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# THE U.S. COMBAT AND TACTICAL WHEELED VEHICLE FLEETS

## ISSUES AND SUGGESTIONS FOR CONGRESS


TERRENCE K. KELLY • JOHN E. PETERS
ERIC LANDREE • LOUIS R. MOORE
RANDALL STEEB • AARON MARTIN


Prepared for the Office of the Secretary of Defense

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RAND NATIONAL DEFENSE RESEARCH INSTITUTE

The research described in this report was prepared for the Office of the Secretary of Defense (OSD). The research was conducted within the RAND National Defense Research Institute, a federally funded research and development center sponsored by OSD, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community under Contract W74V8H-06-C-0002.

**Library of Congress Control Number: 2011921602**

ISBN: 978-0-8330-5173-8



*Cover design by Pete Soriano*



Published 2011 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
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# Summary

In Section 222 of the National Defense Authorization Act for Fiscal Year 2010 (Pub. L. 111-84), Congress directed the Secretary of Defense to contract with an independent body to assess activities for technology modernization of the ground combat vehicle and armored tactical wheeled vehicle fleets, and specifically to

- provide a detailed discussion of requirements and capability **needs**
- identify capability **gaps** for vehicles based on lessons learned from recent conflicts and an assessment of emerging threats
- identify critical technology elements or integration **risks** associated with particular categories of vehicles and with particular missions of such vehicles
- recommend **actions** to develop and deploy critical technology capabilities to address the identified capability gaps.[1]

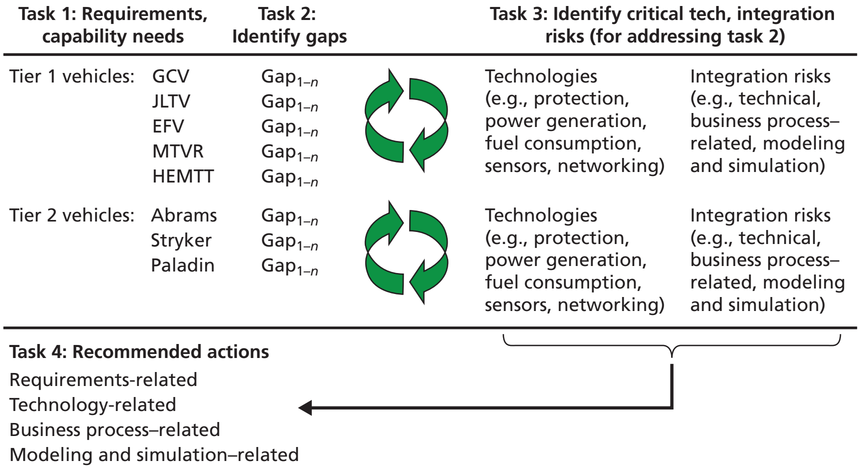
## Methods of Inquiry

This monograph reflects the results of the ensuing effort. Figure S.1 illustrates the basic process and the way in which the project's tasks culminated in a series of recommendations.

As the figure suggests, the research was organized around four tasks. The first task examined the requirements and capability needs

[1] Bold text highlights the logical links among needs, gaps in meeting them, risks that attend enduring gaps, and actions that seek to close them.

**Figure S.1**
**Research Process and Recommendations**




NOTE: GCV = ground combat vehicle. JLTV = joint light tactical vehicle. EFV = expeditionary fighting vehicle. MTVR = medium tactical vehicle replacement. HEMTT = Heavy Expanded Mobility Tactical Truck.

RAND *MG1093-S.1*

for a cluster of vehicles selected in cooperation with the sponsor to reflect attributes that might typify the universe of such vehicles. The research team collected official requirements and design documents from the Army and Marine Corps organizations responsible for them. Task two, identifying capability gaps, involved reviewing the official documentation for each vehicle, talking with Army and Marine Corps officials involved in the vehicles' development and fielding, and arriving at a list of capability gaps for the vehicles in the sample.

Once the capability gaps were identified, the research effort, through task three, identified critical technologies and integration risks for addressing the gaps in question. As the figure indicates, the research team was able to identify technology domains (i.e., protection, power generation, fuels and fuel consumption, sensors and networking) in which the most important capability gaps reside and the integration risks attending them. These risks lay in the technologies identified to close the capability gaps (e.g., immature, high-risk), business processes used by the Army and Marine Corps in managing the initiatives producing these vehicles or supervising their modifications and recapitalization, and modeling and simulation (M&S) in support of the research, development, and acquisition efforts that brought each vehicle into being.

At the point where the research team had formulated tentative observations about the issues confronting combat and tactical wheeled vehicle's research, development, and acquisition, we held a workshop to vet our findings with the DDR&E; the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics and other stakeholders in the Office of the Secretary of Defense; and Army and Marine Corps stakeholders. The workshop featured a plenary session in which the project team briefed its observations and some tentative findings and subsequently lead smaller "breakout" sessions to capture the reactions of subject-matter experts. There were three such breakout groups: one for technology, one devoted to business processes, and one for M&S. These sessions became the engine that drove the research effort to task four, identifying recommended actions.

## Observations on Closing Capability Gaps and Meeting Performance Requirements

Closing capability gaps and addressing performance requirements are difficult tasks. Part of the difficulty arises from the cycle of action-reaction between U.S. and enemy forces as they seek tactical advantages over each other. With tactical wheeled vehicles like the HEMTT, part of the difficulty lies in the fact that these vehicles are "repurposed" commercial trucks.[2] The more extensive the modifications necessary to close capability gaps or satisfy current performance expectations, the more expensive the work is likely to be. The challenge, however, is not limited to tactical wheeled vehicles.

Vehicles must provide the ability to manage the competing demands of operational requirements for power, protection, and pay-

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[2] An observation from an engineer and branch chief at U.S. Army Training and Doctrine Command (TRADOC) during discussions with the project leaders, October 20, 2010.

load or performance that induce size, weight, power, and cooling (SWaP-C) requirements. Sometimes, one of these considerations (e.g., protection) dominates the equation and thus dominates the other design criteria, as shown later in our discussion of the GCV. Sometimes, the appearance of new operational requirements can cause a new vehicle to evolve as a much different and more expensive vehicle than the one it replaces, as illustrated by the case of the JLTV, the successor to the high-mobility multipurpose wheeled vehicle (HMMWV). The current emphasis on affordability places additional constraints on the services' ability to manage SWaP-C requirements, develop materiel solutions to close capability gaps, and satisfy evolving performance requirements, as the Paladin Integrated Management program case demonstrates.[3] There are also instances in which a vehicle can play such a central role in fulfilling a service's mission, as the EFV does in the Marine Corps, that the service will accept lengthy schedule delays, significant cost growth, and substantially revised performance criteria to preserve the capabilities that the vehicle is expected to provide.[4] Finally, Stryker illustrates what can happen when circumstances surrounding a vehicle change dramatically. The Stryker began life as an interim vehicle until the Future Combat Systems (FCS) reached fruition and emphasized air-transportability for crisis responsiveness over other design considerations. Subsequently, the FCS was canceled, thrusting the Stryker into a new, extended role as a major part of Army force structure under circumstances substantially different from those anticipated for the vehicle when it was being acquired initially. As a result, it continues to have capability gaps in protection, mobility, lethality, and networking, despite vigorous Army efforts to adapt the vehicle for current opera-

[3] Affordability has always been a concern, but Under Secretary of Defense Ashton Carter recently emphasized this issue in a memorandum for the secretaries of the armed services and directors of defense agencies (Ashton B. Carter, Under Secretary of Defense for Acquisition, Technology, and Logistics, "Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending," memorandum to acquisition professionals, September 14, 2010c).

[4] As of this writing, Secretary of Defense Robert Gates has announced the cancellation of the EFV, but its fate remains undetermined as its proponents seek to challenge the decision.

tions, and illustrates the challenges of forecasting requirements far into the future.

## Modeling and Simulation

M&S can be helpful in this regard by identifying the limits to on-vehicle trade-offs and representing possible off-vehicle effects. Operational M&S can help with the problem raised earlier and can assist the combat developer and acquisition communities in defining operational and program requirements in the first place; program-oriented M&S designed to inexpensively evaluate individual vehicles (or other systems) or system components is critically important.

The primary challenge to M&S in the U.S. Department of Defense (DoD) appears to be in maintaining the agility to keep up with changing battlefield requirements and ensuring the development of new tactics and technologies. Among the trends we have seen that require a more streamlined and efficient analysis process are the following:

- Nontraditional acquisition and modular electronic architectures require more agile M&S processes to keep up with changing requirements.
- The trade-off of overlapping protection devices means that M&S must be able to quickly represent both the new capability and the impact on space claims, mobility, and power.
- Models will need to better represent special functions for electronic warfare, communication jamming, and interoperability to provide better situational awareness.

## Observations and Conclusions

Our analysis led to the following observations and conclusions.

**Requirements-Related Issues**

In our interactions with combat developers from the Army and Marine Corps, we found no evidence of fundamental flaws in their requirements development processes for the vehicles we considered. We were able to observe that arriving at a satisfactory set of requirements for tactical wheeled and ground combat vehicles is complicated by the fact that the vehicles remain in the services' inventories for decades. Combat developers typically have a deep understanding of current and near-term operating requirements, but they cannot unfailingly predict the future.

The implications of these circumstances are that, all but inevitably, *DoD will have vehicles in its fleets that were designed and built for requirements other than those it finds itself facing in the future*. This fact is driven by the wide spectrum of potential threats and scenarios in the 21st century and the fundamentally different physics and engineering problems presented by these threats. Choices will have to be made.

*The full set of desired operational requirements is unlikely to be met in many cases*. Because of the constraints on the trade space into which all vehicle requirements must fit, the resulting vehicles are unlikely to deliver 100-percent performance against all desired design criteria.

*The iron triangle of trade-offs is permanent*.[5] In particular, DoD will always want vehicles that provide better protection, have more power (electrical and mechanical), and perform better or are more capable (in terms of weight, mobility, and so on). No matter what technical advances are made, there will always be a drive to do better in these categories, and advances will help protect soldiers and marines; make the U.S. military more mobile strategically, operationally, and tactically; and increase performance. Investments in these areas will always be beneficial. As a result, *the vehicles resulting from this process may fail to meet all requirements but may nevertheless be satisfactory*.

These observations with respect to requirements have implications for technology- and engineering-related issues, as well as for acquisition-related processes. The technology- and engineering-related

[5] The "iron triangle" of trade-offs are those among performance (recently emphasizing power), protection, and payload.

issues most closely align with the questions asked by Congress; however, they will be much more likely to come to fruition at reasonable costs and within reasonable time frames if the acquisition process issues are also addressed.

### Technology-Related Issues

The study found four major technology-related issues associated with the vehicle fleets to be the most challenging with respect to meeting operational requirements. They were protection, power generation, fuels and fuel consumption, and sensors, networking, and complexity. We treat each issue in turn.

**Protection.** The critical observations with respect to protection are as follows:

- Protection requirements differ based on expected threats, and technical and engineering solutions will differ based on these requirements.
- Protection requirements consider onboard and offboard technology as well as vehicle design and integration improvements.
- Improving protection will be a permanent task to which technology and engineering will need to contribute (along with tactics, unit designs, and other factors); it will never be good enough.

**Electrical Power Generation.** The critical observations with respect to power generation are as follows:

- The advent of tactical networks, computer-based battle command systems, and expectations of battle command on the move, situational awareness, and various protection devices drive demand for electrical power upward. This trend will likely continue.
- In some instances, fitting larger alternators onto the vehicles to supply the necessary power is adequate, but in other cases, it is not. Some vehicles require large battery storage, fuel cells, or auxiliary power units to provide the necessary electricity and associated capabilities.

- Reducing the need for external generators and associated equipment and support enhances strategic and operational mobility and reduces logistical requirements.
- The demand for additional electrical power means that vehicles must be able to not only provide the electricity but also accommodate the space, weight, and cooling requirements associated with the additional equipment. The vehicle's space, weight, power, and cooling capabilities must be flexible enough to accommodate new equipment that evolves later.
- Their designs must have "open architecture" to accommodate future network-related equipment, along with the additional weight and space this equipment will claim on the vehicle and the heat the new components will generate.
- The demand for additional electricity affects the designs of both tactical wheeled and ground combat vehicles.
- Future vehicles will almost certainly be more expensive than their predecessors, in part because they will need advanced power-generating capabilities.

**Fuels and Fuel Consumption.** The critical observations with respect to fuels and fuel consumption are as follows:

- Fuel costs and availability are major factors in ongoing and possible future operations.
- The fully burdened cost of fuel and the logistics requirements for supplying fuel on the battlefield are important and not always taken fully into consideration during acquisition.
- Future conflict could pose even more challenges with respect to fuel, such as if U.S. forces were unable to secure enough fuel from international supply routes, forcing them to depend on local fuels (which at the moment they cannot use in many places without damaging some equipment).

**Sensors, Networking, and Complexity.** Sensors and networks are outside the formal purview of this study, but due to their significant effects on many aspects of vehicle design and modification—

including protection, power, space, and cooling considerations and providing required vehicle capability—how these functions develop and are implemented must be briefly considered. They are critical technologies that will be important considerations for Congress to examine. Given this fact, the critical observations with respect to sensors and networking are as follows:

- Sensors and networking contribute to vehicle complexity, which represents the possibility that unidentified dependencies and incompatibilities among components and subsystems will cause systems to fail.
- Hedging against the effects of complexity requires additional efforts in systems engineering and systems integration, with the understanding that some aspects of complexity are not well understood and thus cannot be easily identified and fixed.
- Complexity adds a greater chance for schedule slippage and cost growth for the vehicles currently under development than there was with their simpler predecessors.
- Increased complexity is the result of efforts to develop greater operational capabilities and better meet operational requirements. It cannot be done away with, so it must be well managed.

**Acquisition Policy and Business Process–Related Issues**

At least seven key observations based on prevailing DoD policies and business processes bear on the services' ability to field vehicles that are appropriate for the anticipated operating circumstances. These include the following:

- *The funding implications of the survivability of tactical wheeled vehicles:* As a result of current operations, tactical wheeled vehicles are acquiring more situational awareness and protection capabilities, thus growing closer to their ground combat vehicle cousins and more distant from their commercial counterparts. These trends mean more expensive vehicles in most fleets and, due to the large number of tactical wheeled vehicles, much more expensive fleets.

The trade-off between survivability and affordability presents a major policy decision for DoD and Congress.

- *Stable funding and vehicle requirements:* Many acquisition officials believe that funding instability and creeping vehicle requirements are among the biggest threats to their programs.[6]
- *Cost-estimating procedures:* Among the officials interviewed for this work who commented on cost estimating, most believed that life-cycle estimates were superior to unit cost estimates and that different acquisition decisions would be made and net life-cycle costs reduced if cost estimates more thoroughly included these considerations.[7]
- *Aligning the proper M&S tools to support decisions and decisionmakers:* M&S efforts do not appear to be fully aligned with the decisions they are meant to support (e.g., whether a materiel solution is warranted, technology development, analysis of alternatives, milestone decisions) and the information needs of the officials who will make them. If the services are to enjoy the full benefits of the M&S conducted to assist with the research, development, and support of vehicle programs, they must make a greater effort to perfect this alignment.
- *Acquisition category (ACAT) decisions that emphasize risk rather than just cost:* Risk, of which program cost is an important element, should be the dominant factor in ACAT decisions. Risk, the minimizing of which is the driving concept behind the decision, is not currently considered, except to the extent that cost is used as a proxy for risk. As a result, mature, well-understood, but expensive programs contemplating changes and modifications

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6 Funding can be unstable for a variety of reasons, including service or DoD funding decisions, changes in program costs that have the same effect as changes in funding levels (these two being the most common causes), and changes in congressional priorities (e.g., when Congress requires changes in programs that affect overall plans and budgets). This monograph does not examine these causes in detail but does note that unstable funding was the most frequently stated concern among program managers with whom the research team met.

7 There are indications that some of these concerns may be addressed through pending changes to acquisition practices. See the directions on how to consider cost estimates in the memorandum from Under Secretary Carter (2010c).

that pose little risk are nevertheless subjected to stringent requirements meant to manage risk.

- *Adequately resourcing programs from the beginning:* The consensus among the experts with whom we spoke emphasized the need to ensure that programs are appropriately resourced from the outset. This is particularly important for large, complex programs for which having the right managerial and technical talent in place early on is essential for success. While there are real challenges to ensuring that this happens, it is a critical element in the success of complex systems.
- *More fully integrated test and evaluation:* A number of experts interviewed for this work noted that, in practice, independent tests and evaluations sometimes led to new performance requirements for vehicles emerging at the end of a system's development that were not represented in the requirements documents. This late appearance of new performance criteria sometimes led to delays in final certification for the vehicle and often added to program cost and caused schedule delays as the program tried to satisfy the newly evolved standards. Testing and evaluation activities that are more closely integrated throughout the program's development would be more helpful.

## Trends

Equipping the armed services with tactical wheeled and ground combat vehicles will remain a challenging endeavor for the multitude of reasons cited throughout this monograph and summarized here. Some factors are clearly positive and should help ensure the acquisition of vehicles suitable for the anticipated circumstances. Some factors are clearly negative and complicate the task that the services face in equipping their forces. Still other factors are ambiguous at this point but could prove to be positive or negative as their effects become more visible.

### Positive Trends

The preference among program managers for relatively mature technologies at the beginning of the technology development phase of vehicle programs is clearly positive. The practice reduces dependencies on immature technologies that can lead to cost growth and schedule slippage when they do not develop as quickly as estimated. The practice also increases the probability that the technologies that are central to the vehicle's success will be more fully developed than otherwise would be the case and will therefore avoid negatively affecting engineering and manufacturing development.

The services' appreciation of systems engineering expertise is another positive development. Both the Army and Marine Corps seem to recognize the centrality of systems engineering to program success and appear to be trying to grow their capacity in this field.

The services have renewed their efforts to improve management practices and risk management, typified by knowledge points, competitive prototyping, gate reviews, portfolio reviews, requirements-stabilization initiatives, and other efforts described in Chapters Two and Three. To be sure, there is room for improvement here—for example, by insisting that all programs satisfy the criteria for being "born healthy," as discussed in Chapter Three.

Another positive sign lies in the responsiveness of the research, development, and acquisition communities. Collectively, they have shown an improved ability to produce needed vehicles in a hurry: mine-resistant, ambush-protected (MRAP) vehicles and the MRAP all-terrain vehicle (M-ATV) are good examples. They have also demonstrated responsiveness to Joint Urgent Operational Needs Statements and Operational Needs Statements, fielding B-kit armor for HEMTTs and HMMWVs, among other responses.

Modeling, simulation, and experimentation also hold great potential for improving vehicle designs, especially if this field evolves along the lines suggested in Chapter Five.

### Negative Trends

If necessity continues to drive tactical wheeled vehicle requirements closer to those of their ground combat vehicle cousins, that will surely have the salutary effect of affording their crews greater protection and situational awareness, but these positive developments will be accompanied by complexity and cost growth. As a result, new vehicles will almost certainly be significantly more expensive than the ones they replace.

This phenomenon will probably manifest across all vehicle fleets as recapitalization and replacement go forward. In addition, as the case of the JLTV suggests, there may be a divergence in requirements between the Marine Corps and the Army to meet performance criteria exclusive to each service. If this occurs, the unit costs of the vehicles in question will probably increase because of the loss of economies of scale when each service procures its own designs.

Also, there is the persistent vulnerability of the vehicle fleets to adaptive threats. As the GCV example suggests, this state of affairs can emphasize design criteria in favor of protection, and it can compromise all other performance dimensions in the process. Technology-based solutions to mitigate vulnerability are expensive, whereas the enemy's countermeasures are relatively cheap. It is impossible to protect the vehicle fleets from all threats solely with onboard armor, situational awareness, and active protection systems. At the same time, incorporating off-vehicle assets in trade-offs and calculations of vehicle requirements necessitates further assistance from the M&S community.

### Uncertain Trends

The potential of robotics and autonomous systems, on its face, seems significant. Perhaps it is, but until the services advance these technologies and develop concepts for their application in roles that would reduce the threat to tactical wheeled and ground combat vehicles, their future utility remains unclear. Removing soldiers and marines from harm's way is an important but perhaps insufficient contribution, especially if the costs associated with the systems in question rival or exceed those of the manned vehicles they replace.

The effects of the network on vehicles are another question mark. The FCS program revealed some current limitations. The key question is whether on- and off-vehicle capabilities can be integrated so that communication, situational awareness, protection, and power-generation requirements can be reduced for the vehicle fleets without significant increases in complexity and cost.

## What Congress Can Do

In this monograph, we present a number of strategic, technical, and business practice and process considerations that affect DoD's ability to field combat and tactical wheeled vehicle fleets that meet the country's needs. Some of these take the form of things to pay attention to or do, whereas others frame and, in some cases, constrain DoD's ability to field these vehicle fleets.

One major strategic observation that Congress should consider as it interacts with DoD on the development of vehicle fleets is that predicting future threats over the expected life spans of vehicles now in production is very difficult, and choices must be made and risk accepted due to the impossibility of designing vehicles that are optimal for all future threats. DoD leadership should articulate clearly what rationale it is using in vehicle fleet development (e.g., optimizing vehicles against a specific threat, as in the Cold War, or creating vehicles that are adequate for a spectrum of threats). Given the joint nature of conflict, this rationale should be considered by, if not standard across, each armed service. Congress should consider requiring that DoD present the strategic rationale for these choices *fleet wide*, as well as how each individual proposed vehicle fits within this rationale.

We highlight four classes of technical challenges that currently affect, and for the foreseeable future will continue to affect, the ability of the defense research, development, and acquisition communities to field cutting-edge vehicles that meet the operational requirements of fielded forces: the need for improved protection, power generation, and fuel consumption, and the effect that sensors and networking have on the complexity of modern vehicles, as well as the challenges that come with it. Because these are classes of problems that affect almost every vehicle (and many other systems) that DoD fields, they should be considered as such by Congress. In particular, in its oversight role, Congress should consider taking a role in ensuring that defense programs to address each of these challenges are adequate. This would include, but not be limited to, working with DoD to ensure that these areas are thoroughly addressed. Congress should consider making all four of these areas focal points of its interactions with DoD on research and development, new systems, and modifications to existing systems.

We also identify seven areas in which business practices, processes, and policy changes could significantly enhance the research, development, and acquisition and test and evaluation communities' ability to use resources and time more effectively to accomplish their tasks. Some of these challenges can be addressed—and may be in the process of being addressed or readdressed—by DoD (e.g., how cost estimation is done, how programs are staffed and supported for success, how testing and evaluation are done). Some may require congressional action in the form of guidance, changes to laws, or clarification of congressional intent with a focus on regulations (e.g., adopting ACAT decision practices that more realistically address risk rather than using cost as a proxy for risk).[8] And some, if not all, have cost implications that Congress should factor into the way it oversees vehicle fleet developments (e.g., the rising costs of tactical wheeled vehicles). In all seven cases, Congress may decide that the changes required to make progress will demand that it play some role. Furthermore, in all seven cases, Congress should consider asking for updates and challenging DoD to make or recommend changes.

Finally, a more comprehensive M&S capability and leaders who are empowered to use it well will be essential tools in everything from establishing future requirements to research and development to engineering, program design, and manufacturing. DoD and the services should consider improvements to their already substantial capabilities along the lines presented in this monograph, which will require support and guidance from Congress.

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[8] John Birkler, Mark V. Arena, Irv Blickstein, Jeffrey A. Drezner, Susan M. Gates, Melinda Huang, Robert Murphy, Charles Nemfakos, and Susan K. Woodward, *From Marginal Adjustments to Meaningful Change: Rethinking Weapon System Acquisition*, Santa Monica, Calif.: RAND Corporation, MG-1020-OSD, 2010.