Assessing Tracked and Wheeled Vehicles for Australian Mounted Close Combat Operations

Lessons Learned in Recent Conflicts, Impact of Advanced Technologies, and System-Level Implications

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Preface

The Australian government is on the verge of making major recapitalisation decisions about its mechanised land forces. The underlying modernisation initiative is referred to as Project LAND 400, which, along with training and integration capabilities, largely consists of replacing key combat vehicles, including the Australian Light Armoured Vehicle (ASLAV) and the M113AS4 armoured personnel carrier (APC) with an infantry fighting vehicle (IFV).[1] Project LAND 400 involves planning over a relatively long time horizon and by intent is shaping forces through a relatively low-risk approach that will, within this context, maximise combat effectiveness.[2]

To assist with this decision, the Defence Science and Technology (DST) Group asked the RAND Corporation for help in assessing the range of trade-offs between tracked and wheeled combat vehicle classes. This request entailed completing three tasks. The first task involved assessing lessons learned about tracked and wheeled combat vehicles in recent conflict in various parts of the world; the second task involved assessing the implications of advanced technologies on the vehicle classes;

1 The work here is focused on Phase 3 of the Project LAND 400 initiative. Phase 1 of the initiative was largely a scoping activity; Phase 2 is focused on a follow-on mounted combat reconnaissance capability, largely defined by a combat reconnaissance vehicle (CRV) replacement to the ASLAV; and Phase 3 is focused on a follow-on mounted close combat capability, largely defined by an IFV replacement to the M113AS4.

2 An industry presentation given by BRIG Greg McGlone, Director General, Combined Arms Fighting System, on November 27, 2015, indicates an interest in "minimising developmental risk" using "mature technologies with a growth path."

and the third task involved examining system-level implications of the different classes of vehicles.

This work should be of interest to Australian defence policymakers and planners, especially those directly affiliated with the Project LAND 400 initiative. U.S. policymakers and planners and other members of the American, British, Canadian, and Australian (ABCA) armies may find this work of interest, because it identifies the trade-off space that one of the core member allies of this group faces in its effort to modernise its mechanised forces, and it may offer ideas with respect to future integration and collaboration among the larger group of allies.

This research was conducted within the Acquisition and Technology Policy Center (ATP) of the RAND National Security Research Division (NSRD). NSRD conducts research and analysis on defence and national security topics for the U.S. and allied defence, foreign policy, homeland security, and intelligence communities and foundations and other nongovernmental organisations that support defence and national security analysis. For more information on the Acquisition and Technology Policy Center, see www.rand.org/nsrd/ndri/centers/atp or contact the director (contact information is provided on the web page).

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Introduction

In considering the attributes of modern combat vehicles, planners and policymakers often face a dilemma in achieving a balance between mobility, protection, and firepower—what is often referred to as the "iron triangle"—in assessing the combat effectiveness of such vehicles. While this can be said about any modern combat vehicle, achieving the correct balance is particularly applicable to infantry fighting vehicles (IFVs) because they have historically represented a compromise across all three attributes of the iron triangle, particularly when payload or number of personnel carried is added into the mix. For this study, which is being conducted for the Defence Science and Technology (DST) Group, the debate centers on the respective strengths and weaknesses of tracked and wheeled vehicles, because the Australian government faces a key modernisation decision as part of the Project LAND 400 initiative. Phase 1 of the initiative was largely a scoping activity. Phase 2 of the initiative, the mounted combat reconnaissance vehicle, will result in a new wheeled platform, for which the selection process is in the final stage.[1] The focus of this study is Phase 3, which lays out the plan for a new IFV. Existing requirements information suggests a tracked vehicle would be needed; however, the requirements also (as of the time of this writing) leave the option open for a wheeled vehicle.[2]

[1] Phase 1 of Project LAND 400 was a scoping activity to help shape the future direction of the army.

[2] Requirements are listed on the Project LAND 400 website.

The objective of this study was to help the Australian planners and policymakers by assessing the strengths and the weaknesses of tracked and wheeled capabilities in a general sense from three different perspectives, which were related to three tasks. From the first perspective (Task 1), we examined the expected performance in terms of the iron triangle of tracked and wheeled vehicles as a way to assess the lessons learned from the actual use of tracked and wheeled vehicles from recent conflicts in various parts of the world. The case studies examined were developed and prioritised in close coordination with members of the DST Group. The basic idea behind this specific assessment was to "connect the dots" between how combat vehicles were expected to perform based on technical, experimental, and operational analysis and how they actually performed in theater. *What kind of vehicles were employed and under what conditions? How were the different classes of vehicles used? Did the combat vehicles meet expectations? If not, where were the shortfalls and why did they occur?* In examining recent case studies, the balance of mobility, protection, and firepower—the iron triangle—was considered, among other key performance attributes. While this lessons-learned type of assessment only represents a portion of the overall assessment picture, it sets the stage for the other two perspectives in this study.

The second perspective (Task 2) involved examining how advanced technologies could affect the performance of tracked and wheeled vehicle capabilities into the future. In this part of the research, we examined several prospective technological capabilities that could alter the mobility, protection, and firepower of future vehicles. While some of these advanced technologies have not been fully tested nor implemented in the field, these technologies could be incorporated into modern militaries in the coming decade. Some of these technologies should be considered in any decision about the preference of one vehicle class versus another, because such technologies could help to close the existing performance gap between tracked and wheeled vehicles. Other technologies, external to the vehicle itself, such as those involving situational awareness for example, could improve the survivability and operational effectiveness of both wheeled and tracked vehicles over time.

The last perspective (Task 3) involved assessing the implications of tracked and wheeled vehicles from a broader, system-level perspective. Previous research conducted by the lead author showed the importance of considering performance at the system or unit level in addition to examining side-by-side vehicle class performance.[3] In the side-by-side comparison, the heavier vehicle can often be the preferred class because all three iron triangle attributes can concomitantly be improved.[4] However, there is a practical limit to this extrapolation, because heavier vehicles come with an increasing—potentially nonlinear—operational cost. These can take the form of increased logistics, specifically a higher sustainment and supporting force burden that the operational force would subsequently have to bear.[5] The impact of this can be correlated to the level of expeditionary use, in terms of both time and distance, of the deploying force.[6]

Task 1 Results: Expectations of Performance for Tracked and Wheeled Vehicles in Combat

While earlier studies have served to explain why tracked vehicles are better in some situations and wheeled vehicles in others, the technology is continuing to evolve. The long list of Project LAND 400 technical requirements and capabilities could change conventional thinking, albeit on a constrained scale, between tracked and wheeled vehicles. In addition to vehicle-centric technologies, there are weapons-based

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3 The lead author was a principal investigator in a study conducted for the Office of the Secretary of Defense for the U.S. Army's planned next-generation IFV, the Ground Combat Vehicle (GFV).

4 Here, we make the distinction between tactical mobility and strategic mobility; strategic mobility will not be improved.

5 This cost needs to be considered both from an operation and maintenance (O&M) perspective but also from a combat vulnerability and performance standpoint.

6 Ultimately, the marginal improvement in tactical performance (benefit) should be compared to the additional force burden that will be required to operate and sustain the heavier platform (cost). The results of this comparison would be highly scenario-dependent, but could be derived from modern force-level modeling and simulation tools.

technologies that an adversary can adopt that may change the performance of the iron triangle's tactical mobility, protection, and firepower. For example, the widespread proliferation of advanced shoulder-fired missiles, similar to the U.S. Army's Javelin, could change the calculus of traditional armour solutions as a means of protection. Active protection systems (APSs), on the other hand, may be able to defeat these weapons.

Task 1 Results: Lessons Learned About the Performance of Tracked and Wheeled Vehicles Used in Recent Conflicts

In examining recent conflicts for lessons learned about the performance of tracked and wheeled vehicles, we focused on nine case studies, which were developed and prioritised in close coordination with members of the DST Group. Those nine case studies are shown in Table S.1, which shows the scenarios and years, as well as the types of vehicles used, terrain and environment, and level and type of combat. The nine cases—and lessons learned from them—are organised into lower-intensity and higher-intensity categories here.[7]

Lessons Learned from Lower-Intensity Conflicts

Across the nine case studies, four of the cases—Mali, Balkans, Afghanistan, and East Timor—involved what we would refer to as comparatively lower-intensity conflict. In these cases, the missions ranged from peace enforcement and security operations to counterinsurgency (COIN) operations that involved small arms fire and improvised explosive devices (IEDs). Except for Mali, these cases involved the combined use of tracked and wheeled vehicle fleets. However, although both classes of vehicles were present in these venues, the bulk of the operations conducted abroad suggested an emphasis on using wheeled vehicles as the combat capability of choice. In Mali, which involved traversing very long distances of hundreds of miles, the French military planners

[7] The scenarios are presented here in the same order in which DST Group analysts prioritised the respective cases.

Table S.1
List of Recent Conflicts Examined in This Research

Scenario/Year(s)	Types of Vehicles Used (Tracked/ Wheeled)	Terrain and Environment	Level/Type of Combat
Mali 2013–2014	VAB, AMX-10, VBCI	Open desert, mountains, villages	COIN
Panama 1989	M551 Sheridan, LAV-25	Jungle and urban areas	Conventional combat against police and militia forces
Balkans (OAF) 1999–2002	M1, LAV-25, Bradley	Mountains, forest, villages	Peace enforcement
Iraq (OIF) 2003–2011	M1, Stryker, LAV-25A2, Warrior, Bradley	Open desert, suburbs, urban areas	Initially conventional combat, then COIN
Afghanistan (OEF) 2001–2014	Stryker, LAV-25A2, Warrior (UK), CV90 (Swedes, Danes)	Open desert, hilly and mountainous regions	COIN
Falklands 1982	Scorpion, Scimitar Light Tanks (UK), AML-90 (Arg)	Treeless open areas with boggy ground	Division-level conventional combat
Vietnam 1965–1975	M551 Sheridan, M113, M48	Jungle, highlands	Moderate-scale conventional combat and COIN
East Timor 1999–2000	ASLAV, M113	Jungle	COIN
Ukraine 2014–2016	BMP, BTR, T-64/72	Open steppe, urban areas	Conventional combat and guerilla warfare

opted to deploy a lighter and entirely wheeled vehicle fleet, keeping the heavy tracked forces at home but available as a contingency should the light wheeled force not succeed. Good intelligence, streamlined command and control, and favorable terrain were characteristics that contributed to the decision to use light wheeled platforms and ultimately enabled the force to succeed.

In the Balkans, the Kosovo Force (KFOR) units were equipped with both tracked and wheeled vehicles, which were not used in vehicle-to-vehicle combat; the extent of the combat, in both American and Russian sectors of the region, involved dismounted infantry with small arms firefights. In this case, mobility presented a challenge for both classes of vehicles. On the one hand, the rainy, muddy conditions during part of the deployment in cross-country terrain favored tracked vehicles, with some instances of wheeled vehicles getting stuck. On the other hand, infrastructure limitations, both operationally and tactically, constrained the movement of heavy tracked vehicles as they could cause damage to infrastructure, to roads and bridges, some of which were hundreds of years old.

In Afghanistan, where long distances were routinely traveled, U.S. forces relied heavily on Stryker vehicles equipped with slat armour; later in the deployment, they used mine-resistant ambush protected (MRAP) vehicles when the Strykers were shown to be vulnerable to mines and IEDs. These vehicles were often used to provide security to the sustainment forces that were distributing supplies to forward-based units. Although the United States deployed heavier tracked vehicles such as the Abrams, they were not generally used for day-to-day missions in COIN operations. Aside from being relatively burdensome to maintain compared to lighter vehicles, they were not ideal platforms to address the kind of weapons used by the insurgents in theater, which included high-explosive IEDs detonated on the underbelly of the vehicle or in a side attack on it. Other tracked vehicles such as the Warrior and CV90, which had modern mine protection, were used by a few other countries that deployed to Afghanistan. From a firepower perspective, light armoured vehicles (LAVs) available at that time were seen by some commanders as too limited in protection, resulting in heavier systems ultimately being deployed.[8]

In East Timor, the Australian military deployed the combination of tracked M113s and wheeled Australian LAVs (ASLAVs) for the peace enforcement mission. Heavier tracked Leopard main battle tanks

[8] One example of this: In the Canadian experience of combat with the Taliban, LAVs equipped with 25-mm weapons were seen as insufficient in certain situations. As a result, they deployed Leopard tanks, which were used to take down buildings in which enemy forces were located.

(MBTs) were kept as a contingency in the case of escalation; however, this need did not arise.

Lessons Learned from Higher-Intensity Conflicts

The remaining five case studies—Panama, Iraq, Vietnam, Falklands, and Ukraine—tended to involve higher levels of conflict, albeit with a wide variation in level of military training. This ranged from COIN battles to conventional combat against armour formations. In Panama, there was an emphasis on speed in the deployment, which influenced the selection of vehicles. Both light tracked and wheeled vehicles were ultimately used in the operation but in relatively small numbers.[9] For the urban combat part of this operation, the ability to provide high-angle elevation firepower was important, and the large caliber 152-mm weapon on the M551 Sheridan also proved significant in that it could penetrate walls of buildings to enable dismounted infantry entry points and clear roadblocks.[10] Thus, both wheeled and tracked vehicles used to support a U.S. light infantry operation performed as expected. In this particular scenario, lighter tracked vehicles were used in lieu of the heavier Bradley IFVs to streamline logistics and facilitate the speed of deployment.

The conflict in Iraq can be characterised as bimodal, involving both conventional combat and COIN. Early in the war, U.S. and British forces deployed and operated traditional heavy forces in offensive operations against Iraqi heavy forces. As the war unfolded, it quickly transitioned into a COIN that lasted over a decade, marked with pockets of intense but disjointed combat. In both conventional combat and some of the more intense COIN battles, there was clearly a preference for using heavy tracked forces, often centered on MBTs, because of their inherent armour protection and firepower advantage. As in Afghanistan, during the less intense COIN operations in Operation Iraqi

9 The Army did not have LAVs, so they deployed Sheridans and M113s; the USMC deployed LAVs at the Army's request.

10 David E. Johnson, Adam R. Grissom, and Olga Oliker, *In the Middle of the Fight: An Assessment of Medium Armored Forces in Past Military Operations*, Santa Monica, Calif.: RAND Corporation, MG-709-A, 2008.

Freedom (OIF), LAV-type vehicles with additional appliqué and slat armour (by both U.S. Army and U.S. Marine Corps [USMC] units) along with MRAPs were often used for the more day-to-day operations because of the greater efficiencies of these vehicles in long duration and long-distance operations.

In Vietnam, the U.S. Army employed light tracked vehicles such as the M113s and the M551 Sheridans, along with heavier M48s. However, despite much debate within Army leadership, many operations were conducted as infantry operations that had relatively little armour support; lighter tracked vehicles were vulnerable to weapons (mines and rocket-propelled grenades [RPGs]) used by a relatively unsophisticated adversary.

In contrast, UK forces used light tracked vehicles such as the Scorpion and the Scimitar with great success in the Falklands. Part of the difference in outcomes could be attributed to the difference in terrain, as well as to the difference in adversary training.

In the recent conflict in the Ukraine, a combination of medium and heavy tracked and wheeled vehicles were used by both sides, often employing reactive armour. Given the volume and sophistication of antiarmour weapons in this venue, losses of both tracked and wheeled vehicles were seen, albeit more so on the Ukraine side.

Synopsis of Lessons Learned

The cases examined in this research show that armoured vehicles can be exposed to a wide variety of threats. Vehicles originally designed with a specific threat in mind find themselves having to deal with a new, unexpected challenge. The U.S. experiences with mines and IEDs in Vietnam, Iraq, and Afghanistan are examples of this, where many of the armoured vehicles that were deployed were not designed to deal with those threats. This resulted in hasty modifications to tactics and to the vehicles themselves, as well as a need to purchase new equipment (e.g., MRAPs). Terrain also had a clear relationship to threats. For example, in Mali the relatively open terrain meant that the light French armoured vehicles could, for the most part, avoid close-range ambushes where they would have been highly vulnerable to RPG fire. However, in the jungles of Vietnam and the streets of Iraq, the American vehicles could be engaged at close range by these weapons. The reality that vehicles will be exposed to numerous types of threats should be considered when choices are made about future vehicle development and acquisition.

In the majority of instances, the vehicles performed as expected. However, looking across the case studies, we found that heavier tracked vehicles, including IFVs, were employed when one or more of the following circumstances occurred: the threat was known to have powerful antiarmour weapons or heavy armour forces; there was a great degree of uncertainty in the location (and composition), including dismounted forces of the threat; and/or there was a desire to deter escalation of combat. In the most notable conflicts where heavy tracked forces were used—in the combat phase of OIF and in combat in the Ukraine—heavy armour on the dominant side caused numerous adversary losses, with relatively few losses on the dominant side. Much of this can be attributed to notably higher-quality combined armed forces and training in conjunction with the heavy armour materiel. In most other conflicts considered, either light tracked vehicles or wheeled LAVs were used to address the majority of regional conflicts.[11] Part of the rationale for these lighter forces was the strategic and/or operational deployability and logistics benefits, which favor less heavy vehicles, especially so for wheeled vehicle fleets.

In more recent conflicts, there has been a notable desire and shift to wheeled vehicles over light tracked vehicles, which have largely gone away in the U.S. Army. In addition to Armoured Brigade Combat Teams (ABCTs), which feature heavy and medium tracked vehicles (e.g., M1 Abrams and M2 Bradleys), the U.S. Army has now fielded Stryker Brigade Combat Teams (SBCTs) with a family of LAV III variants, which were initially intended to be interim vehicles until the Future Combat System (FCS) was fielded and are now a major part of the deployable Army force structure.

[11] While lighter tracked vehicles such as the M113 and M551 Sheridan were used in some conflicts, they were employed because these were the systems available, particularly in the U.S. Army.

Task 2 Results: Impact of Advanced Technologies

Our research has shown that wheeled and tracked vehicles each have their advantages in terms of the iron triangle attributes (mobility, firepower, and protection) used to assess combat effectiveness and that each can be dominant in different domains and conditions. In critical off-road situations, tracked and wheeled vehicles are becoming closer in performance, primarily because of commercial investment in wheeled vehicle technological improvements. These include ride height adjustable independent suspensions, central tire inflation, antilock braking system (ABS) and stability control, and lockable differentials, which can collectively improve the performance of wheeled vehicles and in some cases mimic tracked vehicles, such as skid steering. Similar advancements for tracked vehicles would require significant expenditures. Even though tracked vehicles still maintain a significant advantage in soft soils and mud, wheeled vehicles are becoming more capable with such incremental improvements in technology. At the same time, wheeled vehicles have maintained or improved their performance in on-road speed, fuel efficiency, and stealth, reduced crew fatigue, and increased range.

New hybrid systems that bridge the gap between tracked and wheeled suspensions, such as tracks over wheels and band tracks, have significant potential to perform well in both off-road and on-road situations, but they are still at a developmental stage. Many of these configurations also have continuing maintenance and logistics issues.

Protection and lethality take many different forms, including passive armour, active measures, agility, stealth, situation awareness, and a variety of medium-caliber guns and small missiles. Tracked and wheeled vehicles allow different approaches to survivability. Tracked vehicles can carry heavier armour and larger weapons while maintaining mobility. Wheeled vehicles, however, are associated with agility, speed, and stealth, and they often have greater IED survivability because of increased ground clearance. But to make up for the lack of traditional heavy armour, the choice of lighter wheeled vehicles may require higher expenditures than tracked vehicles for close-in APSs, mass-efficient armour, long-range sensors, and other electronics.

In terms of lethality, the trade-offs between tracks and wheels is less clear. Today there are wheeled fighting vehicles armed with 105-mm and 120-mm cannons, although recoil can generally be better absorbed by heavy tracked vehicles. In some circumstances, such as moving along paved roads, wheeled vehicles can provide a more stable firing platform for medium-caliber weapons. Heavy tracked vehicles can provide a greater hedge in uncertainty against a reactive future threat, relative to wheeled vehicles that have an inherently lower load capacity.

Task 3 Results: Implications from a Systems-Level Perspective

If vehicle combat performance were the only thing that mattered, the heavier IFV would often be the preferred choice, because the attributes of the iron triangle—tactical mobility, protection, and firepower (and payload) used measure combat effectiveness—are all important and can all be concomitantly improved.[12] Because tracked vehicles have a higher maximum weight, it follows that such a class of vehicles tends to be the default choice for IFVs if they can be supported. But clearly there is a practical limit to the maximum weight, and what defines where that limit lies may change over time.[13] The system-level research that we conducted extends beyond the traditional iron triangle attributes (which tend to be platform-centric) to incorporate a broader impact to the operational units. Earlier research that RAND conducted suggests a strong correlation between vehicle weight, fuel consumption, and fuel resupply capacity.[14] On some level, it may be a reasonable adjustment to proportionally increase the number of refuelers and resupply vehicles in the unit. However, the challenge can be

[12] This assumes the profile or exposed silhouette of the vehicle can be managed with the greater size.

[13] Heavier and larger vehicles are also constrained by limits on bridges and tunnels. This tends to canalise the forces to specific routes, potentially increasing platform and unit vulnerability.

[14] Being fully loaded with appliqué can significantly reduce the fuel efficiency.

much more complicated, especially when force-level implications are considered.

As an example, say an M113 can typically travel approximately four miles per gallon of fuel.[15] In comparison, a Bradley class vehicle can travel approximately 0.6 to 1.2 miles per gallon of fuel over the same terrain, depending on how it is configured. Thus, all other things being equal, it will require somewhere around three to six times the number of refuelers to sustain the heavier vehicle. A natural inclination would be to proportionally increase the refuelers and resupply vehicles to accommodate this change. However, this may only translate to a first step. If the combat environment is not secure—i.e., one where security forces are needed to protect the refuelers—then the requirement for more security forces may have to be increased as well, requiring a larger force structure. This, in turn, may require a larger number of replacement vehicles. Overall, this adjustment process can lead to a cascading increase in support and combat platform requirements, which can significantly affect the size, the vulnerability, and/or the mission tempo associated with the unit.

Given that protection is a key priority identified for the replacement IFV (perhaps the highest, if the mounted combat reconnaissance vehicle priorities transfer to the IFV), the replacement IFV will have to be a much heavier platform than the one it replaces. Basic logic indicates that even as a contingency, some modest level of armour would be desired to protect against a full range of modern small arms fire seen across the spectrum of recent conflicts. Thus, regardless whether it is tracked or wheeled, the M113AS4 will likely be replaced by a system at least two, if not three or four, times heavier to enable this minimal level of desired protection. Current age and reliability issues of the older M113 aside, the supportability requirements of the new IFV platform will likely increase. Based on our research, a tracked vehicle will have significantly more supportability needs than those of an equivalently protected wheeled vehicle. To some extent, the selection of a wheeled IFV

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15 Endy M. Daehner et al., *Integrating Operational Energy Implications into System-Level Combat Effects Modeling: Assessing the Combat Effectiveness and Fuel Use of the ABCT 202 and the Current ABCT,* Santa Monica, Calif.: RAND Corporation, RR-879-OSD, 2015.

alternative will offset some of the added logistics that will be needed to support a heavier platform. Regardless, as a result of fielding these heavier vehicles, the system impact will likely involve some increase in the size of the supporting force that will accompany the new post-Beersheba[16] brigades.[17] Assuming that the IFV represents about one-third of these brigades, this could translate to an increase in logistics platforms from as low as 25 percent to as high as 100 percent, just with this one major change.

What the Assessment Means for Project LAND 400

There are a wide range of vehicles that are available that could effectively serve in the IFV role. This includes light (under 20 tons), medium (20–35 tons), and heavy (over 35 tons) vehicles both tracked and wheeled.[18] However, based on the lessons learned from recent conflicts, the technological changes ahead, and system-level concerns, it appears to us that some of the vehicle classes and/or types can be eliminated. Assuming that the Australian Defence Force (ADF) can only acquire one IFV, the lighter class of vehicles (under 20 tons) can likely be eliminated from further consideration. While these vehicles, both tracked and wheeled, have many excellent attributes, they do not typically offer robust enough protection to the wide range of small arms threats. Even in relatively benign threat environments, some level of armour, appliqué, and the possibility to upgrade to modern APS suggests that at least a medium-class (20–35 tons) vehicle should be considered if only one IFV can be acquired. Also, we find from an iron triangle perspective that the similarities between the tracked and wheeled vehicles in the medium class are becoming more apparent. While tracked vehicles in

[16] The Beersheba initiative refers to a major restructuring of the Australian Army, which effectively redistributes heavy armour across units accounting for the possibility of long-term sustained operations.

[17] At the time of this writing, it was not clear to what extent the weight and subsequent logistics and support growth were included in the post-Beersheba organisation.

[18] References to tons throughout this report refer to short tons.

this class have a tactical mobility advantage, this advantage is shrinking because of the new mobility technologies described above. Furthermore, wheeled vehicles in this class can provide similar levels of protection and firepower as their tracked counterparts, and they come with significant strategic and operational mobility, as well as logistics and supportability advantages. At the time of this writing, there are not many wheeled combat vehicles that weigh around or over 35 tons (examples include the German Boxer and the Israeli Eitan). Clearly, increasing tire size, as is done with large commercial vehicles, can overcome the ground pressure constraint. However, with any additional growth, such tires could become unwieldy for an IFV required to move with agility while maintaining a low profile, which could prove to be important in combined arms maneuver combat.[19] Breakthroughs in tracks over wheels may provide a long-term opportunity to change this; however, implementing this involves some technological risk, which is something the Australian government is seeking to minimise. Thus, by our analysis, this results in two general classes of vehicles that provide a competing set of strengths and weaknesses: a heavy tracked IFV or a medium wheeled IFV.[20]

In considering the broader Australian IFV requirements, the needs seem to be somewhat unique among vehicle acquisition programs and, further, appear to be bimodal. On one hand, there is a desire to provide force capability to directly support the M1A1 MBTs in heavy armour battles. This emphasises (as seen in the mounted combat reconnaissance vehicle requirements) that protection has a higher priority than lethality, that lethality has a higher priority than mobility, and that mobility has a higher priority than sustainability or command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR). This prioritisation scheme would correspond to major

[19] The heavy class of vehicles may accommodate 36 tons, as this appears to be a local maximum for the 475/80R20 tire size. Even with this size, compromises are present at over 35 tons due to more than 30 psi ground pressure, problems with clearance of tires, and increase in turning radius.

[20] Clearly there can be different ways to parse classes of vehicles, since the terminology of “heavy,” “medium,” and “light” as it pertains to vehicle class is evolving.

combat operations (MCOs) that likely could be conducted as part of a coalition effort with the United States. By applying the priorities identified with the mounted combat reconnaissance vehicle, the result tends to favor a heavy tracked IFV alternative.

On the other hand, there are many more demands that do not involve heavy armour battles, many of which reside in the regional engagements that the ADF is likely to confront in their own backyard. While there are needs for tactical mobility over soft terrain, these vie with requirements for long-range force projection over improved roads. The vehicles must be able to move and fight with the forward combat elements but also operate in operations other than war. There should be commonality, modularity, and integration with existing platforms and with the vehicles selected in the other phases of the Project LAND 400 initiative and other similar modernisation programs. If such regional engagements are the priority, the scale shifts in favor of a medium wheeled IFV. A key assumption here is that the regional threats remain on the lower end of the threat spectrum for the foreseeable future and that the type of missions center on operations other than war, such as peacekeeping and peace enforcement, rather than ones focused on heavy armour (non-MCO).

In a sense, it appears that the Australian choice highly depends on the relative importance of these competing bimodal requirements. Acquiring a heavy tracked IFV will ensure that the ADF is ready for the most difficult parts of the higher end of conflict. However, in most venues, this capability will be overdesigned, especially for many of those contingencies that are on the lower end of the threat spectrum. In these cases, there will be a large logistics and support tail that will come with a substantial cost. In a more general sense, high-intensity conflicts are not frequent and the costs incurred in conducting such combat operations are also infrequent, so the cost burden is transitory. So while the cost burden for heavy tracked vehicles can be much greater, its advantage becomes one of having a hedge in dealing with uncertain future threats that may require greater combat vehicle adaptability.

Acquiring a medium wheeled IFV is much more amenable for the many types of conflicts that Australia is likely to see within its own regional engagement zones, but it may introduce constraints in the Australian participation in MCOs where heavy armour forces are prevalent on the battlefield. There is also the cautionary issue of acquiring a platform that has sufficient headroom for adaptability to uncertain future reactive threats.

Currently, the U.S. Army addresses such divergent needs with different classes of vehicles; for example, both the Bradley (and its eventual replacement) and the Stryker families of platforms. In contrast, the USMC, which does not field Bradleys, has incorporated a wheeled fleet focus as it modernises for the future; for example, the replacement for the existing assault amphibious vehicle (AAV-7) was originally envisioned to be another tracked vehicle; however, it now appears destined to be a wheeled platform in the amphibious combat vehicle (ACV). Given that the Australian requirement for fielding a heavy armour force appears to be associated with serving as a partner to the United States in an MCO, it may be possible to predetermine roles where the Australian contribution in such future fights takes into account the relative strengths of combat capability, much like how Joint Forces within the United States are planned for, deployed, and ultimately employed on the battlefield.

The Path Ahead

In a post-Beersheba environment, the Australian Army might consider evaluating the full range of doctrine, organisation, training, materiel, leadership, personnel, and facilities (DOTMLPF) adjustments with both classes of IFV alternatives. Both will have an impact, and a heavy tracked IFV will involve more and/or different logistics units. Fielding these additional units will increase the size of the deployed footprint of the force, which may imply higher total force risk. These risks could be evaluated and understood ahead of time—before key decisions are made. Additionally, such a change will likely require substantive doctrine, training, and personnel changes throughout the force. Evaluating and understanding this impact could help with the specific IFV decision that needs to be made.

In parallel to the above, the Australian Army might consider conducting an official business case analysis (BCA) or similar net cost-benefit analysis.[21] In this analysis, stakeholder elicitation could be conducted to quantify the relative weights of the priorities associated with a future IFV decision. Furthermore, such an examination will provide a means to not only include the spectrum of Australian decisionmakers but also ideally other coalition partners, where key roles can be discussed relative to other force capabilities and future roles can possibly be predetermined. Finally, in parallel to a BCA, detailed force-level modeling and simulation (M&S) could be conducted to assess the force-level impact of specific IFV alternatives. The BCA and the force-level M&S should provide further information and guidance on specific IFV platforms.

[21] These are common analyses that are used to evaluate the viability of programs and alternatives in the U.S. DoD planning process.

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CHAPTER ONE

Introduction

Background

The Australian government is nearing a series of significant decisions about recapitalising its mechanised land forces. The initiative, known as Project LAND 400, consists largely of replacing key combat vehicles, including the Australian Light Armoured Vehicle (ASLAV) and the M113AS4 infantry fighting vehicle (IFV).[1] With a long time-horizon planning focus, Project LAND 400 aims to shape forces through a relatively low-risk approach that will, within this context, maximise combat effectiveness.[2]

Project LAND 400 consists of three phases. Phase 1 was largely a scoping activity. Phase 2 focuses on mounted combat reconnaissance, while Phase 3 focuses on the mounted close combat capability. Specific platform variants of Phase 3 include: 312 turreted direct-fire/high-survivability IFVs, 26 command and control (C2) vehicles, 16 joint fires vehicles, 11 engineer reconnaissance vehicles, 14 ambulances, 14 recovery vehicles, 18 repair vehicles, and 39 combat engineer vehicles. There is also a need for 17 maneuver support vehicles (MSVs). Ideal requirements for the IFV are that it is tracked and turreted, has high levels of protection, has mobility commensurate with the M1A1 main battle

[1] Phase 2 of the initiative is focused on a follow-on mounted combat reconnaissance capability, largely defined by a combat reconnaissance vehicle (CRV) replacement to the ASLAV, and Phase 3 is focused on a follow-on mounted close combat capability, largely defined by an IFV replacement to the M113AS4.

[2] McGlone, 2015.

tank (MBT), and would be capable of lifting a standard eight-man infantry battalion section.[3]

In an effort to keep a broad base of possibilities open (e.g., both acquisition cost and life-cycle cost in conjunction with performance capability), "there is a desire to consider all tracked and wheeled armoured fighting vehicles (AFVs) that have been used in the IFV role."[4]

Assessing Tracked and Wheeled Armoured Fighting Vehicles (AFVs)

Given the mandate to examine both tracked and wheeled vehicles, the Australian government needs to assess both types of AFVs. This includes weighing both the advantages and benefits of the two types of AFVs and understanding the primary mission the proposed AFV is supposed to fulfill.

The Advantages and Benefits of Tracked and Wheeled Vehicles

For the past several decades, a combination of tracked and wheeled vehicles has been used to accomplish a complex set of combat missions across a wide range of venues. The comparative benefits of these respective platforms are generally well understood, as shown in Table 1.1; this table was expanded and adjusted from Hornback (1998)—at the time of that article, Hornback was a general engineer with Training and Doctrine Command (TRADOC) Headquarters, Combat Development Engineering Division. Tracked vehicles have the advantage of offering improved traction over a wider range of terrain types because platform loads can typically be distributed over a larger ground contact or surface area, resulting in lower average ground pressure than if wheels were used.[5] As a result, heavier vehicles tend to be tracked; historically, the breakpoint for this has been around 20 tons for instances where most of the movement can be expected to be off-road, as is usually the case

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[3] "Project LAND 400," n.d.

[4] "Project LAND 400," n.d.

[5] The vehicle ground pressure can be calculated as psi, kPA, or kN/m^2. The softness of the ground directly determined using the vehicle cone index (VCI), the pressure required to press a cone penetrometer into the ground. The vehicle mobility index is then calculated based on a combination of vehicle pressure, weight, and design.

for close combat vehicles. Thus, tracked vehicles can typically offer greater off-road mobility than wheeled counterparts.[6]

In comparison, wheeled vehicles tend to have higher road speeds, involve less logistics support, generate lower operation and sustainment (O&S) costs, have lower operational noise (e.g., for reconnaissance missions), and are easier to transport from a strategic mobility perspective. And while tracked vehicles have traditionally offered much better tactical mobility, protection, and firepower, new technologies have the potential to close the gap somewhat in some situations, such as advanced all-wheel steering in close quarters, improved suspensions and tires, more effective protection against rocket-propelled grenade (RPG) threats, and greater lethality with larger turreted automatic cannons.

From a U.S. perspective, the Stryker vehicle (variant of the LAV III vehicle by General Dynamics and General Motors Canada) was used extensively in recent conflict in both Iraq and Afghanistan by U.S. Army forces. While the Stryker vehicle was initially intended to serve as an *exigent* combat vehicle within the interim force, as a precursor to the Army's Future Combat System (FCS), it was instead used extensively as an infantry carrier vehicle (ICV) in both Iraq and Afghanistan, and it is now a major and enduring combat vehicle for the U.S. Army within its Stryker Brigade Combat Teams (SBCTs). Beyond the addition of slat armour protection, which reduced vulnerability to RPGs, these vehicles have recently undergone further improvements in survivability (e.g., modification to include a double V-shaped hull to improve mine and improvised explosive device [IED] protection). For the most part, the Stryker vehicle has served in recent conflict as an ICV for the U.S. Army, with a range of variants, including the M1128 Mobile Gun System (MGS). However, as new survivability and armament capabilities are included in current and future generations of this platform, there is a greater prospect for it to serve in other capacities on the battlefield.[7]

That said, recent combat experience with the Stryker vehicle, as well as other wheeled combat vehicles, in Afghanistan and Iraq highlights

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[6] References to tons throughout this report refer to short tons.

[7] This can include variants with larger caliber weapons and possibly advanced active protection systems (APSs).

Table 1.1
Areas of Advantage for Tracked and Wheeled Vehicles

Attribute	Tracked Vehicles	Wheeled Vehicles
Route Flexibility	x	X
Cross-Country Mobility	x	
Traction on Slopes	x	
Gap & Obstacle Crossing	x	
Maneuver/Turning Radius[a]	x	
Road Speed		x
Logistics		x
O&S Costs		x
Operational Noise		x
Transportability		x
Survivability[b]	x	
Gross Vehicle Weight, Volume, & Payload	x	
Weight Growth Potential	x	

NOTES: Transportability refers to the ability to move strategically rather than to stability during movement.

[a, b] New technologies can change the outcome in these categories by authors' assessment—please see Chapter Four in this report for details.

This study will also consider other aspects such as acquisition cost, commonality with other platforms, signatures other than acoustic, and shock and vibration leading to fatigue.

SOURCE: Expanded and adjusted from Hornback, 1998.

some of the challenges. Many of the shortcomings go back to the key "iron triangle" concept of tactical mobility, protection, and firepower.[8] As noted earlier, the off-road mobility of tracked vehicles exceeds that of wheeled vehicles, and because tracked vehicles have the growth flex-

[8] The iron triangle is a notion put forward by the warfighting community as a way to think about the trade-offs associated with mechanised armoured vehicles.

ibility to carry heavier payloads, they can offer greater protection and firepower. As a case in point, in its initial plan, the U.S. Army opted to replace the Bradley M2 series IFV with a much larger and much heavier IFV called the ground combat vehicle (GCV), where some early design concepts exceeded 80 tons.[9] Even with a paring down of weight over time, more recent concepts still exceeded 60 tons. While the requirements suggested a need to be able to operate in a major combat operation (MCO), there was clearly a desire to avoid the losses to IEDs seen in Afghanistan and Iraq. This resulted in a platform that would be robust against a representative low-end threat but not necessarily survivable against a higher-end threat. It would certainly not be robust at a system or unit level of operation, particularly when the basic protection concept, the larger physical size, and increase in logistics requirements were taken into consideration. In response, the program was cancelled, and a portion of this effort has morphed into the much lighter Armoured Multipurpose Vehicle (AMPV) program, which is examining options for replacing M113s in key support and command roles by the late 2020s.[10]

The Primary Mission of the Vehicle

As Australia considers replacing its current fleet of M113AS4 and ASLAV vehicles, a key concern beyond any comparison between tracked and wheeled vehicles in terms of combat effectiveness—the iron triangle—is system-level issues; such issues center on what the primary role of a new fleet of ICVs will be. The answer to this question should be based on a consideration of the most likely and/or most important missions of the Australian Army, which may not be the same. Is a replacement vehicle intended mostly to move infantry into the vicinity of their objective—the traditional role of armoured personnel carriers (APCs)—where they will dismount to accomplish their mission, or will a future vehicle be designed to participate in mounted combat where it can

9 Bernard Kempinski and Christopher Murphy, *Technical Challenges of the U.S. Army's Ground Combat Vehicle Program*, Working paper 2012–15, Washington, D.C.: Congressional Budget Office, November 2012.

10 Sydney J. Freedberg Jr., "70-Year-Old M113s: The Army's Long March to AMPV," *Breaking Defense*, March 31, 2015a.

be expected to be exposed to hostile direct fire on a regular basis—an IFV role?

There is an important distinction between APCs and IFVs. Since the half-tracks of World War II, APCs have been primarily designed to help the infantry get close to their objective. Ideally, APCs can find a location where the infantrymen can dismount from the vehicle as close to the objective as possible. APCs mount weapons and have armour, but they are not intended to regularly engage in the direct fire battle, although APCs are frequently used to provide fire support to their infantrymen. The American M113 or Soviet/Russian BTR (Bronetransportyor, lit. "armored transporter" or APC) series vehicles are examples of APCs.

Much more than the APC, the IFV is intended to go into harm's way. IFVs first started to appear in the 1960s when the Soviet BMP-1 (Boyevaya Mashina Pekhoty, or "combat vehicle for infantry") and the West German Marder were fielded. With much heavier armament than APCs, IFVs often had much heavier armour, although the Soviet BMPs have very limited protection. By the 1980s, IFVs were being armed with a variety of cannons from 20-mm to 100-mm caliber, often complemented with an antitank missile. Western IFVs, such as the Marder, the American Bradley, and the British Warrior, had much better protection compared to the earlier APCs like the M113, although their protection is much less than the heavier MBTs.

Directly related to the above consideration is the question of the types of threats with which the IFV will have to contend. Even APCs that are not intended to regularly engage in the direct fire battle ideally will have adequate protection against a variety of threats, including hostile indirect fire that includes artillery and mortars, side and underbelly protection against mines and IEDs, and some degree of enemy direct fire such as heavy machine guns or light cannons (e.g., 14.5-mm). If, on the other hand, a new IFV is intended primarily to engage in the direct fire maneuver battle along with MBTs, it will need larger weapons and much better protection. In either the APC or IFV role, the level of protection will be a key variable in terms of vehicle weight.

Threats to combat vehicles can be generally broken down into a series of categories.

Mines and IEDs

These are primarily threats to the sides and underbelly of vehicles. Depending on the level of protection required, a considerable amount of weight might have to be devoted to mitigating this class of threat, since for the foreseeable future mine and IED protection will probably require passive, ballistic armour.

Indirect Fire

Hostile mortars and artillery (including both cannons and rocket launchers) are the primary threats here. Most hostile indirect fire will be unguided high-explosive or scatterable submunition warheads that could achieve an occasional direct hit on the vehicle, or more likely, burst close by, showering the vehicle with fragments. As time passes, the indirect fire challenge will increasingly include precision weapons or submunitions that will have a much greater likelihood of scoring a direct hit on a target vehicle, often on the top surface (engine, hull, or turret). Against some types of indirect fire threats, passive armour on the top of the vehicle may be sufficient, but as the indirect fire weapon increases in size, a point will be reached where the only means to defeat the weapon will be to use some kind of active system to destroy or spoof the incoming weapon before it strikes the target vehicle.

Chemical Energy and Shaped-Charge Weapons

High-explosive antitank rounds and antitank guided missiles (ATGMs) and RPGs are the prime examples of this type of threat. In recent years the penetrating power of shaped-charge weapons has increased considerably, forcing armoured vehicle designers to consider new versions of explosive reactive armour (ERA) and APSs to defeat these warheads before they contact the hull or turret of their target. Some of the heaviest MBTs can still resist these weapons with their base passive armour. However, for vehicles of 40 tons or less, passive protection is increasingly problematic against this class of threat. That said, it is possible that vehicles of less than MBT weight can defeat these threats if they have the right type of defensive systems such as ERA and APSs.

Kinetic Energy (KE) Weapons

These are primarily munitions fired from the medium (20–50-mm) or large-caliber (75–125-mm) guns on fighting vehicles. There are still a few armies that field towed antitank guns, but these are increasingly rare given the capability of modern ATGMs. KE weapons rely on the speed, density, and mass of the projectile to defeat and penetrate armour. Usually achieving velocities of 1,500 meters per second or higher, KE penetrators are very difficult for APSs to defeat, and ERA tends to be only marginally effective against them. When fired from medium-caliber guns, the KE penetrators are usually fired in a burst of several projectiles, which makes it even harder for APSs to cope with them. For the foreseeable future, the defence against KE rounds will mostly be in the form of passive, ballistic armour. This is an important issue, because depending on what level of KE weapon must be defended against, the weight of the vehicle will grow accordingly. It is unlikely for an APC or IFV that weighs less than 50 tons to defend against a KE penetrator fired from a tank main gun. Modern 30–40-mm medium-caliber guns can also penetrate considerable amounts of armour, although much less than a 100–125-mm tank gun. Selecting an appropriate level of protection against this class of threat will have a major impact on vehicle weight.

Objective and Approach

In mid-2016, the Defence Science and Technology (DST) Group asked the RAND Corporation to help it assess the range of trade-offs between tracked and wheeled combat vehicle classes. The request involved three tasks as follows:

1. Assess lessons learned about tracked and wheeled combat vehicles in recent conflict.
2. Assess the implications of advanced technologies on the vehicle classes.
3. Examine the system-level implications of the different classes of vehicles.

In terms of the first task, Tenant Number 7 of key factors to be considered[11] in Project LAND 400 reads as follows:

> **Informed by Lessons Learned.** The process of modernising our AFV fleet is constantly informed by a variety of sources. Threat assessments from the Defence Intelligence Organisation and the views of our friends and allies are essential in developing and refining the user requirements of the respective platforms. Experimentation from Defence Science and Technology Organisation and Army's experimentation unit have informed key decisions on numbers of vehicles and methods of operation. AFV programs undertaken in other nations have yielded key observations and lessons on the management of project costs, risks associated with setting aspirational capability requirements and the need for constant engagement with key stakeholder audiences. And a rigorous program of risk mitigation, tests and evaluation is planned to ensure the vehicles can do what manufacturers say they can do and meet the key requirements of Australia's operational circumstances. Perhaps most importantly, the utility and flexibility of AFVs being pursued under Land 400 has been proven over the last decades of operations, from peace support operations in Somalia and East Timor (Timor-Leste) to high-end warfighting in Afghanistan . . . and continues to be proven in current operations across the globe.

Our approach for the first task—understanding and assessing lessons learned—had two major components: (1) a technical assessment of tracked and wheeled vehicles in terms of their expected performance in combat relative to the iron triangle attributes that are typically used to measure combat effectiveness; and (2) a review of recent case studies or scenarios where tracked and wheeled vehicles were used. By taking a two-pronged approach, we were able to more fully address two key research questions:

- What has been the expected performance, based on earlier analysis, of tracked and wheeled vehicles in combat?

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11 "Armoured Fighting Vehicles," n.d.

- Did the respective tracked and wheeled vehicles meet expectations once fielded in recent combat situations?

To address the first question, we developed a context for what is meant by "performance." Because combat vehicles are intended to do different things, performance measures vary considerably based on missions and conditions—these performance measures need to be defined at least to the first order. In addition, we reviewed the relevant technical literature and corresponding analysis.

To address the second question, we conducted a literature review of recent scenarios where wheeled and/or tracked vehicles were used. The RAND team then compared the observed performance to expectations of performance to determine whether the tracked and wheeled vehicles performed as expected. It is possible the vehicles did not perform well in a scenario, but this poor performance may have been based more on *how they were used* rather than because they fell short of expectations or requirements. It is also possible that adaptations were made, in the field or otherwise, that enabled superior performance, above and beyond expectations. In these cases, we call out these examples, because they might apply to Australia's future needs.

This lessons-learned type of assessment only represents a portion of the overall assessment picture here—the first of the three tasks. However, the lessons-learned assessment is important in setting the stage for the other two tasks—assessing the implications of advanced technologies on the vehicle classes and examining the system-level implications of the different classes of vehicles.

In terms of the second task, there are many different current and future technologies that could mitigate the historical problems noted with both tracked and wheeled IFVs—technologies that can change the expectations for performance (e.g., through new and lighter armour, APSs, and new advanced weapons). Based on our previous research, as well as discussions with U.S. Army, U.S. Marine Corps (USMC), and military and civilian staff from other countries, we compiled and assessed a list of key vehicle technologies.

In terms of the third task, we focus on the system-level impacts of the selection of combat vehicles—on how the decisions made on both the weight and the type (tracked or wheeled) of vehicle can have a significant impact on the unit as well. For example, heavier tracked vehicles will mandate more logistics support than less heavy wheeled vehicles. These implications can be quite significant given the starting point of the vehicle to be replaced, specifically the M113AS4, which is a relatively light tracked vehicle. Here, we examine the system-level lessons learned from examining the U.S. Army's modernisation plan.

Organisation of This Report

This work is organised into five subsequent chapters. Chapters 2 and 3 focus on the results for the first task—the expected performance based on earlier analysis of tracked and wheeled vehicles in combat to highlight expectations of performance (Chapter 2), and the detailed lessons learned in the case studies, highlighting how different vehicles performed in conflict (Chapter 3). Chapter 4 focuses on the results of the second task, providing information on the role that advanced technologies can have in changing future expectations of performance. Chapter 5 focuses on the results of the third task, providing a discussion of the system-level implications of going with tracked or wheeled vehicles. Chapter 6 summarises our key findings and identifies a possible path ahead.

CHAPTER TWO

Task 1 Results: Lessons Learned About the Expected Performance of Tracked and Wheeled Vehicles in Combat

As noted in Chapter 1, Task 1 seeks to answer two questions. The answer to the first of those questions—what has been the expected performance, based on earlier analysis, of tracked and wheeled vehicles in combat?—is presented here, with the answer to the second question presented in the next chapter. We start by defining the measures of performance of combat vehicles, before turning the technical requirements for performance laid out for the Project LAND 400 IFV. Then, we discuss the lessons learned about IFV performance from previous tests and studies.

Defining the Measures of Performance of Combat Vehicles

Combat vehicle planners have used various criteria for examining performance of combat vehicles. Some criteria are driven by the level of protection needed, some are driven by number of soldiers carried, some driven by the class of the weapon mounted, and the list continues. However, it is normally a combination of requirements that ultimately defines a design. Some methodologies have been proposed for developing, scaling, and evaluating combat vehicles, in particular IFVs, from a combined-needs perspective.[1] However, if history serves as any example, designing a vehicle from the ground up to meet all requirements simultaneously,

[1] David R. Gillingham and Prashant R. Patel, *Method of Estimating the Principal Characteristics of an Infantry Fighting Vehicle from Basic Performance Requirements*, Alexandria, Va.: Institute for Defense Analyses, P-5032, August 2013.

especially where some capabilities have yet to be successfully demonstrated, has been an elusive goal.[2]

Ultimately, what warfighters seem to relate to in thinking about combat vehicles is the relatively simple tradespace known as the "iron triangle," which we discussed in Chapter 1. In this space, for a specified weight class, the three major key attributes that can be emphasised include tactical mobility, protection, and firepower. (In examining APCs and IFVs, the payload or number of passengers can also be included, which will contribute to the physical size.) As noted in Chapter 1, tracked and wheeled vehicles today come with known constraints that essentially define the shape of the triangle or tradespace that is available.[3]

For example, wheeled combat vehicles have recently been produced that exceed 25 tons, which was typically seen as the breakpoint based on ground pressure analyses conducted over a decade ago.[4] While many fielded wheeled combat vehicles tend to fall under the 25-ton threshold, there is a new IFV class of vehicles that have recently emerged and/or are forecast for the future that now exceed 35 tons. These are wheeled combat vehicles that have relatively good mobility and can carry a large number of passengers, but compared to heavier tracked IFVs, they still cannot match the tactical mobility and armour protection. While there are trades within the iron triangle that can be made, for wheeled vehicles, they tend to come with key concessions.

For example, there are wheeled combat vehicles that have large weapons to increase their firepower, but they sacrifice payload mobility and/or protection in doing so. One example of this is the MGS M1128 built on a Stryker (GM LAV III) platform. The MGS has a 105-mm

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2 The U.S. Army in particular has had difficulty designing combat vehicles to meet specifications. In some cases, such as the Crusader self-propelled howitzer and the FCS, the advanced technology was not ready; in other cases, such as the GCV, which relied on existing technology, meeting all the requirements resulted in a very large and heavy platform, which presented other operational challenges.

3 It should be noted that the variables in the tradespace are not strictly independent. Mobility and firepower can contribute to protection, and the added weight of additional protection can impair mobility and the size of weapon that can be carried.

4 There are wheeled combat vehicles well exceeding 20 tons, such as the South African Rooikat, European (German-Dutch) Boxer, and Italian VBM Freccia.

cannon, M68A2, and a crew of three to operate the vehicle. The ICV variant of this vehicle (M1126) is equipped with a .50-mm-caliber machine gun and has a crew of two, but it can carry nine combat-ready infantrymen and has slightly better protection. Wheeled combat vehicles in this weight class tend to have protection levels somewhere between 7.62-mm and 14.5-mm ammunition. While options exist for adding appliqué armour to increase protection, this typically comes with degradation in vehicle payload and/or mobility.

Tracked vehicles, in contrast, have a much higher upper bound for weight. As a result, they span a much wider range of the tactical mobility, protection, and firepower spectrum of tradespace. Tracked vehicles have exceeded 70 tons and within this weight range much heavier weapons can be mounted, along with massive armour and other protection systems. However, even with this weight, tracked vehicles such as MBTs still achieve high levels of off-road mobility. Protection of tracked vehicles, particularly those exceeding 40 tons, can be fairly high, because of their thick armour, low profile, ability to avoid ambushes by going off-road, and suitability for mounting APSs. At the same time, these heavy vehicles have serious shortcomings in highway speed and many other aspects.

Technology-Related Goals for Project LAND 400 IFV Performance

Phase 3 of Project LAND 400 posits or implies a large set of interacting (and sometimes competing) goals for the performance of armoured fighting vehicles in the IFV role:[5]

- low- and moderate-speed movement off-road, wet and dry, and significant slope; keeping up with armour vehicle fleet
- ability to cross obstacles, traverse ditches, and push vehicles aside

[5] See Australian Department of Defence, "RFI for Land 400 IFV Phase 3 Mounted Close Combat Capability," issued November 16, 2015; Julian Kerr, "More on Land 400 Phase 3," *Australian Defence Magazine*, November 27, 2015; and "Land Combat Vehicle System," Australian Department of Defence, n.d.

- high-speed movement over roads
- ability to survive IED attacks and continue even with suspension damage;
- agility in complex terrain
- ability to handle large combat loads, including armour packages and weapons
- carry sufficient firepower to fight the last 300 meters onto the objective
- fuel efficiency and low logistics burden
- ability to carry and protect infantry, mounting, and dismounting as required in combined arms operations
- operate quietly, with low acoustic, thermal, and other signatures
- commonality with other systems in the force.

Many of these factors are directly related to the ground pressure of the vehicles. The nominal contact pressure of a vehicle is obtained by dividing the vehicle's weight by the overall area of track or tire in contact when the vehicle is resting on a firm surface. For tracks, openings in the tracks and spacings between the links are considered part of the track in computing the area.[6] As a result, tracked vehicles often exhibit a ground pressure two to three times lower than wheeled vehicles.[7] Soil and terrain are also important in this mobility examination. Soils may be fine or coarse, have low or high strength or shear resistance, and can be sticky, slippery, or exist as mats of vegetation. These soils may also vary considerably under different weather conditions—wet, dry, freezing, or thawing. The soils can also be on level plains or on steep slopes and can have obstacles such as boulders,[8] ponds, ditches, and hedge-

[6] D. R. Freitag, *Tracks Versus Wheels in Soft Soil and Snow*, Miscellaneous Paper No. 4-651, Vicksburg, Miss.: Department of the Army, Waterways Experiment Station, Corps of Engineers, May 1964.

[7] Lutz Unterseher, *Wheels or Tracks? On the "Lightness" of Military Expeditions*, Project on Defense Alternatives Briefing Memo No. 16, Cambridge, Mass.: Commonwealth Institute, July 2000 (rev. December 2001). Unterseher notes that the mean maximum pressure (MMP) averages 300–450 kN/m^2 for wheeled and 200–270 kN/m^2 for tracked vehicles.

[8] Steep slopes can present problems for heavy tracked vehicles; as they move down the slope, the weight of the tank shifts downward and can make it more prone to throwing a

rows. Across virtually all these conditions, tracks have been found to be superior to wheels in traction, thrust, and maximum slope.[9]

However, off-road mobility is only part of the question. Project LAND 400 identifies many other factors in its evaluation, such as operation in the full spectrum of conflict against all levels of threat, ability to carry extra loads such as modular armour, survivability against mines and IEDs, ability to tow heavy vehicles, and the requirement for force projection with long road marches.[10] Some of these objectives can be better accomplished with wheeled vehicles. For example, it has been estimated that a 150-mile (250-km) intersectoral movement by a tracked unit would take anywhere from 14 to 18 hours, while a wheeled unit could accomplish this in about six hours.[11] The crew would be less fatigued, the roads less damaged, and support requirements greatly reduced.

In general, one of the primary operating environments for Australian Defence Force (ADF) is in the Asia-Pacific region, particularly the chain of island countries in the northwest area of the region, sometimes referred to as their regional engagements. This is largely littoral, with a combination of jungle, mountain, and urban terrain. The forces deployed to this region could be required to conduct fast-moving, dispersed offensive and defensive operations (non-MCO) on rough terrain and in urban areas with very poor infrastructure and relatively lower threat forces.

As shown in Figures 2.1 and 2.2, there are extensive rainforests to the north of Australia, and large portions of the rural population in those areas do not have access to all-season roads.[12] In Figure 2.2, the percentage of all-season roads in South Asia is compared to that in

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track. Boulders are also problematic because they can get into the workings of the track, causing it to lift up and out of the sprocket.

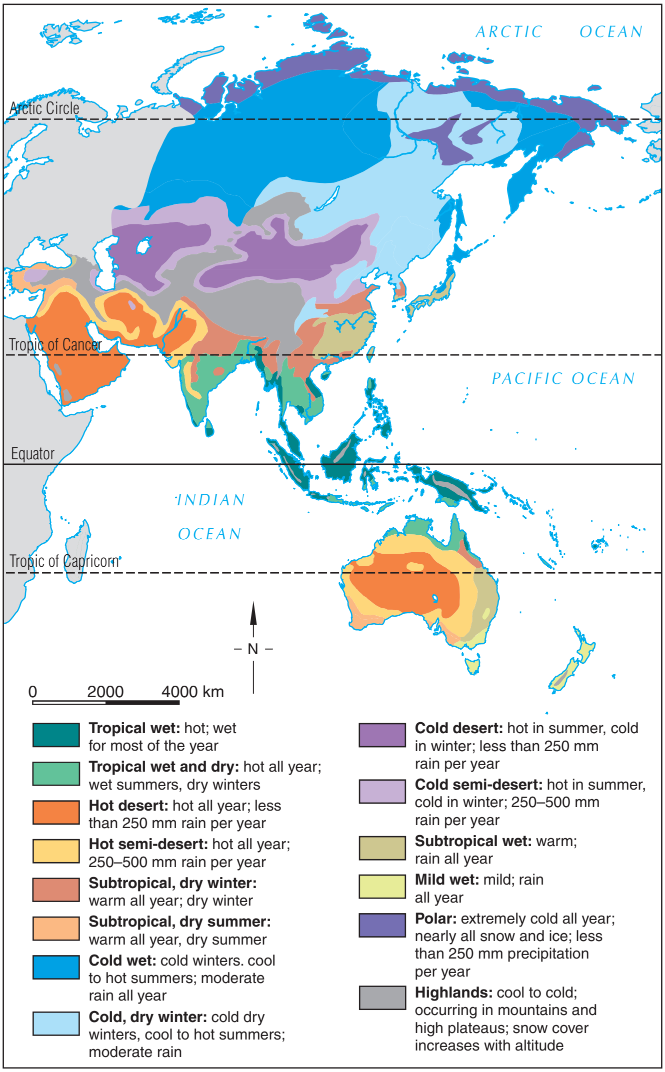
9 Wong and Huang, *Road and Off-Road Vehicle System Dynamics Handbook*, ed. Masinu and Ploachl, Boca Raton, Fla.: CRC Press, 2014.

10 Australian Department of Defence, 2015.

11 "Light Armoured Fighting Vehicles vs. Tracked," *South Asia Defence and Strategic Review*, 2011.

12 See R. Butler, "Where Rainforests Are Located: Biogeographical Tropical Forest Realms," *Mongabay*, as of July 22, 2007; "Climates from People and Places of the Asia-Pacific"; Matthew E. Boyer et al., *Assessing Conventional Army Demands and Requirements for Ultra-Light Tactical Mobility*, Santa Monica, Calif.: RAND Corporation, RR-718, 2015.

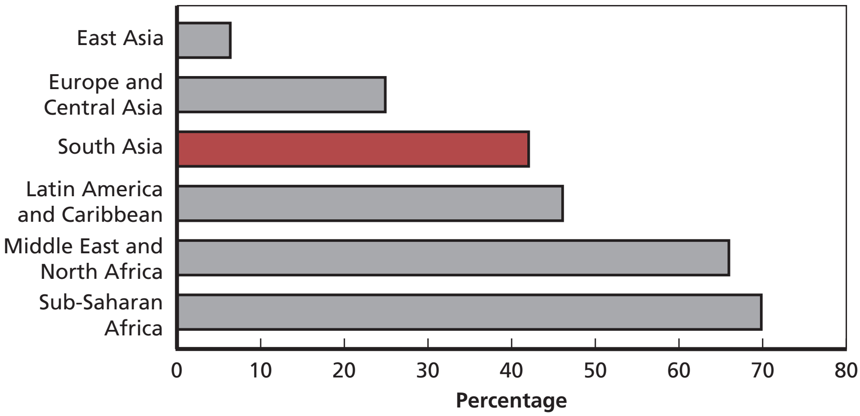
Figure 2.1
Climates of the Asia-Pacific Region Tend to Be Tropical and Wet



SOURCE: Jacaranda Essentials, "Humanities 1: Climate in the Asia-Pacific," Chapter 7.4, p. 164. Copyright John Wiley & Sons Australia, Ltd. Used with permission.

RAND *RR1834-2.1*

Figure 2.2
One Method of Comparison: Percentage of Rural Population Without Access to All-Season Roads



SOURCE: Peter Roberts, K. C. Shyam, and Cordula Rastogi, "Rural Access Index: A Key Development Indicator," Transport Papers, The World Bank Group, Transport Sector Board, March 2006 (Creative Commons, CC BY 3.0 IGO).
RAND *RR1834-2.2*

other areas of the world. While this combination of conditions does not immediately favor one mode of suspension over another, tracks are typically favored in such demanding terrain.

The requirements also change depending on the mission or scenario. Combat scenarios emphasise protection and off-road mobility, while noncombat missions often require on-road efficiency and large payload capability. Figure 2.3 summarises a rough, subjective weighting of different requirements across general scenario classes conducted by the authors. These weightings were assembled from discussions with subject-matter experts and from summarisations of the literature in the field.

Finally, Project LAND 400 should ideally allow for potential future growth and flexibility. It is assumed that the platform will be derived from an existing system to meet the low-risk requirement, but the long time horizon of the program (out to 2030 and beyond) necessitates that the IFV will be able to adapt to a variety of new technolo-

Table 2.1
Rough Weightings of Possible Requirements Across Scenarios Classes

	Combat		Noncombat	
Threats and Considerations	**Major Combat Operations**	**Irregular/Urban/ Special Operations**	**Peacekeeping/ Humanitarian**	**Disaster Relief**
Protection—RPG and ATGM	High	High	Med	Low
Protection—KE rounds	High	Med	Low	Low
Protection—IEDs and mines	High	High	Med	Low
Off-road mobility	High	High	Low	High
On-road efficiency	Med	Med	High	High
Payload	High	Med	High	High
Commonality	High	High	High	High
Signature	High	High	Low	Low
Presence/negative perception	Low	Med	High	Med

gies and tactics.[13] These include the ability to (1) up-gun or add a variety of ATGMs; (2) integrate APSs and advanced armour; (3) incorporate crouching, adaptive suspensions, and advanced steering, (4) allow incorporation of hybrid electric drive with exportable power; (5) airlift with C-17 transport aircraft; (6) possibly provide amphibious capability;[14] and (7) provide space and control for unmanned systems such as

[13] The original Project LAND 400 requirement statement indicates that the vehicle must achieve task flexibility and agility of effort across the spectrum of threat, environments, and complex terrain. See *Army User Requirement LAND 400—Land Combat Vehicle System*, March 30, 2011.

[14] Wheeled vehicles typically have much greater amphibious capability than tracked vehicles, due to the inherent flotation of tires; many more wheeled vehicles can "swim" than tracked vehicles; the Project LAND 400 program does not require amphibious capability, possibly because it is expensive and adds weight and complexity. Sophisticated technology is needed to deal with currents and have directional control and buoyancy.

unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), and unattended sensors. The system may even need to allow at some point for unmanned or optionally manned operation.

Lessons Learned About IFV Performance from Previous Tests and Studies

Some insights can be gained from the great number of ground pressure, mobility, and vehicle performance tests that have been performed pitting tracked and wheeled vehicles against each other. For example, in 1974 a competition for three-man command and reconnaissance vehicles matched the Lockheed XM800W articulated 6×6 wheeled vehicle against the FMC MX800T tracked vehicle. The wheeled XM800W was found to have quiet, fast, efficient operation on roads, but it was inferior to even the M113 in cross-country capability and safety because of hazards associated with lateral instability and directional control.[15]

A subsequent analysis done in the 1985–1988 period for the U.S. Army TRADOC Wheeled-Versus-Track Study showed advantages of tracks over wheels as the percentage of cross-country movement increased above a threshold (see Figure 2.4).[16] The studies also showed that when a vehicle's mission requires off-road usage greater than 60 percent and gross vehicle weight exceeds 10 tons, a tracked configuration is preferred.

A 1988 Waterways Experiment Station study of wheeled and tracked vehicles compared the M113A1, LAV25, and Heavy Expanded Mobility Tactical Truck (HEMTT) vehicles over a variety of soil types and wetness levels. Traction loss was consistently found to be more appreciable with wheeled vehicles than with tracked ones.[17]

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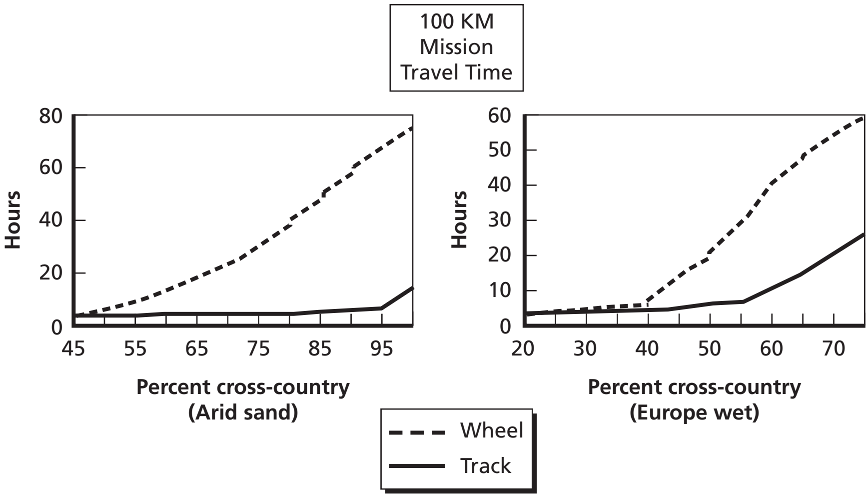
[15] "Command and Reconnaissance Vehicles," Russian Tanks, May 17, 2014.

[16] Robert F. Unger, *Mobility Analysis for the TRADOC Wheeled Versus Track Vehicle Study, Final Report*, Vicksburg, Miss.: Geotechnical Laboratory, Department of the Army, Waterways Experiment Station, Corps of Engineers, September 1988; also summarised in Paul Hornback, "The Wheeled Versus Track Dilemma," *Armor*, March–April 1998.

[17] Dennis W. Moore, *The Influence of Soil Surface Conditions on the Traction of Wheeled and Tracked Military Vehicles*, Technical Report GL-89-6, Vicksburg, Miss.: Department of the Army, Waterways Experiment Station, Corps of Engineers, April 1989.

Figure 2.3
Travel Time for Different Terrain Types, Showing Increasing Delays with Wheeled Vehicles as Surface Becomes More Challenging



SOURCE: Paul Hornback, "The Wheel Versus Track Dilemma," *Armor Magazine*, March–April, 1998. Figure 2, p. 34. Used with permission. Statistics are from the "Wheeled Versus Track Vehicle Study, Final Report," Fort Monroe, Va.: Studies and Analysis Activity, Headquarters U.S. Army Training and Doctrine Command, March 1985.
RAND *RR1834-2.3*

In 2004, the Engineer Research and Development Center (ERDC) conducted a mobility analysis for the USMC of wheeled high-mobility artillery rocket system (HIMARS) platforms with and without a trailer. The NATO Reference Mobility Model was used to predict mobility performance in three terrain regions: Germany, Korea, and Iraq, with dry and wet conditions. The portion of cross-country operation ranged from 6 to 20 percent. Wheeled vehicles were forced to avoid many no-go areas but made up for this with fast road speeds.[18]

[18] Randolph Jones, Stephanie Price, and Richard Ahlvin, *Mission Level Mobility Analysis of the U.S. Marine Corps HIMARS Vehicles*, ERDC/GSL TR-04-3, Vicksburg, Miss.: Geotechnical and Structures Laboratory, U.S. Army ERDC, February 2004.

The 2012 Congressional Budget Office (CBO) report on U.S. Army GCV program notes that tracked vehicles can produce significant wear and tear on roads and that they may not fit on narrow bridges, in tunnels, and on roads common in some parts of the world. This study also examined ground pressures of armoured vehicles, and found that both the 15 psi initial design goal and the 12 psi final goal of the GCV program were only achieved by tracked vehicles.[19] Table 2.1 summarises the ground pressures they observed with current tracked vehicles, supplemented with corresponding estimates for modern wheeled vehicles (calculated from combat weights and tire areas), and highlights the very strong differences.

Considering tracked and wheeled vehicles in the U.S. Army, a recent competition was conducted for the AMPV program. This was different from the Project LAND 400 effort, despite the similar intention to replace M113s by the late 2020s, because the missions were mostly rear-area in nature—armoured ambulance, support vehicles, mobile command post, and mortar carrier.[20] AMPVs had to keep up with the force but did not have to fight with forward elements or carry a full squad. Because of stringent mobility requirements in rough terrain, only tracked vehicles were considered. Specifically, a Stryker was found to be able to traverse 96 percent of the terrain encountered, but the other 4 percent of mostly soft terrain was a deal-breaker. The BAE Systems entry, essentially a turretless, upgraded Bradley, was the tracked vehicle chosen.[21,22]

Perhaps a more relevant albeit much smaller comparison program to Phase 3 of Project LAND 400 is the Canadian Close Combat Vehicle (CCV) Project. This is a 25–45-ton vehicle competition started by the

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[19] Kempinski and Murphy, 2012.

[20] Andres Feickert, *The Army's Armored Multi-Purpose Vehicle (AMPV): Background and Issues for Congress*, Washington, D.C.: Congressional Research Service, September 14, 2016.

[21] Sydney J. Freedberg Jr. "General Dynamics: We Can't Compete for AMPV Unless Army Changes Course," *Breaking Defense*, April 1, 2014; Sydney J. Freedberg Jr., "BAE and SAIC Win Amphibious Combat Vehicle: It Swims!," *Breaking Defense*, November 24, 2015b.

[22] Interestingly, the USMC Amphibious Assault Vehicle (AAV) appears to be changing from a tracked to a wheeled vehicle, with BAE producing a variant of the Italian Iveco Super AV and SAIC offering a variant of the Singapore Terrex.

Table 2.2
Observed Ground Pressures for Different Vehicles

	Tracked	
CV90 IFV	23 tons	8.3 psi
M2A3	32 tons	11.6 psi
BMP1/3	15/20.6 tons	8.5/8.7 psi
Warrior	30.8 tons	9.2 psi
M1A1/M1A2	65–70 tons	13.8–15 psi
	Wheeled	
Stryker	20–23 tons	29 psi
Patria	20–32 tons	34 psi
Boxer	25–30 tons	33 psi
Piranha	20–28 tons	16–30 psi[a]

[a] The minimum 16 psi number for Piranha is for a special 20-ton, 10×10 version. Most 8×8 wheeled AFVs have combat weight 18–30 tons, 147–280 in^2 mud and sand footprint (depending on tire size; typically 11.00R20–16.00R20), so ground pressure for vehicles should roughly range from 22–40 psi.

SOURCES: MilitaryPeriscope.com; Army-Technology.com; *Mission Ready Goodyear Military Tires*, n.d.; Goodyear "Off-the-Road Engineering Data" (online).

National Defence Office in 2009 and terminated in 2013 because of funding problems. The goal was to acquire 108 vehicles that could carry troops but fight like a light tank, with an explicit requirement to be able to keep up with the Leopard II MBTs already in the inventory.[23] Both tracked and wheeled IFVs were in the running, including the BAE-Hagglunds CV9035, the Nexter VBCI, and the GDLS Piranha 5

[23] Murray Brewster, "Military to Announce Demise of $2-Billion Order for Close Combat Vehicles," *CTV News*, December 19, 2013.

Figure 2.4
Three Candidates for the Canadian CCV Competition (Clockwise from Left: CV9035, VBCI, and Piranha 5)

SOURCES: CV9035: Ashley Piper, "Army Assesses Current Vehicles as Part of Ground Combat Vehicle Development Process," May 21, 2012; VBCI: Christopher F. Foss, "Exports Expected [DSEI15, D1]," September 15, 2015. Reproduced with permission from Christopher F. Foss; Piranha 5, U.S. Navy photo.
RAND *RR1834-2.4*

(Figure 2.4).[24] In the end, the locally produced GDLS LAV 6.0 was chosen, with upgrades to the vehicle's firepower, mobility, and sensors.[25]

Supporting the Canadian study, Wong and Huang looked at acceleration in climbing slopes or pulling loads. They applied models to an 8×8 wheeled vehicle, and found wheels could not match tracks on sand, clay, and loam. They also noted that 54 experimental models confirmed

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[24] "Improved Steel/Rubber and Band-Tracks Make Tracked Vehicles Superior to Wheeled Armored Cars in All Categories," Combat Reform, September 12, 2009.

[25] David Pugliese, "Canadian Army Light Armored Vehicle Reconnaissance and Surveillance Contract Awarded," *Ottawa Citizen*, November 14, 2014.

this.[26] The most damning statement was that the VCI—the minimum strength of the soil in psi permitting successful vehicle passage—of wheeled vehicles was 10–15 points higher than that for tracked vehicles. For a vehicle to attain mobility over 90 percent of the terrain in a temperate area in the wet season, a VCI of 20 and slightly lower ground pressure in psi were deemed necessary.

The USMC is also examining tracks and wheels for its Automated Guided Vehicle (AGV) program. The system being replaced—the AAV—is tracked, but the leading contenders for the USMC Amphibious Combat Vehicle (ACV) program are wheeled, despite the fact that the USMC mission profile is roughly 70 percent off-road and 30 percent on-road, the inverse of the U.S. Army's Stryker profile. Part of the reason for the preference for wheels is that the heavy wheels provide stability during amphibious operations because they hang down in the water, and that the USMC requires a VCI of roughly 25–30, slightly less than that required by the U.S. Army. Also the USMC's design requirements are often fashioned around the Medium Tactical Vehicle Replacement (MTVR), which is the Marines' medium tactical truck. This truck was seen as a war winner for the USMC, seldom getting stuck even when loaded up with armadillo kits, protected cabs, and armoured turrets. The MTVR draws on an independent suspension design that the Russians developed in their wheeled vehicle series to cope with poor road infrastructure and rivers. This suspension is more capable off-road than the torsion bar Stryker design. The MTVR also draws on advances in commercial wheeled vehicle technology, primarily the oil and mining companies. Very large wheels with large footprints and aggressive treads in the 16.00R20 range are able to allow wheeled mobility similar to tracked mobility, at least up to the 30–35-ton range. Off-road mobility and stability are also enabled by single-button central tire inflation systems, along with modern automotive features like automatic braking systems and active stability control.

Another reason for the USMC to consider wheels for the ACV is operational. The Marine Air-Ground Task Force (MAGTF) deploys as a combination of wheeled and tracked platforms, and the wheeled support vehicles cannot operate in the most challenging soft soil condi-

[26] James M. Hasik and Julian E. Platón, "Wheels Versus Tracks," presentation, March 2015.

tions. Heavy vehicles such as M1s within the USMC are preferred for heavy armour and firepower that may be needed, not for their off-road capability. Finally, the USMC has found that in terms of reliability, wheels do very well. The legacy tracked AAV-7 was found to have a mean time between failure (MTBF) of 43 hours when new, dropping to 25 hours currently. The ACV is expected to achieve 70 hours MTBF with an objective of 140 hours.[27]

Summary of Expectations of Performance

While earlier studies have served to explain why tracked vehicles are better in some situations and wheeled vehicles in others, the technology is continuing to evolve. The list of technical requirements and capabilities discussed earlier (in the "Technology-Related Goals for Project LAND 400 IFV Performance" section) could change conventional thinking, albeit on a constrained scale, between tracked and wheeled vehicles. In addition to vehicle-centric technologies, there are weapons-based technologies that an adversary can adopt that may change the performance of the iron triangle's tactical mobility, protection, and firepower. For example, the widespread proliferation of advanced shoulder-fired missiles, similar to the U.S. Army's Javelin, could change the calculus of traditional armour solutions as a means of protection. APSs, on the other hand, may be able to defeat these weapons.

The next chapter provides a summary of lessons learned from historical combat actions, insurgency operations, and humanitarian missions in which medium-weight systems had major roles.

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[27] Discussions were conducted on ACV development with USMC personnel in August 2016.

CHAPTER THREE

Task 1 Results: Lessons Learned About Tracked and Wheeled Vehicles Meeting Expected Performance in Recent Conflicts

As mentioned, Task 1 seeks to answer two questions. The answer to the first of those questions was presented in Chapter 2. Here, we focus on answering the second one: Did the respective tracked and wheeled vehicles meet expectations once fielded in recent combat situations. We start by summarising the cases examined and then discuss each one in more detail; finally, we summarise our lessons learned from them.

Summary of the Cases Examined

Table 3.1 shows a list of the nine recent scenarios that we addressed in this research. The RAND team mapped this to the attributes shown earlier in Table 1.1, and, perhaps more critically, also examined performance in a larger context. These cases were determined based on consultation with the sponsor; the order in which the cases are examined, also determined by the sponsor, is reflected in the order in Table 3.1; the scenarios are presented here in the same order in which DST Group analysts prioritised the respective cases.

The cases included a variety of missions, threats, and geographies to gain insights on how well light and medium armoured vehicles performed in different situations. Each included the use of wheeled and/or tracked light or medium armoured combat vehicles in the 7–35-ton weight class. The cases varied considerably in terms of the numbers of vehicles involved, the nature of the operation (conventional combat or irregular warfare), the terrain, and the types of threats that the vehicles

Table 3.1
List of Recent Conflicts Examined in This Research

Scenario/Year(s)	Types of Vehicles Used (Tracked/ Wheeled)	Terrain and Environment	Level/Type of Combat
Mali	VAB, AMX-10, VBCI	Open desert, mountains, villages	Counterinsurgency (COIN)
Panama 1989	M551 Sheridan, LAV-25	Jungle and urban areas	Conventional combat against police and militia forces
Balkans (OAF) 1999–2002	M1, LAV-25, Bradley	Mountains, forest, villages	Peace enforcement
Iraq (OIF) 2003–2011	M1, Stryker, LAV-25A2, Warrior, Bradley	Open desert, suburbs, urban areas	Initially conventional combat, then COIN
Afghanistan (OEF) 2001–2014	Stryker, LAV-25A2, Warrior (UK), CV90 (Swedes, Danes)	Open desert, hilly and mountainous regions	COIN
Falklands 1982	Scorpion, Scimitar Light Tanks (UK), AML-90 (Arg)	Treeless open areas with boggy ground	Division-level conventional combat
Vietnam 1965–1975	M551 Sheridan, M113, M48	Jungle, highlands	Moderate-scale conventional combat and COIN
East Timor 1999–2000	ASLAV, M113	Jungle	COIN
Ukraine 2014–2016	BMP, BTR, T-64/72	Open steppe, urban areas	Conventional combat and guerilla warfare

faced. Additionally, a considerable number of nations are represented. Together, these cases provide a fairly wide range of examples of how this class of vehicles performed and present useful information to inform future Australian Army acquisition.

Because a number of countries are represented in these cases, the concepts of employment of wheeled and tracked vehicles vary considerably. For example, in the U.S. case, the USMC employed its eight-wheeled LAVs primarily in a reconnaissance role. Meanwhile, the Army used its very similar Stryker wheeled vehicles as APCs or ICVs. In both cases, the Army and USMC vehicles are a family of systems based on a common chassis. Importantly, the tactical roles given the LAV and Stryker reflect different operational concepts for the two American services.

Ever since the first use of tanks in World War I, there has been a constant tension between the three key attributes of an armoured fighting vehicle categorised as the "iron triangle": mobility, protection, and firepower. Very well protected vehicles tend to be heavy, which can detract from their tactical mobility and strategic deployability, in addition to the greater logistics burden that heavier vehicles create. Then again, very heavy vehicles tend to be both well-armed and well-protected. The mobility-protection-firepower trade-offs may be even more difficult in the relatively light vehicles featured in these cases. Indeed, some of the light armoured vehicles in these cases weighed less than 10 tons. Such a manned combat vehicle might be very mobile, but will by definition have very limited protection and probably modest firepower. Many of these trade-offs are highlighted in the cases examined in this research.

In the case studies below, we start by providing an overview of the case, provide some background on it, discuss the vehicles used and how they performed, and then offer some observations and insights.

Case 1—Mali, Operation Serval (January 2013–July 2014)

Scenario Context

This operation involved the French intervention in Mali, a former French colony. The introduction of French troops was at the request of the Malian government, because radical Islamic extremists threatened the northern region of the country. The French quickly deployed a brigade-sized organisation assembled from forces already in Africa and units located in France. A notable aspect of the operation is the large use of wheeled armoured fighting vehicles.

The French used three main light armoured vehicles in Mali: (1) the VBCI, a new 25-ton wheeled infantry fighting vehicle armed with a 25-mm gun capable of carrying a 9-man squad in addition to the crew;

(2) the AMX-10 RC, a wheeled armoured car armed with a 105-mm main gun; and (3) the 1970s-era VAB four-wheeled APC capable of carrying 10 men. The French were prepared to deploy MBTs to Mali if the situation called for using heavy armour, but they were never forced to execute that option.[1]

The use of an all-wheeled light armoured force in Mali was noteworthy. French units had to deploy many hundreds of miles by road from ports of arrival or other locations in Africa. The infrastructure in Mali was very limited, and the French force was operating far from its bases. Logistics and maintenance were a challenge from the start of the operation. The fact that wheeled vehicles are generally less of a maintenance and logistics burden compared to tracked vehicles was certainly to the French advantage.

The threat faced by French forces consisted of relatively poorly armed and trained insurgents. Mines and RPG-type weapons were the greatest threat to French vehicles. Apparently, the rebels employed no ATGMs. This is noteworthy because the Islamic rebels certainly had weapons from looted Libyan military stocks. Additionally, the insurgents had some light indirect fire weapons such as mortars. Small arms were by far the most common insurgent weapon. Since most of the French light armoured vehicles were protected against 14.5-mm armour-piercing ammunition, that level of armour proved for the most part adequate.

Specifically, in January 2013, the country of Mali was on the verge of collapse. Simultaneous humanitarian, political, and security crises were causing the country to fracture. Drought and ongoing conflict displaced hundreds of thousands of Malians. The nation's government remained paralysed by the effects of the recent coup and by ongoing economic crises.[2] These predicaments amplified an ongoing rebellion in northern Mali by Islamist and secessionist forces. These forces consisted of battle-hardened groups, including Al Qaeda in the Islamic Maghrib (AQIM), the Movement for Unity and Jihad in West Africa (MUJWA), ethnic Tuareg separatists, and the Islamist group Ansar Dine. By the fall of 2012, the Malian Army began to collapse in the face of these enemies. The

1 "VBCI Wheeled Infantry Fighting Vehicle, France," Army-Technology.com, n.d.

2 Alexis Arieff, *Crisis in Mali*, Washington, D.C.: Congressional Research Service, 2013, p. 4.

insurgent forces overran many Malian Army bases, forcing the army into full retreat. The country's government pleaded for external aid.[3]

French President François Hollande declared on January 11 that France would intervene to protect Mali. Hollande justified the intervention on humanitarian grounds and cited the Malian government's request for help.[4] In addition to the humanitarian reasoning, France also had significant geopolitical interests in Mali.

Within hours of President Hollande's declaration, the French military went into action, commencing Operation Serval to retake Mali. Special operations forces (SOF) already in theater rode helicopters to the front lines to stymie the insurgent advance. Those army companies that were ready on the French mainland embarked on any available transportation to head to Mali. By January 14, the French military footprint grew from negligible numbers to well over 1,000 personnel on the ground.[5] By February 3, France had three battalion-sized task forces, numbering around 4,000 people. France initially saw itself as an enabling force to bolster the Malian Army at this time of crisis. Once it was on the ground with substantial numbers, the French military took the lead in conducting combat operations.[6] The troops were ordered to keep the initiative to roll back all advances by the militants.[7]

Despite this quick response, military success was not guaranteed for France. In Mali, French forces would be fighting alongside a shaken military partner in the form of the Malian Army. Additionally, the French force itself was a cobbled-together task force consisting of units from various locations in France and elsewhere in Africa that had not trained together nor with some of their equipment.

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3 Jean-Philippe Remy, "A Markala, l'armee francaise se prepare a l'affrontement," *Le Monde*, January 19, 2013.

4 French Presidency, "Déclaration du Président de la République sur la situation au Mali," *Elysee.fr*, January 11, 2013.

5 M. Shurkin, *France's War in Mali: Lessons for an Expeditionary Army*, Santa Monica, Calif.: RAND Corporation, RR-770, 2014, pp. 15–16.

6 Christopher S. Chivvis, *The French War on Al Qa'ida in Africa*, Cambridge: Cambridge University Press, 2016, p. 102.

7 Chivvis, 2016, p. 113.

Figure 3.1
The Wheeled AMX-10R and VAB APC

SOURCE: AMC by davric, VAB by AlfvanBeem (Wikimedia Commons, CC BY 1.0).
RAND *RR1834-3.1*

Vehicles Used in the Conflict

French commanders made a conscious decision to deploy units equipped with lightly armoured and wheeled vehicles (see Figure 3.1). Its decision to do so stemmed from two significant factors: (1) France's understanding of the enemy it faced; and (2) the logistical support system the French army employed in this campaign. In their view, these lighter, more adaptable vehicles were more likely to endure the upcoming hardships of warfare in the Sahel, especially given the lack of logistical support in country.

The fleet of French vehicles consisted primarily of lightly armoured wheeled vehicles and personnel carriers. The VAB APC was staged in theater as an asset for contingencies in West Africa.[8] Many of the units that deployed to Mali received these vehicles as their transportation once they disembarked in theater, despite the fact that most French commanders prefer the heavier and more expensive VBCI infantry combat vehicle.[9] France's all-terrain GBC cargo trucks built by Renault were used to pro-

[8] The Véhicule de l'avant blindé (VAB) or armoured vanguard vehicle is a 4×4 wheeled APC built by GIAT Industries.

[9] Shurkin, 2014, p. 43.

Table 3.2
Most Numerous Ground Vehicles Flown or Shipped to Mali

Vehicle	Quantity	Weight (Tons)
VAB Armoured Personnel Carrier	177	13
GBC Cargo Truck	154	8.6
VBL Light Armoured Vehicle	109	4.2
VBCI Infantry Fighting Vehicle	36	24–28
AMX-10RCR Light Tank	21	17

SOURCE: "Operation Serval," 2013.

vide logistical support to the combat vehicles. Table 3.2 provides a breakdown of the number of vehicles involved in the operation. Despite many soldiers' misgivings, the lightweight VAB enabled the French to relieve their constrained logistics system. However, many of these vehicles are decades old and expected to soon be replaced by the newer Scorpion vehicle system.

How the Systems Performed

On the eve of its intervention, France had conducted extensive intelligence preparation of the battlefield, enabling it to know that the enemy threat to its vehicle fleet would be minimal.[10] In the months prior to the intervention, French aircraft conducted dozens of reconnaissance flights over the soon-to-be battlefield.[11] Several European surveillance satellites fed information to French forces.[12] French commanders could also tap into the extensive human intelligence network fostered by years of interpersonal relationships in the country. Additionally, since the Islamist groups sought to seize territory from the apparently collapsing

[10] Chivvis, 2016, p. 115.

[11] Jean-Christophe Notin, *La Guerre de la France au Mali*, Paris: Tallandier, 2014, pp. 125–126.

[12] François Heisbourg, "A Surprising Little War: First Lessons of Mali," *Survival: Global Politics and Strategy*, Vol. 55, No. 2, April–May 2013.

Malian Army, they deployed into conventional military formations to best maximise their firepower. These flying columns of hundreds of armed pickup trucks carrying fighters and heavy machine guns made the forces easily recognisable to French aerial and human intelligence assets.

By the time Operation Serval launched on January 11, 2013, French military commanders thoroughly understood the composition, strength, equipment, and dispositions of most of the insurgent forces. Because nearly all intelligence indicators pointed to the insurgents using Soviet-made small arms and pickup trucks for transport and fire support, the French realised that even a lightly armoured force would very likely have overmatch against any assets utilised by the Islamist forces. The only intelligence gap of note was whether any of the Islamist forces had any significant antiaircraft missile capabilities and where hidden fighting positions might be.

The French Army centrally manages its vehicle fleet for expeditionary operations to maximise durability. It also enables the optimal utilisation of vehicles in roles and locations French commanders deem most optimal. After decades of constrained resources and tightening budgets, the French vehicle management system, named PGEP, enables French commanders to control where and how their few vehicles are employed. As discussed previously, this system means that French troops that regularly deploy to Africa do not typically bring their own vehicles, instead using vehicles available in theater. These vehicles are treated as theater assets, not belonging to a specific fighting unit, and are rotated annually for maintenance and replaced with newer vehicles. The French vehicles deployed to Africa then are able to use local infrastructure to maintain their supply.[13] During Operation Serval, the French were able to source their diesel gas from local African refineries. The only fuel that had to be resourced externally was jet fuel.

The logistical demands for moving the force into northern Mali to fight the Islamists also dictated that these lighter vehicles would be

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[13] "D'Abidjan à Tessalit, le SEA au coeur du dispositif Serval," Ministère de la Défense, July 16, 2013.

needed. These vehicles would be arriving at the front in Mali from several sources, including air, sea, and land routes—all of which dictated that lighter vehicles would be most appropriate. French and allied aircraft flew in the lightest vehicles and personnel. The Royal Air Force (UK), Denmark, Canada, Belgium, United Arab Emirates, Sweden, and the United States all provided airlift to help the French forces fly into Mali when Operation Serval began. According to a French Senate report, allied aircraft were responsible for moving 75 percent of the French Army into Mali from abroad.[14] To help accelerate the rate of force insertion into Mali, the French Air Transport Command leased a small fleet of Russian Antonov 124s to supplement the other nations' contributions.[15] Shipping ground vehicles over water drastically increases the tonnage that can be moved at a given time. However, since Mali is landlocked, any ground forces would have to drive a thousand miles to reach the front lines. Figure 3.2 illustrates the distances to be taken from the ports in Abdijan, Cote d'Ivoire, and Dakar, Senegal, to the staging area in Bamako and to the frontlines in northeast Mali. Other assets prestaged in theater in neighboring Burkina Faso were able to simply drive directly into the fight. However, like their counterparts coming from mainland France, these assets also had to face daunting distances over land. These distances were also over barely functional roads and, in many cases, barren deserts and mountains, reinforcing the value of lighter wheeled vehicles.

Overall, the French fleet of lightly armoured wheeled vehicles appears to have performed well, meeting the needs for the French Army and its allies. The fleet managed to move the French force across thousands of miles of terrain. In addition to their logistical role, these light vehicles proved valuable as fire support to infantry and SOF in minor skirmishes. However, the limitations of this force became apparent when the light armour and low levels of firepower proved insufficient against

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[14] Jean-Pierre Chevènement and Gérard Larcher, *Rapport d'information fait au nom de la commission des affaires étrangères, de la défense et des forces armées par le groupe de travail "Sahel,"* Paris: Sénat, 2013, p. 20.

[15] Chivvis, 2016, p. 102.

Figure 3.2
Distances of Operation for French Forces into Mali

SOURCE: Michael Shurkin, *France's War in Mali: Lessons for an Expeditionary Army*, Santa Monica, Calif.: RAND Corporation, RR-770-A, 2014; base map via Google; distance measurements from Mapcrow.info.
RAND *RR1834-3.2*

entrenched and determined enemies. To summarise how the French believed their vehicles performed, the commander of Task Force 3 boasted during the six weeks of combat operations that the vehicle fleet kept the force "almost entirely in the zone of operations, near or in contact with the enemy."[16]

The French fleet of vehicles enabled the expeditionary force to deploy within a matter of days to the front line and begin counterattacks against Ansar Dine and MUJWA. This was most clearly seen in the successful battles to retake the major cities of Timbuktu and Gao,

[16] Chivvis, 2016, p. 102.

each a symbolic city with ancient history. Additionally in Timbuktu, French military commanders initially planned an airborne operation to seize the city. However, on the side of caution, they waited until a ground convoy consisting of the mechanised infantry from the 2nd Régiment d'Infanterie de Marine with its VABs moved up in support.[17] Once the convoy arrived on January 27, the airborne infantry parachuted into key points of the city and its nearby airport. The convoy and infantry faced minimal resistance and all managed to reach their objectives. However, one issue worth noting is that during the initial staging for the convoy to reclaim Timbuktu, the heavier logistics trucks loaded with supplies sank into the sand of the lesser-paved roads.[18] This occurred several times during the drive north, and each time the column had to stop to dig out the heavily laden trucks, slowing the progress of operations.

Meanwhile in the city of Gao, a small special forces team and an armoured squadron of ERC 90 vehicles successfully routed the limited resistance they faced. ERC 90 armoured cars proved vital in providing armour and fire support to the special forces teams as they maneuvered through Gao.[19] The town was declared secure by January 28. Even though this same armoured squadron had just arrived in Gao after driving 1,100 miles (1,800 km) from Abijan, Cote d'Ivoire, it was ordered to drive 400 more miles to Markala to take control over that town.[20]

However, the Battle of Ifoghas demonstrated the constraints of this choice for lighter wheeled vehicles. By mid-February, French forces were consolidating their control over northern Mali's territory to pass stabilisation responsibilities over to the United Nations (UN) and the Malian government. During these activities, they identified a remote yet significant stronghold for AQIM. This stronghold consisted of a

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17 Shurkin, 2014, p. 16.

18 Chivvis, 2016, p. 124.

19 Chivvis, 2016, p. 125.

20 "L'engagement des forces prépositionnées en Afrique: D'Abidjan à Tombouctou et Gao: Le raid blindé du 4e escadron du 1er RHP," *Béret Rouge: Le Magazine des Parachutistes*, May 2013. Shurkin, 2014, p. 19.

network of weapons caches, freshwater reservoirs, and cave hideouts throughout the Ifoghas mountains in northeastern Mali. French intelligence at one time believed this area served as a holding area for French hostages throughout the years.

As in previous operations, the French vehicle fleet successfully drove hundreds of miles to this remote location. However, this time they were met by entrenched and determined AQIM fighters, including significant leadership figures such as Moktar Belomoktar and Abu Zeid. The reconnaissance vehicles and elements sent to patrol Ifoghas came under heavy fire, pinning the French element.[21] The French only had 120-mm mortars, vehicle-mounted weaponry for heavy weapons, and close air support for any heavier ordinance.[22] This proved insufficient, requiring the French to reinforce with helicopters.

In preparation for the next battle to evict this discovered AQIM presence, France and its allies relied on the same vehicle fleet. The force, facing extreme heat conditions around 50 degrees Celsius (122 degrees Fahrenheit), had to stockpile enough water and supplies to maintain its push into the Ifoghas valley. Air transport capabilities proved insufficient, forcing France to rely on its ground transportation. The AMX-10RCs played a significant role in the Battle of Ifoghas.[23] They drove over 300 miles (500 km) with little to no logistical support and delivered their troops to this front line with no reported issues. Their delivery proved critical, because they transported nearly 400 troops to the battlefield, including a paratrooper task group, logistical subgroup, medical unit, and command post.

Meanwhile, because of the Ifoghas valley's proximity to the Chadian border, a 1,000-strong Chadian element, with its own ERC 90s and VABs, moved to the Eastern flank of the AQIM position. The Chadians charged the AQIM positions head-on, triggering an intense firefight. They suffered drastic casualties, resulting in a confirmed 26 Chadian soldiers killed and 62 wounded. Nearly all observers noted the bravery

21 Chivvis, 2016, p. 132.

22 Shurkin, 2014, p. 13.

23 Chivvis, 2016, p. 131.

and commitment of the Chadian soldiers. As one French observer described the battle, "The Chadians are very courageous but they attack a position like the French in 1914."[24] For the Chadians as well, the smaller ERC 90s and VABs proved adept at maneuvering in the rough terrain composed of small inlets and steep hills; however, they provided very limited protection and firepower in the face of a determined defence. As the Chadians pressed from the east, the French forces also attacked from the west, ultimately flushing out the AQIM presence. The fighting in Ifoghas resulted in over 400 jihadists killed, including their regional commander, Abu Zeid.

While the French wheeled vehicle fleet did in the end meet the French Army's needs, many commanders noted that the fleet required continuous maintenance that came close to causing mission failure. The commander of one of the task forces commented that the decades-old VAB and AMX-10RC were "breathing their last," adding that their "performance reached a level that was at times preoccupying and makes their replacement indispensable for continuing to conduct engagements at this level of difficulty."[25]

Observations and Insights

By mid-2013, France saw fit to slowly end its combat operations and hand over its tasks to UN and Malian forces. By that point, France and its partner nations had managed to kill between 500 and 700 of the estimated 1,000 strong jihadist force.[26] This effectively dispersed the insurgent threat to Mali, even if only temporarily.

The decision by the French Army to equip its expeditionary ground forces with light armoured and wheeled vehicles also made a significant impact on their success in the Mali intervention. While the use of smaller, lighter vehicles made the ground forces vulnerable to intensive

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[24] Chivvis, 2016, p. 134.

[25] Interview with Colonel Frédéric Garnier, October 2, 2013; Opération Serval: Le retour de la manoeuvre aéroterrestre dans la profondeur, Réflexions Tactiques, Numéro Spécial, Paris: Armée de terre, Centre de doctrine d'emploi des forces, 2014, p. 50.

[26] Chivvis, 2016, p. 143.

firefights, it enabled them to traverse hundreds of miles to enter the fight. This took place with minimal logistical support, little preparation, and under the strains of uncertainty and physical threat. Finally, the French were prepared to deploy heavy armoured units to Mali if the situation had deteriorated seriously. Units armed with the Leclerc MBTs were on call to deploy, but the situation never reached the point where tanks were needed. Given the distances involved in Mali, the challenges of maintaining heavy armour in those conditions would have been considerable.

Case 2—Panama, Operation Just Cause (December 1989–January 1990)

Scenario Context

The U.S. invasion of Panama—Operation Just Cause—started on December 20, 1989, and effectively ended with the surrender and capture of the Panamanian president, Manuel Noriega, on January 4, 1990. Prior to the major combat operation, tensions had been building between the United States and Panama over a period of years, starting in 1985 when the Americans were becoming increasingly concerned about the Noriega regime's involvement in drug trafficking. Several incidents from 1987 to 1989 resulted in heightened tensions between the two countries. In May 1989, the United States deployed additional forces to reinforce its long-standing garrison in the Canal Zone.

Operation Just Cause included the use of both tracked and wheeled light armour vehicles. Although the Americans had time to deploy a considerable invasion force (which ultimately included some 27,000 personnel), no MBTs were dispatched. The light armour employed included 14 Army M551 Sheridan light armoured reconnaissance airborne/assault vehicles (a 15.6-ton tracked vehicle) and 14 USMC LAV-25 wheeled vehicles weighing roughly 14 tons and armed with the same 25-mm cannon that is used on the Army's Bradley IFV. The Panama operation was the first combat use of the LAV, whereas the Sheridan had been employed in Vietnam in the 1960s. Interestingly, Operation Just Cause was the only time the Sheridan was parachuted into combat. Four of the 14 M551s had been air-deployed to an Air Force base in Panama to await the attack.[27] The ten remaining vehicles were parachuted at the start of the attack, but two of them were destroyed in the air drop.

The LAVs had been in Panama prior to the invasion, performing extensive patrolling during which their mobility was praised. When combat started, a very unusual Army-USMC provisional armoured company team was formed that included a platoon of four Sheridans and a platoon of four LAV-25s. These vehicles supported the assault on La Commandancia, the headquarters of the Panamanian Defence Force (PDF). During that assault, both vehicles fired on the well-built structure—with mixed results. It was noted that the large 152-mm main gun on the Sheridan was effective in engaging structures. However, that same weapon was often regarded as too large for the chassis of the 15-ton M551, a problem that had been noted during Vietnam, causing the vehicle to rock violently because of the recoil forces.[28]

In addition to the two vehicles mentioned above, the U.S. Army forces in Panama also had M113 APCs armed with .50-caliber machine guns. These vehicles proved popular because of their relatively small size and ability to turn sharply in the narrow streets of Panama City and other towns. The .50-caliber machine guns were described as effective and quickly responsive suppressive weapons.

The PDF had a small number of 15-ton U.S.-made V-300 six-wheeled armoured cars armed with 90-mm guns. These vehicles looked very similar to the USMC LAV-25s and were sometimes mistaken for them; AT-4 antitank rockets knocked some of the Panamanian vehicles out in close-quarters fighting.

Vehicles Used in Conflict

The deployment included a company of 14 USMC LAVs. The LAV was new to the Marines at that time. The LAVs were deployed at the request of the U.S. Army commander in Panama and were given the mission

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27 "M551 Sheridan Armored Reconnaissance Airborne Assault Vehicle," MilitaryFactory.com, n.d.

28 N. Reynolds, *Just Cause: Marine Operations in Panama 1980–1990*, Washington, D.C.: History and Museums Division, Headquarters, USMC, 1996.

of patrolling and conducting reconnaissance in the months before the invasion. In that role, the mobility of the LAVs was of considerable value. At that time, the Army had no wheeled armoured vehicle similar to the LAV. Interestingly, the LAV program had originally been a joint Army-USMC effort, but the Army backed out, leaving the Marines to develop the vehicle on its own. The LAVs were from D Company, 2nd Light Armored Infantry Battalion. At that time, the Marines considered the units equipped with LAVs as light armoured infantry. After Panama, the battalions equipped with LAVs were redesignated light armoured reconnaissance (LAR), and their role was focused on reconnaissance and scouting-type missions.[29]

The LAV came in several variants, including a command vehicle, a logistics vehicle, and a recovery vehicle. The most common and best-armed version was the LAV-25, a 14-ton, 8-wheeled vehicle armed with the same 25-mm automatic cannon as the Army's Bradley IFV (see Figure 3.3). Able to carry 3–4 infantrymen in the rear compartment, the LAV was fast and mechanically reliable. As noted earlier, the LAVs were new vehicles during Operation Just Cause, which certainly helped minimise the prospect of any mechanical problems. The main weakness of the LAV was its armour. Designed only to prevent penetration by small arms fire and some artillery and mortar fragments, the LAVs could not take a hit from an antiarmour weapon. That reality greatly influenced USMC tactics for the vehicle.

In addition to the USMC LAVs, the other armoured vehicles available for use in Panama were from the Army. The 4th Battalion, 6th Infantry, from the Army's 5th Infantry Division (Mechanised) was armed with M113 APCs. This tracked vehicle was originally fielded in the early 1960s and had seen considerable action in Vietnam. Weighing only 12–13 tons, the M113 was a versatile vehicle that could carry an infantry squad and was normally armed with a .50-caliber heavy machine gun. The main drawback of the M113 was its light aluminum armour. That weakness had already been exposed in Vietnam. Able to deflect rifle-caliber small arms fire and fragments from near misses

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29 Reynolds, 1996, pp. 14–17.

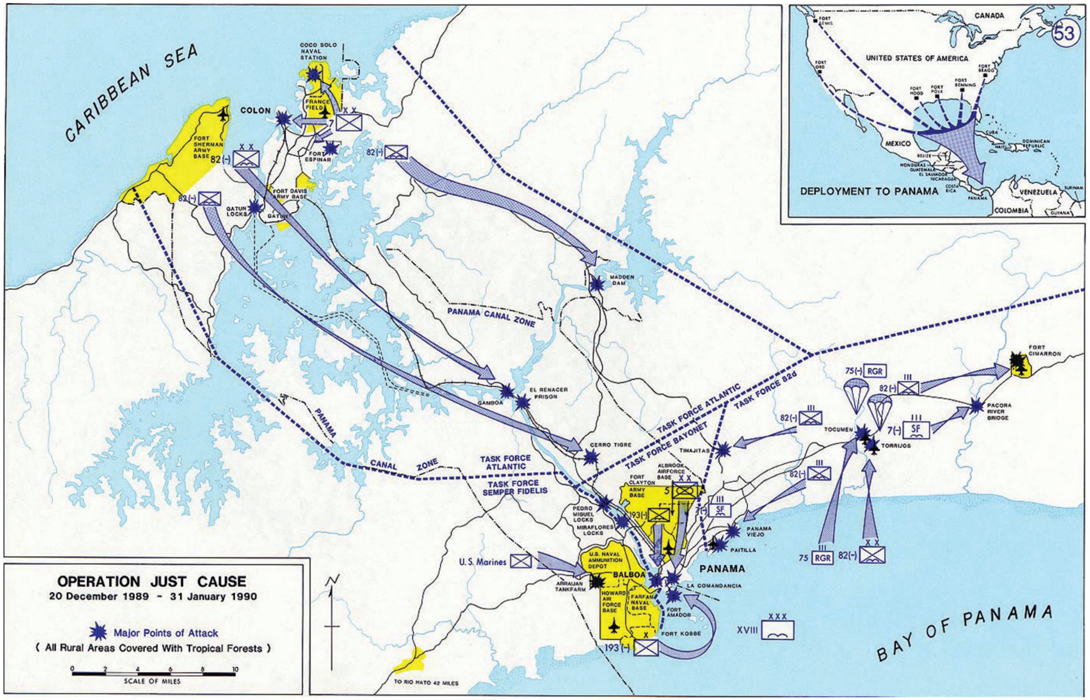
Figure 3.3
USMC LAV-25

SOURCE: U.S. Navy.
RAND *RR1834-3.3*

from artillery and mortars, the M113 would almost certainly be penetrated by any antiarmour weapon that scored a hit. The vulnerability of the M113 to mines was also well known from Vietnam.

The other Army combat vehicle was the M551 Sheridan armoured reconnaissance/airborne assault vehicle. Used extensively in Vietnam in armoured cavalry units, the Sheridan was designed for use by airborne units. Therefore, the vehicle's size and weight were constrained by the need to fit inside a C-130 aircraft. Weighing 15.6 tons, and armed with a 152-mm gun/missile system, the Sheridan was fast but lightly armoured. The Sheridans suffered losses from RPGs and mines. The vehicles used in Panama were from Company C, 3rd Battalion, 73rd Armor from the Fort Bragg-based 82nd Airborne Division. Prior to the invasion of Panama, four Sheridans were flown to Panama and secretly positioned in

Figure 3.4
Schematic of U.S. Invasion of Panama



SOURCE: Wikicommons.

RAND *RR1834-3.4*

a hangar at Howard Air Force Base. The remaining ten vehicles were to be air-dropped as part of the Army's Task Force Pacific.[30] Figure 3.4 shows the laydown and movement of forces.

At the time of the December attack, the U.S. armoured vehicles were divided among several company-sized task forces and included in the following forces:

- **Task Force Gator:** This force had the four-vehicle Sheridan platoon that had entered Panama and been hidden in a hanger at Howard Air Force Base, as well as a platoon of four USMC LAVs. These vehicles supported the infantry attack on the headquarters of the PDF, La Commandancia. The large 152-mm guns on the Sheridans were particularly valuable for blasting large holes in buildings through which the infantry advanced. The LAVs used their rapid-fire 25-mm guns to support the infantry.
- **Task Force Pacific:** Ten Sheridans were parachuted into the area around Torrijos airport, northeast of Panama City. Two of the Sheridans were lost in the airdrop (the only time they were parachuted in combat), but the remaining eight vehicles provided valuable direct fire in support of infantrymen from the 82nd Airborne Division.
- **Task Force Semper Fi:** The majority of the LAVs from D Company, 2nd Light Armored Infantry Battalion, were used against the PDF in Arraijan and later against the PDF's headquarters in La Chorrera. The mobility and firepower of the LAVs were noted in both engagements.[31]

How the Systems Performed

The PDF had a small number of light wheeled armoured vehicles, in particular U.S.-made Cadillac V-150s armed with machine guns and the V-300 with a 90-mm gun and machine guns. These 10–15-ton vehicles were poorly employed by the PDF, which lost several to AT-4 infantry antitank rockets fired by U.S. infantrymen. It should be noted that the PDF was essentially a paramilitary constabulary force, not a

[30] Johnson, Grissom, and Oliker, 2008, pp. 101–103.

[31] Johnson, Grissom, and Oliker, 2008, pp. 97–106.

field army. Its units were not well trained in combined arms tactics and their employment of the few armoured vehicles reflected that. No U.S. armoured vehicles were lost to PDF antiarmour weapons, which were very few in number.[32]

Important insights from this short operation included the following:

- Despite the fact that the M113, LAV, and Sheridan were all lightly armoured against a force that had some antiarmour weapons, these vehicles performed well, particularly as infantry support platforms.
- Large-caliber (152-mm), medium-caliber (25-mm), and heavy machine guns (.50-caliber) all proved useful in this conflict. There were times when armoured vehicles were operating among buildings where there was a sudden need to engage targets atop the buildings. The ability of the .50-caliber machine guns on the M113s to quickly swing to high elevation and put suppressive fire on the enemy was noteworthy. The ability of the 152-mm guns on the Sheridans to engage buildings has already been highlighted.[33]
- Relatively light armoured vehicles were able to traverse the poor quality bridges found in Panama.[34]
- Tracked vehicles had some advantage operating in narrow streets because of their ability to pivot-steer.
- The Army and USMC created ad hoc company-size task forces with vehicles of different capabilities that complemented each other. The 25-mm Bushmaster automatic cannons of the LAVs provided accurate and rapid fire, while the 152-mm guns on the Sheridans had the hitting power to engage targets that were inappropriate for the LAVs' weapons.

[32] William H. Huff, *The United States 1989 Military Intervention in Panama: A Just Cause?*, thesis, Baton Rouge, La.: Louisiana State University, 2002, pp. 32–37.

[33] Kevin Hammond and Frank Sherman, "Sheridans in Panama," *Armor*, March–April 1990.

[34] Hammond and Sherman, 1990.

Observations and Insights

Operation Just Cause was a short battle against poorly armed, constabulary-type forces. Had the PDF been better armed with antiarmour weapons, it is likely that losses would have occurred among the Army and USMC vehicles employed. That said, this operation demonstrated that against light opposition, this class of armoured vehicle was effective. Light enough to negotiate the bridges, able to operate among buildings, and well enough armed to provide useful support to the infantry, the M113s, LAVs, and Sheridans contributed much to the quick victory that U.S. forces achieved in Panama.

The airdrop of the Sheridans may have not been necessary given that U.S. forces were already deployed in the Canal Zone. However, the airdrop of Sheridans demonstrated the ability to deliver light armour in this manner. The loss of two of the ten air-dropped Sheridans does, however, provide a cautionary note about the ability to air-drop light armour. Additionally, if the PDF had been armed with antiaircraft weapons, this mode of deployment may not have been feasible.

Case 3—The Balkans and Kosovo (1999–2002)

Scenario Context

Since 1999, NATO has led a coalition of more than 31 countries in a peace enforcement campaign in Kosovo, a southern province of Serbia. For years, Kosovo's ethnic-majority Albanian population fought to maintain its autonomy from the Yugoslavian federal government under Slobodan Milošević. Milošević sent the Yugoslavian Army from Serbia to Kosovo to bring the province more directly under his control. As a result of this move by Milošević, the Albanian population of Kosovo formed the Kosovo Liberation Army (KLA) to carry out attacks against the Serb-dominated military and police forces occupying Kosovo. Following months of skirmishes with the KLA, the Yugoslavian Army began to ethnically cleanse Kosovo of ethnic Albanians. By 1999, the fighting had resulted in 1,500 Kosovar Albanian deaths and the displacement of more than 400,000 people.

The international community, led by NATO, sought to stop the violence and stabilise the province. Two rounds of internationally brokered talks failed to stop the violence between the KLA and the Yugoslavian Army. After each failed round of talks during the spring of 1999, the Yugoslavian Army escalated its attacks against the Kosovars. NATO attempted to dissuade Milošević by conducting Operation Allied Force, an air campaign targeting his forces in Kosovo and targets in the rest of Yugoslavia. After over two months of continuous air strikes, the Yugoslavian government acquiesced. All concerned parties agreed to a Military-Technical Agreement, soon to be supported by NATO and the UN. Yugoslavia agreed to withdraw its military and police forces from Kosovo. International peace enforcers, led by NATO, would move into Kosovo to stabilise the province. All local militant groups, including the KLA, were to be demilitarised.

The multinational peacekeeping force came to be known as Kosovo Force (KFOR). At its full strength, KFOR comprised 50,000 personnel.[35] KFOR was grouped into four regionally based multinational brigades, including a 5,000-person American component. By late 2003, the number of troops had decreased to roughly 17,500. During that time, a variety of armoured vehicles were employed in the Balkans by NATO forces.[36] Operation Allied Force did not include the use of ground troops, although a U.S. Army task force of some 5,000 personnel deployed to Albania to support possible attack helicopter missions into Kosovo. (The attacks never took place.) Task Force Hawk included a small number of M1A1 Abrams MBTs and M2 Bradley IFVs. These were air-deployed from Germany to Rinas airfield in central Albania to provide protection to the rest of Task Force Hawk. Interestingly, the perception of the inappropriateness of heavy armoured vehicles gave considerable emphasis to the U.S. Army's plans to procure medium armour and contributed directly to the purchase of the Stryker series. At the time of Operation Allied Force, the U.S. Army had no medium-weight fighting vehicles, although the Marines had been using the LAV since 1989.[37]

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35 "Conflict Background," Kosovo Force—Trust and Commitment, n.d.

36 "NATO's Role in Kosovo," NATO, September 6, 2016.

37 Bruce R. Nardulli et al., *Disjointed War: Military Operations in Kosovo, 1999*, Santa Monica, Calif.: RAND Corporation, MR-1406, 2002, ch. 4.

Once NATO forces moved into Kosovo to secure the peace, a variety of armoured vehicles were employed, including both tracked and wheeled systems. The mountainous terrain of much of the Balkans restricted the use of heavy armour, but MBTs were still deployed by several countries. No fighting took place in Kosovo between NATO and Yugoslavian forces, so other than mobility, there were no lessons on armour protection or firepower from this operation.[38]

Vehicles Used in the Conflict

KFOR included a mixture of both tracked and wheeled combat vehicles. These included both heavy armour and lighter wheeled infantry fighting vehicles. While there was no vehicle-on-vehicle combat, many vehicles, particularly in the American and Russian sectors, experienced firefights with dismounted infantry using small arms.

KFOR countries faced severe restrictions on the number of mechanised forces they could deploy to Kosovo. Transporting heavy vehicles to Kosovo was very difficult given the lack of regional infrastructure.[39] The nearest friendly port was the Albanian coastal city of Durrës, which is a shallow port with minimal offloading capacity. The only road from Durrës to Kosovo had two lanes and was hardly capable of supporting heavy vehicles. Security during the movement to Kosovo also was an issue given that banditry was rampant, with locals seeking to procure petroleum and military equipment. Additionally, many military planners assumed that the mountainous terrain was too rugged for very heavy vehicles such as tanks and simply did not plan to deploy them.

The core of the American presence, Task Force Hawk, consisted of two companies of Bradley IFVs and one company of Abrams MBTs, both heavy tracked vehicles.[40] Figure 3.5 shows the terrain and emplacement of the M1A1 in theater. These M1A1 Abrams tanks, from the "Steel Tigers" 1st Battalion, 77th Armor, constituted the main heavy tank presence for KFOR and NATO. While there were occasional firefights between these

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38 Since Serbian forces were equipped with heavy mechanised armour, the presence of both high levels of protection and firepower would likely have been needed if armed conflict occurred.

39 Nardulli et al., 2002, p. 91.

40 Nardulli et al., 2002, p. 98.

Figure 3.5
M1A1 Abrams on Perimeter Security Near the Task Force Hawk Headquarters

SOURCE: Peter W. Rose, II, and Keith E. Flowers, "Command and Control (C2)," GlobalSecurity.org, Figure 3, undated. Used with permission.
RAND *RR1834-3.5*

heavy tanks and local militants, the tankers found themselves most often enabling civil-military operations by providing a threatening capability that would-be truce violators would have to consider. Accompanying the tanks and Bradleys was a battalion-sized element of dismounted infantry from the 82nd Airborne Division's 2-505th Parachute Regiment.

Other countries deployed their own tracked and wheeled vehicles as well. France, Germany, and Italy each deployed light armoured wheeled vehicles for utilisation as troop carriers.

The primary threat to these KFOR vehicles came not from combat but rather from mines left over from years of fighting. These mines initially forced the KFOR vehicles to travel only on well-paved roads. However, after several months of operating in their respective areas, KFOR and U.S. engineer teams were able to engage with local populaces who helped to identify and clear remnant minefields.[41] Eventually, KFOR vehicles were able to operate in the countryside with full freedom of maneuver. This freedom of maneuver proved critical as U.S. and allied forces were then able to crisscross Kosovo, taking straight-line paths to respond to gunfire between Albanians and Serbs.[42]

The potential for firefights erupting at any time caused KFOR and American leadership to emphasise force protection, drastically increasing the demand for armoured vehicles. Even after the first year of operations in Kosovo and the onset of reasonable stability in the region, U.S. commanders were concerned that American soldiers were high-value targets for any would-be militants. For years, U.S. forces were only allowed to travel off base in at least two-vehicle convoys with body armour, helmets, and loaded weaponry.[43] The only units not subject to this requirement were SOF and intelligence collection teams, a small fraction of the overall force. This hampered the force's ability to readily conduct civil-military operations. Many civil affairs and psychological operations teams were unable to leave their bases to engage with the local populace because of their inability to meet the two-vehicle requirement for force protection purposes.[44]

In addition to dispersing ongoing firefights, these mounted units conducted a full spectrum of civil military operations (see Figure 3.6 for a depiction of training exercises conducted). The commander of the Steel Tigers described his unit's actions: "They functioned as police for crime prevention, apprehension, running traffic control points, and developing school registration policies."[45]

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41 Abrams Company Goes to Kosovo, p. 11.

42 R. Cody Phillips, *Operation Joint Guardian: The U.S. Army in Kosovo*, Washington, D.C.: U.S. Army Center of Military History, 1999, p. 23.

43 L. Wentz, *Lessons from Kosovo: The K-FOR Experience*, Washington, D.C.: Command and Control Research Program, July 2002, p. 490.

44 Wentz, 2002, p. 555.

45 Timothy Reese, Kevin Farrell, and Matthew Moore, "An Armor Battalion in Kosovo," *Armor*, November–December 1999, p. 27.

Figure 3.6
KFOR Vehicles Assisting with Riot Control Training

SOURCE: Headquarters, Kosovo Force, "Silver Sabre Exercise," October 16, 2013. Used with permission.
RAND *RR1834-3.6*

Local resistance forces used large, heavily laden sports utility vehicles (SUVs) to convoy contraband and weaponry to storage sites for future utilisation.[46] These vehicles were able to easily navigate the less well-paved roads and the steep hills and proved good at navigating wood-lined smaller paths in between villages, allowing them to bypass NATO surveillance. But those that dared to go into more rugged or mountainous terrain became liable to identification and subsequent interdiction by NATO aerial assets.

[46] Phillips, 1999, p. 43.

How the Systems Performed

KFOR's vehicles, and particularly the American vehicles, were able to accomplish their mission. However, it should be noted that there was essentially no opposition to KFOR. The difficult hills and mountains of Kosovo did not actually hinder even the heaviest of vehicles' ability to traverse them. The vehicles provided the necessary firepower and force protection needed to quell firefights and riots, respectively. The only deficiency of the vehicles in Kosovo was that the tracked vehicles caused negative second-order effects because of their weight and size.

While many military planners assumed the Balkans and Kosovo to be hostile terrain to heavy vehicles because of the dense forests and steep mountains, reports indicate that even the heaviest vehicles successfully navigated these environments. Even the mountainous passes proved safe enough for M1A1 Abrams to operate in and offered superb overwatch points to monitor nearby activity.[47] One reason for the vehicles' ability to operate in hostile terrain was the focus on maintenance. KFOR and U.S. forces deployed as many maintenance personnel to forward positions as possible to deal with the wear and tear on the vehicles resulting from continuous operations. As one American commander described the situation, "it rained mechanics."[48]

Insights and Observations

In Kosovo, the mere presence of armoured vehicles had an intimidation effect that forced many would-be hostiles to stand down. The M2 Bradley IFV proved sufficient on many occasions to disperse hostile crowds at protests.[49] The M1A1s served as effective deterrents when placed on positions overlooking several Serbian farms, allowing locals to harvest their crops without fear of militant attacks. Over time, however, many locals became aware of the restrictions on KFOR and would impede the ability of vehicles to move by sitting down on roads, knowing that the vehicles would not intentionally run over pedestrians.[50]

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[47] Abrams Company Goes to Kosovo, p. 10.

[48] Phillips, 1999, p. 17.

[49] Phillips, 1999, p. 35.

[50] Phillips, 1999, p. 35.

However, the larger, heavier tracked vehicles had deficiencies that affected the KFOR mission. Heavier vehicles on larger bases such as Camp Bondsteel generated so much dust that they impaired electronic and computing equipment for nearby headquarters posts.[51] NATO forces were expecting economic development campaigns to bolster the peacekeeping efforts. The heavy American M1A1s and the M2 Bradley IFVs particularly angered many locals because their treads damaged many fields and road systems.[52] Also, the larger vehicles' inability to navigate urban terrain led to additional casualties. In 2014, one American soldier died when his vehicle antennae struck a power line.[53] Two more soldiers died that same day when their Bradley fell off a road.

Case 4—Iraq, Operation Iraqi Freedom (2003–2011)

Scenario Context

Operation Iraqi Freedom (OIF) started in March 2003 with a multidivision conventional ground attack by U.S. Army, USMC, and British forces. By April 10, Iraqi forces had been overwhelmed and Saddam Hussein's government overthrown. This was accomplished by a coalition force that included considerable amounts of heavy armour.

By the middle of 2003, the occupying coalition forces were confronted by a growing insurgency, and the nature of operations had changed dramatically compared to the initial drive to Baghdad. The number of countries participating in the coalition had also increased. From the perspective of armoured vehicles, the following are some of the most important features of the multiyear counterinsurgency (COIN) phase that followed the initial MCO-like invasion.

Vehicles Used in Major Combat Operations

- Tanks and mechanised infantry led the advance, supported by artillery and considerable amounts of close air support. This com-

51 Wentz, 2002, p. 551.

52 Wentz, 2002, p. 551.

53 Phillips, 1999, p. 25.

bination quickly overwhelmed any Iraqi opposition that it encountered, with very low losses to coalition units.

- The Army's primary armoured formation during the initial advance to Baghdad was the 3rd Infantry Division (Mechanised) from Fort Stuart, Georgia. The three brigades of the division had a total of roughly 200 M1A1 Abrams MBTs and a similar number of Bradleys operating as infantry and cavalry fighting vehicles.
- The 1st Marine Division operated as a de facto mechanised infantry formation with over 150 M1A1 MBTs and roughly 400 AAV-7P amphibious vehicles used in an APC/IFV role.[54]
- The Marines deployed three LAR battalions, each armed with 100 LAVs of various types. Those vehicles provided advanced reconnaissance for the main body of the 1st Marine Division and protected the flanks of advancing USMC units.
- The British Army deployed the two-brigade 1st Armoured Division to Kuwait. This formation was armed with roughly 150 Challenger II MBTs and a similar number of Warrior IFVs.
- The British also had a squadron of Scimitar light tanks that were used in a reconnaissance role. Each 8-ton Scimitar was armed with a 30-mm Rarden medium-caliber cannon, the same weapon used on the Warrior IFV.

Importantly, no U.S. Army Strykers were available at the time of the initial invasion of Iraq.

During the initial drive to Baghdad in March–April 2003, heavy armoured units were the dominant force. The USMC and British Army employed their respective LAVs and Scimitars in a reconnaissance role, avoiding situations where those lightly protected vehicles would be exposed to heavy fire. Shortly after the fall of Baghdad in early April, the Marine Expeditionary Force commander grouped all three LAV-equipped LAR battalions into a provisional unit, Task Force Tripoli, which also included infantry and support elements from the 1st Marine Division. By this point in the campaign, the wheeled LAVs were in generally

[54] John Gordon and Bruce R. Pirnie, "Everybody Wanted Tanks," *Joint Force Quarterly*, No. 39, 2005, pp. 89–90.

better maintenance condition than the tracked M1A1 MBTs and AAV-7s. Task Force Tripoli rapidly advanced northward from Baghdad and took the city of Tikrit on April 15, 2003.

Because of the large-scale collapse of the conventional Iraqi military following the invasion by coalition forces, the threats to vehicles during the MCO phase consisted of a mix of regular and irregular opposition. A few tank battles took place, all of which were very much one-sided affairs, as U.S. and British armoured units quickly overwhelmed the enemy. Irregular forces were very common, particularly the Fedayeen Saddam militia units that tried to engage advancing coalition units with small arms and RPGs. Although a few coalition vehicles were lost, the effectiveness of this resistance was very limited, usually resulting in heavy casualties to the militia units that tried to engage U.S. and UK armoured units at close range. The armour of the Challenger II and Abrams proved very effective against the RPG-7, the most common antiarmour weapon of the Fedayeen Saddam. Figure 3.7 illustrates the movement locations in the MCO portion of the conflict.

The major combat operations phase saw a number of cases of urban combat, including around Basra in southern Iraq, Nasiriyah, and in Baghdad itself. The generally poor quality opposition, the effectiveness of the armour of the MBTs (which were followed by the less-well-armoured IFVs), and good combined arms tactics meant that there were few vehicle losses even in urban terrain.

Vehicles Used in the Insurgency or COIN Phase

The nature of operations during the protracted insurgency phase (which lasted from mid-2003 to the end of 2011 when U.S. forces completed their withdrawal from Iraq) changed considerably. Whereas the major combat phase saw company- and battalion-sized engagements, most fighting during the insurgency consisted of small-scale ambushes, including the increasing use of IEDs of various types.

From the perspective of armoured vehicles, the following are some of the most important features of the multiyear COIN phase that followed the initial invasion:

- Of greatest importance was the emergence of the IED threat. Initially, this took the coalition by surprise and casualties rapidly

Figure 3.7
Depiction of Movement of the Major Combat Operation Phase in Iraq

SOURCE: Eric Shinseki, "On Point: The United States Army in Operation Iraqi Freedom," GlobalSecurity.org, October 9, 2002. Used with permission.
RAND *RR1834-3.7*

mounted, especially among personnel riding in lightly protected vehicles. The first IEDs were conventional mines and modified artillery shells taken from Iraqi Army ammunition depots. Large amounts of ammunition were stored all over the country, and the coalition forces initially lacked the manpower to secure many of these sites. Therefore, the insurgents had a ready source of munitions to convert into IEDs. Over time, the IEDs became more sophisticated and dangerous. Remote control devices were used to detonate the devices. Of particular importance was the emergence of the explosively formed penetrator IED (EFPIED) that shot a self-forging fragment at very high velocity into the side of a passing vehicle.

- The IED and mine threat resulted in several types of vehicles eventually being withdrawn from the area or limited to use within coalition bases. Examples include the high-mobility multipurpose wheeled vehicle (HMMWV), the Marines' AAV-7, and the Army's Bradley IFV. In the case of the Bradley, the vehicle was designed in the 1970s for a Cold War battle in Germany where it would be fighting mostly on friendly territory. Therefore, the vehicle was not designed with the mine threat in mind. Meanwhile, by early 2005, the HMMWV was regarded as being highly vulnerable, despite attempts to add some armour.
- The mine and IED threat led to crash programs to buy mine-resistant ambush protected vehicles (MRAPs).[55] Eventually, the U.S. and coalition nations purchased some 24,000 of these vehicles that took the place of many different types of vehicles.[56] Compared to tracked vehicles, wheeled MRAPs could be higher off the ground and the bellies of the vehicles could be armoured and made in a V-shape to deflect blast away from the vehicle.[57]
- Tanks were retained in action in Iraq, albeit with increased belly and side protection. Tanks proved to be far less vulnerable to IEDs, although there were losses, particularly to very large IEDs (which are hard to emplace) and EFPIEDs. However, the weight of tanks grew considerably because of all the additional armour that was

55 Mark L. Reardon and Jeffrey A. Charlston, *From Transformation to Combat: The First Stryker Brigade at War*, Washington, D.C.: U.S. Army Center of Military History, CMH Pub. 70-106-1, November 2006.

56 Alex Rogers, "The MRAP: Brilliant Buy or Billions Wasted?," *Time*, October 2, 2012.

57 The EFPIED threat in large part was reduced by the time MRAPs were introduced into theater.

mounted. For example, the British Challenger II's weight increased from roughly 62 tons to some 75 tons.[58]

- The other primary insurgent antiarmour weapon was the RPG. Various versions of RPGs were employed in Iraq, including the modern RPG-29 that has a tandem warhead capable of defeating reactive armour. The main disadvantage of the RPG for the insurgents was that it was far more dangerous to employ compared to using IEDs, which could be remotely exploded. Nevertheless, the severity of the RPG threat resulted in various armies making improvements to the protection of their vehicles, such as the use of so-called bar armour to catch RPGs before they could strike the vehicle.

A mix of tracked and wheeled vehicles remained in use during the COIN phase. The first combat use of U.S. Army Strykers took place in November 2003.[59] The first U.S. Army Stryker brigades were being formed when the invasion of Iraq took place. Unlike the USMC LAR battalions whose mission is reconnaissance, the roughly 5,000-man Stryker brigades are essentially motorised infantry formations that move their infantry into the vicinity of the battle using the eight-wheeled Stryker vehicles (which are a modified version of the LAV-III); the infantry fights dismounted. The most common version of the Stryker is the M1126 Infantry Carrier, but there are other variants, including C2, 120-mm mortar carrier, ambulance, etc. The 105-mm armed M1128 MGS version was not ready for use when the first Stryker Brigade (the 3rd Brigade, 2nd Infantry Division, from Fort Lewis, Washington) deployed to Iraq in late 2003.

The first Stryker unit deployed by ship to Kuwait and drove more than 500 miles from the port to its operational area around the city of Samarra, north of Baghdad. This was an excellent demonstration of the operational agility of the formation. Within days of the unit arriving at

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[58] David E. Johnson and John Gordon, *Observations on Recent Trends in Armored Forces*, Santa Monica, Calif.: RAND Corporation, OP-287-A, 2010, p. 3.

[59] "Stryker Armored Combat Vehicle Family, United States of America," Army-Technology.com, n.d.

Samarra it suffered its first losses from an IED—an underbelly blast that damaged a Stryker.[60]

As with other vehicles, it was soon discovered that Strykers needed better protection against mines, IEDs, and RPGs. This resulted in the use of the bar armour mentioned above, as well as modifications to the hull of the vehicle. The bar, or slat, armour could often catch or prematurely detonate RPGs before they hit the hull of the vehicle (see Figure 3.8). Development of the slat armour package had started even before the first Stryker brigade deployed to Iraq. This armour package's main disadvantage was that it added roughly 2.5 tons of weight to the vehicle and roughly 3 feet to the width of the system. This, of course, affected the vehicle's mobility, including its ability to turn in narrow streets.[61]

In addition to the slat armour, the Army began working on reactive armour packages for Stryker, starting in 2010.[62] The Army also fielded reactive armour for the Abrams MBT and the Bradley IFV during this period.

The initial production versions of the Strykers had a flat bottom, similar to tracked vehicles. Combat lessons resulted in subsequent vehicles being redesigned to have V-shaped bottoms. Since wheeled vehicles generally do not use cross-vehicle torsion bars on the bottom, as do tracked systems, they are better able to have shaped hull forms. The South African military made extensive use of wheeled armoured vehicles with V-shaped bellies to defect the blast of mines exploding under the vehicle.[63]

All these various armour enhancements added weight to the basic Stryker vehicle. When originally fielded in 2003, the infantry carrier version of the system weighed approximately 19 tons. The additional weight had an effect on the mobility and to some extent the stability of the vehicles. By the end of the conflict, some versions of Stryker had added 3–4 tons of weight because of combat-related modifications, including armour.

In addition to the formal tracked and wheeled fighting vehicles that were deployed to Iraq, a very large number of MRAP vehicles were

[60] Reardon and Charlston, 2006, pp. 21–22.

[61] Reardon and Charlston, 2006, 16.

[62] "General Dynamics, Rafael to Replace the Stryker's SLAT Armor Protection with Reactive Armor," *Defense Update*, May 2009.

[63] "Stryker Armored Combat Vehicle Family, United States of America," n.d.

Figure 3.8
Stryker Infantry Carrier in Iraq Fitted with Slat Armour

SOURCE: Defense Industry Daily, "M1126 Strykers in Combat: Experiences & Lessons," October 11, 2005.
RAND *RR1834-3.8*

procured to provide better protection to the troops. MRAPs were purchased in an essentially crash effort to field better protection. The United States and other militaries purchased MRAPs originally modeled on the South African vehicles that had been used since the 1970s to give enhanced mine protection. As vehicles such as trucks and HMMWVs were quickly shown to be very vulnerable to mines and IEDs, as well as small arms fire, there was a pressing need to quickly deploy more appropriate systems. However, MRAPs were not intended for use in conventional combat operations against an opponent with traditional antiarmour weapons or fighting vehicles. Sitting very high off the ground, MRAPs would have been ideal targets on a conventional battlefield. Over 12,000 MRAPs of various types were procured from 2007 to 2012 for use by Army and USMC units in Iraq and Afghanistan.[64]

64 "MRAP," U.S. Marine Corps, n.d.

Insights and Observations

Operations in Iraq included both short-duration ones (less than two months) and MCOs, as well as a multiyear COIN phase. The U.S. military used both tracked and wheeled fighting vehicles. Each type of vehicle had its strengths and weaknesses. During the march to Baghdad, heavily armoured tanks led the advance and were prized for their protection and firepower. Tracked IFV and AAVs complemented the tanks and closely followed their advance.

Wheeled vehicles had excellent mobility when they could use roads. During the major combat phase, the Marines' LAVs arrived at Baghdad following a 450-mile advance in better mechanical shape compared to tanks and AAVs. In the case of the Army, by the time Baghdad was reached, most tracked vehicles were still combat-capable but far from fully mission-capable because of the wear and tear of the long, rapid advance. When the Army's Stryker brigades started to arrive in late 2003, their operational mobility was used to advantage to quickly move units around the country and within each brigade's sector.

Mines and IEDs knocked out both tracked and wheeled vehicles during the COIN phase. Several vehicle types that had not been designed to prioritise the mine threat (e.g., the AAV) had to be withdrawn from combat because of their underbelly vulnerability. All vehicles, tracked and wheeled, that remained in combat had to be modified in various ways to increase their survivability. Slat armour, reactive armour, and increased armour on the bottom of the vehicles all added protection, but they also added weight and bulk to the systems.

Case 5—Afghanistan, Operation Enduring Freedom (2001–2014)

Scenario Context

Coalition military operations in Afghanistan began in October 2001 and are still under way at the time of this writing. The initial military operations against the Taliban and al Qaeda in late 2001 and early 2002 consisted of air strikes by long-range bombers and carrier-based aircraft, directed and controlled by a few hundred U.S. military special operations personnel who had joined anti-Taliban groups, such as the Northern Alliance, which provided most of the ground combat power during the first few months of combat.

By the early spring of 2002, coalition conventional ground combat forces started to enter the country. This presence gradually grew over time, and by 2010 the coalition force had reached its peak of some 130,000 personnel. By that point, 51 countries were participating in Operation Enduring Freedom (OEF).[65] As would be expected with such a large number of military forces present, a considerable variety of armoured fighting vehicles were deployed to Afghanistan, including both wheeled and tracked vehicles, ranging in weight from very light wheeled vehicles of the HMMWV class to 70-ton MBTs.

Many challenges confronted the armies operating in Afghanistan. These included the terrain (deserts, mountains, and occasional urban areas), weather, a determined enemy, and distance from normal bases and ports. The last factor was particularly important because military personnel, equipment, and supplies had to be moved to this remote country that was far from a port; historically, most fighting vehicles typically deploy to an operational area by way of ships. The difficulty of transporting, maintaining, and supplying armoured vehicles at such distances influences countries' decisions about whether and how much armour to deploy, and what type.

Vehicles Used by Different Countries and How They Performed

Some of the first U.S. fighting vehicles to enter the country were USMC LAVs. These were flown into Kandahar airfield in Afghanistan early in 2002.[66] As time passed, the number and variety of armoured systems in Afghanistan increased. Below are examples of the range of approaches taken by various armies.

Canadian forces operated in the Taliban stronghold of Kandahar Province in the southern portion of the country. Initially, the Canadian

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65 "NATO and Afghanistan," NATO, October 13, 2016.

66 "Unclassified Documents from Marine Task Force 58's Operations in Afghanistan," StrategyPage, n.d.

Figure 3.9
Map of Afghanistan

SOURCE: Created by Michael Meuser, mapcruzin.com. Used with permission.
RAND *RR1834-3.9*

Army deployed its LAV-III series vehicles, which included versions armed with 25-mm automatic medium-caliber cannons. The eight-wheeled LAV was successful, but by 2006 it was determined that there were circumstances where more firepower, better cross-country performance, and more protection was needed. The LAV-III vehicles had their worst problems in fine sand and soil and with snow and mud. In fact, the frequent on-road operation of wheeled vehicles made them vulnerable to IEDs and ambushes, especially in areas with few roads.[67] This resulted in the deployment of a squadron of 105-mm armed Leopard I MBTs. The success of tanks in southern Afghanistan resulted in the Canadian Army reversing its plans to do away with tanks and purchase the much more capable Leopard II, which was deployed to Afghanistan as quickly as possible. It should be noted that the LAVs remained and were supplemented by MRAP vehicles of various types.[68]

The Danes, Norwegians, and Swedes all had positive experiences with the Swedish-built CV90 in the battle for Panjwai and other engagements (see Figure 3.10). Off-road mobility was said to be excellent, bettering even the M113s.[69] Also the ability of tracked vehicles to pivot in place was found to be essential for tight mountain trails; however, this capability would be hard on road surfaces.

In the case of the CV90, the vehicle had originally been designed in the late 1980s for operations in northern Sweden to defend against a possible invasion by the Soviet Union. Much of the terrain in northern Sweden is wet, marshy ground in summer and covered by deep snow in winter. The CV90 was specifically designed to operate in those conditions and thus had a very high power-to-weight ratio and a suspension system optimised for those conditions. Although the vehicles employed in Afghanistan were heavier (the Norwegian vehicles were roughly 33 tons, because of additional armour) than the original 23-ton Swedish Army versions of the mid-1990s, the vehicles used in Afghanistan retained excellent mobility and provided a very high level of IED protection. The Norwegians initially deployed the CV90 to Afghanistan in 2007, followed by the Danes in 2008 and Sweden in 2010.[70]

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67 The Canadians noted that the worst mobility in mud was the Stryker with an RPG cage; in general, there was good support for LAV and Stryker for low-intensity and urban combat, but the vehicle did not pass the Sinatra test ("If you can make it there, you can make it anywhere . . .") in Panjwai because it could not breach many of the obstacles or survive RPG or recoilless rifle fires (Hasik and Platón, 2015).

68 Johnson and Gordon, 2010, pp. 3–4.

69 Hasik and Platón, 2015.

70 Interviews with BAE-Haaglunds, Sweden, May 2016.

Figure 3.10
Norwegian CV90 in Afghanistan

SOURCE: "De Forsvaret (Army Norway)," Tarafdari.com, undated. Used with permission.
RAND *RR1834-3.10*

In the U.S. case, a variety of combat vehicles were employed in Afghanistan, including the USMC LAV and the Army's Stryker. The Marines retained their LAVs in Afghanistan, and in late 2010 reinforced them with M1A1 Abrams tanks.[71] However, the U.S. Army did not deploy tanks to Afghanistan.

The U.S. Army first deployed Strykers to Afghanistan in the summer of 2009 as part of the effort to reinforce the troop presence in the country in preparation for the important elections, scheduled for late August 2009. The first Stryker unit in Afghanistan was the 5th Stryker Brigade, 2nd Infantry Division (5/2). Unlike the first Stryker brigade that deployed to Iraq in 2003, the formation that went to Afghanistan was armed with the 105-mm MGS version of the vehicle. Additionally, by this time Stryker units had gained considerable combat experience operating in Iraq, including tactics to reduce the IED and

71 Barbara Starr and Moni Basu, "US Sending Tanks to Afghanistan for the First Time," *CNN.com*, November 19, 2010.

RPG threats and the use of bar or slat armour on the vehicles. Also unlike the first Stryker units that engaged in combat in Iraq, by the time 5/2 arrived in Afghanistan, MRAPs had replaced many of the lightly protected vehicles such as HMMWVs. The first Strykers that deployed to Afghanistan were the original, flat-bottom versions of the vehicles. In that regard, the brigade's Strykers were less protected from underbelly IED explosions compared to the MRAPs with their armoured, V-shaped belly plates.

The unit was dispatched to Kandahar Province in the southern part of the country, long a Taliban stronghold. By the time the brigade arrived in Kandahar, the area was already infested with antipersonnel and antivehicle IEDs. It immediately became clear that IEDs would be the main threat to the Strykers (see Figure 3.11). The experience of the Stryker unit in Afghanistan helped convince the U.S. Army that better underbelly protection was required to reduce the effectiveness of under-vehicle blasts. Unfortunately, some IEDs were so large that they could literally flip a 23–25-ton Stryker over. Probably the most powerful IED that the brigade encountered was a massive 9-ton device that detonated under a Stryker in October 2009, killing seven soldiers aboard the vehicle. It should be noted that no AFV, including a MBT, could survive an explosion of that magnitude.[72]

The U.S. Army troops who made the first Stryker deployment to Afghanistan appreciated the vehicle's mobility and ease of maintenance. The presence of the 105-mm MGS vehicles and 120-mm mortar variants were described as providing considerable extra firepower to the infantry companies whose Strykers were armed with .50-caliber machine guns. As mentioned above, the unit had to develop tactics to reduce the ever-present IED and RPG threats.[73]

The losses suffered by 5/2 (37 men killed and over 250 wounded in action) in terms of personnel and vehicles led the second Stryker brigade to deploy to Afghanistan, the 3rd Brigade of the 2nd Infantry Division (3/2) to leave its Strykers behind at Fort Lewis and substitut-

[72] Kevin Hymel, *Strykers in Afghanistan: 1st Battalion, 17th Infantry in Kandahar Province 2009*, Fort Leavenworth, Kan.: Combat Studies Institute Press, 2014, p. 80.

[73] Hymel, 2014, pp. 80–90.

Figure 3.11
Stryker After an IED Blast in Afghanistan

SOURCE: Photo by C-52 of 3/2 Stryker Brigade Combat Team.
RAND *RR1834-3.11*

ing MRAPs. This contributed further to the Army's decision to refit many of its Strykers with V-shaped bottom plates.[74]

The heaviest vehicle used by the British Army in Afghanistan was the tracked Warrior IFV, which was used in its original IFV role and as a light tank to support the infantry with its 30-mm gun. Although the British did not deploy Challenger II MBTs to Afghanistan, British units were frequently supported by Canadian and Danish units armed with the Leopard II. British Army sources noted that the main reason that MBTs were not deployed to Afghanistan was because it was difficult to maintain very heavy tanks in that environment (they were far from main logistics and maintenance sites) and because most of the threats encountered in southern Afghanistan could be dealt with by

[74] Spencer Ackerman, "Army Stryker Brigade Won't Take Strykers to Afghanistan," *Wired .com*, October 28, 2011.

the 30-mm cannon on the Warrior.[75] The British Army did, however, attach additional armour to the Warriors to better protect them from RPGs and IEDs, the main antiarmour weapons available to the Taliban.

Insights and Observations

There were several reasons why few MBTs were sent to Afghanistan, including the terrain, the relatively low-level threat, the difficulty of deploying those vehicles so far from ports, and the lack of major repair facilities. However, those tanks that were deployed provided a very useful capability. Most of the armies that operated in Afghanistan employed various versions of MRAPs. It was quickly discovered that the flat bellies of tracked vehicles were vulnerable to mine and IED threats. Most armies conducted emergency purchases of MRAPs, which took the place of APCs and IFVs.

Case 6—The Battle of the Falklands (April–June 1982)

Scenario Context

The Falklands War represented ten weeks of military conflict between the United Kingdom and Argentina. The two nations contended with each other over who should hold sovereignty over a set of islands known in English as the Falkland Islands and in Spanish as Islas Malvinas. Despite being located near the Argentina mainland, these islands had been an English colony for nearly 150 years. Throughout this time, the Argentine government primarily relied on diplomatic efforts to instill their sovereignty over these British isles. However, by the early 1980s, while under a military junta, the political order of Argentina faced severe strain because of an ongoing economic crises and a simmering insurgency. To unify their citizenry and boost their domestic legitimacy, the military leaders of Argentina decided to militarily seize control of the Falklands. On April 2, 1982, the Argentine Army and Navy invaded and occupied the Falkland, South Georgia, and South Sand-

[75] Johnson and Gordon, 2010, pp. 2–3.

wich Islands. The seizure of the islands proved to be the political boon the Argentine government had expected. National pride swelled, and within days, crowds in the capital's plaza had gone from conducting mass protests to expressing patriotic unity.

What the Argentine government did not expect was for the British to immediately mobilise their military to recapture the islands just as forcefully as they had been taken. As VADM Juan Lombardo, the commander of Argentine naval forces during the conflict, stated: "We could not believe it; it seemed impossible that the British would go to such trouble over a place such as the Malvinas."[76] On April 5, a naval task force set sail from bases in the United Kingdom and Gibraltar to trek 8,000 miles to reach the disputed islands (see Figure 3.12). As each day passed, the British embarked every available light infantry formation for an eventual expedition to retake the Falklands.

From April to May 1982, the Argentine Air Force and Navy exchanged blows with the British naval task force as they fought to maintain naval and air superiority around the Falkland Islands. The Argentines were a force to be contended with, keeping the British at bay for well over a month as they exchanged blows. By mid-May, the British had an open window to begin their land campaign to reclaim the island.

The land war would begin in earnest on May 21 when the British conducted an amphibious assault on the Port of San Carlos, establishing their beachhead. After several more days of buildup on the beachhead, the British were able to strike out. After a brief but ferocious firefight, they captured the Argentine stronghold of Darwin-Goose Green on May 28. Then, over the next few days, the entirety of the British land element conducted a grueling land march across the cold bogs and mountains of the Falkland Islands. On June 11, the battle to surround the capital, Port Stanley, commenced. The Argentines, who were numerous and well-entrenched on a series of ridgelines, fought hard against the British Army but ultimately collapsed (see Figure 3.13 for timeline and movements). On June 14, a cease-fire was declared. The commander of the Argentine garrison, BG Mario Menendez, surrendered to the British commander, MG Jeremy Moore, that day.

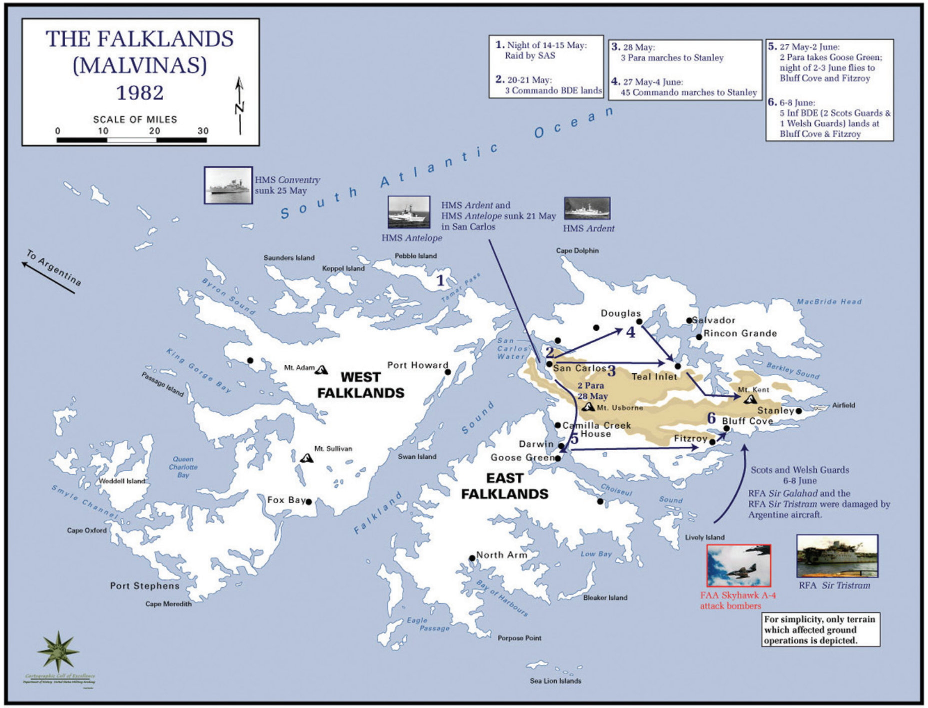
[76] Martin Middlebrook, *The Fight for the Malvinas*, New York: Viking, 1989, p. 48.

Figure 3.12
The Falkland Islands/Islas Malvinas in Relation to Britain and Argentina

SOURCE: Department of History, U.S. Military Academy West Point, "Falklands, Campaigns (Distances to Bases)," 1982.

RAND *RR1834-3.12*

Figure 3.13
British Ground Force Movements in the Falklands



SOURCE: Department of History, U.S. Military Academy West Point, "The Falklands (Malvinas)," 1982.

RAND *RR1834-3.13*

Vehicles Used in the Conflict

The Argentine military invaded the Falklands in early April 1982, quickly overwhelming the small Royal Marine garrison of less than 100 men. Within days, British military forces started deploying to the South Atlantic. The British ground force ultimately consisted of a provisional division of British Army and Royal Marines, numbering roughly 12,000 men. The force was primarily light infantry (eight battalions), but it also included two platoons of light armour from the Blues and Royals Regiment—a total of four 8-ton Scimitar light tanks armed with 30-mm cannons, and four very similar Scorpion light tanks armed with 76-mm guns. Of these eight light tanks, one Scimitar was damaged by an Argentine mine, but it was successfully recovered.

The British decision to deploy light armour to the Falklands was because of the presence of Argentine armour. The initial invasion had included U.S.-made amphibious tractors, but those were quickly withdrawn. When the British ground force arrived in the South Atlantic, the Argentines had a company of twelve 5-ton French-built Panhard AML-90 armoured cars armed with 90-mm guns on the Falklands.

The British apparently deployed light tracked vehicles to the Falklands for two reasons: the presence of Argentine armoured vehicles and the nature of the terrain. Most of the treeless Falklands Islands is soft, peat-like terrain that makes the off-road movement of wheeled vehicles difficult. The 8-ton British vehicles were able to maneuver off-road, while the Argentine wheeled armour was apparently largely confined to movement along roads in the vicinity of Port Stanley, the only major town and where most Argentine forces were located.

The land forces involved in the battle over the Falklands had a rough numerical parity. The British land component comprised two infantry brigades—the 3rd Commando Brigade and 5th Army Infantry Brigade—which together contained about 12,000 combat and combat support troops. Because of logistical challenges though, only about half of these larger forces were able to land and take part in the conflict on the island. These two brigades were bolstered by the 2nd and 3rd Parachute Battalions, known by their shorthand names of 2nd PARA and 3rd PARA, as well as two squadrons from the famed Special Air Service.

Not only were the Argentines numerically comparable to the invading British force, but they were also well-equipped. By the end of April, the Argentines had around 13,000 men in the Falklands. Of that, roughly 5,000–6,000 were from eight infantry regiments.[77]

However, the quality of the Argentine equipment masked several critical deficiencies. The Argentine soldiers had much less training than the British. The Argentines occupied the Falklands with mostly barely trained conscripts who were unaccustomed to the frigid climate, while the British Commandos sent there trained regularly for the winter warfare conditions they faced.[78]

The British also had the ability to call in a full spectrum of indirect fires to help them overcome any ground resistance. The Royal Air Force and Navy as well as disembarked artillery batteries were all available to coordinate fires in support of British maneuvers. The Argentines had to rely on a handful of outgunned batteries that were ill-trained to coordinate fires with their infantry forces.

The final deciding factor between the two armies was their availability of vehicles. While the British did not bring many vehicles to the battle, those vehicles that did arrive proved their worth in both logistical and fire support. The Argentines were unable to effectively utilise the few vehicles they had. The British made a conscious decision to have as few vehicles as possible during the Falklands.[79] The British operational plans called for 300 vehicles to support a force that normally uses 3,000.[80] The Blues and Royals, an armoured reconnaissance regiment, sent a detachment of two troops of Scimitar armed with a 30-mm cannon (see Figure 3.14) and Scorpion light tanks armed with a

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77 Lawrence Freedman, *The Official History of the Falklands Campaign*, *Vol. I: The Origins of the Falklands War*, London: Routledge, 2005, p. 564.

78 Max Hastings and Simon Jenkins, *The Battle for the Falklands*, New York: W.W. Norton, 1983, p. 321.

79 Paul Valovcin, *Logistical Lessons for the Operational Commander: The Falklands War*, Newport, R.I.: Naval War College, February 13, 1992, p. 17.

80 Neville Trotter, "The Falklands Campaign: Command and Logistics," *Armed Forces Journal International*, June 1983, p. 21.

Figure 3.14
Scimitar Armoured Reconnaissance Vehicle

SOURCE: Graeme Main, "Scimitar Light Tank," UK Ministry of Defence, undated. Contains public sector information licensed under the Open Government License v3.0.
RAND *RR1834-3.14*

76-mm gun (see Figure 3.15); four vehicles of each type were deployed.[81] Additionally, a Samson recovery vehicle was sent for maintenance support. The remainder of the vehicles were Bandvagn 202s (BV 202s), which are tracked vehicles used solely for transportation. The Royal Marines had obtained these vehicles from Sweden in the years before the operation in the Falklands. At the time, the Falklands had only a dozen miles of paved road. The countryside was filled with wet bogs, loose soil, and steep hills that were hostile to fleets of wheeled motorised vehicles.[82] The BV 202s, with their heavier tracks, proved necessary to navigate the challenging terrain. This lack of mobility capacity hampered frontline logistics, because the British had to rely on very limited helicopter support.

The Argentines meanwhile only had around a dozen wheeled armoured Panhard AML-90 armoured vehicles.[83] These vehicles made a brief appearance in combat toward the end of the battle. However, their only other reported utilisation was in transporting Argentine

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[81] Freedman, 2005, p. 43.

[82] Freedman, 2005, p. 502. This did not stop the locals from helping the British by offering their civilian vehicles to move supplies for them.

[83] Hastings and Jenkins, 1983, p. 178; and Middlebrook, 1989, pp. 58–59.

Figure 3.15
FV101 Scorpion

SOURCE: AlfvanBeem via Wikimedia Commons (CC BY 1.0).
RAND *RR1834-3.15*

commanders to and from meetings in Port Stanley.[84] This also stems from the fact that the Panhard AML-90s were wheeled vehicles that were unable to travel off-road and traverse the bogs of the Falkland Islands.

The lack of motorised forces on the Falklands was a symptom of a systemic problem for the Argentines in that they could not sufficiently resupply their forces. Those stationed away from the capital of Port Stanley suffered the worst, running out of rations and other supplies days before the British arrived. Once the British Royal Navy achieved maritime superiority around the Falklands, the Argentines were only able to resupply their forces from the air. This exasperated their already dismal supply capabilities. Even for those supplies that did

[84] Hastings and Jenkins, 1983, p. 300.

arrive, the lack of motorised transport prohibited the Argentines from being able to move them to the front lines.[85]

How the Systems Performed

The British armoured vehicles had a limited yet notable role during this ground campaign. This was primarily an infantry-on-infantry battle over a small island. It took some time for the British to employ their armoured vehicles. British commanders withheld the Scorpions and Scimitars from participating in the Battle for Darwin-Goose Green because of the residual threat from the Argentine Air Force. As a result, only the BV 202s (see Figure 3.16) conducted resupply runs from Port San Carlos to Darwin-Goose Green. However the British vehicles played a crucial role in the final push to end the conflict. The British BV 202s, Scimitars, and Scorpions proved essential in helping move the ground force across the marshy island and provide critical fire support in the battle around Port Stanley.

After the Battle for Darwin-Goose Green, however, the British sought to bring their force to bear on the remaining Argentine force, which was focused on Port Stanley on the Eastern edge of the island. This required moving their forces over 40 miles eastward toward the capitol. In this capacity, the vehicles performed very well on the harsh terrain. During the long march from Port San Carlos to the approach to Port Stanley, the Scorpion and Scimitar armoured reconnaissance vehicles performed reliably, with no reported breakdowns, and covered the long distances across the island. The night of May 31, BV 202s, two Scimitars, and a Samson recovery vehicle moved the brigade headquarters closer to more forward positions.[86] Their tracked BV 202s performed superbly on the terrain and could handle the marshy off-road trek across the island.[87] Those units without the BV 202s, such as the Welsh Guards, advanced much more slowly.[88]

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[85] Ronald Schepl, *The Falklands/Malvinas 1982: Why Didn't Argentina Win the War?*, research paper, USMC Command and Staff College, Marine Corps University, 2009, p. 18.

[86] Schepl, 2009, p. 18.

[87] Hastings and Jenkins, 1983, p. 263.

[88] Hastings and Jenkins, 1983, p. 274.

Figure 3.16
A BV 202 Traverses an Icy Road

SOURCE: K. A. Gallis, "Volvo BM BV202NF1," May 3, 2006 (Creative Commons, CC BY-SA 2.5).
RAND *RR1834-3.16*

The Scorpions and Scimitars had several tools that proved invaluable in the culminating battle outside of Port Stanley.[89] Those units that were supported by the Scorpions and Scimitars, such as the Welsh Guards, fared well in the face of fixed Argentine defences during the fight over Wireless Ridge. They had formidable 76-mm guns, 30-mm Rarden cannons, and better night vision sites than the infantry carried.[90] These vehicles were able to provide near-continuous

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89 Freedman, 2005, pp. 642–651.

90 Hastings and Jenkins, 1983, p. 305.

view of the battlefield for British leadership. Their night vision sensors were sensitive enough to identify Argentine positions by sensing their lit cigarettes in the dark.[91] These vehicles also proved critical in repulsing the only Argentine counterattack during June 13–14. Only three British vehicles encountered any significant problems on the eve of battle. One of the vehicles struck a mine, while two others fell into artillery craters. Those units without the fire support of the vehicles fared much worse. Units such as 2 and 3 PARA took considerable casualties as they assaulted Darwin-Goose Green and Mount Longdon.[92]

Observations and Insights

The Falklands operation saw a well-trained, experienced British military force pitted against a far less well-prepared Argentine Army that for years had been focusing on internal security duties. The British were much better at all aspects of combined arms operations, including the employment of armoured vehicles.

The terrain in the Falklands restricted the number and use of vehicles of all types, including armoured systems. In this case, tracked vehicles had a significant advantage over wheeled systems because of the soft, boggy terrain. At the tactical level, the limited number of light tanks and reconnaissance vehicles that the British deployed to the Falklands provided valuable support for what was an infantry-centric operation. The Argentines were not able to make effective use of the small number of armoured vehicles they sent to the Falklands. The terrain forced the wheeled Argentine vehicles to stay mostly on roads, and there is little evidence that the Argentines employed their wheeled vehicles to support their infantry, despite the fact that the guns on the Argentine vehicles could have easily defeated the British Scorpion and Scimitar light tanks.

[91] Freedman, 2005, p. 651.

[92] 3 PARA, 1983, annex C, paras. 9, 10, 11, and 13.

Case 7—Vietnam (1965–1975)

Scenario Context

The Vietnam War, also known as the Second Indochina War, lasted from 1955 to 1975. On one side of the conflict was North Vietnam, supported by the Soviet Union and its communist allies. In the south was the Republic of Vietnam (South Vietnam), supported by the United States and its anti-Communist allies. After the withdrawal of French forces from Vietnam in 1954, the government of South Vietnam was faced with an increasingly aggressive insurgency supported directly by North Vietnam. During this period, local rebels, the Viet Cong (VC), aided and reinforced by the North Vietnamese Army, attempted to gain control of the South Vietnamese countryside. These territorial gains directly threatened to topple the South Vietnamese government.

To stymie the growth of these communist forces, the United States sharply increased its involvement in 1961 and 1965. Other allied nations soon joined the campaign by sending their own troops to help bolster the South Vietnamese government, including Australia, Thailand, South Korea, and the Philippines. By 1965, nearly all these countries decided to escalate; they sent special operations advisers and airstrikes, as well as entire field units numbering in the tens of thousands.

The U.S. involvement in Vietnam started in the early 1960s in what then was mostly a COIN effort where SOF and U.S. advisers were the most important elements, assisting South Vietnamese forces. By 1965, U.S. conventional forces started to deploy to Vietnam. In January 1969, the first Sheridan armoured reconnaissance airborne/assault vehicles arrived to equip U.S. cavalry units. The M551 had entered production in 1966, but there was a delay in producing the 152-mm main gun ammunition, which in turn delayed the deployment of the vehicle to Vietnam.

The Sheridan was relatively light at 15.6 tons. This was because there was a requirement that the vehicle could be parachute-dropped from a C-130 transport plane. Harking back to the traditional mobility-protection-firepower relationship—the “iron triangle” that influences all armoured vehicle designs—the Sheridan represented a huge bias toward firepower; never before had such a light vehicle been armed with a weapon that large. The M551's mobility was good, but there was a price paid in terms of protection.

In combat from 1969 to 1971, the Sheridan was used in several armoured cavalry units. The power of its 152-mm main gun was impressive, but the crews noted that they needed a high-explosive round rather than the high-explosive antitank projectile which was the vehicle's primary munition. The relatively small size of the vehicle meant that only 30 rounds could be carried. It was, however, the vehicle's light armour that was the main problem.

The VC and North Vietnamese Army (NVA) were well-armed with RPGs, and they made extensive use of mines. It was quickly noted that the Sheridan was very vulnerable to both types of weapons. The vehicle's belly armour was very thin, and most of the armour and structure was aluminum. When the vehicle struck a mine or was hit by an RPG, there was often an explosion of the main gun's propellant charges that frequently resulted in the loss of most or all the four-man crew. In contrast, the other U.S. tank in Vietnam was the 46-ton M48 MBT, armed with a 90-mm gun. Combat experience quickly showed that Sheridans hit by mines or RPGs would often be destroyed, whereas M48s would be damaged but usually recoverable and would have fewer crew casualties. It was also noted that the heavier M48s could more easily push their way through heavy jungle compared to the much lighter Sheridans. Because of the RPG and mine threat, some Sheridans were fitted with extra armour, primarily on the belly plate.[93]

The other main U.S. light armoured vehicle in Vietnam was the M113 APC. This vehicle—the most widely produced armoured vehicle in history—was used extensively in Vietnam. It was a robust vehicle that filled many roles in addition to APC. In armoured cavalry units, two-to-four vehicle patrols consisting of a mix of Sheridans and M113s were employed, starting in mid-1969. The M113s, with all or part of an infantry squad aboard, would follow the Sheridans, ready to support them with machine gun fire (most M113s had additional .30-caliber machines

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93 Steven J. Zaloga, *M551 Sheridan: US Airmobile Tanks 1941–2001*, London: Osprey, 2014, pp. 27–29.

guns mounted to supplement the single .50-caliber that factory-fresh vehicles arrived with), and if need be, their infantry could dismount.

Vehicles Used in the Conflict

The preponderance of fighting vehicles deployed to Vietnam by the United States and its allies were tracked vehicles. While the French had previously fielded lighter wheeled vehicles, by 1955 tracked vehicles became preponderant. Initially, it was difficult for American and allied leadership to see the value of armoured vehicles in an environment such as Vietnam. And even at the height of their utilisation, they still mainly served in supporting roles to infantry units.

Initially, the United States and allied countries did not deploy significant numbers of vehicles to Vietnam. From 1955 to 1965, the allied presence consisted mostly of SOF and other trainers embedded in the Army of the Republic of Vietnam (ARVN). Once the decision to escalate occurred in 1965, the United States sent nearly 16,000 troops within a matter of weeks.[94] However, nearly all these troops were infantry that was meant to be airlifted into battle by helicopter.

The U.S. Army consciously chose not to deploy armour for several reasons. Then U.S. ambassador to South Vietnam, Maxwell Taylor, discouraged the usage of armour in country, stating that "armored vehicles are not appropriate for counter-insurgency."[95] U.S. Army commanders believed that heavily armoured vehicles could not navigate the difficult terrain of Vietnam. As then commander of U.S. forces General Westmoreland stated in a message to subordinates, "Except for a few coastal areas, mostly in I Corps area, Vietnam is no place for either tank or mechanised infantry."[96] Additionally, there was a belief at the onset of the campaign that U.S.-armoured vehicles would be relegated to only defensive missions, such as protecting airstrips and key terrain. There-

[94] Although some Marine units in Vietnam did have M48A3s and LVTH-6As prior to this period, these vehicles were held in reserve as a reaction force.

[95] Simon Dunstan, *Vietnam Tracks: Armor in Battle 1945–75*, Novato, Calif.: Presidio, 1982, p. 60.

[96] Extract of message from Military Assistance Command, Vietnam, to Chief of Staff, Army, 051230 Jul 65, U.S. Army Chief of Military History Files, Washington, D.C.

Figure 3.17
M113s Lead an Infantry Unit Under Fire

SOURCE: Lieutenant General John H. Hay, Jr., Department of the Army, "M113 Advance in Vietnam," April 29, 2006.
RAND *RR1834-3.17*

fore, armoured forces would not be worth the cost of deployment. By 1966, there were five American infantry divisions, but only two tank battalions in country. Each of these infantry divisions had only a battalion of mechanised infantry, equipped with the M113A APC (see Figure 3.17).

But the Siege of Plei Me showed the value of armoured forces in Vietnam. In October 1965 the NVA besieged a U.S. Special Forces camp at Plei Me. When the camp was nearly overrun, the ARVN, with American assistance, coordinated for an armoured column to relieve the camp. The column consisted of nearly 50 ARVN vehicles, M41 Walker

Bulldog light tanks, and M113A APCs.[97] The combination of the convoy's firepower, heavy protective armour, and accompanying American close air support enabled the U.S. and ARVN forces to fend off the NVA attack.

By the summer of 1966, the United States began to field combined arms and fully armoured units in Vietnam. Within months of the Siege of Plei Me, two American tank battalions moved into country. These units fielded the M48A3 MBT, as well as supporting tractors for maintenance and retrieval. By midsummer, these units were executing General Westmoreland's strategy of "search and destroy" operations throughout the Vietnamese countryside.

Armour strength in country reached its peak in July 1968, when a third tank battalion entered the country. Other participating nations in Vietnam also deployed their available armoured forces. Notably, the 1st Australian Task Force fielded a squadron of their British-made Centurion MBTs. These tanks took part in several significant battles with the NVA. They also helped in developing new protective covers for armoured vehicles, enabling them to operate in dense foliage without impediment. The ARVN continued to field the Walker Bulldog light tank in addition to its fleet of M113 APCs.

How the Systems Performed

The performance of armoured vehicles in Vietnam was decidedly mixed. While nearly all the vehicles deployed from 1965 to 1975 were tracked, only the heavier tanks exhibited consistent performance in both firepower and mobility. The lighter vehicles such as the M113A performed worse in the terrain and often failed in their ability to provide overwhelming firepower.

The VC and NVA were well armed with RPGs, and they made extensive use of mines. It was quickly noted that the Sheridan was very vulnerable to both types of weapons. The vehicle's belly armor was very thin, and most of the armour and structure was aluminum. When the vehicle struck a mine or was hit by an RPG, there was often an explosion

[97] Melvin Porter, *The Siege of Plei Me*, report prepared for Pacific Air Force Headquarters, Tactical Evaluation Center, Project Checo, February 24, 1966, p. 3.

of the main gun's propellant charges that frequently resulted in the loss of most or all the four-man crew. The other U.S. tank in Vietnam was the 46-ton M48 MBT, armed with a 90-mm gun. Combat experience quickly showed that Sheridans hit by mines or RPGs would often be destroyed, whereas M48s would be damaged but usually recoverable and would have fewer crew casualties. It was also noted that the heavier M48s could more easily push their way through heavy jungle compared to the much lighter Sheridans. Because of the RPG and mine threat, some Sheridans were fitted with extra armor, primarily on the belly plate.[98]

The main limitation of the M113 was its light aluminum armour. At roughly 12 tons, the M113 was easily penetrated by RPGs and mines. Indeed, the mine threat was so serious and the belly plate of the vehicle so weak that it became common for the crew (except the driver) and the infantry to ride atop the vehicle. When additional armour was added to the belly, it was concentrated around the driver's position (as was the case with the Sheridan). Like the Sheridan, the M113 also experienced difficulty when trying to plow through thick jungle. As noted, heavier MBTs were generally much more capable of doing that.

Compared to tanks, the M113A APCs did not provide the necessary firepower to their accompanying troops.[99] The .50 M2 machine guns equipped on most M113As fired too slowly to provide the necessary suppression in close-quarters combat and was very difficult to aim. For most of the war, the turret gunner on the M113A was exposed to enemy fire. VC cadres were aware of this weakness and regularly trained their heavy machine gunners to fire on the open turret prior to engaging dismounted infantry.[100] After the turret gunner was suppressed, the rest of the NVA or VC force would utilise man-carried recoilless rifles and other antiarmour weaponry to destroy the vehicle.[101]

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[98] Zaloga, 2014, pp. 27–29.

[99] William Gessner, *The Role of the Fighting Vehicle on the Airland Battlefield*, thesis, Fort Leavenworth, Kan: U.S. Army Command and General Staff College, June 1, 1990, pp. 65–68.

[100] *Mechanized Rifle Troop (M113) (U)*, Interim Test Report No. 8, San Francisco, Calif.: Army Concept Team in Vietnam, September 1963, p. 1.

[101] *Mechanized Rifle Troop (M113) (U)*, 1963, pp. 2–5.

Tanks operated in both support of infantry and in flying columns meant to disrupt enemy activity in the countryside. The shock of their arrival and heavy armour were frequently the deciding factor in many engagements. These effects were not relegated just to offensive maneuvers, but also in defence of friendly installations. At the Battle of Ap Bau Bang II in 1967, the presence of M48A3 tanks was essential in preventing a VC regiment from overrunning an American Fire Support Base. After a firefight at night, the VC regiment launched a human wave attack against the fire base and even managed to overwhelm the perimeter. The VC believed that by keeping their persons as close as possible to the tanks, the defenders would be unable to fire upon them. The M48A3s responded by firing at each other's vehicles with small arms, trusting the armour of their vehicles to protect them. Meanwhile, a tank platoon on the outside of the compound counterattacked along the base's perimeter with the assistance of heavy amounts of close air support and artillery.[102] Estimates for VC killed that day range from 250 to 400.

Both the heavy tanks and APCs were generally able to navigate Vietnam's terrain. Contrary to the popular perception, Vietnam is not a monolithic riverine jungle; rather, it has the full gamut of terrain types. In addition to its jungle foliage, it also has mountain ranges, foothills, and plains. Contrary to the expectations of American leadership at the onset of the war, the heavy treads of the APCs and tanks were able to successfully navigate each of these settings. In plains, foothills, and even in mountainous terrain, armoured vehicles were able to maintain their mobility and keep pace with any dismounted infantry.[103] Finally, if a VC base camp was discovered with underground tunnels, tanks served as a brutally effective method to cause the tunnels to collapse simply by driving over them.

The exception to this navigability was in riverine settings. The M113s had trouble traversing swift-moving rivers, even when shallow. Many M113s were swept far downstream when entering into canals or

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[102] Frederick Eugene Oldinsky, *Armor in Vietnam*, thesis, San Antonio, Tex.: Trinity University, May 1976, pp. 101–109.

[103] Oldinsky, 1976, pp. 38–39.

rivers during high tide in the Vietnamese Delta region.[104] For this reason, it would require long amounts of time and careful navigation to bring the M113As through any river while on patrol.

The APCs and tanks were also able to provide a number of non-combat-related support to accompanying infantry.[105] The M113s' tracks enabled them to plow through improvised road blocks such as dirt mounds that impeded other smaller wheeled vehicles.[106] The armoured vehicles could carry much more ammunition in their storage than any accompanying infantry could possibly carry. They offered protection to accompanying infantry—not just with their armoured hulls, but also by being able to run over booby traps and detonate antipersonnel mines with impunity. The vehicles could also create impromptu helicopter landing zones in heavy brush by driving in circular patterns. The tanks were able to plow trails directly through the jungle canopy for the infantry to follow, enabling easier passage through the dense jungle. Otherwise, infantry would find themselves exhausted by having to continuously clear terrain. This rendered the vehicles susceptible to NVA and VC ambushes from very close range, however. The RPG-7, fielded later in the war, was particularly effective at being able to penetrate even tank armour. Many NVA and VC units were skillful enough to be able to ambush armoured units from only 10–15 feet away, often resulting in the destruction of the armoured vehicle.[107]

Insights and Observations

The utilisation of the fighting vehicles in Vietnam resembled their original conception in World War I—they were primarily infantry support weapons.[108] The fighting vehicles led dismounted infantry into battle, crushing any potential obstacles or environmental hazards. They focused

[104] Oldinsky, 1976, p. 28.

[105] Oldinsky, 1976, p. 85.

[106] Oldinsky, 1976, p. 2.

[107] *Mounted Combat in Vietnam*, Fort Knox, Ky.: Armor in Vietnam Monograph Task Force, June 15, 1976, pp. 80–64.

[108] Gessner, 1990, p. 70.

their fire on threats to the infantry, while the infantry protected the vehicle from any nearby antitank weapons. Finally, they helped push through the line of resistance to flank enemy positions from a more advantageous approach. The North Vietnamese made very limited use of armour in Vietnam prior to the American withdrawal in 1973. There were considerable numbers of North Vietnamese tanks in the so-called Easter Offensive in the spring of 1972, but by then there were few American ground combat units left in South Vietnam. Therefore, the general absence of enemy armour in South Vietnam meant that the primary role of U.S. and ARVN armour was to support the infantry.

The heavier M48 MBTs were more successful compared to the lighter Sheridans because the latter had limited armour protection. It is noteworthy that with the exception of airborne units, the Sheridan was retired from U.S. Army use fairly soon after the end of the Vietnam War, with MBTs (either M60s or M1s) taking their place in armoured cavalry units. The M113 became a jack-of-all-trades in South Vietnam, demonstrating both strengths (versatility and large-scale availability) and weaknesses (limited protection and some mobility constraints in jungle terrain).

The Vietnam experience largely foreshadowed the IED challenge of the 2001–2016 period. Many of the armoured vehicle losses in Vietnam were from mines, a fact that forced units to modify their tactics and attempts to improve the mine protection of their vehicles. The short ranges of most combat in Vietnam (given the terrain) also highlighted the RPG threat.

Case 8—East Timor (1999–2000)

Scenario Context

Since the 1990s, Australia has often taken on the role of lead nation for military operations in its region. The area stretching from Indonesia to Fiji is of immediate importance to Australia, with instability in that region always of concern to the government in Canberra. This interest in its near-abroad region was clearly shown when Australian forces were deployed to

Figure 3.18
Map of East Timor

SOURCE: Central Intelligence Agency, "The World Factbook: East and Southeast Asia Timor-Leste," January 12, 2017.
RAND *RR1834-3.18*

East Timor in 1999 and remained there for a number of years to maintain the peace (see Figure 3.18). The title of the operation that took Australian forces to East Timor was International Force for East Timor (INTERFET). Importantly, this was a UN-sanctioned operation.

Vehicles Used in Conflict

In terms of armoured vehicles, the Australian Army deployed medium armour to INTERFET. Both tracked M113A4s and wheeled ASLAV were used. New Zealand also deployed fighting vehicles, in their case

M113s. Several variants of ASLAV were sent to the operation, the most heavily armed being the ASLAV 25, with a 25-mm automatic cannon.

No MBTs were deployed to East Timor. At the time of the operation, the Australian Army operated the German-built Leopard I tank, a 1960s vehicle armed with a 105-mm gun. Although the Leopard I has modest armour compared to today's MBTs, it was much better protected than the ASLAVs or M113s that were deployed to East Timor. The main reasons the tanks were not deployed included the desire to get an armoured force to the operational area and the recognition that tanks were going to be more of a logistics and maintenance burden compared to lighter vehicles.[109]

While a few Australian armoured vehicles were flown to East Timor, most deployed by ship. The first two M113s of the Royal Australian Regiment arrived at Dili, the capital of and largest city in E. Timor, via C-130 transport plane on September 20 (see Figure 3.19). The following day HMAS *Tobruk* arrived at Dili harbor with 22 ASLAVs of the 2nd Cavalry Regiment. From that point on, the vast majority of vehicles arrived by sea.

The threat in East Timor consisted of pro-Indonesian militia groups. INTERFET was an UN-sanctioned multinational force, meaning that if Indonesia tried to incite the militias into violence, they would have faced considerable pressure and opposition from the UN. This reality was a major reason that there was very little opposition to the Australian-led INTERFET force. Additionally, the weapons available to the militias were primarily small arms and machine guns. Therefore, they would have been at a severe disadvantage compared to the INTERFET units equipped with light armoured vehicles. It should be noted that mines and IED-type devices were an option for the militias, but very little use was made of them. Because of the lack of armed resistance, there was little opportunity to assess the protection and survivability of the vehicles sent to East Timor.

As the size of the INTERFET force increased, control was expanded outward from Dili to the rest of the country. As the force continued to

[109] Johnson, Grissom, and Oliker, 2008, pp. 142–143.

Figure 3.19
Australian Troops Debark from an M113 in Dili

SOURCE: John Martinkus, "The Truth About John Howard's East Timor 'Liberation,'" *Tasmanian Times*, November 1, 2016.
RAND *RR1834-3.19*

disperse around the country, vehicle patrols became longer and more frequent. It was noted that the presence of armoured vehicles had an intimidating effect on the population, including would-be or actual militia members.[110]

Australian troops were generally pleased with the performance of the M113 and ASLAV; both vehicles were employed for patrolling, escort, and reconnaissance. It was noted, however, that in poor terrain and weather conditions the tracked M113 had superior mobility to the ASLAV. Indeed, there were times when the muddy conditions off-road essentially prevented the wheeled ASLAVs from operating.[111]

[110] Johnson, Grissom, and Oliker, 2008, pp. 254.

[111] Johnson, Grissom, and Oliker, 2008, pp. 137–145.

How the Systems Performed

The following observations were made about the aging, but still effective, M113s:[112]

- They had an aging and maintenance-intensive power train and an obsolete steering and braking system that ran "hot" when the vehicle negotiated hills, bends, and corners.
- They had a mix of old and new communications systems.
- They had no effective shade protection for stationary vehicles.
- They had no Global Positioning System (GPS) and no integrated tactical navigation system linked to the Battlefield Command Support System.
- They had no effective wide field of view night driving system.
- They had no effective integrated AFV crewman ensemble.

In terms of armament, the lack of night sights and stabilisation of the .50-caliber main armament were also noted as limitations.

The problems noted above were probably primarily the result of the age of the M113s and the fact that the vehicle is a 1950s design. The ASLAVs were more modern (the vehicle entered Australian Army service in 1992) and were less prone to mechanical problems relative to the M113s. The two vehicles have generally the same level of armour protection (i.e., resisting small arms fire and fragments from near misses of mortar and small artillery rounds). The main advantage of the M113s was their better mobility in wet, muddy terrain. Indeed, in some terrain, the ASLAV simply could not operate. Had more serious resistance been encountered, the superior armament of the 25-mm armed ASLAVs would probably have been a major advantage of that system compared to the machine gun-armed M113s.

Insights and Observations

INTERFET was a very successful operation that brought stability to East Timor at a critical time—a bloody internal conflict could have easily broken out had it not been for the deployment of this UN-sanctioned

[112] Johnson, Grissom, and Oliker, 2008, p. 256.

force. In that regard, speed of deployment was essential, and the presence of light armour in the Australian Army was of considerable value.

Because of the lack of significant opposition, the modest protection levels of the M113s and ASLAVs were not challenged. The possible strengths and weaknesses of those vehicles' armament was also not an issue because of the lack of resistance. It was noted by several Australians who participated in the operation that had there been significant resistance, the presence of Leopard I MBTs might have been vital.[113]

For this operation, the Australian Army had the right tools for the task. The mix of wheeled and tracked light armour appears to have worked in this case, although the advantage of tracked vehicles in muddy terrain is noteworthy.

Case 9—Eastern Ukraine (2014–2016)

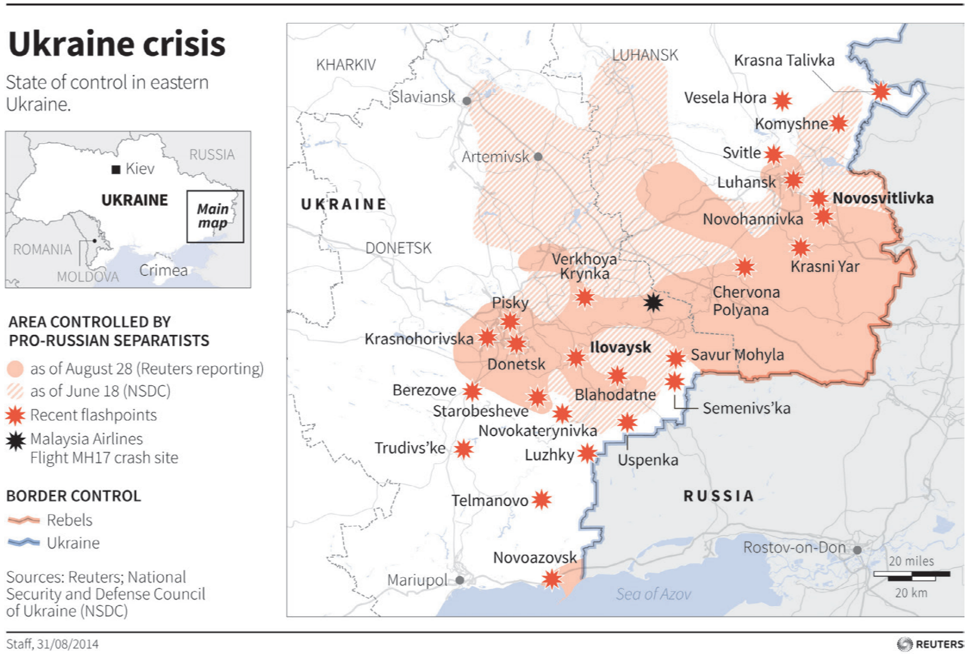
Scenario Context

Combat in Ukraine has been between the armed forces of the Ukrainian government and pro-Russian separatist rebels who are heavily backed by the government in Moscow. Indeed, as time has passed, the amount of military support provided to the rebels by the Russians has increased considerably and become more overt. The conflict, which started in April 2014, has included both unconventional and conventional combat operations. Figure 3.20 depicts the areas under separatist/Russian control in August 2014.

This section considers the recent combat experiences of the Ukrainian armed forces against pro-Russian separatists and regular Russian forces in the Donetsk and Luhansk oblasts (provinces collectively called the Donbass) in Ukraine's east. Eastern Ukraine has been the site of intense combat involving a wide range of armoured fighting vehicles, and some early insights may be gleaned from a close look at the available evidence from a few official Ukrainian sources, press reporting, and an abundance of social media sources of evidence.

[113] Johnson, Grissom, and Oliker, 2008, pp. 142, 258.

Figure 3.20
Map of Areas Under Separatist/Russian Control, August 2014



SOURCE: RNGS Reuters. Used with permission.

RAND *RR1834-3.20*

The conflict itself has gone through a number of phases and can be summarised briefly:

- **March–April 2014:** Pro-Russian separatists seized control over much of the Donetsk and Luhansk oblasts, including most of the major cities there and, particularly, both provincial capitals.
- **May–August 2014:** Ukrainian military units, following some initial setbacks, managed to build sufficient combat power and launched an operation to recover separatist-held territory.[114]
- **August–September 2014:** With separatist units on the verge of military defeat, a number of battalion tactical groups (BTGs) of the Russian military crossed the border and inflicted battlefield losses on the Ukrainians. The sides implemented the Minsk Protocol on September 5, which resulted in a stabilisation of the lines and a cease-fire.
- **September 2014–January 2015:** Both sides fortify the front lines, which remain roughly consistent through this period; cross-border shelling continues.
- **January–February 2015:** Fighting intensifies in the Ukrainian-held town of Debaltsevo; pro-Russian forces ultimately force a Ukrainian withdrawal and secure the town as negotiators reached a second Minsk agreement.
- **February 2015 to present:** Return to an uneasy "cease-fire" with sporadic cross-border shelling, and occasional periods without exchanges of fire.

The periods of greatest interest for this study are those with the most intense combat, namely the period of the Ukrainian offensive through the Russian intervention (with the heaviest fighting taking place from July to early September 2014) and the Battle of Debaltsevo in early 2015.

We stress that these are preliminary findings, given that there are serious limitations on the reliability of the sources available; the assessment here can be considered in no way comprehensive. The conflict in eastern Ukraine has not yet been resolved, and multiple factions on each

[114] The Ukrainians call this the Anti-Terrorist Operation (ATO).

side have been attempting to actively control the narrative of how the conflict has taken place. But available reporting, from mainstream press and from a number of dedicated private researchers utilising a virtually unprecedented amount of data secured from social media, can help paint a basic picture of what appears to have been a very lethal environment for armoured vehicles.

Vehicles Used in the Conflict

Both sides in this conflict used Soviet-developed armoured fighting vehicles, or vehicles that were largely derived from Soviet-era models. There was heavy use of tracked IFVs as well as of tracked and wheeled APCs. As will be noted further below, there were also large numbers of MBTs, again used by both sides. Although detailed numbers of vehicles used by either side are unavailable, we can be reasonably assured that large numbers were present because there is abundant photographic evidence of large numbers (in the hundreds) of destroyed vehicles of each type.

Infantry Fighting Vehicles

The two main types of IFVs used on both sides were the BMP series and the BMD (Boyevaya Mashina Desanta, or "combat vehicle for airborne") series. The BMP series is noteworthy for their high firepower and mobility and their relatively light armour. The original BMP-1 included a 73-mm low-velocity gun and a 9M14 Malyutka (AT-3 Sagger) ATGM; the BMP-2 (see Figure 3.21), which is still the most prevalent version in Russian service, is armed with a 30-mm autocannon and a 9M113 Konkurs (AT-5 Spandrel) ATGM launcher. Both vehicles featured a number of innovations when they were first fielded, but overwhelmingly the emphasis by designers was on preserving mobility and lethality; the protection levels on the vehicles are light—they are protected against heavy machine guns and fragments, but not autocannons or shaped-charge warheads. Both sides appear to have relied on these vehicles.[115]

[115] For an overview of the BMP-1 and BMP-2, see "Russian Infantry Fighting Vehicle BMP-1," in *World Equipment Guide, Vol. 1: Ground Systems*, Fort Leavenworth, Kan.: TRADOC, December 2011; and "Russian Infantry Fighting Vehicle BMP-2," in *World Equipment Guide, Vol. 1: Ground Systems*, Fort Leavenworth, Kan.: TRADOC, December 2011. For a remark-

Figure 3.21
Russian BMP-2

SOURCE: Vitaly V. Kuzmin, "Military Exhibition in Park Patriot for Minister of Defense," blog, August 15, 2015 (Creative Commons CC BY-SA 3.0). No changes were made to this photo.
RAND *RR1834-3.21*

The BMD series is similar to the BMP in armament, but these vehicles were designed to equip airborne forces. They are even smaller and lighter in weight, permitting them to be flown aboard heavy-lift helicopters or delivered via parachute from transport aircraft like the IL-76. A number of Ukrainian airborne and airmobile units participated in the air tasking order; Russian airborne units equipped with BMDs also seem to have participated in late August 2014.[116]

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ably detailed look at the design and characteristics of the BMP-2, see the excellent "BMP-2: Eastern Breeze," *Tankograd*, May 27, 2016.

[116] "Russian Airborne Fighting Vehicle BMD-1, BMD-1P and BMD-2," in *World Equipment Guide, Vol. 1: Ground Systems*, Fort Leavenworth, Kan.: TRADOC, December 2011. For much additional detail on BMD-2, see also "BMD-2: Metal Storm," *Tankograd*, October 9, 2015.

Figure 3.22
Russian BTR-80

SOURCE: Vitaly V. Kuzmin, "The Day of Internal Troops 2016 and Tactical Exercises," blog, March 25, 2016 (Creative Commons CC BY-SA 3.0). No changes were made to this photo.
RAND *RR1834-3.22*

APCs

Both sides have utilised APCs, in both tracked and wheeled varieties. These primarily included Soviet-era BTRs and MT-LBs (light multi-purpose armoured towing vehicles). The BTR-80 is an 8×8 wheeled armoured car that appears to have been the most common wheeled armoured vehicle in use in eastern Ukraine (see Figure 3.22). It is very lightly armoured for a combat vehicle, providing protection against small arms and perhaps some 12.7-mm machine gun rounds against its frontal arc if fired from normal battlefield ranges. It is amphibious and armed with a 14.5-mm heavy machine gun.[117] Additionally, a limited

[117] "Russian Armored Personnel Carrier BTR-80," in *World Equipment Guide, Vol. 1: Ground Systems*, Fort Leavenworth, Kan.: TRADOC, December 2011. For abundant additional detail

number of more modern BTR-82As have also been used by pro-Russian forces. This is a modernised BTR-80 with a stabilised 30-mm cannon, a more powerful engine, and some modest improvements to survivability. We can say this was used in more limited numbers because it is not yet widely fielded in the Russian armed forces, and only one has been seen to have been destroyed, near Luhansk in late August 2014, with photos uploaded a few days after Russian forces crossed the border.[118]

The Ukrainians also seem to have used limited numbers of their newer, Ukrainian-developed BTR-3 and BTR-4 in Donbass. These are descendants of the BTR-80 with somewhat heavier armour (intended to protect against 12.7-mm caliber ammunition) and may be outfitted with slat armour for additional protection against ATGMs and RPGs. The BTR-4 is frequently armed with one of a number of turret modules that include a 30-mm cannon.

Finally, the MT-LB tracked APC is in wide use on both sides as a prime mover for artillery and is the base platform for many other specialist vehicles, such as radars, air defences, ATGM launchers, and ambulances. Like the BTR, it is very lightly armoured. Its continued use in Russian service is largely a feature of its exceptional mobility; it is the primary vehicle for several Russian motorised rifle brigades that are intended for use in difficult or arctic terrain. These vehicles may be equipped with wide tracks that give them very low ground pressure (0.28 kg/cm^2, or just under 4 psi).[119]

Common Themes in Soviet Light Armoured Fighting Vehicle Design

All the vehicles outlined above share a common theme: they were designed to be inexpensive, mass-produced fighting vehicles that could be easily transported and sustained and could help ensure Soviet forces were able to maintain a high rate of advance in the event of a conflict with

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on all aspects of this vehicle, see "BTR-80: Sanguine," *Tankograd*, November 18, 2014.

[118] Reported as a BTR-82AM, which is the name given to a BTR-80 updated to the BTR-82A standard. See "BTR-82AM," Lost Armour, August 29, 2014.

[119] "Ukrainian/Russian Light Armored Multi-Purpose Vehicle MT-LB," in *World Equipment Guide, Vol. 1: Ground Systems*, Fort Leavenworth, Kan.: TRADOC, December 2011.

NATO in Europe during the Cold War. The designers of these vehicles made clear choices in favor of mobility; they are highly mobile, amphibious, and, in the case of the BMD series, may be delivered by air transport. The BMP series also has substantial firepower, including both cannon and missile armament. The inherent protection of these vehicles is essentially enough that they can survive incidental engagement—fragments or small arms, potentially up to heavy machine gun fire—but not direct combat with an enemy well-equipped with antiarmour weapons.

The Soviets developed these vehicles as part of a system that envisioned their use in concert with large numbers of (relatively) more survivable MBTs and supported by large volumes of indirect fires. Their survivability was a function of their advantages in numbers, mobility, and total formation lethality, which was substantial. As will be seen below, their survivability performance in more static, positional warfare where large numbers of antiarmour weapons were present was predictably poor.

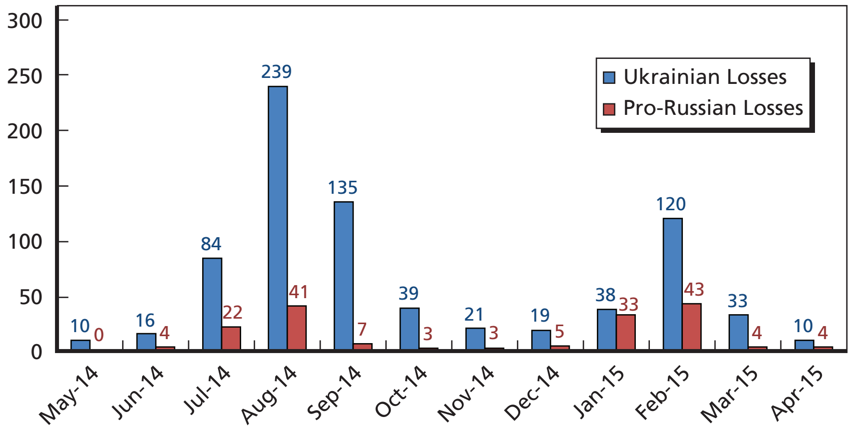
How the Systems Performed

The fighting has involved Ukrainian regular military, Ukrainian volunteers, pro-Russian separatists, and regular Russian military forces. With the possible exception of some of the regular Russian units, the level of training and proficiency of vehicle crews was probably quite low. This may have compounded the problem of attempting to operate combat vehicles in an environment where there were large numbers of antitank weapons and heavy use of artillery by both sides.

Both Russian and Ukrainian regular forces appear to have organised their forces into BTGs—essentially reinforced battalions assembled and task-organised for combat. According to one pro-Ukrainian source, an example BTG from the Russian 35th Separate Motorised Rifle Brigade of the Central Military District consisted of the following elements:

- a motorised rifle battalion, with 30–40 BMP-1s
- 10–15 tanks (T-72Bs)
- 2–3 batteries of artillery, including cannons (both 2S19 and 2S3) and multiple rocket launchers

Figure 3.23
Summary of Total Combat Vehicle Losses, May 2014–April 2015



SOURCE: LostArmour.info (collected social media images).
RAND *RR1834-3.23*

- air defences (gun-missile launcher vehicles, probably 2S6)
- reconnaissance and engineering elements.[120]

This approach integrates combined arms at the battalion level; these units are tailored for fighting by their parent formation.

Over a thousand fighting vehicles consisting of BMP, BTR, BMD, or MT-LB series vehicles have been destroyed in eastern Ukraine since the beginning of the conflict (see Figure 3.23 for a summary). The actual numbers may be higher; as of mid-July 2016, there were 1,039 vehicle wrecks that have photos uploaded to the website www.lostarmour.info (collected social media images). A further 428 were recorded as trophies.[121] The overwhelming majority of the wrecks in photos are catastrophic losses, and many other vehicles may have been damaged,

[120] This unit was photographed while on the border with Ukraine in December 2014. See Falcon Bjorn, "The BTG of the 35th Motorized Rifle Brigade of the Russian Invasion Force," *InformNapalm*, December 21, 2014b.

[121] LostArmour.info.

Table 3.3
Combat Losses for Selected Fighting Vehicle Types, May 2014–Present

Destroyed Vehicles	Ukrainian	Pro-Russian
Tanks	166	81
BMPs	285	36
BTRs	145	14
MT-LBs	53	15

SOURCE: LostArmour.info.

perhaps severely, and recovered. It is also likely that some recovery operations are taking place because several destroyed recovery vehicles have been photographed. In short, while firm details are evasive, it is clear that this conflict has seen very high losses of combat vehicles.

There are some risks involved in drawing conclusions from the available data on combat losses from LostArmour.info, but a few things can be shown from this source. First, it appears that combat vehicle losses peaked dramatically in July–August 2014 during the height of the ATO and the direct intervention by Russian units, and again in January–February 2015 during the Battle of Debaltsevo.

The source LostArmour.info is interesting and worth discussing further here. This site amasses and catalogues the social media images of destroyed vehicles in eastern Ukraine. It includes, for the majority of cases, location data, dates recorded, and usually several photos of each vehicle destroyed, frequently from multiple sources. However, it has some limitations. For example, as mentioned above, nearly all the vehicles recorded here are catastrophic losses. The data show a great deal more losses for Ukrainian forces than for the separatists and Russian regular forces. While it is likely that Ukrainian losses were higher for a number of reasons, it is also very possible that fewer Russian regular force vehicles were knocked out and not recovered. The breakdown of combat losses by type and side are shown in Table 3.3.

The state of the destroyed vehicles is revealing. Since they have been abandoned, most are catastrophic losses, and very frequently show the rust and marks characteristic of having burned. The BMP-2

Figure 3.24
Destroyed BMP-2 near Marinovka, August 2014

RAND *RR1834-3.24*

in Figure 3.24 is relatively intact compared to many others; turrets are frequently found next to the vehicle and in some cases vehicles have been hit with munitions of sufficient force to rend their hulls into multiple pieces. It is also clear from a great many photos that the long lines of sight in this area of Ukraine offered relatively little cover and concealment.

The knocked-out BTR-80 in Figure 3.25 is fairly representative of the more than 150 vehicles of this type that have been recorded destroyed in eastern Ukraine. It burned at some point after being hit; the tires, as is common in these photos, have burned away as well.

There is some anecdotal data about the challenges to combat vehicles in eastern Ukraine. A common issue was damage to the optics of

Figure 3.25
Destroyed BTR-80 near Elenovka, October 2014

RAND *RR1834-3.25*

vehicles because of artillery fragments and small arms fire. One of the Kharkiv-based Ukrainian defence companies reported hits from sniper fire on armoured glass on a BTR-4E, and one account from the Battle of Illovaisk mentioned damage from artillery fire to the optics of a captured Russian T-72B3.[122]

Observations and Insights

We can infer some reactions to the many lost vehicles based on new procurement plans from both sides. In the case of the Ukrainians, there seems to be an effort to purchase 50 BMP-64 heavy APCs based on the hull of the T-64 tank. These vehicles would be much better protected than the BMPs and BTRs currently fielded by the Ukrainian ground forces. Such vehicles would have armour protection more com-

[122] "Ukraine Army Receives 100 Armored Vehicle and Tanks," *Defence Blog*, December 6, 2014; and Falcoln Bjorn, "The Story of Colonel Evgeniy Sidorenko Who Broke Out from Ilovaisk in a Russian T-72 Tank," *InformNapalm*, September 14, 2014a.

parable to that of a tank hull, the engine mounted forward to permit infantry to mount and dismount from the rear, and substantially improved underbelly protection to reduce the risk from mines and improvised explosive devices.

In the case of the Russians, there are some organisational and procurement approaches, as well as a few sources writing openly about lessons from the conflict. Russia is in the process of an ambitious modernisation effort for essentially all its combat vehicles, replacing their current main tank, the T-72B3, eventually with the T-14 Armata; replacing the BMP series with a new IFV called Kurganetz-25, and the BTR series with an 8×8 wheeled APC called Bumerang. Kurganetz-25 and Bumerang are much more comparable to Western IFVs and wheeled APCs, respectively. Additionally, Russia appears to be exploring a version of the Armata platform that would be a heavy IFV based on the tank platform (T-15).

Organisationally, one notable change in recent years is the announcement that tanks are being fielded in the Russian Airborne Troops. These are MBT units (presumably equipped for the time being with T-72B3s) that will be used to augment airborne BTGs when they deploy for ground operations, as is frequently the case.[123] There has also been evidence of cross-attachment between airborne and tank units from the ground forces. The Russians are undeterred by the additional complexity of fielding wheeled and tracked vehicles in the same formation. BTR-equipped brigades also have tank battalions and tracked self-propelled howitzers; it is thus not surprising that they might consider making heavy armour available to airborne forces on a more permanent basis.[124]

Russian analysts have taken note of the implications of the conflict in Ukraine for future ground vehicle development. Writing in *Moscow Defense Brief*, Anton Lavrov commented on the role of tanks in the conflict, considering lessons from the fighting in eastern Ukraine:

[123] Russian Airborne Troops are equipped with light armoured fighting vehicles and are frequently used as high readiness infantry forces.

[124] "Russian Airborne Adding Heavy Tanks to the Ranks," 2015.

> the Ukraine conflict has clearly demonstrated the diminished independent role of tanks. Even in a limited local conflict with irregular (and later quasi-regular) forces, tanks have proved very vulnerable when used autonomously because of the growing availability of effective antitank infantry weapons, especially antitank missiles.[125]

Lavrov went on to emphasise the need for accelerated development of APSs:

> Russia, which has long relied on tanks, needs to speed up the entry into service of the latest active protection systems for armoured vehicles. . . . An advanced modern active protection system should be an automated, all-aspect, multiple-round system capable of intercepting several missiles in the same sector in quick succession. Missiles should be intercepted as far away from the tank as possible, providing greater protection from explosively formed penetrator ammunition and enabling the tank to protect not only itself but also nearby infantry and hardware in a broad range of scenarios, including battle, guard duty, and convoys.[126]

The Ukrainian and Russian experience in combat operations in eastern Ukraine is still opaque in open sources, but it was clearly a highly lethal environment for ground vehicles up to and including tanks.

Lessons Learned from the Nine Case Studies

Inside each of the nine case studies discussed above, we have identified some lessons learned from those conflicts that are captured in the "Insights and Observations" subsections. Here, we go a step further and discuss broader lessons that run across the gamut of case studies—lessons that can be divided into those that focus on lower-intensity and higher-intensity combat.

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[125] Anton Lavrov, "The Use of Tanks in Ukraine: Lessons Learnt," *Moscow Defense Brief*, No. 3, 2016.

[126] Lavrov, 2016.

Lower-Intensity Combat Lessons

Across the nine case studies examined, four—Mali, Balkans, Afghanistan, and East Timor—involved what we would refer to as comparatively lower-intensity conflict. In these cases, the missions ranged from peace enforcement and security operations to COIN operations that involved small arms fire and IEDs. With the exception of Mali, these cases involved the combined use of tracked and wheeled vehicle fleets. However, even though both classes of vehicles were present in these venues, the bulk of the operations conducted abroad suggested an emphasis toward using wheeled vehicles as the combat capability of choice. In Mali, which involved traversing very long distances (hundreds of miles), the French military planners opted to deploy a lighter and entirely wheeled vehicle fleet, keeping the heavy tracked forces at home but available as a contingency should the light wheeled force not succeed. Good intelligence, streamlined C2, and favorable terrain were characteristics that contributed to the decision to use light wheeled platforms and ultimately enabled the force to succeed.

In the Balkans, the KFOR units were equipped with both tracked and wheeled vehicles, which were not used in vehicle-to-vehicle combat; the extent of the combat, in both American and Russian sectors of the region, involved dismounted infantry with small arms firefights. In this case, mobility presented a challenge for both classes of vehicles. On one hand, the rainy, muddy conditions during part of the deployment in cross-country terrain favored tracked vehicles, with some instances of wheeled vehicles getting stuck. On the other hand, infrastructure limitations, both operationally and tactically, constrained the movement of heavy tracked vehicles because they could cause damage to roads and bridges, some of which were hundreds of years old.

In Afghanistan, where long distances were routinely traveled, U.S. forces relied heavily on Stryker vehicles equipped with slat armour and, later in the deployment, MRAP vehicles when the Strykers were shown to be vulnerable to mines and IEDs. These vehicles were often used to provide security to the sustainment forces that were distributing supplies to forward-based units. Although the U.S. forces deployed heavier tracked vehicles such as the Abrams, they were not generally used for day-to-day missions in COIN. Aside from being relatively burdensome to maintain compared to lighter vehicles, they were not ideal platforms to address the kind of weapons used by the insurgents in theater, which included high-explosive IEDs detonated on the underbelly or side attack. Other tracked vehicles such as the Warrior and CV90, which had modern mine protection, were used by a few other countries that deployed to Afghanistan. From a firepower perspective, the LAVs that were available at that time were seen by some commanders as too limited in protection, resulting in heavier systems ultimately being deployed.[127]

In East Timor, the Australian military deployed the combination of tracked M113s and wheeled ASLAVs for the peace enforcement mission. Heavier tracked Leopard MBTs were kept as a contingency in the case of escalation; however, this need did not arise.

Higher-Intensity Combat Lessons

The remaining five case studies—Panama, Iraq, Vietnam, Falklands, and Ukraine—tended to involve higher levels of conflict, albeit with a wide variation in level of military training. This ranged from COIN battles to conventional combat against armour formations. In Panama, there was an emphasis on speed in the deployment, which influenced the selection of vehicles. Both light tracked and wheeled vehicles were ultimately used in the operation but in relatively small numbers.[128] For the urban combat part of this operation, the ability to provide high-angle elevation firepower was important, and the large-caliber 152-mm weapon on the M551 Sheridan also proved important because it could penetrate walls of buildings to enable dismounted infantry entry points and clear roadblocks.[129] Thus, both wheeled and tracked vehicles used to support a U.S. light infantry operation performed as expected. In this particular scenario, lighter tracked vehicles were used in lieu of the heavier Bradley IFVs to streamline logistics and facilitate the speed of deployment.

[127] One example of this: In the Canadian experience of combat with the Taliban, LAVs equipped with 25-mm weapons were seen as insufficient in certain situations. As a result they deployed Leopard tanks, which were used to take down buildings where enemy forces were located.

[128] The Army did not have LAVs, so they deployed Sheridans and M113s; while the USMC deployed LAVs at the Army's request.

[129] Johnson, Grissom, and Oliker, 2008.

The conflict in Iraq can be characterised as bimodal, involving both conventional combat and COIN. Early in the war, U.S. and British forces deployed and operated traditional heavy forces in offensive operations against Iraqi heavy forces. As the war unfolded, it quickly transitioned into a COIN operation that lasted over a decade, marked with pockets of intense but disjointed combat. In both conventional combat and some of the more intense COIN battles, there was clearly a preference for using heavy tracked forces, often centered on MBTs, because of their inherent armour protection and firepower advantage. As in Afghanistan during the less intense COIN operations in OIF, LAV-type vehicles with additional appliqué and slat armour (by both U.S. Army and USMC units) along with MRAPs were often used for the more day-to-day operations because of the greater efficiencies of these vehicles in long duration and long distance operations.

In Vietnam, the U.S. Army employed light tracked vehicles, such as the M113s and the M551 Sheridans, along with heavier M48s. However, despite much debate within the Army leadership, many operations were conducted as infantry operations that had relatively little armour support; lighter tracked vehicles were vulnerable to weapons (mines and RPGs) used by a relatively unsophisticated adversary.

In contrast, light tracked vehicles such as the Scorpion and the Scimitar were used with great success by UK forces in the Falklands. Part of the difference in outcomes could be attributed to the difference in terrain, as well as the difference in adversary training.

In the recent conflict in the Ukraine, a combination of medium and heavy tracked and wheeled vehicles was used by both sides, often employing reactive armour. Given the volume and sophistication of Russian weapons used in this venue along with the wide spectrum of vehicles the weapons were mounted on, a majority of losses were seen on the Ukraine side.

Synopsis of Lessons Learned

The cases examined in this research show that armoured vehicles can be exposed to a wide variety of threats. Vehicles originally designed with a specific threat in mind often had to deal with a new, unexpected challenge. The U.S. experiences with mines and IEDs in Vietnam, Iraq, and Afghanistan are examples of this, where many of the armoured vehicles deployed were not designed to deal with those threats. This resulted in hasty modifications to tactics and to the vehicles themselves, as well as to a need to purchase new equipment (e.g., MRAPs). Terrain also had a clear relationship to threats. For example, in Mali the relatively open terrain meant that the light French armoured vehicles could, for the most part, avoid close-range ambushes where they would have been highly vulnerable to RPG fire. However, in the jungles of Vietnam and the streets of Iraq, the American vehicles could be engaged a close range by these weapons. The reality that vehicles will be exposed to numerous types of threats should be taken into consideration when choices are made about future vehicle development and acquisition.

In the majority of instances, the vehicles performed as expected. However, from a review across the case studies, heavier tracked vehicles including IFVs were employed when one or more of the following circumstances occurred: the threat was known to have powerful antiarmour weapons or heavy armour forces; there was a great degree of uncertainty in the location (and composition), including dismounted forces of the threat; and/or there was a desire to deter escalation of combat. In the most notable conflicts where heavy tracked forces were used—in the combat phase of OIF and in combat in Ukraine—heavy armour on the dominant side caused numerous adversary losses, with relatively few losses on the dominant side. Much of this can be attributed to notably higher quality combined arms forces and training in conjunction with the heavy armour materiel. In most other conflicts considered, either light tracked vehicles or wheeled LAVs were used to address the majority of regional conflicts.[130] Part of the rationale for these lighter forces was the strategic and/or operational deployability and logistics benefits, which favor less heavy vehicles, especially so for wheeled vehicle fleets.

In more recent conflicts, there has been a notable desire and shift to wheeled vehicles over light tracked vehicles, which have largely gone

[130] While lighter tracked vehicles were used in some conflicts, such as the M113 and Sheridan, they were employed because these were the systems available, particularly in the U.S. Army.

away in the U.S. Army. In addition to Armoured Brigade Combat Teams (ABCTs), which feature heavy and medium tracked vehicles (e.g., M1 Abrams and M2 Bradleys), the U.S. Army has now fielded SBCTs with a family of LAV III variants; these were initially intended to be interim vehicles until the FCS was fielded but are now a major part of the deployable Army force structure.

CHAPTER FOUR

Task 2 Results: The Impact of Advanced Technologies

As noted in Chapter 2, there are many different current and future technologies that could mitigate the historical problems noted with both tracked and wheeled IFVs and that were discussed in the lessons learned from the case studies in the last chapter. Based on our previous research, as well as on discussions with U.S. Army, USMC, and military and civilian staff from other countries, we compiled a list of key vehicle technologies to consider in this chapter in terms of how they could affect performance as measured by the "iron triangle." These include hybrid designs that blur the lines between tracks and wheels, new suspension systems, lightweight APS, and advanced weapon systems. Such technologies may turn out to be critical in the decision to move toward lighter or heavier vehicles, with resulting impacts on the choice of wheels or tracks. The technologies also influence the capability of different platforms to perform under different conditions, threats, and mission requirements.

Hybrid Approaches That Bridge Tracks and Wheels

Traditional 8×8 wheeled IFVs and steel-tracked IFVs both have critical shortcomings when it comes to meeting some of the Project LAND 400 requirements. Some of these limitations have since been overcome by new developmental programs, which blur the lines between tracks and wheels. The first approach is the use of removable tracks that can

Figure 4.1
Tracks Over Wheels Prototype Shown at 2016 Singapore Air Show

SOURCE: Tamir Eshel, "Amphibious Capabilities at the Singapore Air Show, Defense Update, February 17, 2016. Used with permission.
RAND *RR1834-4.1*

be placed over sets of two wheels. An application on a Terrex 2 IFV by ST Kinetics in shown in Figure 4.1.[1]

Installation is said to take less than an hour, and resulting ground pressures can drop by 50–100 percent, depending on the track design and width. In the larger perspective, tracks over wheels kits are available from many different manufacturers[2] and exhibit different levels of flotation, drag, self-cleaning, and weight. The concept (also called loop-wheel and track-wheel) has been used widely on forest machines such as loggers, loaders, and other skid-steer vehicles, as shown in Figure 4.2. On an IFV, modifications to the steering may be necessary

1 Kevin Wong, "Singapore Airshow 2016: ST Kinetics Debuts 'Tracks Over Wheels' Concept on Terrex Armoured Vehicle," *IHS Jane's International Defence Review*, February 22, 2016.

2 Manufacturers include McLaren Industries, Grouser, Solideal, and Prowler.

Figure 4.2
Illustration of Tracks Over Wheels for Forest Machines and Construction Vehicles

SOURCE: McLaren Industries, "Over the Tire Tracks," undated. Used with permission.
RAND *RR1834-4.2*

to allow skid steering or variable wheel rotation on those wheels in which the tracks are fitted.[3]

The U.S. Army has some experience fitting removable commercial tracks on a 6×6 Family of Medium Tactical Vehicles (FMTV) series medium truck.[4] Much like experiences with half-tracks in World War II, the Army found that with tracks on the rear wheels, the forward steering wheels tended to plow in soft soil conditions. This might be reduced with dual-forward steering wheels on an 8×8. The Army also found that for military applications, a specialised track tensioner was needed; otherwise slippage would occur with sand and small rocks between the treads. When fitted, the tensioner intruded somewhat into the payload compartment. Finally, the Army noted that at high speeds, hysteresis could result in heating and failure of the track couplings. It appears that the tracks over wheels approach should be constrained to the small percentage of off-road situations when low ground pressure is needed, which are often low-speed movements, at least until effective tensioning systems, innovative steering mechanisms, and new track designs are developed.

Wheeled vehicles also can reduce their ground pressure by simply increasing the tire size or number of tires. A team at the U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) found this to be problematic because of volume impingement, resulting in drive shaft issues, suspension travel limitations, deployment width problems, and turning radius increases. As noted earlier, however, the USMC is pursuing designs that increase the size of tires beyond the larger 16.00×20R category, such as 475/80R20. This should reduce ground pressure by as much as 15 percent compared to the current tires.

Tracked vehicles have benefited from the addition of rubber band tracks. These are either segmented or continuous tracks made up of

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[3] A wide range of steering options have been developed for 8×8 vehicles, including steering for all eight wheels on the Piranha (see "Piranha V Armoured Wheeled Vehicles, United Kingdom," n.d.); skid steer on some pairs of wheels would allow the tracks to stay aligned, and some new designs now have partial skid steering, in which inside wheels in a turn rotate at a different speed than outside wheels (see "Tracked Vehicle Steering," Gizmology.net, n.d.); unfortunately, skid steer is difficult to control at high speeds, with a lack of lateral stability and yaw issues.

[4] Steven J. Tarnowski and Glen R. Simula, *Segmented Track Over Wheels Development*, Houghton, Mich.: GS Engineering, December 12, 2010.

rubber pads on a flexible composite backing with steel cable cores. They are said to have roughly double the life of steel tracks (even those with rubber pads), are much quieter, lighter in weight, and lead to much as a 70 percent reduction in vibration, resulting in a less fatigue for the occupants.[5] They also are said to reduce fuel consumption on roads. However, if these band tracks are continuous, there are logistics challenges in supplying them and replacing them by crews. As the number of segments increase, the weight reduction advantage diminishes, but the logistic and replacement issues improve.[6]

Rubber band tracks for military vehicles are more mature and battle-tested than tracks over wheels. Figure 4.3 shows a CV90 fitted with Soucy rubber tracks; this combination has been used by the Swedish forces in Afghanistan and in Liberia,[7] and by Danish and Norwegian forces in Afghanistan.[8]

Speeds of 60–65 miles per hour have been achieved with band tracks, although high levels of wear have been seen even at 45–50 miles per hour in M2A2 tests.[9] The M1 Abrams with steel tracks has been test driven at speeds of 60 miles per hour on improved surfaces, but they are limited to 45 miles per hour because of the risk of damage to the drive train and injuries to the crew.[10] Most other tracked vehicles are limited to similar speeds.

TARDEC personnel noted some limitations of the band tracks, such as the need to carry a heavy spare continuous track on a wrecker

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5 "Rubber Band Tracks: The Future of Tracks?" *Warfare Technology*, June 1, 2014.

6 Unfortunately, experiments at TARDEC with these segmented tracks have shown that heating effects occur at the linkages, resulting in some failures. Some redesign and refinements may be needed; see Alice Gowan, *Test Report of the Experimental Band Track for the M2A2 Bradley Fighting Vehicle*, Report No. 02-036, Yuma Country, Ariz.: Yuma Proving Ground, October 2002.

7 Richard Lindstrom, "Missions Experience with CV90," FMV briefing, February 18, 2010.

8 "Danish Army sends CV90 Vehicles to Afghanistan," Army-Technology.com, March 3, 2010; "Norway Buys Rubber Tracks for CV90 Afghan Operations," *BAESystems.com*, February 10, 2011.

9 Abel Moreno, *Abbreviated Test Report for the Technical Feasibility Test of the Demonstration of the Future Combat Vehicle System 15-Inch M1113A3 "Heavy" Band Track*, Yuma Country, Ariz.: Yuma Proving Ground, May 2004.

10 Tankpoly.com website, "M1 Abrams Main Battle Tank."

Figure 4.3
CV90 with Soucy Rubber Tracks

SOURCE: Soucy group, "CV 90," April 9, 2014. Used with permission.
RAND *RR1834-4.3*

and hysteresis/heating problems with the more logistics supportable segmented track. The segmented track also does not offer the roughly 50 percent weight savings of the continuous track. It appears that a development program is needed to find an appropriate number of segments and the right tensioning system for this medium-weight application.[11]

Enemy Threats and Countermeasures

Vehicles will have to deal with a variety of threats and countermeasures that come from all directions. The enemy may stage ambushes or attack directly with KE or chemical energy (CE) rounds and missiles, indirect

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[11] Band tracks do seem to offer good load carry capabilities. Soucy demonstrated a 50-ton vehicle with their tracks in the summer of 2016 at the Eurosatory meeting in Paris. DST (formerly Diehl) also develops both continuous and segmented tracks, although these are primarily for lighter weight vehicles, such as the M113 and BV 206.

fire munitions, IEDs, electronic warfare (EW) devices, mines, obstacles, decoys, deception, and many other weapons or tactics. These threats will have different impacts on wheeled and tracked vehicles. For example, IEDs, mines, rounds, and missiles can destroy an axle or wheel assembly, but the vehicle may still be able to move or limp home. A similar attack on a tracked vehicle may require a recovery vehicle. A 1-m obstacle may be surmountable with tracks but may stop a wheeled vehicle. A missile may miss a shorter tracked vehicle such as the CV90 but hit a taller wheeled vehicle. EW may have much greater impact on a light, electronically sophisticated wheeled vehicle than on a traditional heavier tracked vehicle relying primarily on armour for protection. Some threats, such as rapid-fire autocannons and salvos of RPGs and ATGMs, will be extremely difficult to counter, even with APSs backed by substantial base armour.

Enemy tactics may differ depending on the type of vehicle attacked. Against a heavier tracked vehicle with strong frontal arc, the enemy may attempt to flank the force and try for side and rear shots. This rear shot issue is serious for combat vehicles that have rear fuel tanks that lack sufficient armour. Against vehicles with manned turrets, the enemy may target these with top attack weapons. If a vehicle has added visible systems, such as ATGMs or many communications antennae, it may more likely be attacked.

Influence of Vehicle Weight on Choice of Suspension

Weight is critical to the choice of vehicle type. There appear to be two directions for vehicle design in the future: (1) a relatively light, high-technology platform that emphasises agility, electronic developments, unmanned turret, minimal base armour, and moderate-power drive train; and (2) a heavier, more robust vehicle with substantial base armour, manned or unmanned turret, large payload, and high-power drive train. Lighter systems would be more deployable, have lower signatures, and be more agile on most terrains than heavier systems but would likely be more expensive and less robust to jamming, EW, and other countermeasures than heavier vehicles. Regardless, it appears that a capable vehicle for Project LAND 400 requirements will have at least a 30-ton minimum

Table 4.1
30-Ton Vehicle Weight Is Likely Minimum for Project LAND 400 IFV Requirements

	Wheeled Vehicles (tons)	Tracked Vehicles (tons)
Engine and accessories[1]	2–3	3–4
Transmission, drives	2–3	3–4
Suspension[2]	4–5	5–6
Electronics	2–3	2–3
Payload (troops, equipment)	8–10	8–12
Hull with level 4 protection	12–14	10–13
Total	**30–38**	**31–40**

weight and could range as high as 45 tons. Table 4.1 shows some estimated components and total weights for wheeled and tracked vehicles with combat capability.[12] The weight ranges would be even higher than those shown if level 5 protection is provided (currently available on some tracked vehicles such as the CV90, including 30-mm protection across the frontal arc).[13]

Unfortunately, 40 tons appears to be the maximum that an 8×8 wheeled vehicle can support, even with tracks over wheels on both its front and rear axle pairs. The largest tires currently fitted to these vehicles, at their lowest off-road pressure to maximise footprint, provide some 1,900–2,200 square inches of ground area.[14] This is expected to increase to almost 3,000 square inches with a single set of tracks over wheels on

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[12] David R. Gillingham, *Mobility of Tactical Wheeled Vehicles and Design Rules of Thumb*, Alexandria, Va.: Institute for Defense Analyses, NS D-3747, June 2009; Gillingham and Patel, 2013; also see Periscope.com articles on various IFVs and APCs. Note that Gillingham specifies that engine and accessories are typically 10 lb/hp and suspension tends to be about one-sixth of vehicle weight.

[13] FMV, "CV90—A Development at Bofors and Hagglunds," FMV briefing, May 24, 2016. Level 4 protection is typically 14.7 mm all around, while level 5 protection generally raises this to 20–25 mm all around and 30 mm in the frontal arc (ref).

[14] *Mission Ready Military Tires*, Goodyear.com, n.d.

two axles (four wheels), and almost 4,000 square inches with two sets covering all eight wheels. With all eight wheels covered by tracks, the target ground pressure of 20 psi can thus be attained at 40 tons.

Then again, tracked vehicles can have a footprint the full length of the vehicle, and are only constrained by the skid-steer limit of approximately 1.7:1 ratio of length to width.[15] This provides over a 5,000 square inch footprint in some cases and allows up to 50 tons to be supported with a reasonable width track. However, there is some controversy about the ability of band-track designs to handle this level of load.[16]

Designs over 40 tons become an extreme burden for airlift. The C-17 can carry up to 70 tons, but the A400 is limited to about 37–40 tons (with constrained range and airfield issues), although it has sufficient length to carry two 8×8 vehicles.[17]

In general, it appears that targeting a 30–35-ton design may be ideal for many amphibious missions, and the USMC teams note that can be accomplished with wheels. These have had more development transfer from the commercial sector (central inflation systems, stability control, crouching, long suspension travel, all-wheel steering, etc.) than tracked vehicles and have much more potential for off-road improvement in the future.

Possible Mitigating Factors for Wheeled Vehicles

Past studies seem to strongly favor tracked vehicles for the conditions faced by a Project LAND 400 force, but new developments have reduced the dominating off-road advantage of tracked vehicles.[18] These include:

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[15] FMV, "CV90—A Development at Bofors and Haaglunds," FMV Report, May 24, 2016.

[16] A demonstration of a 50-ton band-track application is scheduled for this summer at the SOUCY plant in Canada; a description was given at the Eurosatory Conference in Paris on June 15, 2016.

[17] "Airbus A400M: Medium Range Transport Aircraft," Military-Today.com, n.d.; "A400M Design," GlobalSecurity.org, n.d.

[18] Note that many of these developments are included in the current U.S. Future Fighting Vehicle (FFV) program. This is an effort with General Dynamics and BAE Systems to research future vehicle technologies, including armour, weapons, drive systems, and networking; see

- long travel, height-adjustable independent suspensions that can better clear obstacles and improve ride[19]
- low-pressure, radial ply, run-flat tires that reduce ground pressures and improve reliability
- central tire pressure regulation systems that can adjust to terrain
- four-axle steering reducing turning radius, thus increasing agility
- an articulated/coupled chassis such as Twister, BV 206, and articulated M113, thus improving obstacle clearance and spreading the load[20]
- modular combinations of manned and unmanned vehicles, thus reducing loads
- loop-wheel/track-wheel designs that blur the lines between wheels and tracks removable tracks (often used with commercial forest vehicles) can be fitted to wheeled vehicles, thus reducing ground pressure significantly;[21] similar hybrid systems such as band tracks can be applied to tracked vehicles
- detailed, real-time mapping of terrain and obstacles that facilitates the avoidance of no-go or slow-go areas[22]
- APSs, possibly resulting in lighter base armour and overall weight
- independent axle suspensions that allow a wheeled vehicle to continue to fight or "limp home" even after multiple individual wheels have been blown off, unlike tracked vehicles that are unable to move if a track is lost

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Stew Magnuson, "New Research Holds Promise for Lighter, Tougher Vehicle Armor," *National Defense*, April 2016.

19 Loren Thompson, "The Rise of Wheeled Combat Vehicles," *Real Clear Defense*, November 19, 2014.

20 Jean Dasch and David Gorsich, "Survey of Modular Military Vehicles Benefits and Burdens," *Defense Acquisition University*, January 2016.

21 Natchammai Revathi Palaniappan, *Forest Machine Track-Soil Interaction*, thesis, Stockholm: KTH Royal Institute of Technology, 2013; "Improved Steel/Rubber and Band-Tracks Make Tracked Vehicles Superior to Wheeled Armored Cars in All Categories," 2009; Wong, 2016.

22 See, for example, Bruce Blundell, Verner Guthrie, and Edmundo Simental, *6.2 Terrain Gap Identification and Analysis for Assured Mobility*, Alexandria, Va.: U.S. Army ERDC, September 30, 2004; and Chris Kramer, "Chapter 3: Terrain Analysis Considerations," Globalsecurity.org (Center for Army Lessons Learned Report 1-19), n.d.

- larger, longer range autocannons and missile systems, thus allowing greater standoff and protection through offensive capability.

Integrating Protection with Mobility

As shown earlier in Table 4.1, probably the greatest contributor to added weight on an IFV is armour protection. All-around level 4 protection through the use of base armour—even with advanced spaced armour, reactive armour, or electric armour technologies—can result in a 35-ton minimum weight.[23] A more efficient approach is to use APSs in combination with lighter base armour.[24] These APSs can be light, on the order of 0.5 to 1 ton, relatively low cost, and effective against volley RPGs, some ATGMS, and even medium-caliber cannon fire.

APSs have traditionally taken the form of heavy, expensive long-range missile packages, such as the Israeli Trophy and Russian Drozd and Arena systems.[25] These engage enemy fires at tens of meters from the vehicle, and the resulting sprays of fragments can injure infantry and noncombatants. Recently, smaller and more affordable short-range APSs have been developed, such as the U.S. Iron Curtain and German AMAP-ADS.[26] These systems use shorter-range sensors to detect incoming missiles and engage missiles and rounds inches from the vehicle. They are typically mounted with soft-kill systems such as jammers and smoke grenades. The short-range systems have the advantages of lower cost, greater magazine depth, and reduced signature and EW vulnerability

[23] New armour approaches include spaced steel, ceramic, depleted uranium and composite armour, along with explosive reactive, bulging, and electronic armour. All of these can be defeated by salvo attacks, KE threats, and large powerful ATGMS. See "The Armour Strikes Back," *Economist*, June 2, 2011.

[24] Against RPS, a minimum level of base armour for residuals appears to be level 4 protection; against more capable ATGMs, a minimum level of level 6 protection (30 mm) may be needed.

[25] For a comparison of systems, see Kris Osborn, "Army Looks Beyond Armor to Upgrade Vehicle Fleet," Military.com, October 30, 2013; and Daniel Gouré, "Now Is the Time to Provide U.S. Armored Vehicles with Active Defense Systems," Lexington Institute, August 3, 2015.

[26] The German AMAP-ADS is a hard-kill active protection system (APS), developed by the German company ADS collaboration with Rheinmetall and IBD Deisenroth Engineering.

Figure 4.4
A Short-Range APS

SOURCE: Artis, "Iron Curtain Active Protection System," undated. Used with permission.
RAND *RR1834-4.4*

compared to longer-range systems.[27] As shown in Figure 4.4, they are typically mounted in a frame around the vehicle. Some designs can use the same frame to protect both the top and sides of the vehicle. They can be integrated with V-hull configurations to provide added IED protection.

One possible option for integrating protection and mobility is to hang removable tracks on the side of a wheeled vehicle, increasing the base armour under a short-range APS frame. When running on wheels without tracks, which should occur 90 percent or more of the time, the tracks would hang on the sides as shown in Figure 4.5. The APS would

27 Some new longer range systems, such as the IMI Iron Fist Light Configuration, are also relatively light (250 kg for overall protection). See "IMI Iron Fist Specifications," (n.d.).

Figure 4.5
A Design for Integrating an APS and Tracks Over Wheels on an IFV

SOURCE: Promotional image from ST Kinetics with author overlay.
RAND *RR1834-4.5*

cover the entire surface of the vehicle against attacks. The hanging tracks under the APS would only cover the upper hull and provide added depth of protection against residuals and medium-caliber KE rounds. The uncovered lower surface (still protected by downward-firing APS) would have the shape of the V-hull adding protection against both residuals and IEDs. A short-range APS can similarly be attached to a tracked vehicle with steel- or band-track segments or could be used over other forms of appliqué armour.

A short-range APS can similarly be attached to a tracked vehicle with steel or band tracks, as shown in Figure 4.6. A segmented band-track spare section could provide additional protection on the upper flank.

Of course, these designs produce a great deal of external clutter on the vehicles, which may be stripped off by trees, obstacles, fragmenting weapons, and other hazards. If cost is not a constraint, it may be cleaner to equip the vehicle with a longer-range, more expensive missile-based APS; however, this may increase the prospect of unintended casualties because of debris from successful engagements.

Figure 4.6
A Similar Design for Integrating Mobility and Protection on a Tracked Vehicle

SOURCE: Promotional image from BAE Systems with author overlay.
RAND *RR1834-4.6*

Firepower Options

IFVs can use firepower to defend themselves, provide offensive punch, and suppress the enemy, offsetting the need to rely entirely on protection, stealth, and agility to survive. The most common weapons are up-gunned autocannons, ranging from 20 to 45 mm. These can have ranges from 2 to 3 kilometers and can be mounted in manned or unmanned turrets. Some of the larger calibers can be reduced in size by using telescoping ammunition, and the combination of remote turrets and case telescoped ammo can allow 40–45-mm weapons to be mounted without major weight and size penalty.[28] The autocannon can augmented with antitank guided missile systems such as Javelin, TOW (tube-launched, optically-tracked, wire-guided), and Griffin. In the far future, if sufficient onboard power is available and battlefield dust and weather conditions are favorable, directed energy can be used to jam, spoof, and even disable incoming missiles, nearby enemy unmanned

[28] For a thorough description of applications throughout the world, see "The 40mm Cased Telescoped Armament System (CTAS)," ThinkDefence.co.uk, n.d.

aerial systems, mines, and IEDs, assuming there is sufficient dwell time to do damage.[29]

Other Areas to Consider

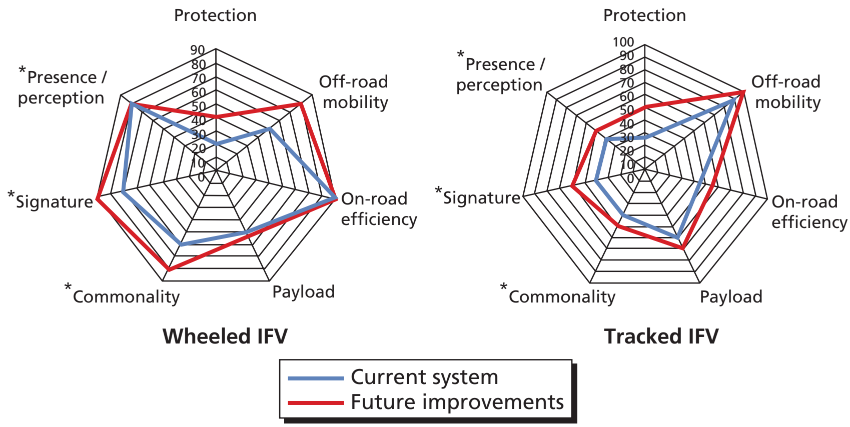
While tracked vehicles have superior off-road capabilities and growth potential, if we look at the overall flexibility of IFV options, wheeled vehicles offer some potential improvement in areas beyond the iron triangle attributes. Figure 4.7 shows some the areas and their possible levels of flexibility in spider graph form and was derived from both quantitative and qualitative assessments by the authors to show respective areas of advantage by vehicle type. The values ascribed on the figure are normalised for comparative purposes on a 0–100 scale, but they are based on the quantitative scales as follows: the protection scale runs the range from 0 to 90 mm KE defeat, off-road mobility is quantified as 15 to 50 psi ground pressure, on-road efficiency is rated from one to five miles per gallon, and payload goes from 0 to 20 tons. Signature, presence, and commonality are all qualitative and subjective. Both the quantitative and qualitative estimates were determined from interactions with subject-matter experts and, in some cases, specifications of current and developmental systems.

Of course, many questions need to be answered before committing to a course of action, including the following:

- Are tracks over wheels feasible and effective on a vehicle weighing 30 or more tons? Can skid or variable speed steering be programmed in the platforms?
- Can a short-range APS be fitted to the candidate IFV platforms?
- How reliable and capable are APSs to a reactive threat?

[29] Note that some researchers feel that high power laser systems will result in excessive weight and cost penalties for a medium-weight vehicle, even in the longer time horizons. On the other hand, soft-kill systems such as smoke grenades and EW systems are incorporated in many fielded APSs, and require much less energy than defence lasers. Directed energy has no real advantage in countering mines or IEDs due to long dwell times given the weight, size, and power needed to trigger the explosive.

Figure 4.7
Some Other Attributes to Consider in Comparing Wheeled and Tracked Vehicles and the Prospective Level of Flexibility



NOTE: Ranges in spider charts: Payload 2 to 20 tons, off-road mobility 40 to 10 psi, protection 7.62 to 120mm; others based on 100 percent of arbitrary max.
*Qualitative estimates
RAND *RR1834-4.7*

- How large a payload is required in terms of squad size and equipment weight?
- Are there any new band tracks in development that have the potential for efficient on-road transport?
- What proportion of the rest of the force will be wheeled or tracked? How much commonality is possible?
- Are new in-stride detection and identification capabilities available that can spot mines, ambushes, and IEDs?
- Have mobile communications at a brigade level and below coupled with advanced artificial intelligence been sufficiently exploited to take full advantage of situational awareness data and further advance the tactical capabilities and training of platform operators?

At this point, there seems to be insufficient information and development about either of the hybrid approaches—tracks over wheels or band tracks—to advocate such an approach over traditional designs. Tracks over wheels have been proven in commercial applications but have not been shown to be effective in combat situations requiring fast movement over soft terrain under fire. The modifications needed to ensure effective operation—room for tracks under the sponsons, changes to the drive systems (possibly including some form of programmable skid steer), sophisticated tensioning systems, and fast mounting equipment—make this option high-risk.

Band tracks suffer fewer of these shortcomings and have been proven in the field on some systems, but they still have some problems with tensioning, wear, load bearing, and replacement. There are few requirements to modify the vehicle to prepare for this option, beyond new drive sprockets.

CHAPTER FIVE

Task 3 Results: System-Level Implications

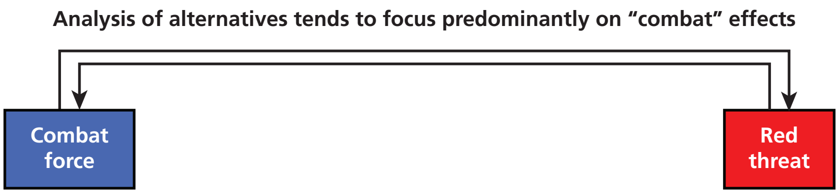
Chapters 2 and 3 focused on Task 1—expected performance of tracked and wheeled vehicles in combat and the performance they had in nine case studies, respectively, in terms of the "iron triangle" measures of combat effectiveness, and Chapter 4 focused on Task 2—assessing the impact on advanced technologies for tracked and wheeled vehicles, again in terms of combat effectiveness in terms of iron triangle measures of performance. Here we discuss the results of Task 3, which focuses on the system-level implications—implications that are outside the traditional iron triangle measure of performance. We start by discussing why a system-level perspective is important, before turning to system-level lessons learned from U.S. Army's modernisation plan. We close with a discussion of the system-level impact of a new IFV for Australia.

Why a System-Level Perspective?

As noted earlier, from a pure iron triangle perspective, if vehicle combat performance is the only thing that matters, the heavier IFV is often the preferred choice, since tactical mobility, protection, and firepower (and payload) are all important, and they can all be concomitantly improved.[1] Since tracked vehicles have a higher maximum weight, it follows that such a class of vehicles tends to be the default choice for IFVs if they can be supported. But clearly there is a practical limit to

1 This assumes the profile or exposed silhouette of the vehicle can be managed with the greater size.

Figure 5.1
Traditional Analysis of Combat Vehicles Tends to Be Platform-Centric, Focusing on Combat Effectiveness (Iron Triangle Attributes)



RAND *RR1834-5.1*

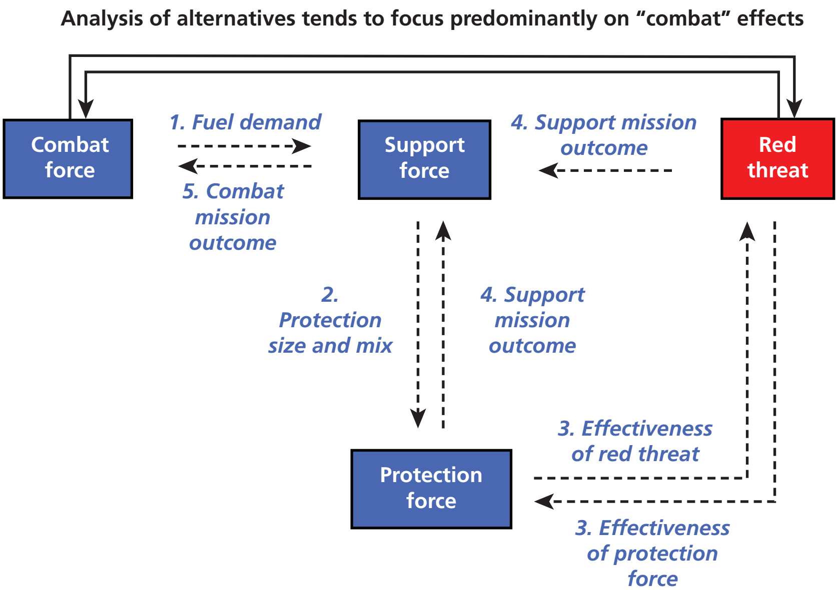
the maximum weight, and ultimately what defines where this limit lies may change over time. Earlier RAND research suggests a strong correlation between vehicle weight, fuel consumption, and fuel resupply capacity.[2] On some level, it may be a reasonable adjustment to proportionally increase the number of refuelers and resupply vehicles in the unit. However, the challenge can be much more complicated, especially when force-level implications are considered.

As depicted in Figure 5.1, in the traditional examination of combat capability, which tends to focus on combat effectiveness, a heavier armoured force going up against a less armoured force is generally at an advantage. Here, all three IFV attributes of mobility, protection, and firepower—the iron triangle—in theory can be higher.

However, it is possible that in a case of overmatch, a knowledgeable adversary will choose not to directly engage a superior heavier combat force. Rather, such an adversary may opt to attack or counterattack other elements of the force, such as the combat support of combat service support elements. If this is a viable threat option, the force-level perspective can look very different, as shown in Figure 5.2. In this portrayal of the force-level options, the threat can attack the supporting force or the protection force that would then be proscribed to protect the supporting force. If these threat contingencies are addressed, the

2 Fully loaded with appliqué can significantly reduce the fuel efficiency.

Figure 5.2
A Broader Force-Level Perspective Includes Vulnerabilities at the System Level



RAND *RR1834-5.2*

heavier combat force would, thus, have to be larger to provide protection to the supporting force.

As an example, say an M113 can typically travel approximately four miles per gallon of fuel.[3] In comparison, a Bradley class vehicle can travel approximately 0.6 to 1.2 miles per gallon of fuel over the same terrain, depending on how it is configured. Thus, all other things equal, it will require somewhere around three to six times the number of refuelers to sustain the heavier vehicle. A natural inclination would be to proportionally increase the refuelers and resupply vehicles to accommodate this change. However, this may only translate to a first step. If the

[3] Daehner et al., 2015.

combat environment is not secure where security forces are needed to protect the refuelers, the requirement for more security forces may have to be increased as well, requiring larger force structure. This, in turn, may require a larger number of replacement vehicles as well. Overall, this adjustment process can become a cascading increase in support and combat platform requirements, which can significantly affect the size, the vulnerability, and/or the mission tempo associated with the unit.

Lessons Learned from U.S. Army's Modernisation Plan

As noted earlier, in the context of an IFV, generally the heavier platform, the more capable it will be from an iron triangle perspective. But this does have a practical limit. In the context of the U.S. Army's GCV, early paper designs indicated that it could exceed 80 tons.[4] As with the Australian priority, survivability was a major concern given the lessons coming out of Iraq and Afghanistan with regard to IEDs. The need to provide internal space to carry nine soldiers and provide mine blast protection, including a V-shaped hull, made this vehicle both heavy and large. As a result, more armour was needed, which translated to a heavier chassis. This, in turn, mandated a larger and heavier engine. Ultimately, concessions were made to bring the weight of competing new vehicle designs down to 60–70 tons, but key capabilities were absent from these newer design concepts.[5] From a survivability perspective, no APS was included; from a firepower perspective, no ATGM such as the TOW missile or TOW IIB (wireless variant) were integrated into the vehicle. Though intended for operations within an MCO, the GCV designs still had a very large exposed silhouette, potentially making it much more vulnerable than the Bradley to enemy ATGMs and tank rounds.

However, one of the additional major issues associated with the GCV was its impact on the supporting force. The GCV designs were

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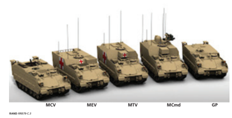
4 Kempinski and Murphy, 2012.

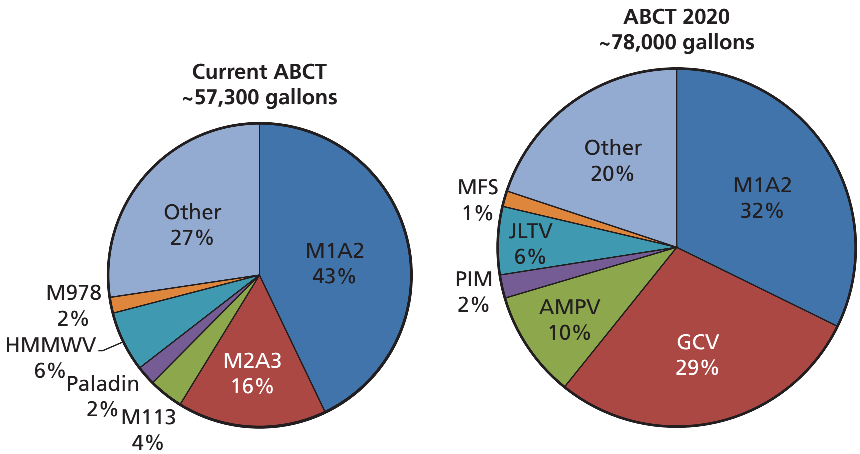
5 There was also a GCV variant that included a modification to the Bradley vehicle, which was lower in weight.

Table 5.1
New ABCT Systems Replace Existing Systems Generally on a One-for-One Basis

Current	New Vehicle (% of 2020 ABCT[a])	
M2A3 Bradley	Ground Combat Vehicle [GCV] (7%)	
M113	Amoured Multi-Purpose Vehicle[b, c] [AMPV] (10%)	
High Mobility Multi-Purpose Wheeled Vehicle (HMMWV)	Joint Light Tactical Vehicle[d] [JLTV] (33%)	
Paladin	Paladin Integrated Management Program [PIM] program vehicle (3%)	
M978	Modular Fuel System[e] [MFS] (4%)	

[a] Based on 1,311 ABCT vehicles.
[b] Assumes AMPV Bradley chassis variant.
[c] AMPV General Purpose is one of five variants.
[d] This is one of three JLTV prototype variants.
[e] Trailer that accompanies HEMTT.

Figure 5.3
ABCT 2020 Fuel Needs in a Notional MCO



NOTE: Fuel expended includes movement to objective, at objective, idling, and fuel loss through vehicle attrition.
RAND *RR1834-5.3*

expected to consume nearly three times the amount of fuel per traveled mile relative to its replacement, the M2A3 Bradley. Other vehicles associated with the Army's new ABCT 2020 concept (which are shown in Table 5.1) involved great fuel consumption. But as can be seen by comparison in Figure 5.3, most of the increase in fuel needs was driven by the GCV concept. The ABCT 2020 requires approximately 36 percent more fuel to operate in a notional MCO; the GCV portion alone of the increase is 24 percent.

What Is the System-Level Impact of a New IFV for Australia?

Given that protection is a high priority identified for the replacement IFV (perhaps the highest, if the mounted combat reconnaissance vehicle priorities transfer to the IFV), the replacement IFV will have to be a much heavier platform than the M113AS4 that it replaces. Basic logic indicates that even as a contingency, some modest level of armour would be desired to protect against a full range of modern threats, including advanced small arms threats, likely to be seen across the spectrum of recent conflicts. Thus, regardless of whether it is tracked or wheeled, the replacement IFV for the M113AS4 will likely be at least twice if not three or four times heavier to enable this minimal level of desired protection. Current age and reliability issues of the older M113 aside, the supportability requirements of the new IFV platform will likely increase.

Based on our research, a tracked vehicle will have significantly more supportability needs than that of an equivalently protected wheeled vehicle. To some extent, the selection of a wheeled IFV alternative will offset some of the added logistics that will be needed to support a heavier platform. Regardless, as a result of fielding these heavier vehicles, the system impact will likely involve an increase in the size of the supporting force that will accompany the new post-Beersheba brigades.[6] Assuming that the IFV represents approximately one-third of these brigades, this could easily translate to an increase in logistics and support platforms from as low as 25 percent to as high as 100 percent, just with this one major change.

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6 At the time of this writing, it was not clear to what extent the weight and subsequent logistics and support growth was included in the post-Beersheba organisation.

CHAPTER SIX

What the Assessment Means for Project LAND 400 and the Path Ahead

In this chapter, we discuss what our assessment means for Project LAND 400 in terms of the two vehicle types and weigh classes for each, and our suggestions for a path ahead.

What the Assessment Means for Project LAND 400

The examination of mobility, protection, and firepower issues faced by combat vehicles recently deployed into combat highlights the many trade-offs seen between tracked and wheeled options. Tracked vehicles have traditionally shown their advantages in off-road mobility, flexibility in weight growth, and ability to fight and survive on the battlefield, while wheeled vehicles have shown better on-road mobility, lower signature, savings in maintenance, and reduced crew and squad fatigue. Historically, these distinctions have been significant, but they are blurring somewhat with the introduction of new technologies and systems. As we consider different weight classes of the different vehicle types, the picture becomes even more blurred on some level. That is, there are light, medium, and heavy tracked and wheeled vehicles that might all be potential candidates for a replacement IFV for the Australian Army. We have chosen somewhat arbitrarily the weight classes of under 20 tons, 20–35 tons, and over 35 tons as representative of the respective weight classes of light, medium, and heavy combat vehicles, respectively. The relative attributes of these classes of vehicle by type are summarised in Table 6.1.

Table 6.1
Tracked and Wheeled Vehicles by Weight Class

	Tracked Vehicles	Wheeled Vehicles
Heavy Class of Vehicles (over 35 tons)	• Good levels of tactical mobility • High sustainment and O&M penalty • Protection against medium threats (w/APS) • Large DF weapon/ATGM	• Ground pressure levels and tire size tend to limit tactical mobility at this level • Alternatively, vehicle size can increase but tactical practically may come into question
Medium Class of Vehicles (20 to 35 tons)	• Very good tactical mobility • Medium sustainment and O&M penalty • Protection against small arms and some medium (w/APS) • Medium to large DF weapon/ATGM	• Good levels of off-road mobility—and improving • Low sustainment and O&M • Protection against small arms and some medium (w/APS) • Medium to large DF weapon/ATGM
Lighter Class of Vehicles (under 20 tons)	• Excellent tactical mobility (low VCI) • Low sustainment and O&M penalty • Limited protection from small arms (slat armour) • Small DF weapon or missile	• Very good tactical mobility • Very low sustainment and O&M penalty • Limited protection from small arms (slat armour) • Small DF weapon or missile

Based on the recent lessons learned and technological changes ahead, it appears to us that some of the vehicle classes and/or types can be eliminated. Assuming that the ADF will only acquire one IFV, the lighter class of vehicles can likely be eliminated from further consideration. While these vehicles, both tracked and wheeled, have many excellent attributes, they do not typically offer robust enough protection to the wide range of threats to include proliferating RPGs and the emerging class of ATGMs. Even relatively benign threat environments may call for the consideration of at least a medium-class vehicle to allow for incorporation of different survivability options, given that many modern environments will demand some level of armour, appliqué, and the possibility to upgrade to modern APSs.

Also, we find from an iron triangle perspective that the differences between the tracked and wheeled vehicles in the medium class

(20–35 tons) are decreasing. While tracked vehicles in this class have a tactical mobility advantage, this advantage is shrinking because of new mobility technologies described earlier in this report. Furthermore, wheeled vehicles in this class can provide similar levels of protection and firepower as their tracked counterparts, and they come with significant strategic and operational mobility, as well as logistics and supportability advantages. While the difference between tracked and wheeled vehicles in this class is not quite to the point where wheeled vehicles are a dominant choice, the technology trends are shifting in this direction.

At the time of this writing, given ground pressure level constraints, heavy wheeled combat vehicles exist, but just at or over the 35-ton threshold. Clearly, increasing tire size, as is done with large commercial vehicles, can overcome the ground pressure constraint. However, with any additional growth, these could become unwieldy for an IFV required to move with agility while maintaining a low profile, which could prove to be important in combined arms maneuver combat.[1] Breakthroughs in tracks over wheels may provide a long-term opportunity to change this; however, implementing this involves some technological risk, which is something the Australian government is seeking to minimise. Hence, while vehicles in this class may have attractive attributes today, they will likely have limited opportunities to accommodate new downstream technologies. This may not be a critical constraint for armies that have alternative tracked IFVs that can be so equipped to address the more difficult contingencies that will arise; however, it could represent a major constraint for an Army that is centralising its IFV around a single platform, with a plan to maintain this platform in the fleet for decades to come. A tracked platform, in this weight class, provides much greater headroom to accommodate growth and account for uncertainty.

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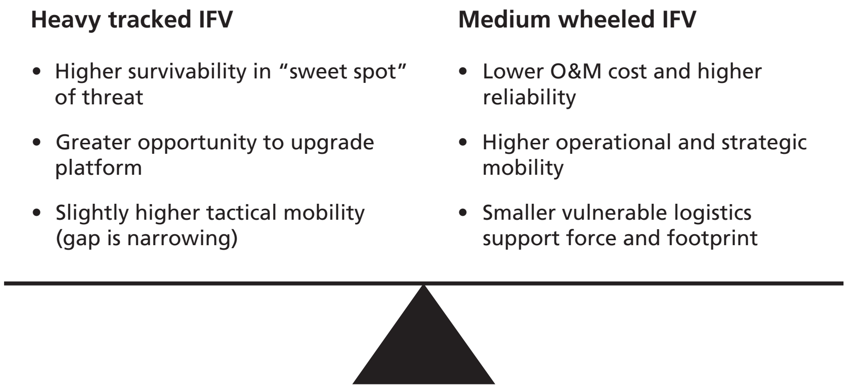
[1] Heavy class of vehicles may accommodate 36 tons, as this appears to be a local maximum for the 475/80R20 tire size. Even with this size, compromises are present at over 35 tons due to more than 30 psi ground pressure, problems with clearance of tires, and increase in turning radius.

Figure 6.1
Respective Strengths and Weaknesses of Heavy Tracked and Medium Wheeled Vehicles



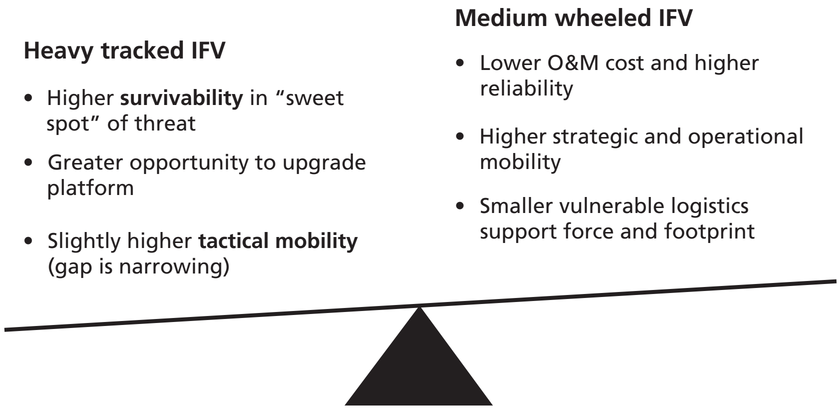
RAND *RR1834-6.1*

It is important to stress that the vehicle classes that have been eliminated in this analysis may be both applicable and ideal for specific situations. That is, if a key scenario was identified as the "defining scenario," it is possible that vehicles in one of the eliminated classes could be a dominant choice. However, given the broad nature of contingencies with which the Australian Army must contend, as identified by existing requirements, some level of robustness was assumed to be necessary to address both scenario breadth and uncertainty depth. Thus, based on our analysis, two classes of vehicles provide a competing set of strengths and weaknesses: a heavy tracked IFV or a medium wheeled IFV. Figure 6.1 illustrates the strengths and weaknesses of the two.[2]

In considering the broader Australian IFV requirements, the needs seem to be somewhat unique among vehicle acquisition programs, and further they appear to be bimodal. On the one hand, there is a desire to provide force capability to directly support the M1A1 MBTs in heavy armour battles. This emphasises (as seen in the mounted combat

2 "Sweet spot" of threat refers to high-end threats seen in MCO operations.

Figure 6.2
Applying Priorities Identified with Mounted Combat Reconnaissance Vehicle



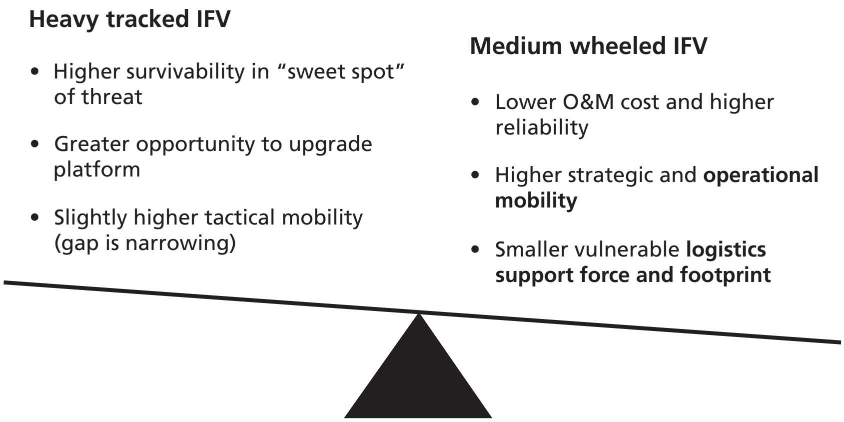
RAND *RR1834-6.2*

reconnaissance vehicle requirements) that protection has a higher priority than lethality, that lethality has a higher priority than mobility, and that mobility has a higher priority than sustainability or command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR). This prioritisation scheme would correspond to MCOs that could likely be conducted as part of a coalition effort with the United States. By applying the priorities identified with the mounted combat reconnaissance vehicle, the result tends to favor a heavy tracked IFV alternative, as Figure 6.2 depicts.[3]

On the other hand, there are many more demands that do not involve heavy armour battles, many of which reside in the regional engagements that the ADF is likely to confront in its own backyard. While there are needs for tactical mobility over soft terrain, these vie with requirements for long-range force projection over improved roads. The vehicles must be able to move and fight with the forward combat elements and also operate in operations other than war. There should be

[3] Using this weighting schematic, the lower IFV is the preferred choice.

Figure 6.3
Designing to Meet the Needs of Key Regional Engagements Near Australia



RAND *RR1834-6.3*

commonality, modularity, and integration with existing platforms and with the vehicles selected in the other phases of the Project LAND 400 initiative and other similar modernisation programs. If such regional engagements are the priority, the scale shifts in favor of a medium wheeled IFV, as shown in Figure 6.3. A key assumption here is that the regional threats remain on the lower end of threat spectrum for the foreseeable future and that the type of missions are centered around operations other than war, such as peacekeeping and peace enforcement, and not focused on heavy armour (non-MCO).

In a sense, it appears that the Australian choice highly depends on the relative importance of these competing bimodal requirements. Acquiring a heavy tracked IFV will ensure that the ADF is ready for the most difficult part of the higher end of conflict. However, in most venues, this capability will be overdesigned, especially for many of those contingencies on the lower end of the threat spectrum. In these cases, there will be a large logistics and support tail that will come with a substantial cost. In a more general sense, high-intensity conflicts are not frequent and the costs incurred in conducting such combat operations are also infrequent, so the cost burden is transitory. So while the cost burden of a heavy tracked vehicle can be much greater, its advantage becomes one of having a hedge in dealing with uncertain future threats that may require greater combat vehicle adaptability.

Acquiring a medium wheeled IFV is much more amenable for the many types of conflicts that Australia is likely to see within its own regional engagement zones, but it may introduce constraints in the Australian participation in MCOs where heavy armour forces are prevalent on the battlefield. There is also the cautionary issue of acquiring a platform that has sufficient headroom for adaptability to uncertain future reactive threats.

Currently, the U.S. Army addresses such divergent needs with different classes of vehicles: both the Bradley (and its eventual replacement) and the Stryker families of platforms. In contrast, the USMC, which does not field Bradleys, has incorporated a wheeled fleet focus as it modernises for the future; for example, the replacement for the existing AAV-7 was originally envisioned to be another tracked vehicle; however, it now appears destined to be a wheeled platform in the ACV. Given that the Australian requirement for fielding a heavy armour force appears to be associated with serving as a partner to the United States in an MCO, it may be possible to predetermine roles where the Australian contribution in such future fights takes into account the relative strengths of combat capability, much like how Joint Forces within the United States are planned for, deployed, and ultimately employed on the battlefield.

The Path Ahead

In a post-Beersheba environment,[4] the Australian Army might consider evaluating the full range of doctrine, organisation, training, materiel, leadership, personnel, and facilities (DOTMLPF) adjustments with

[4] The Beersheba initiative refers to a major restructuring of the Australian Army which effectively redistributes heavy armour across units accounting for the possibility of long-term sustained operations.

both classes of IFV alternatives. In DOTMLPF terms, both classes of alternatives will have an impact, with a heavy tracked IFV involving more and/or different logistics units than a medium wheeled IFV. Fielding these additional units will increase the size of the deployed footprint of the force, which may imply higher total force risk. These risks could be evaluated and understood ahead of time—before key decisions are made. Additionally, such a change will likely require substantive doctrine, training, and personnel changes throughout the force. Evaluating and understanding this impact could help with the specific IFV decision that needs to be made.

In parallel to the above, the Australian Army might consider conducting an official business case analysis (BCA) or similar net cost-benefit analysis.[5] In this analysis, stakeholder elicitation can be conducted to quantify the relative weights of the priorities associated with a future IFV decision. Furthermore, such an examination will provide both a means to include the spectrum of Australian decisionmakers and ideally other coalition partners, where key roles can be discussed relative to other force capabilities and future roles can possibly be predetermined. Finally, in parallel to a BCA, detailed force-level modeling and simulation (M&S) could be conducted to assess the force-level impact of specific IFV alternatives. The BCA and the force-level M&S should provide further information and guidance on specific IFV platforms.

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5 These are common analyses that are used to evaluate the viability of programs and alternatives in the U.S. DoD planning process.

Abbreviations

AAV	assault amphibious vehicle
ABCA	American, British, Canadian, and Australian
ABCT	Armoured Brigade Combat Teams
ACV	amphibious combat vehicle
ADF	Australian Defence Force
AFV	armoured fighting vehicle
AMPV	armoured multipurpose vehicle
APC	armoured personnel carriers
APS	active protection system
AQIM	Al Qaeda in the Islamic Maghrib
ARVN	Army of the Republic of Vietnam
ASLAV	Australian Light Armoured Vehicle
ATGM	antitank guided missile
ATO	Anti-Terrorist Operation (Ukraine)
ATP	Acquisition and Technology Policy Center
BCA	business case analysis
BMD	Boyevaya Mashina Desanta (Russian combat vehicle for airborne)

BMP	Boyevaya Mashina Pekhoty (Russian combat vehicle for infantry)
BTG	battalion tactical groups
BTR	Bronetransportyor (Russian armoured personnel carrier)
C2	command and control
C4ISR	command, control, communications, computers, intelligence, surveillance and reconnaissance
CBO	Congressional Budget Office
CCV	close combat vehicle
COIN	counterinsurgency
DOTMLPF	doctrine, organisation, training, materiel, leadership, personnel, and facilities
DST	Defence Science and Technology
EFPIED	explosively formed penetrator improvised explosive device
ERA	explosive reactive armour
ERDC	Engineer Research and Development Center
EW	electronic warfare
GCV	ground combat vehicle
HEMTT	Heavy Expanded Mobility Tactical Truck
HIMARS	high-mobility artillery rocket system
HMMWV	high-mobility multipurpose wheeled vehicle
ICV	infantry carrier vehicle
IED	improvised explosive device
IFV	infantry fighting vehicle

INTERFET	International Force for East Timor
KFOR	Kosovo Force
KLA	Kosovo Liberation Army
LAR	light armoured reconnaissance
LAV	light armoured vehicle
M&S	modeling and simulation
MBT	main battle tank
MCO	major combat operation
MGS	Mobile Gun System
MRAP	mine-resistant ambush protected
MSV	maneuver support vehicle
MTBF	mean time between failure
MTVR	Medium Tactical Vehicle Replacement
MUJWA	Movement for Unity and Jihad in West Africa
NVA	North Vietnamese Army
O&M	operation and maintenance
O&S	operation and sustainment
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
PDF	Panamanian Defence Force
RPG	rocket-propelled grenade
SOF	special operations forces
TOW	tube-launched, optically tracked, wire-guided
UN	United Nations

USMC	U.S. Marine Corps
VAB	Véhicule de l'avant blindé (French light armoured personnel carrier)
VBCI	Véhicule blindé de combat d'infanterie (French armoured vehicle for infantry combat)
VC	Viet Cong
VCI	vehicle cone index

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The Defence Science and Technology Group asked RAND for help in assessing the range of trade-offs between tracked and wheeled combat vehicle classes. This report details three key tasks: (1) assessing lessons learned about tracked and wheeled combat vehicles in conflict around the world; (2) assessing the implications of advanced technologies on the vehicle classes; and (3) examining system-level implications of the different classes of vehicles.

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