhead, Restrain Spending," *CNN Politics*, May 9, 2010, http://articles.cnn.com/2010-05-09/politics/gates.defense_1_defense-budget-defense-secretary-robert-gates-pentagon?_s=PM:POLITICS (accessed February 13, 2011).

The Operational Context

Operational Flexibility

Operational flexibility is about having alternative ways of delivering value on operationally relevant timelines, in response to changing requirements.⁶ Flexibility is a key requirement that comes from the planning process. Flexibility begins in the mind of the commander and staff as they gain an understanding of the environment and look for ways to achieve their goals. The purpose of planning is to position the organization so it has the ability to shift from one path to another to achieve an envisioned end state based on new information. Operational flexibility also provides the capability to conduct new missions based on new information or changes in the environment. The diagram below from U.S. Army Field Manual 5-0, *Army Planning and Orders Production*, shows a conceptual method for achieving an envisioned goal.

⁶John Q. Dickmann, “Operational Flexibility in Complex Enterprises: Case Studies from Recent Military Operations” (PhD diss., Massachusetts Institute of Technology, 2009), 234, http://lean.mit.edu/index.php?option=com_docman&task=doc_details&gid=2194&Itemid=332 (accessed February 14, 2011).

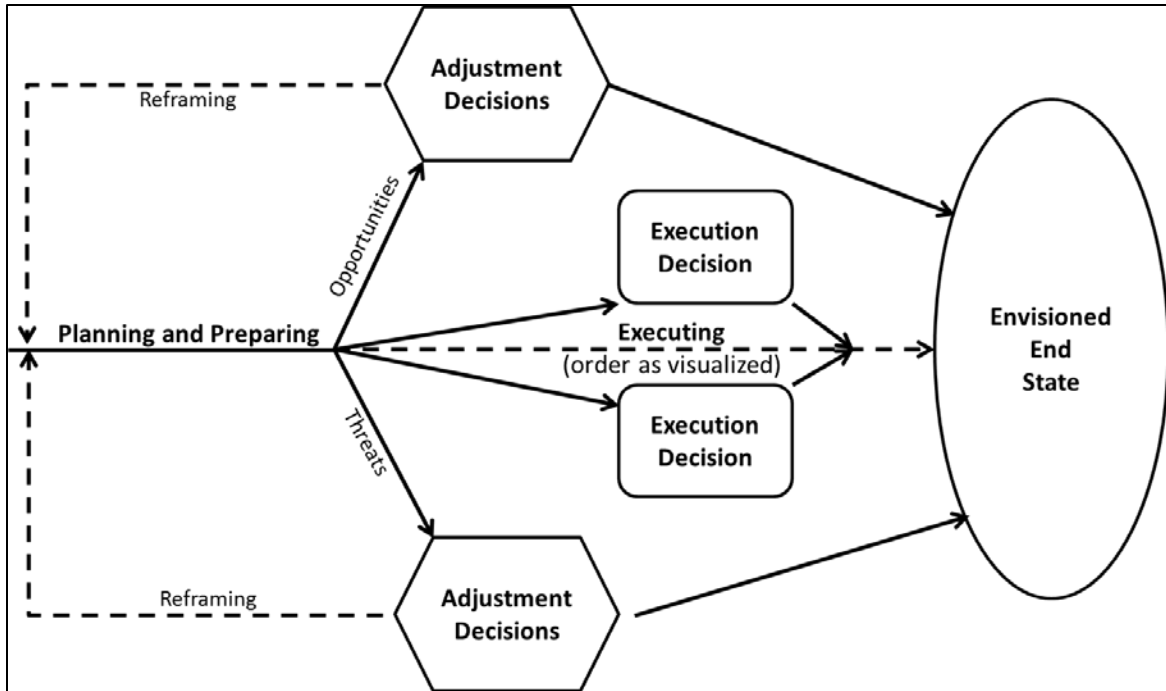


Figure 1 Decisions in Execution⁷

Operations rarely develop exactly as planned making commander’s decisions “critical to an operation’s success.”⁸ Through their understanding of the adversary, physical environment, friendly capabilities and positioning, commanders can modify the plan to adjust for unperceived opportunities and threats. However, the fundamental requirement is that there are other options available. If the situation is so divergent from the plan that the organization cannot adjust, then the organization must ‘reframe’ and envision a new approach that is within their abilities.

In a world of limited resources (time, training, intelligence, money, people, equipment and supplies), as more resources are committed towards a particular action, flexibility to accomplish additional tasks decreases. It is the responsibility of the people within the organization to see the potentials, both positive and negative, and move the organization in the

⁷Ibid., 5-4.

⁸U.S. Department of the Army, Field Manual (FM) 5-0, *Army Planning and Orders Process* (Washington, DC: Government Printing Office, March 2010), 5-5.

direction that provides the commander operational flexibility. Securing a single road in an area does not provide the commander options (other than forward or backward). Add an airfield, a port, critical infrastructure and local logistical support and now the commander has more flexibility on how to enter the area of operations and the methods by which to conduct his operations. Below are some examples where the military has provided increased flexibility to its organization within the context of the 2003 transformation of the Army.

- Maneuver. Brigade combat teams (BCT) were “pooled for use as part of an expeditionary force packages.”⁹ This provides “smaller, more versatile formations able to deploy more promptly.”¹⁰ Previously the standard for deployments was division and corps sized organizations.
- Distribution. Each brigade support battalion (BSB), designated to support a brigade combat team, received increased assigned transportation assets allowing them to haul more supplies. This increase in capacity allows maneuver commanders to operate more independently.
- Equipment. Distribution companies within the brigade support battalions were equipped with multiple Oshkosh Defense’s M1120 Load Handling System (LHS) trucks and trailers during this transformation. This vehicle provided an increased off-road hauling capacity to move 22 tons of equipment, ammunition, water and supplies wherever the mission required.¹¹ The system is also able to self-download, which reduces a requirement for forklifts or hand downloading in forward, austere locations.¹²

A critical requirement of any operation is the sustainability of the force. Sustainment is “the provision of logistics, personnel services and health services support necessary to maintain operations until mission accomplishment.”¹³ Sustainment has historically been the largest constraint of flexibility on military operations. The following are two contemporary examples

⁹U.S. Department of the Army, Field Manual (FM) 3-0, *Operations* (Washington, DC: Government Printing Office, February 2008), C-1.

¹⁰Ibid.

¹¹Oshkosh Defense, website, <http://www.oshkoshdefense.com/products/13/hemtt-a4/20/m1120-a4-lhs> (accessed January 30, 2011).

¹²A single truck can download 16 tons of supplies and equipment in one minute without the driver leaving the cab of the vehicle.

¹³U.S. Department of the Army, Field Manual (FM) 4-0, *Sustainment* (Washington, DC: Government Printing Office, April 2009), Glossary 11.

where the military's sustainment forces hindered an operational commander's flexibility. Just prior to the attack into Iraq and Kuwait in 1991, GEN Norman Schwarzkopf told his logisticians he wanted the ground invasion to start on 1 Feb. After studying the requirements to reposition XVIII and VII Corps and build up forward logistical stocks, LTG William "Gus" Pagonis came back with a 21-day requirement, which was five days later than the commander wanted.¹⁴ Based on this, GEN Schwarzkopf delayed in order to build up the required supplies. A second example occurred during the 2003 invasion of Iraq. The military concept of the war did not include a large build-up of forces before the invasion but rather the divisions would follow Third Infantry Division (Mechanized) and First Marine Expeditionary Force into Iraq after they arrived in Kuwait and organized for combat. Third U.S. Army and V Corps commanders were "constantly balancing the rapid maneuver against the need to secure the lines of communication and ensure the forces did not reach a culmination point due to logistics shortfalls."¹⁵ The lack of ability of transportation units to deliver and reload rapidly reduced the flexibility for the ground maneuver commanders.

The military organization receives its flexibility by "ensuring freedom of action, extending operational reach and prolonged endurance of the supported force."¹⁶ Each of these attributes has an element of human capacity and the physical nature of the military equipment that the organization employs. The challenge is to determine if the organization has the right capabilities to enable mission accomplishment for current and future conflicts.

¹⁴William G. Pagonis, *Moving Mountains: Lessons in Leadership and Logistics from the Gulf War* (Boston: Harvard Business Press, 1992), 138-140.

¹⁵E. J. Degen, Gregory Fontenot, and David Tohn, *On Point: The United States Army in Operation Iraqi Freedom* (Washington, DC: First Naval Institute Press, 2005), 90.

¹⁶U.S. Department of the Army, FM 3-0, *Operations*, 4-5.

Operational Environment

U.S. Army Field Manual (FM-1), *The Army*, describes the four types of challenges that the Army is preparing to meet in future conflicts.¹⁷ Each challenge, strives to develop an environment in which units will be able to operate successfully with their equipment. Traditional challenges require “mastery of major combat operations” by having “the ability to counter today’s conventional threats by preparing for tomorrow’s anti-access environments.”¹⁸ Historically and into the likely future, the U.S. military’s major equipment purchases will be oriented towards this challenge. Tanks, armored personnel carriers, artillery, attack and scout helicopters are the combat equipment that enables combating the traditional challenge. Logistically, transport of supplies and equipment must be capable of moving off-road, avoiding some obstacles (e.g. minefields) to deliver supplies to units who are constantly repositioning. Operations Desert Shield/Storm and Iraqi Freedom, the initial invasion in 2003, are two contemporary examples of these challenges.

Irregular challenges arise when “state and non-state sources [use] unconventional methods” to achieve their goals. Since the United States “cannot afford two armies,” the force designed to fight and win in major combat operations must be versatile and agile enough to counter irregular challenges.¹⁹ Operations in this environment will likely occur in urban terrain, along established roads and therefore will have a higher interaction with the civilian population. As the pace of operations slows down, the quantity of supplies and equipment grows, straining the ground distribution network. In the current context of Iraq and Afghanistan but as far back as the Revolutionary War, the military looks to use contractors to increase its capacity to support

¹⁷U.S. Department of the Army, Field Manual (FM) 1, *The Army* (Washington, DC: Government Printing Office, April 2009), 2-3.

¹⁸Ibid., 4-2

¹⁹Ibid.

operations.²⁰ Future transportation systems should be able to integrate with civilian contractors to provide the quantity of supplies demanded by the military forces.

The third problem is catastrophic in nature, which arises “from terrorists and rogue states threatening the use of weapons of mass destruction or other means of causing catastrophic effects. This challenge primarily involves relatively small numbers of military forces and currently is low consumer of transportation assets. The difficulty in addressing these threats occurs following the catastrophe. Systems have to be able to recognize the changes in their environment that may not present themselves through imagery and react accordingly. Additionally, autonomous vehicles, without a human crew, will not be able to render physical assistance to those in immediate need.

The final challenge, described in FM 1, “The Army,” is disruptive, whereby competitors develop, possess and employ “breakthrough technologies to gain an advantage in a particular operational domain.”²¹ An area that the military has pursued for a number of years in the field of logistics is the reduction of fuel and water required to support the soldier on the battlefield. Currently, these two commodities absorb over 80 percent of the total weight to be transported forward. Once a feasible means is found to reduce these requirements how supplies are moved to support combat operations will change drastically but until then the military must look for ways to move the supplies using its proven vehicles.

Speed and Complexity of Military Environment

The future battlefield described in “Joint Logistics (Distribution) Joint Integrating Concept,” produced by the Joint Staff, dated 7 February 2006, defines the environment and requirements that the U.S. military logistician should expect to operate within from 2015–2025.

²⁰U.S. Congressional Budget Office, “Contractors’ Support of U.S. Operations in Iraq,” (Washington, DC, August 2008), <http://www.cbo.gov/ftpdocs/96xx/doc9688/MainText.3.1.shtml> (accessed March 15, 2011), table 2.

²¹U.S. Department of the Army, FM-1, *The Army*, 2-3.

The future battlefield, which appears to be remarkably similar to the early stages of Operation Desert Shield (1990) and invasion of Iraq during Operation Iraqi Freedom (2003), requires a “rapid closure of joint expeditionary forces” that are “ready for immediate employment” into “multiple entry points” with the capability to “ [rapidly] establish ... distribution capabilities within a theater.”²² Dispersed operations require a blended approach to achieve rapid establishment of distribution capability. Ships, aircraft, helicopters, host nation trucks and rail lines are all likely to be required for this task. Each method has its role in ensuring that distribution operations “consistently provide the right materiel at the right place and time, in the right quantity and quality.”²³ However, based on the quantity of supplies consumed by soldiers, current technology and equipment purchases, only ground distribution methods, in the form of 20-foot and longer truck beds, has the capacity to handle this task. To put this in perspective, roughly 98 percent of the military’s equipment and supplies for operations in Iraq moves by ground transportation.²⁴ While the Air Force can remove some supplies from the ground routes their contribution remains a small percentage of the whole requirement.²⁵

Breaking apart the previous paragraph provides a more nuanced understanding of the problem and some potential ways to meet the challenges. Each of these will be put in the context of Operation Iraqi Freedom (2003). If the forces are to be “ready for immediate employment,” personnel, vehicles and supplies need to arrive in the theater at the same time. The challenges of ensuring the linkup occurs quickly include timing flight arrivals with ships, accommodations for personnel to download the vehicles and movement of the drivers to the port, to name a few. On

²²U.S. Department of Defense, *Joint Logistics (Distribution) Joint Integrating Concept Version 1.0* (Washington, DC: Government Printing Office, February 7, 2006), 7-8.

²³*Ibid.*, 16.

²⁴David Kincaid, “Convoy Mitigation: A Full Spectrum Approach to Counterinsurgency Logistics” (Research Report, Air Command and Staff College, Air University, Maxwell Air Force Base, AL, April 2006), 2.

²⁵John Hendren, “US Takes to Air to Move Cargo in Iraq,” *Los Angeles Times*, December 15, 2004, <http://articles.latimes.com/2004/dec/15/world/fg-supplies15> (accessed March 13, 2011).

21 March 2003, as Third Infantry Division's main body was crossing into Iraq, it was the only U.S. Army division of four prepared for combat. "The remaining units were still moving into the theater, linking with equipment or moving forward to attack positions."²⁶ During this time, ground transportation enabled the critical joining of equipment, supplies and personnel into combat formations and supported the onward movement into Iraq.

"Multiple entry points" infers there are uncontrolled spaces among our forces, at least initially. Forces at dispersed locations will probably require more supplies and equipment than aerial means can distribute, leading to convoys having to traverse the extended distances to connect the nodes. The primary injury and death producer on the current battlefields of Iraq and Afghanistan is the improvised explosive device. From 2005 to 2009, according to U.S. Army casualty reports, IEDs accounted for 44 percent of the total 36,285 documented injuries and deaths.²⁷ Loss of vehicles attributable to mines and improvised explosive devices is not a new problem and it has been growing as a problem since WWII. The following chart shows the increase over time up to 1993's Operation Restore Hope in Somalia.

²⁶Degen, Fontenot, and Tohn, 94.

²⁷Fred Wham, CALL Analyst, data pulled from <https://dcs.army.mil>. This database tracked every reported event, of the injuries (hospitalization) or deaths that were reported in Iraq, Afghanistan, the Horn of Africa and in the Philippines. This list was not exclusive to combat casualties. Casualties were grouped into categories based on the nature of their injury and type of mission they were conducting, using the description in the remarks.

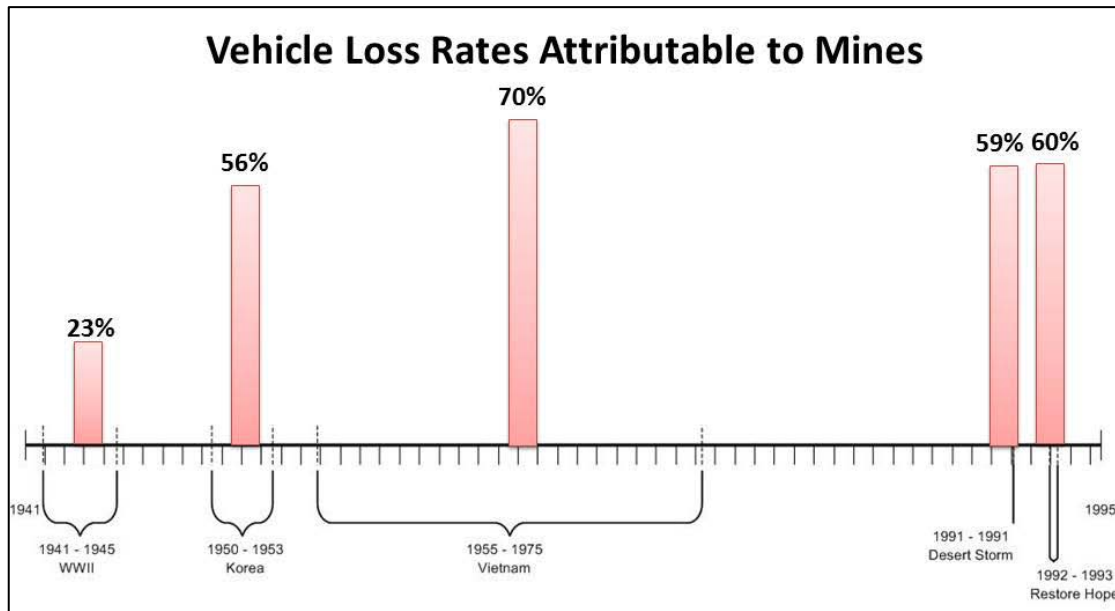


Figure 2 Vehicle Loss Rates Attributable to Mines ²⁸

The Department of Defense has a comprehensive program to reduce the number and scope of IED related injuries. One of the first steps of the program was improving body armor. Soldier body armor has significantly increased in capability, from flak jackets designed to provide protection against artillery fragments to the current body armor that can stop high velocity rifle rounds.²⁹ Another portion of the program increased protection for truck drivers by armoring vehicle cabs, beginning in late 2004.³⁰ Multiple shipments of new armored vehicles (M1114, M1151 and MRAP) followed to increase the survivability of the soldiers as enemy weapons became more potent. Motivated by a desire to save lives and provide a product to the U.S. military manufacturers were able to derive multiple solutions to mitigate the threat.³¹ Despite the

²⁸Jacques Gansler, William Lucyshyn, and William Varettoni, “Acquisition of Mine-Resistant, Ambush Protected (MRAP) Vehicles: A Case Study” (slides for 7th Annual Acquisition Research Symposium, May 12-13, 2010 in Monterey, CA), slide 8.

²⁹Ian Graham, “Battlefield Science: Body Armor,” Defense Media Activity, Emerging Media, <http://www.dodlive.mil/index.php/2011/02/battlefield-science-body-armor/> (accessed February 12, 2011).

³⁰U.S. Department of Defense, Office of the Assistant Secretary of Defense (Public Affairs), “Special Defense Department Briefing on Uparmoring HMMWV,” News Transcript, December 15, 2004, <http://www.defense.gov/transcripts/transcript.aspx?transcriptid=1983> (accessed 8 February 2011).

³¹Gansler, Lucyshyn, and Varettoni, slide 23.

reduced threat, in each of these cases one thing that did not change was that a human was still in the contested area.

The Promise of Robotics

The Army's Training and Doctrine Command (TRADOC) published TRADOC Pamphlet 525-3-1, *The Army Operating Concept: Operational Adaptability—Operating Under Conditions of Uncertainty and Complexity in an Era of Persistent Conflict*, which describes the broad capabilities required by the Army in 2016–2028. Specifically, “the Army must gain operational advantage and efficiency through the increased use of robotics capabilities and unmanned systems to reduce Soldier exposure to dangerous materials and hazardous incidents.”³² The U.S. Congress has placed a continued emphasis on the development and application of unmanned systems with directives to the Department of Defense contained within them. Section 220 of the Floyd D. Spence National Defense Authorization Act for FY2001 (Public Law 106-398) instructed the military to develop one-third of the conceptual Future Combat System as unmanned by 2015.³³ Section 941 of the John Warner National Defense Authorization Act for FY2007 (Public Law 109-364) increased the charter to ensure a preference for unmanned vehicles in new systems.³⁴

The military's requirement of the robotics developers is to reduce the amount of dull, dirty and dangerous work soldiers must conduct in the performance of their missions. Since 1989, when Congress directed that all military robotics programs consolidate, the Joint Ground Robotics Enterprise (JGRE) has been the director for the Department of Defense's robotics

³²U.S. Department of the Army, TRADOC Pam 525-3-1, *The United States Army Operating Concept, 2016-2028* (Washington, DC: Government Printing Office, August 19, 2010), 27.

³³U.S. Congress, Public Law 106-398, *National Defense Authorization, Fiscal Year 2001* (Washington, DC: Government Printing Office, October 30, 2000), www.dod.gov/dodgc/olc/docs/2001NDAA.pdf (accessed February 12, 2011).

³⁴U.S. Congress, Public Law 109-364 (Washington, DC: Government Printing Office, October 17, 2006), www.csg.org/knowledgecenter/docs/PL109-364.pdf (accessed February 12, 2011).

program. The “FY 2009–2034 Unmanned Systems Integrated Roadmap” shows the current direction and priority for unmanned systems within the Department of Defense. This document recognizes the success of these systems in the air, on land and in maritime domains, but also states the need for the military services to look for ways to improve their operations.³⁵ One change from the 2007 version of the road map to the 2009 version is the addition of the concept of “Autonomous Convoy,” which is the only system in the document out of 56 ground domain systems without a description.³⁶ To simplify, the assumption for this monograph is that the “Autonomous Convoy” will have the same form and function of current sustainment convoys—moving equipment and supplies on the battlefield. Research, development, test and evaluation of the autonomous convoy capability should begin in fiscal year 2022. Five years later, in 2027, the JGRE expects to begin purchasing, operating and maintaining this capability for the military.

The military’s research and development to enable major logistics operations appear to have centered on the Convoy Active Safety Technology (CAST).³⁷ CAST is a system of sensors, computers and actuators installed on multiple vehicles whereby a manned lead vehicle guides up to five follower vehicles along a route.³⁸ The system, as currently conceived, allows the driver to pay more attention to his surroundings to find threats more quickly. During testing in late 2009, crews were able to identify targets “20 to 25 percent faster (about 10 meters earlier) with CAST engaged.”³⁹ The system, using sensors around the vehicle to ascertain its position among other vehicles and within the environment, has demonstrated a 93 percent reduction in the frequency of

³⁵U.S. Department of Defense, *FY 2009-2034 Unmanned Systems Integrated Roadmap* (Washington, DC: Government Printing Office, April 6, 2009), 1-2.

³⁶*Ibid.*, 21-23.

³⁷There are other systems being developed to help the dismounted infantry soldiers identified in the 2009 UMS Integrated Roadmap. They are the CENTAUR Ground Mobility System and Tactical Amphibious Ground Support System (TAGS). However, these systems currently do not have the capacity potential that the CAST system enables.

³⁸Gary R. Carpenter, “Follower Robotic Vehicles Improve Convoy Safety,” *Army Magazine* 59, no. 9 (August 2009): 62-64.

³⁹*Ibid.*, 64.

the driver taking control of the vehicle.⁴⁰ CAST is capable of maintaining a specified distance between vehicles and rejoining a convoy when conditions force the vehicles to separate from the main route. It reacts faster than a human reacts with higher accuracy, operates in day, night and limited visibility conditions at relatively high speeds (50 mph during the day and 35 mph in blackout conditions).⁴¹

Third Infantry Division's (Mechanized) after action review from Operation Iraqi Freedom (2003) describes some conditions that an autonomous convoy (albeit with appropriate programming instructions) could have mitigated.

“[There was a] Failure by units to comply with accepted convoy procedures. Units moved on routes without march [movement] credits, stopped on roads for rest halts, and moved on the routes without regard for other units on the route.⁴² This lack of convoy discipline caused traffic jams and created situations where units move three abreast on two-lane routes. Vehicle damage and delays in [the] movement were the result of all of this uncoordinated activity.”⁴³

The current state of CAST and other civilian programs over the recent years show the tremendous increase in the potential of robotics to replace a human driver. While the technology has not yet proven itself in its ability to handle all the complexities of a civilian environment without some degree of direct human intervention, the improvements suggest that autonomous vehicles may be likely soon. The development of an autonomous ground vehicle traces its origins

⁴⁰Ibid.

⁴¹Blackout conditions occur when vehicles drivers turn off their lights and drive their vehicles using night vision equipment. According the US Army's manual for night driving “as a general rule, driving with Night Vision Goggles should never exceed 25 mph under any circumstance.” U.S. Department of the Army, Field Manual (FM) 21-305, *Manual for Wheeled Vehicle Driver* (Washington, DC: Government Printing Office, August 1993), 23-7, www.enlisted.info/field-manuals/fm-21-305-manual-for-the-wheeled-vehicle-driver.shtml (accessed February 12, 2011).

⁴²Movement credits are the authorization for one or more vehicles to move over a controlled routed during a fixed time window according to movement instructions. U.S. Department of the Army, Field Manual (FM) 1-02, *Operational Terms and Graphics* (Washington, DC: Government Printing Office, September 2004), 1-129.

⁴³3rd Infantry Division (Mechanized), U.S. Army, “Operation Iraqi Freedom Third Infantry Division (Mechanized) ‘Rock of the Marne,’” After Action Report, (Final Draft) (Ft. Stewart, GA: United States Army, 2003), 209, www.globalsecurity.org/military/library/report/.../3id-aar-jul03.pdf (accessed 12 February 2011).

back to 1977. The following chart shows the key developments in the growth of an autonomous capability imposed over the major United States combat operations.

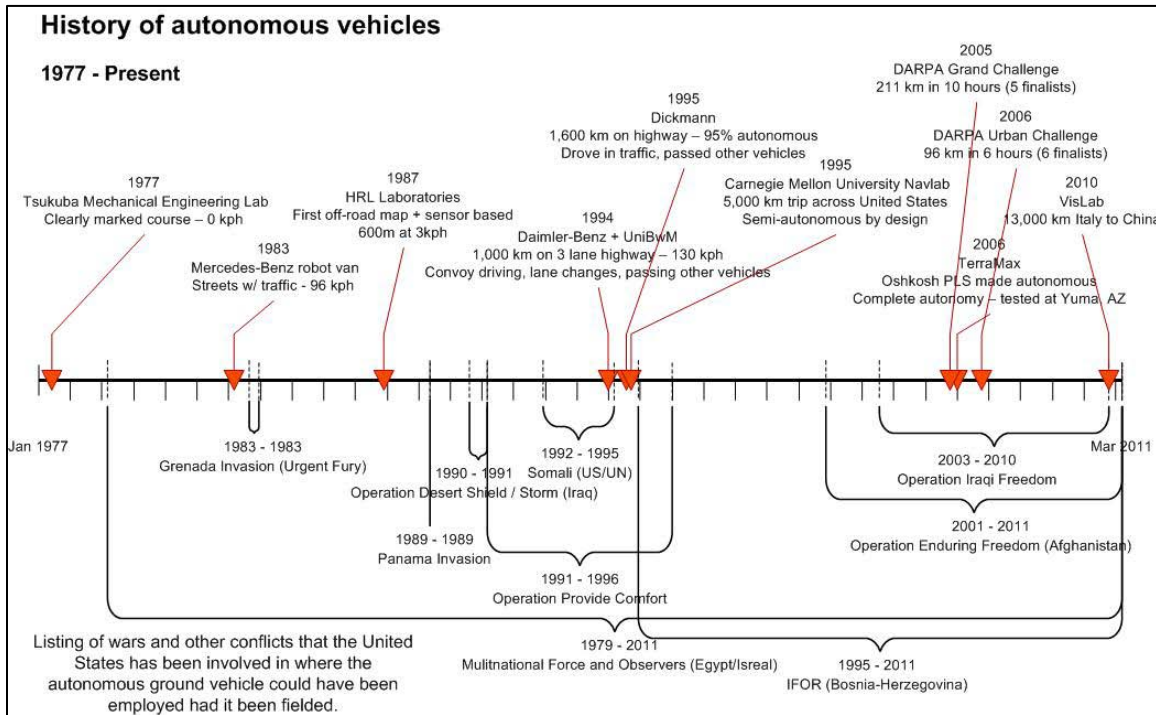


Figure 3 History of Autonomous Vehicles⁴⁴

Civilian car manufactures have included elements of autonomous vehicles in their current production lines for several years. Cruise control, which ensures that you traveled at a specific speed without engaging the brake or accelerator, has been improved. Now adaptive cruise control using lasers or radar, automatically adjusts a car's speed by braking and accelerating depending on the distance to the vehicle in front of you.⁴⁵ The Volkswagen Tiguan is capable of

⁴⁴Ride Systems, "The History of Autonomous Vehicles," <http://www.mikechiafulio.com/RIDE/history.htm> (accessed March 15, 2011); Richard Grimmett, *Instances of Use of United States Armed Forces Abroad, 1798-2004* (Washington, DC: Congressional Research Service, October 5, 2004), <http://www.au.af.mil/au/awc/awcgate/crs/r130172.htm> (accessed March 15, 2011).

⁴⁵This capability was first offered by Mitsubishi in 1995 on the Japanese Diamante. It has expanded to Toyota, Mercedes, Mercedes-Benz, BMW, Acura, Cadillac, Chrysler, Dodge, Ford, Jeep, Lexus, Porsche, Subaru, Volvo, and others.

self-parking using light detecting and ranging (LIDAR) sensors, video cameras and computers in the vehicle's trunk. All the driver has to do is get close to the parking spot, engage the self-park button and as required move the gearshift from drive to reverse.⁴⁶ Confidence in the technology's ability to identify and anticipate human actions has led Volvo to announce an initiative to guarantee fatality-free cars by 2020.⁴⁷

Many other innovations are occurring beyond the private sector. Steven Rainwater's website Robots.net identified at least 123 robot contests and competitions that are occurring around the world between April 2010 and March 2011.⁴⁸ The United States government does not have a research and development program, in the area of autonomous vehicles, equal to the capabilities of civilian robotics programs. These contests and competitions inspire new ideas, research and development that the government does not have to pay for. Once the technology reaches an acceptable technological point, it can be militarized. However, this has not always been the case, in 1988, 67 percent of the federal science budget was devoted to defense issues.⁴⁹

Martin van Creveld's book *Technology and War: From 2000 BC to the Present* reminds the reader that over the course of the twentieth century, "none of the most important devices that have transformed war – from the airplane through the tank, the jet engine, radar, the helicopter, the atom bomb and so on all the way down to the electric computer – owed its origins to a

⁴⁶CARmagazineTV. "Video of Volkswagen Tiguan Self-parking." YouTube video. <http://www.youtube.com/watch?v=xmaZ9vBW5mw> (accessed February 14, 2011).

⁴⁷Rebecca Boyle, "Volvo Initiative Aims to Guarantee Fatality-Free Cars By 2020," POPSCI, entry posted August 6, 2010, <http://www.popsci.com/cars/article/2010-08/future-cars-may-be-fatality-free> (accessed February 14, 2011).

⁴⁸Steven Rainwater, "Robot Contests and Competitions FAQ," <http://robots.net/rcfaq.html#LNK068> (accessed August 31, 2010).

⁴⁹John Abbots, "Time for rebirth of civilian R&D," *Bulletin of the Atomic Scientists* 46, no. 9 (November 1990): 11, http://books.google.com/books?id=jAwAAAAAMBAJ&pg=PA12&lpg=PA12&dq=what+benefit+does+the+military+gain+from+civilian+research&source=bl&ots=XpkJFloPDF&sig=4y9AEuSvr6TEAOQra0QcOJGLHko&hl=en&ei=5eZZTbPqH5HGSApEmvCXCg&sa=X&oi=book_result&ct=result&resnum=1&ved=0CBYQ6AEwAA#v=onepage&q&f=false (accessed February 14, 2011).

doctrinal requirement laid down by people in uniform.”⁵⁰ Often, “inventors turn to the military in order to obtain support for their ideas.”⁵¹ “No organization is better placed than the armed forces to guide its development and bring it to fruition.”⁵² The Department of Defense’s most prominent research developer in autonomous ground vehicle systems research is the Defense Advanced Research Projects Agency (DARPA). Established in 1958, in response to the Soviet superiority in space, DARPA “played a major role in the development of our defense technologies.”⁵³

The DARPA Challenge, created in response to a Congressional and DoD directive, was a field test intended to stimulate research and development in autonomous ground vehicles that will save American lives on the battlefield.⁵⁴ The 2004 and 2005 DARPA Challenges required civilian competitors to drive a 131.2-mile through the Mohave Desert within a 10-hour time limit, to claim the \$2,000,000 congressionally funded award.⁵⁵ In 2004, none of the competitors completed the course. However, in 2005, of the 23 finalists that entered the race, five were able to finish it with the allotted time, receiving the funds allocated by Congress. The 2007 Urban Challenge increased the level of complexity by requiring operations in an urban environment. Besides the robots on the courses, manned vehicles were on the course, testing the robots ability to merge, pass, park and negotiate intersections.⁵⁶ Six robots of the thirty-five that began the

⁵⁰Martin von Crevald, *Technology and War: From 2000 BC to the Present* (New York: The Free Press, 1989), 220.

⁵¹Ibid.

⁵²Ibid., 221.

⁵³DARPA, “The Post-Soviet Year: 1989-Present,” Online video, <http://www.darpa.mil/50thanniversary.html> (accessed February 12, 2011).

⁵⁴DARPA, “Grand Challenge Overview,” <http://www.darpa.mil/grandchallenge05/overview.html> (accessed February 1, 2011).

⁵⁵DARPA, “Robots conquer FARPA Grand Challenge,” News Release, October 8, 2005, <http://www.darpa.mil/grandchallenge05/> (accessed February 1, 2011).

⁵⁶DARPA, “2007 DARPA Urban Challenge,” <http://www.darpa.mil/grandchallenge/index.asp> (accessed February 1, 2011).

eight-day testing period completed the four courses. Three teams received prize money funded by the U.S. Congress.⁵⁷

The U.S. Marine Corps Warfighting Laboratory working with TORC, a robotics company, and Virginia Tech have demonstrated the potential for unmanned vehicles on the battlefield in a couple proof of concept tests.⁵⁸ During the summer of 2009, two modified High Mobility Multipurpose Wheeled Vehicles (HMMWV) conducted three resupply missions in support of a pre-deployment exercise at the Mountain Warfare Training Center in Bridgeport, CA.⁵⁹ The two Marines received the mission, uploaded the data into the vehicles, loaded the vehicles with the supplies and drove them to the staging area. From the staging area, the autonomous vehicles self-navigated to the designated resupply location traveling at speeds up to 25 miles per hour.

Two research laboratories, Artificial Vision and Intelligent Systems Laboratory (VisLab) of Parma University (Italy) and Google have pushed the technology even further, based on the knowledge gained from the DARPA Challenges. On 28 October 2010, VisLab completed a three-month, 13,000 kilometers (8,077 miles) trip with multiple unmanned electric powered vehicles from Italy to China.⁶⁰ A manned but autonomously capable van, generally operated without human guidance, led a second unmanned vehicle along the route, which included Russia,

⁵⁷After investing \$5.5 million in prize money and sponsoring three competitions, DARPA funded projects do not include a follow on challenge according to the U.S. Department of Defense, *Fiscal Year (FY) 2010 Budget Estimates* (Washington, DC: Government Printing Office, May 2009) www.darpa.mil/Docs/2010PBDARPA_May2009.pdf (accessed 1 February 2011).

⁵⁸TORC is a company specializing in supporting the development of teleoperated control and autonomous navigation for unmanned vehicles. TORC, "About TORC," <http://www.torcotech.com/content/about-torc> (accessed February 13, 2011).

⁵⁹Grace V. Jean, "No driver required: robotic humvees resupply troops downrange," *National Defense Industrial Association*, November 1, 2009, <http://www.thefreelibrary.com/No+driver+required%3a+robotic+humvees+resupply+troops+downrange.-a0212033293> (accessed August 31, 2010).

⁶⁰Jo Ling Kent, "Driverless van crosses from Europe to Asia," *CNN*, October 27, 2010, <http://edition.cnn.com/2010/TECH/innovation/10/27/driverless.car/> (accessed November 13, 2010).

Siberia and China. This company was part of a team that competed during the 2004, 2005 and 2007 DARPA Challenges.⁶¹

Google's multiple self-driving compact vehicles (six Toyota Priuses and an Audi TT) have driven on California's highways and local roads logging over 140,000 miles.⁶² Supervised by a safety driver behind the wheel, a software engineer in the passenger seat, and traveling along a pre-surveyed path, Google has brought together leading U.S. engineers, some of whom had participated in the DARPA Challenges, to make this project possible. The only accident so far, occurred when a manned vehicle rear-ended the robotic vehicle at a traffic light.⁶³

The Benefits

Overcoming Human Frailty

Equipped with sensors, continuous power, and quality programming, computers can react faster than humans and with a more consistent response. Able to see in different directions simultaneously and at farther distances, for a price, robotics can provide the right answer provided human beings program them correctly. Should humans be in the vehicle? It is time to acknowledge our weaknesses.

Studies show that by removing humans from the routine operation of the vehicle the vehicles can travel much closer together. This decreased spacing benefits both fuel savings and

⁶¹DARPA, Team Terramax, DARPA Grand Challenge 2005, Information sheet, http://websearch.darpa.mil/search?entqr=0&access=p&output=xml_no_dtd&sort=date%3AD%3AL%3Ad1&entsp=0&ie=UTF-8&client=default_frontend&q=convoy&ud=1&site=default_collection&oe=UTF-8&proxystyle=sheet=default_frontend&ip=76.92.185.67&start=20 (accessed February 1, 2011). Team TerraMax consisted of Oshkosh Truck Corporation, Rockwell Collins and the University of Parma, Italy. The TerraMax vehicle was provided by Oshkosh Truck and is based on Oshkosh Truck's Medium Tactical Vehicle Replacement (MTVR) defense truck platform that was designed for the US Marine Corps. The MTVR was designed for a 70% off-road mission profile. It can carry a 7.1-ton payload off-road or a 15-ton payload on-road.

⁶²Google Blog, "What We're Driving At," entry posted October 9, 2010, <http://googleblog.blogspot.com/2010/10/what-were-driving-at.html> (accessed December 2, 2010).

⁶³John Markoff, "Google Cars Drive Themselves, in Traffic," *The New York Times*, October 9, 2010 <http://www.nytimes.com/2010/10/10/science/10google.html?pagewanted=1&r=2&partner=rss&emc=rss> (accessed December 3, 2010).

maximizes the available road space. A series of California Partners for Advanced Transit and Highways (PATH) studies, between 1999 and 2004, noted that when using automated technologies to reduce vehicle separation to ten meters resulted in a reduction of aerodynamic drag that led to an average of eight percent fuel savings per vehicle.⁶⁴ Decreasing the spacing to just three meters would result in a twelve percent fuel savings. Human controlled vehicles cannot travel safely in order to gain that savings. Normal military convoys travel at a safe follow distance (vehicle gap) of 100 meters on the highway or four to six seconds between vehicles. The separation decreases in urban areas to roughly half of that due to the decreased speed limit.⁶⁵ Decreasing the vehicle separation allows movement planners to increase the number of vehicles along a mobility route.⁶⁶ By allowing automated systems to make the calculations, even more capacity can be gained by reducing the time gaps between convoys. This could provide combatant commanders with more forces or capacity at a critical time and place to affect a tactical or operational objective. During the repositioning of corps just before the start of Operation Desert Storm, LTG Pagonis described the pipeline as “flowing full speed, an average of eighteen trucks per minute, 24 hours a day, seven days a week.”⁶⁷ Incorporation of autonomous systems, if they were available during that time, could have increased the rate to over fifty trucks a minute.

⁶⁴F. Browand, J. McArthur, and C. Radovich, “Fuel Saving Achieved in the Field Test of Two Tandem Trucks,” California PATH Program, Institute of Transportation Studies, University of California, Berkeley, June 2004, <http://www.path.berkeley.edu/PATH/Publications/PDF/PRR/2004/PRR-2004-20.pdf> (accessed 8 Aug 2010), 18.

⁶⁵U.S. Army Safety Center, “Military Convoy Safety Brief,” Military Convoy Operations, https://safety.army.mil/...Convoy.../Military_Convoy_Safety_Brief.doc (accessed August 8, 2010).

⁶⁶If vehicles were spaced 20 meters apart you can expect to have 500 vehicles an hour flow through a point on the ground. Reducing the spacing to 3 meters provides fivefold increase to more than 3,000 vehicles an hour. If the system were installed on the M1120 truck type a 11,000 short tons an hour capability would be increased to 66,000 short tons. A convoy of 20 vehicles, which would have taken up half a kilometer, now occupy one-tenth of a kilometer.

⁶⁷Pagonis, 146.

Fatigue is not unique to warfare and studies conducted on civilian truck drivers provide scientific validation of this problem and some potential solutions. In the United States over 42,000 people die each year due to vehicle related accidents and, on average, the rest of the population loses about a week of time in traffic. This extrapolates to a \$300 billion dollars cost to society.⁶⁸ According the National Highway Transportation Safety Administration report of Congress on the causation of large truck crashes, over 13 percent of these accidents can either fully or partially be attributed to the effects of drowsiness or fatigue which compromised driver's attention, judgment and/or performance.⁶⁹ The human body requires an average of eight hours of sleep each night to maintain an optimal level of alertness and most people reported getting around seven to seven and one half. When the National Sleep Foundation commissioned a Gallop survey on daytime alertness in drivers, they found that 75 percent reported daytime sleepiness, with 32 percent of these reporting severe levels.⁷⁰

In 2005, the U.S. Department of Transportation noted a 20 percent decline in large truck fatalities by reducing civilian truck driver's time on the road to 11 hours every 24 hours,⁷¹ with an additional stipulation that the driver only work a 14-hour day.⁷² The remaining ten hours of

⁶⁸Scott Belcher, "Green Light for Robotic Roads," Discovery Video, <http://videos.howstuffworks.com/discovery/33469-discovery-tech-robot-cars-video.html> (accessed August 5, 2010).

⁶⁹U.S. Department of Transportation, *Report to Congress on the Large Truck Crash Causation Study* (Washington, DC: Government Printing Office, March 2006), 15. This studies finding, based on examination of 967 crashes involving at least one large vehicle, found that 87 percent of the crashes were due to the driver. The most common factors include driving too fast for the conditions, illegal maneuver and unfamiliarity with the terrain.

⁷⁰National Transportation Safety Board, *Evaluation of U.S. Department of Transportation Efforts in the 1990s to Address Operator Fatigue* (Washington, DC: Government Printing Office, 1999), 69. <http://www.nts.gov/publicatn/1999/SR9901.htm> (accessed October 5, 2010).

⁷¹5,240 in 2005 and 4,229 in 2008. If you were to look at this from the perspective of airliners, it would be the equivalent of ten 777 aircraft crashing annually. The problem is that the deaths are dispersed over the entire nation and spread out over time. They do not normally occur in a concentrated time and place.

⁷²Jim Spencer, "Weary Truckers Pose a Highway Threat," *Star Tribune*, July 22, 2010, http://www.startribune.com/local/98977259.html?elr=KArksLckD8EQDUoaEyqyP4O:DW3ckUiD3aPc:_Yyc:aUnciatkEP7DhUsl (accessed August 5, 2010).

the day were allotted to sleeping and relaxation. The Department of Defense's policy for driver rest is to have at least eight hours of rest for every ten hours of driving within a 24-hour period, while traversing public highways in the United States. Driving more than 12 hours in a 24-hour period will only happen in justified emergencies.⁷³ However, the reality for many deployed transportation units is that convoys can last up to 24 hours.

Consider a planned movement that presumes a 40-kph average movement speed for 12 hours.⁷⁴ The convoy must stop in a safe haven, at the end of the 12 hours, to rest for the next leg of the convoy.⁷⁵ What cannot be accurately planned for are the unknowns such as time spent reacting to IEDs, enemy attacks and/or spending time behind convoys that have stopped reacting to similar situations. While an autonomous convoy will probably run into the same challenges, the system will be able to respond more quickly and precisely, since it has not become fatigued.

From 2005–2009, there were at least 996 documented casualties of vehicle accidents attributed to combat operations in Iraq and Afghanistan.⁷⁶ While the data is not specific, fatigue was likely to be a contributing factor. Lawrence Korb, senior fellow at the Center for American Progress captured the essential difference between garrison and deployed operations with the following quotation: "You are not sleeping as well, and the things that we take for granted began to weigh on the body. The longer you are away from home, the less sleep you are getting, the

⁷³U.S. Transportation Command, *Defense Transportation Regulation—Part III* (Washington, DC: Government Printing Office, August 17, 2007), III-F-12, www.transcom.mil/j5/pt/dtrpart3/dtr_part_iii_app_f.pdf (accessed October 5, 2010).

⁷⁴Drew Dawson and Kathryn Reid, "Fatigue, Alcohol and Performance Impairment," Scientific Correspondence, igitur-archive.library.uu.nl/.../frenkel_97_entropy_face-centred_cubic.pdf (accessed October 5, 2010). Drew Dawson and Kathryn Reid found that after 24 hours of being awake was the equivalent of 0.10% blood alcohol concentration (i.e. the equivalent of being legally drunk in the United States).

⁷⁵The military term is a convoy support center (CSC). Situation dependent, they are separated by a line haul distance (equivalent to an 8-10 hour driving distance or 120 km).

⁷⁶Data was pulled from <https://dcs.army.mil> and interpreted by Fred Wham, Center For Army Lessons Learned on 15 September 2010. A casualty is defined by FM 1-02, *Army Operational Terms and Graphics* as any person who is lost to his organization by reason of having been declared dead, wounded, injured, diseased, interned, captured, retained, missing in action, beleaguered, besieged, or detained.

higher the chance of a mistake."⁷⁷ By encouraging drivers to get the required rest, leaders may possibly reduce the risk of drowsiness, but they must do it within a context of a 'mission first' mentality. However, this may not be possible given the circumstances as was seen in the Third Infantry Division's after action report from Operation Iraqi Freedom.

Another physical condition related to the need to remove humans from logistics convoys are our circadian rhythms. The circadian rhythm is the body's internal clock that regulates biological processes, including our sleep-wake cycle, over an approximate 25-hour period.⁷⁸ The human body, when the retinas are exposed to sunlight, switches off the production of the hormone melatonin. After the sunset, melatonin levels increase in the body causing people to become drowsy.⁷⁹ A critical aspect of logistics is the ability to provide support to the war fighter what they want, when and where they want it, no matter the time of day. The human body can operate when our circadian rhythm is disrupted but it does so with some severe impacts. A soldier on a military convoy in a combat zone constantly transitioning from one sleep cycle to another to support the demands of the customer, will have to deal with some or all the following issues: impaired performance, including a reduction in cognitive skills, daytime sleepiness, poor concentration and headaches.⁸⁰ None of these symptoms are ideal for a civilian driving in a new

⁷⁷Domorris Lee, "War Deaths Not Limited to Combat: Vehicle Crashes, Heat, Suicide Increase Toll in Middle East," *The News and Observer*, June 1, 2004, <http://www.globalsecurity.org/org/news/2004/040601-war-deaths.htm> (accessed December 3, 2010).

⁷⁸Matsangas, 232

⁷⁹National Institute of Neurological Disorders and Stroke, "Brain Basics: Understanding Sleep," http://www.ninds.nih.gov/disorders/brain_basics/understanding_sleep.htm#circadian_rhythms (accessed October 5, 2010).

⁸⁰Mary Cataletto and Gila Hertz, "Sleeplessness and Circadian Rhythm Disorder," http://www.emedicinehealth.com/sleeplessness_and_circadian_rhythm_disorder/page3_em.htm (accessed 5 October 2010), 3.

time zone but in a military context they can be deadly for the vehicle crew and catastrophic to the success of the mission.⁸¹

Currently, through natural means,⁸² circadian rhythms can only be shifted by one to two hours forward or backward per day.⁸³ During military operations, it is essential that logistics units remain responsive to “changing requirements on short notice and [are able] to sustain efforts to meet changing circumstances over time.”⁸⁴ If we also believe in keeping risks to our soldiers at a minimum, to shift someone from a day to night shift, properly changing the circadian rhythm, is six to twelve days responsive to our supported customers? Increasing the number of drivers for transportation units, while not changing their current mission, would help provide a responsive support while not compromising the soldier’s health or even life. However, given the cost of personnel on the Department of Defense’s budget this option is not feasible.

Another weakness of humans is our ability to perceive our environment. While humans can understand intentions and potentialities better than a computer now, our field of vision inhibits that perception. By placing a second person in the passenger seat increases the perception around portions of the vehicle. However, this only improves their situational awareness to the right side of the vehicle. The view to the rear of the vehicle and other areas not

⁸¹U.S. Air Force pilots, under specific internal regulations, have the option of consuming dextroamphetamine and other performance-sustaining pharmacological compounds, in order to counter fatigue in the cockpit. Amphetamines have been used during World War II, 1960-1996 and were reapproved for select combat Air Force operations in 2001. John Caldwell, “Go Pills in Combat: Prejudice, Propriety and Practicality,” *Air & Space Power Journal* (Fall 2008), <http://www.airpower.au.af.mil/airchronicles/apj/apj08/fal08/caldwell.html> (accessed March 10, 2011).

⁸²Researchers at the University of California-San Diego have discovered a new molecule that has potential effects on the biological clock. They have conducted successful tests on animals lengthening the biological clocks of the animals by more than 10 hours. Future tests will confirm the molecules effectiveness on lab mammals. Rebecca Boyle, “New Molecule Can Reset Your Biological Clock with Unprecedented Effectiveness,” *POPSCI*, entry posted December 15, 2010, <http://www.popsi.com/science/article/2010-12/new-compound-can-reset-your-biological-clock-could-someday-cure-jet-lag> (accessed December 15, 2010).

⁸³U.S. Department of Transportation, *Regulatory Impact and Small Business Analysis* (Washington, DC: Government Printing Office), <http://www.fmcsa.dot.gov/rules-regulations/topics/hos/regulatory-impact-analysis.htm> (accessed October 5, 2010).

⁸⁴U.S. Army, FM 4-0, *Sustainment*, 1-2.

within the mirror's line of sight remain unseen. Add to that, body armor, helmet and seatbelts, which further restricts the movement of the driver and passenger, coupled with radios, computer screens, high noise levels and heat, and humans remain the lowest common denominator.

Autonomous vehicles have the capacity for nearly instantaneous reactions among multiple vehicles. A vehicle braking, several vehicles ahead, will not necessarily be noticed by a human driver until it is too late for themselves and following vehicles. Of the 2,584 on and off-duty accidents reported by the U.S. Army from 2005 to 2010, human error accounted for sixty-three percent.⁸⁵ In combat or stressful conditions, a driver's attention is not solely concentrated on the vehicle(s) in front of them. The head is constantly on a swivel attempting to obtain information about the surroundings. CAST technologies have shown that for a cost, technology can assist drivers in sensing and most importantly reacting to dangerous conditions on military operations, preventing the accident from occurring.

Reduction in Costs in Deploying Humans

One of the military's highest costs within its budget is personnel.⁸⁶ Military personnel are the second highest proportion of the Department of Defense's (DOD) annual budget behind operations and maintenance. In 2009, it made up 23.1% or \$147,348,000. In a peacetime environment, it costs the U.S. Army roughly \$1 billion for every 10,000 soldiers. To deploy a soldier to Afghanistan the military annually spends between \$750,000 and \$1,250,000. This

⁸⁵U.S. Army Safety Center, "U.S. Army Accidents Report (2005-2009) 20101008_AMV_ACV_FY06-10-Final, Electronic correspondence with author, October 12, 2010.

⁸⁶Office of Management and Budget, Table 3.2, *Outlays by Function and Subfunction: 1962–2015*, <http://www.whitehouse.gov/omb/budget/Historicals/> (accessed on August 31, 2010).

includes the movements to, from and within the country, construction requirements, quality of life resources, force protection material and the equipment required to perform the mission.⁸⁷

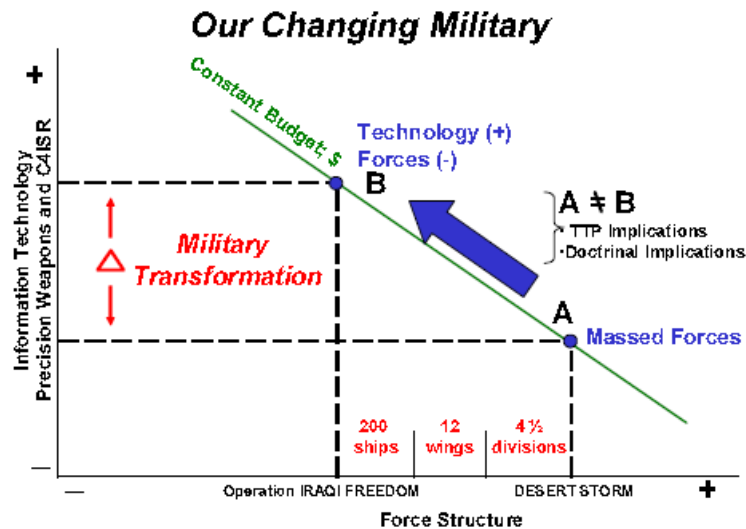


Figure 4 Our Changing Military⁸⁸

The Army historically follows wars by removing soldiers from the force structure of as a way to meet budgetary constraints.⁸⁹ The peace that follows the wars the United States has fought in has provided significant opportunities to reduce defense spending. In 2011, the Pentagon announced plans to “freeze its ballooning budget, forcing the services to shrink the Army and Marines and increase health care premiums for military retirees and their families.”⁹⁰ Technology can provide a possible solution to help the Department of Defense in accomplishing its mission while reducing the number of soldiers it requires to perform it.

⁸⁷MediaMatter for America, “Varney’s claim that Obama inflated deployment costs undermined by Pentagon assessment that is reportedly in line with White House, <http://mediamatters.org/research/200912010031> (accessed August 31, 2010).

⁸⁸Gary Luck, “Insights on Joint Operations: the Art and Science,” Paper, Joint Warfighting Center, U.S. Joint Forces Command, September 2006, asc.army.mil/.../Insights_on_Joint_Operations_%20-The_Art_and_Science.Pdf (accessed February 13, 2011).

⁸⁹History.com, “The United States Army,” <http://www.history.com/topics/united-states-army> (accessed March 14, 2011).

⁹⁰Anne Flaherty and Annie Gearan, “Pentagon To Cut Spending For First Time Since 9/11,” *Huffington Post*, January 6, 2011, http://www.huffingtonpost.com/2011/01/06/pentagon-spending-cuts_n_805628.html (accessed March 14, 2011).

The CAST equipped transportation company would likely reduce this per person cost to the military once the initial purchase costs were made. For example, a sixty-vehicle transportation company that requires 120 drivers could be reduced to 24 soldiers to perform the same tasks.⁹¹ An added benefit occurs when the transportation workload changes from one installation to another. A vehicle or group of vehicles can be transferred from one unit to another and after paying the shipping costs, the transfer is complete. If a manned system filled the requirement, moving costs would include not just the vehicle but also soldier, family and households. The following are some options that the reduced driver requirement provides the military leadership:

Option One: Some of the remaining ninety-six soldiers, per company transformed, could fill roles that are necessary but not built into the company's manning and equipping documents. For example, they could operate armored gun trucks for convoy security (one gun truck per five CAST vehicles) and the remaining soldiers could be the second shift for all the equipment. This would double the capacity of the company in supporting of the maneuver commander's mission.

Option Two: Reassign the remaining ninety-six soldiers plus a percentage of leadership that is not required for the company's mission. This could be to an organization that has a shortfall of drivers, to make another CAST equipped transportation company or more drastically to a new military occupational specialty (MOS) based on the needs of the Army. As stated in FM 1 "The Army," the military does not have the capacity for a second army for the irregular challenge but this could provide forces towards that challenge.

Option Three: Remove the authorization for the soldiers and use it as a cost savings. For each transportation company equipped with CAST, the military could save more than \$3.8

⁹¹Lockheed Martin, "Convoy Active Safety Technology (CAST) Product Card," <http://www.lockheedmartin.com/> (accessed February 6, 2011). The company has proven its ability to operate in five-vehicle autonomous convoys. The above math assumes that the military adopts CAST as an aid to the vehicle driver and man's only one vehicle out of every five with a driver and troop commander (right seat passenger).

million.⁹² The breakeven point would occur during the third year of ownership and might occur even quicker if there was another major combat deployment. Over time, as the technology becomes more prevalent, the breakeven point would be realized quicker as the industry is able to reduce the component costs for new production models.

Requirements for Success

Requirements for Integration

Before discussing what the Department of Defense and Army would have to accomplish as part of the integration of autonomous logistics vehicles into the force structure, the issues of buy-in and trust need to be addressed. Without trust, we will not have a revolutionary change in transportation; rather it will be evolutionary through incremental improvements. The U.S. Air Force's chief scientist, Werner Dahm, said in *Aviation Week & Space Technology*, "It is the lack of trust in autonomous systems... that hinders our development of more capable and adaptable autonomous systems."⁹³ Aurélien Godin and Jérôme Lemaire affirmed this requirement for confidence in the system, which is demonstrated in proven reliability and robustness.⁹⁴

U.S. Army Field Manual (FM) 1, The Army, establishes the fundamental principles for the United States Army as the dominant land power of the United States to fulfill its responsibilities. In it, the Chief of Staff of the Army, General Peter Schoomaker states "without

⁹²U.S. Department of Defense, OUSD (P&R) Directorate of Compensation, *Selected Military Compensation Tables* (Washington, DC: Government Printing Office, January 1, 2011), A1, <http://militarypay.defense.gov/Reports/greenbooks.html> (accessed February 2, 2011). A married Private First Class received \$43,075.22 every year in pay in regular military compensation. Lockheed Martin's CAST (currently projected to cost approximately \$150,000 per vehicle) does not have official cost estimate for operations and maintenance of a CAST equipped vehicle, therefore the break-even point might occur at a different time with more information and study.

⁹³Amy Butler, "Autonomous Path," *Aviation Week & Space Technology Magazine*, July 19, 2010, www.aviationweek.com/awst (accessed 8 August 2010), 40.

⁹⁴Aurélien Godin and Jérôme Lemaire, "Towards the Introduction of Robots into the Land Forces," *Military Technology* 34, no. 6 (2010): 89-90.

Soldiers there is no Army.”⁹⁵ This statement creates an interesting dynamic with the rise in the use of robotics within the military to aid it in the conduct of warfare. The natural reaction to autonomous vehicles from the military personnel likely to be replaced will not be one of support.

Published by the Army Combined Arms Support Command (CASCOM) the *Army Sustainment* magazine, formerly *Army Logistician*, is a bi-monthly publication that serves “as the Army’s professional bulletin for the sustainment war fighting function, including logistics, personnel services, and medical logistics and evacuation.” This magazine provides a wealth of knowledge released for public distribution on the current state of logistics in the U.S. Army. A review of the articles over the last decade found only one that discussed the need for autonomous vehicles to transport supplies for combat forces.⁹⁶ This suggests that the community does not believe there is an urgent need for this capability.

Most of current ground robotic systems purchased for the wars in Iraq and Afghanistan were commercial off-the-shelf (COTS) items based on operational needs statements (ONS) from the field. The preponderance of these systems were used to identify and dispose explosive ordnance on the battlefield.⁹⁷ Forces deployed in Iraq and Afghanistan has a powerful voice in what equipment is procured to support their operations. Based on the information available in the press, creating a less manned or unmanned logistical vehicle capability has not reached the same fervor that adding armor to unarmored vehicles did in 2004.

⁹⁵U.S. Army, FM 1, *The Army*, Washington, DC: Government Printing Office, June 2005), Foreword, http://armypubs.army.mil/doctrine/Active_FM.html (accessed October 26, 2010).

⁹⁶Army Logistics, “Army Researches Unmanned Ground Vehicle for Convoy Operations,” *Army Logistics Magazine* (May-June 2009), http://www.almc.army.mil/alog/issues/May-June09/alog_news.html (accessed December 3, 2010).

⁹⁷MarcBot, Talon, PackBot, Mini-Explosive Ordnance Device (EOD).

The Need for Leadership Buy-In and a Champion

Providing funding, manpower and leader emphasis should help overcome the stagnant situation, but what is truly required is a champion. The British experience in transforming to a mechanized army in 1900 described in *From Horse to Helicopter* captures a unique way to obtain leader buy-in.⁹⁸ After institutionalizing the Mechanical Transport Committee, the British recognized the power of operational leaders on the acceptance of this new form of transportation. As a result, the corps commander received the first four-seat car purchased, in 1902. Within “a few short years a number of dedicated and enlightened officers had turned the tide of uncertainty and mistrust that had been threatening the efficient operation of its transport.”⁹⁹

Lieutenant General Rick Lynch, currently the commanding general of U.S. Army Installation Management Command and holder of a master’s degree in mechanical engineering focusing on robotics from Massachusetts Institute of Technology, appears to be the Army’s primary champion for ground robotics at the general officer level.¹⁰⁰ While serving as the commanding general of Fort Hood, Texas, and Third Corps, General Lynch said during a recent National Defense Industrial Association robotics symposium in Dallas, TX, the emphasis needs to be on providing the technology to those in the field.¹⁰¹ Again, during the Association for Unmanned Vehicle Systems International conference in Washington, D.C., he reinforced that “the Army has failed to field the right kinds of robots that would save war fighter’s lives.” His third priority, following removing soldiers from inside route clearance vehicles and a capability to

⁹⁸John Sutton and John Walker, *From Horse to Helicopter* (London: Leo Cooper, 1990), 71-72.

⁹⁹*Ibid.*, 71.

¹⁰⁰Stew Magnuson, “Efforts to Field New Kinds of Ground Robots have had Little Success,” *National Defense* (June 2010), <http://www.thefreelibrary.com/National+Defense/2010/June/1-p5284> (accessed August 31, 2010).

¹⁰¹Lawrence Farrell, “Robots are Major Players in U.S. Military Strategy,” National Defense Industrial Association, May 2009, <http://www.ndia.org/Resources/PresidentsPerspective/Pages/May2009.aspx> (accessed August 31, 2010).

constantly observe historical IED emplacement locations, would be for “convoy following” technology.¹⁰² General Lynch believed, based on his knowledge, education and experience, that convoy following technology could save lives by reducing the number of soldiers exposed to the IED threat. Unfortunately, since these capability demonstrations, he has been moved out of the combat command leadership position and he is not in a significant position to influence the discussion of robotics and its employment in the operational force.

During the research on this topic, there was little information published advocating the requirement, need or even desire for an autonomous ground distribution capability for the military. The reason might lie in how operations are supported. LTG Pagonis’ description of the role of the logistician in supporting a projection force is “to capture the host-nation infrastructure.”¹⁰³ This describes operations in Iraq, Afghanistan and many other operations where contracted civilians fill the gaps in military transportation support. These contractors perform or augment the military mission shortfalls. If there are no or very limited shortfalls in distribution operations, then a system that automates driver responsibilities will not be a high priority to request, fund, research, develop and procure.

The next obstacle is the allocation of funding for unmanned systems. The President’s Budget for Unmanned Systems allocates an average of 82 percent of the available funds towards aerial systems for fiscal years 2009 to 2013. Ground systems will receive 14 percent and maritime systems only four percent.¹⁰⁴ The downward trend suggests that that ground systems are not the priority for the next couple of years. Additional study would be required to determine the correct allocation that would best support an unmanned ground logistics system.

¹⁰²Stew Magnuson, “Failure,” *National Defense Magazine*, October 2009, <http://www.nationaldefensemagazine.org/archive/2009/October/Pages/FailureToFieldRightKindsofRobotsCostsLives,ArmyCommanderSays.aspx> (accessed August 31, 2010).

¹⁰³Pagonis, 207-208.

¹⁰⁴U.S. Department of Defense, *UMS Integrated Roadmap 2009*, 4.

	Funding Source	FY09		FY10		FY11		FY12		FY13		TOTAL	
UGV	RDT&E*	\$ 1,291,200,000		\$ 747,500,000		\$ 136,200,000		\$ 108,700,000		\$ 68,900,000		\$ 2,353,000,000	
	PROC*	\$ 33,400,000	28%	\$ 42,300,000	18%	\$ 53,500,000	6%	\$ 59,500,000	6%	\$ 21,100,000	3%	\$ 210,000,000	14%
	O&M*	\$ 2,900,000		\$ 3,900,000		\$ 3,000,000		\$ 12,800,000		\$ 10,100,000		\$ 33,000,000	
UAS	RDT&E	\$ 1,347,000,000		\$ 1,305,100,000		\$ 1,076,400,000		\$ 894,000,000		\$ 719,500,000		\$ 5,342,000,000	
	PROC	\$ 1,875,500,000	70%	\$ 2,006,100,000	79%	\$ 1,704,700,000	89%	\$ 1,734,300,000	89%	\$ 1,576,200,000	90%	\$ 8,897,000,000	82%
	O&M	\$ 154,300,000		\$ 251,700,000		\$ 249,000,000		\$ 274,900,000		\$ 320,200,000		\$ 1,250,000,000	
UMS	RDT&E	\$ 57,300,000		\$ 73,800,000		\$ 63,200,000		\$ 70,100,000		\$ 76,900,000		\$ 341,000,000	
	PROC	\$ 56,700,000	2%	\$ 78,400,000	3%	\$ 95,900,000	5%	\$ 91,600,000	5%	\$ 103,700,000	7%	\$ 426,000,000	4%
	O&M	\$ 5,000,000		\$ 4,500,000		\$ 11,300,000		\$ 13,500,000		\$ 13,900,000		\$ 48,000,000	
TOTAL		\$ 4,823,000,000		\$ 4,513,000,000		\$ 3,393,000,000		\$ 3,260,000,000		\$ 2,911,000,000		\$ 18,900,000,000	

Table 1 FY2009–13 President’s Budget for Unmanned Systems¹⁰⁵

Based on the available information, the autonomous convoy capability appears to be towards the bottom of the Department of Defense’s unmanned system priorities. Unmanned aerial vehicles have proven worth on the battlefield, with their ability to gather intelligence and even conduct combat operations, but perhaps they have reached an acceptable level of capability and capacity.¹⁰⁶ Reprioritizing the funding and thereby research talent towards development of an autonomous ground transportation system will help save lives. Within the unmanned ground vehicle category, the explosive ordnance disposal (EOD) robots have a higher priority than the autonomous convoy. This is understandable, given that the EOD technicians are highly trained soldiers who routinely place themselves in extremely dangerous situations. However, based on the CAST’s demonstrated ability to aid military drivers in discovering threats to their convoys more quickly, perhaps the Department of Defense should consider changing its funding priorities. Identifying the threat is the critical first step before the EOD technician is even made aware of the problem. Changing the funding priorities is likely to increase civilian capacity thus lead to the development of an autonomous convoy capability earlier than the current 2022 goal.

¹⁰⁵Ibid. The original chart has been modified to show the percentages within each fiscal year, comparing each of the categories.

¹⁰⁶Defense Industry Daily, “Too Much Information: taming the UAV Data Explosion,” May 16, 2010, <http://www.defenseindustrydaily.com/uav-data-volume-solutions-06348/> (accessed March 14, 2011).

Robotics Development Challenges

Operations against an unknown adversary, at an unknown location, in complex environments (environmental, societal and political) will “degrade the conventional military advantages of speed and knowledge.”¹⁰⁷ This causes the Army to ensure that any fielded system is able to gather enough contextual information from its environment to perform its mission without significant degradation. This future system must not rely on any one means of obtaining and processing that information into knowledge. Mountains can block global positioning satellite signals;¹⁰⁸ satellites may be shot down;¹⁰⁹ and there are sure to be hundreds more examples of events that have not been anticipated. The DARPA Challenges pushed civilian research and development to find ways to gather information from the environment, quickly process it and have the autonomous vehicle respond in an appropriate manner. New technology should not inhibit or put at risk the maneuver plan any more than current systems do. It must perform at the same or better than the distribution systems in the current force structure.

Military sustainment operations cannot hinder operations or be rendered obsolete when the military deploys to a new part of the world and must be able to “integrate with multiple new partners.”¹¹⁰ Military equipment, as the autonomous convoy capability comes into being, must be as capable of understanding and operating within the environment it is placed. Vehicle operations will not be confined to just one military service or just within an American military

¹⁰⁷U.S. Army, FM 1, *The Army*, 2-3.

¹⁰⁸Eric Schmitt and Thom Shanker, “More Satellites Will Act as Eyes for Troops,” *The New York Times*, 23 February 2010, <http://www.nytimes.com/2010/02/24/world/asia/24satellites.html> (accessed February 12, 2011).

¹⁰⁹CNN, “Navy Missile Hits Dying Spy Satellite, Says Pentagon,” February 21, 2008, <http://www.cnn.com/2008/TECH/space/02/20/satellite.shootdown/index.html> (accessed February 12, 2011).

¹¹⁰U.S. Department of Defense, *Joint Supply Joint Integrating Concept* (Washington, DC: Government Printing Office, March 31, 2010), ii.

footprint, so programming must not be confined to a single set of processes.¹¹¹ Autonomous vehicles must interact with the environment. Determining specific upload and download locations, how to get to those locations and understanding changes in the environment are likely actions that would be determined on the ground with verbal cues and/or hand and arm signals.

Reducing the number of drivers moves the burden in two directions; either to another person or machines will have to perform these critical tasks. The challenge for developers is to find the best way to reduce reliance on humans while not increasing the cost per unit with accessories. Some driver responsibilities to consider include strapping down the load, tightening straps during movement, refueling, taking accountability for the load, camouflaging the vehicle, maintenance inspections and help with maintenance repairs. Every permutation of a driver's responsibility must be considered, by the vehicle developer in consultation with the military, to enable product development that enables sustainment operations within the complex environment in which the military operates.

DOTMLPF

The DOTMLPF (doctrine, organization, training, materiel, leadership and education, personnel and facilities) model provides the Department of Defense with a frame for building and maintaining its joint forces from a strategic perspective. It is one of “three key processes in the DOD that must work in concert to deliver the capabilities required by the war fighter: the requirements process; the acquisition process; and the Planning, Programming, Budget and

¹¹¹Phillip Henson and David McClean, “Moving the Force Across Europe: EUCOM’s Joint Movement Center,” *Army Logistician* (September-October 2004), <http://www.almc.army.mil/alog/issues/SepOct04/europe.html> (accessed March 14, 2011). EUCOM’s support to Balkans highlights the challenges that must be considered. How does an autonomous vehicle convoy move across eight countries, over multiple days, using host nation support along the route? At least initially, the answer requires a human to help with the processes that are beyond a vehicles capacity. Kent Jo Ling’s article about the autonomous vehicles that drove from Italy to Asia highlighted this challenge when humans had to pay the tolls. VisLab overcame the refueling problem by using solar power, which came at the price of time to complete the trip, which took over three months to accomplish.

Execution (PPBE) process.”¹¹² Bringing an autonomous vehicle onto future battlefields requires detailed planning to reduce the potential for failure. Assuming that Joint Requirements Oversight Committee (JROC) concurred with the capability gap within the U.S. Army and U.S. Marine Corps, what are the likely considerations for the services? Below, each portion of the model has been broken down and filled in with some of the many, but likely not all, complicated and complex issues that must be addressed prior to and during implementation as well as revalidation over the course of the Army’s use of autonomous logistics vehicles within its formations.

Doctrine addresses how the military’s land forces fight (e.g. emphasizing combined arms warfare).¹¹³ The inclusion of this technology into the military should allow maneuver commanders to increase the tempo of their operations. Autonomous sustainment vehicles should be able to supply almost double the number of supplies as a manned vehicle in the right conditions. As the unmanned logistical systems become more capable operating with forces, the newfound abilities may allow commanders to envision a new methodology for “achieving a position of advantage [relative] to the enemy.”¹¹⁴ U.S. Army sustainment doctrine is currently adequate for the implementation of the CAST technology. Soldiers remain with each grouping of vehicles, providing onsite controls when the situation overwhelms the onboard computers and sensors. Movement control doctrine should consider, as autonomous vehicles become more prevalent, how to respond quickly to convoys along the routes. Without humans, simple problems will require quick fix teams (mechanical and computer) capable of moving quickly to the convoy in order to get them operational again.

¹¹²U.S. Defense Department, CJCSI3170.01G, *Joint Capabilities Integration and Development System* (Washington, DC: Government Printing Office, March 1, 2009), <https://acc.dau.mil/CommunityBrowser.aspx?id=267681&lang=en-U.S.> (accessed December 3, 2010).

¹¹³ACQuipedia, “DOTMLPF Analysis,” <https://acc.dau.mil/CommunityBrowser.aspx?id=28870&lang=en-U.S.> (accessed December 3, 2010).

¹¹⁴U.S Army, FM 3-0, *Operations*, 4-3.

Organization is how we put together our units in order to fight (e.g. brigade support battalions assigned to brigade combat teams and sustainment brigades attached to the theater sustainment command).¹¹⁵ Given the nature of the technology, there should be a shift in the organization of transportation units to support military operations. This shift though, will start within the current organizations, reducing the required drivers required to operate the current equipment. With technological improvements gained from feedback from users, the driver-supervised vehicle will likely transition to autonomous operations monitored digitally from a tactical operations center. In the event of a vehicle breakdown, autonomous convoys must have the ability to recover or to tow broken vehicles back to a repair facility.

The highest requirement needed is to ensure that the convoy gets to and from its intended destinations. Since the technology draws value by making more trips than a manned convoy is capable of, it loses its benefit every time it is stopped on the road. Given the level of financial investment, initially these autonomous vehicles cannot be put on the road without some physical protection. Unfortunately, the quality of software programming is not yet sophisticated enough to trust the vehicle with a weapon. As technology improves, the vehicles could handle convoy security themselves, but in the meantime, the responsibility for convoy protection must remain with manned vehicles.

Robotics requires highly technical individuals to keep them operational. The significant increase in electronics hardware, in the vehicles, without an equal decrease in other military maintenance requirements, will overwhelm the current authorization of electronics maintenance technicians. Though contractors provide the first couple of years support, deploying with the organization, eventually maintenance responsibility falls back on the supporting maintenance unit. The existing maintenance structure should have enough structure and leadership to absorb the additional maintenance soldiers.

¹¹⁵ACQuipedia.

The additional manpower gained with autonomous vehicles provides options to the military services. In the short-term, soldiers could be reallocated to another transportation company to fill shortages. As the equipment proves its ability, the decision-maker has to make tougher choices: reduce the military's overall strength or rebalance the force (retraining transportation soldiers to be another branch, such as military police or engineers).

Training describes how we prepare to fight (e.g. soldiers attending basic training and training exercises).¹¹⁶ The education and continuing training of ground vehicle system repairers will be critical to ensuring operations will continue. Initially, the contractor must train units receiving the equipment and soldiers going through their advanced training. After a period of two to four years, the military should be capable of sustaining the education of its sustainment soldiers at Fort Lee, Virginia. Training exercises in their current form will likely remain the same.

The materiel category considers both the vehicle system itself and repair parts that are required by military forces to perform their missions.¹¹⁷ For at least the next 10 years, the military should modify its existing logistical vehicles to perform the autonomous vehicle role.¹¹⁸ If the 'experiment' fails to provide an actual improvement in efficiency or effectiveness, the hardware can be removed and military operations can continue with minimal impact. However, if over time, the system proves itself; new vehicles may not have that kind of flexibility. For example, having a cab, armoring and communication for a driver and vehicle commander might be a waste of space and considered for removal from future designs, in favor of a lighter vehicle or increased cargo-carrying capability. If, at this point, the environment in which the military

¹¹⁶Ibid.

¹¹⁷Ibid.

¹¹⁸Department of the Army, *Modernizing the Army's Tactical Wheeled Vehicle Fleet* (Washington, DC: Government Printing Office, 2005), 1, www.army.mil/aps/05/pdf/twv_whitepaper.pdf, (accessed February 20, 2011). As of 2005, the military's tactical wheeled vehicle fleet averaged 30 years old, with over 50 percent of the fleet approaching or exceeding its economical useful life.

must operate in exceeds the system's abilities, our flexibility to change back will be significantly hindered.

Robotics repairer(s) require environmentally controlled spaces to conduct missions in the field. Potentially, the requirement would be an additional cargo vehicle, maintenance shelter and, if the power required exceeded existing resources available, an additional generator. The tools of the trade required to diagnose faults and make repairs, to include the spare parts would add additional costs to this endeavor.

Leadership and Education describes how we prepare our leaders to fight, including professional development.¹¹⁹ Trust is the critical requirement to be gained here. During the formative years, it will likely take a concerted effort by leaders at all levels in showing acceptance of this new technology. Leaders that show interest in incorporating the technology, discovering new ideas and providing feedback to the developers will enable organizational gains. Over time, as technology proves its capacity, leaders may be more likely to trust the robot in a more autonomous role.¹²⁰

The personnel portion of the model ensures that the military has available qualified personnel for its organizations to perform their missions in war, peace and contingency operations.¹²¹ Until a completely autonomous vehicle is integrated into the military, as fewer operators are required to man vehicles, other requirements cannot be forgotten. Currently the loss of two soldiers, because of leave or becoming casualties, decreases a unit's ability by one vehicle. With more vehicles per soldier and fewer soldiers available, organizations still require some depth in personnel in order to provide the commander flexibility.

¹¹⁹Ibid.

¹²⁰Godin and Lemaire, 90.

¹²¹ACQuipedia.

Facilities are the real property (installations and industrial facilities) that are required to support our forces.¹²² Our current military facilities should prove to be sufficient for the inclusion of an autonomous add-on package on our existing logistical vehicles with some slight modifications. Units conducting robotics maintenance operations and instruction will need space to conduct their mission in a garrison facility. Whether this requirement exceeds existing structures would need to be studied on a unit-by-unit basis.

Conclusion

Contemporary and projected future military operations will continue to occur in complicated and complex environments. Operational commanders require a new capability to sustain their operations, in order to have an operational edge over their adversaries. Autonomous convoys will provide that flexibility. Since the U.S. Army and Marine Corps are resupplied predominantly by ground, the discussion about this capability has implications for both services. In future conflicts, soldiers and Marines are likely to be exposed to the same types of hazards they are encountering now in support of combat operations.

While the military recognizes the ability of robotics to remove some of these hazards to its personnel and equipment, it has been unable to advance the technology beyond research and development. In the interim, civilian manufacturing companies have taken on the challenge of developing solutions in their own interests, which could produce future military capabilities. Defense spending for unmanned systems has and continues to favor unmanned aerial systems over the ground domain. Over the next four years that prioritization will continue to grow, increasing the capabilities of air over that of ground based systems.

Reducing the forces required to deploy in order to support ground distribution operations provides the commander flexibility. Convoys can be put on the road almost immediately after

¹²²Ibid.

they arrive in the theater of operation. An autonomous convoy capability should provide a continuous and uninterrupted support needed by land combat forces. Vehicles will be traveling closer together at higher speeds in conditions that humans would be reluctant to travel in. Additionally, these autonomous convoys will help reduce injuries and death associated with the highest percentage killer on the modern battlefield, the improvised explosive device.

Autonomous vehicles will provide increased flexibility to the ground forces commander, since availability would no longer be tied to the alertness of the driver. Convoys will not be constrained by human concerns of rest but rather held back by the size of the fuel tank and maintenance readiness of the system. Once loaded, convoys can depart (individually or in groups with security, depending on the situation) much more quickly, increasing turn-around times. Weather conditions that would have prevented or at least hindered a manned convoy such as fog, blowing dust and nighttime operations might become feasible. The final consideration that normally is considered following the conflict is the cost of war. In recent conflicts, this cost has risen to over \$750,000 per soldier per year. Robots performing human tasks should decrease this financial consideration. With the obligation to provide medical care for our wounded troops long beyond the end of the conflict, any opportunity to remove soldiers and Marines from the combat zone should be pursued.

An autonomous convoy capability to sustain military operations would change the dynamics on the military's ground lines of communication in a positive manner. While any prediction about a future possibility is speculative, the evidence suggests the commander on the ground will gain the flexibility he needs to win our nation's wars.

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