Saving General Shinseki: on the future of wheeled armor

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In the course of the recent war against Iraq and in its aftermath, it has become clear that the mix of U.S. Army ground vehicles for combat-related tasks is unbalanced and even inadequate.

Trivial insight[1]

The Abrams Main Battle Tank (MBT) has had a relatively good show. Due to its considerable frontal armor protection it has been able to effectively spearhead many tactical maneuvers. But it has weaknesses: a vulnerability to RPG fire from the rear and, more importantly, serious shortcomings in operational and strategic mobility, because this exceptionally heavy vehicle is driven by a very thirsty gas turbine.

The Bradley Mechanized Infantry Combat Vehicle (MICV) appears to have better protection and stamina than predicted by its critics. Nevertheless, it is a less well-protected vehicle than the Abrams, and its survival in battle is dependent on very close co-operation with the MBT, which almost always has to take the lead in combined-arms operations. Even under ideal conditions of cooperation with, and protection by heavy tanks, it is quite risky to ride on a Bradley. If this MICV is penetrated by fire, too many lives are endangered. Its 3+6 complement puts “too many eggs in the basket.”

“Stryker” brigades, part of former Army Chief Eric K. Shinseki's interim force, were not ready to be employed in the conflict. They would have been considered inadequate in any case. The example of the U.S. Marines operating similar equipment (the wheeled LAV III) has demonstrated that relatively bulky, lightly armored vehicles can not be used successfully if the going gets somewhat tougher (Hilmes 2003, p. 27). The Marines appear to have instead relied on the combination of MBTs and tracked personnel carriers with considerable add-on armor (AAVs).

The problems with multi-wheeled armored vehicles extend to the future envisioned by General Shinseki. An increasing number of experts on both sides of the Atlantic doubt the feasibility of the Army's master plan, according to which, by the end of this decade, the function of heavy, tracked armor could be taken over by a family of relatively light wheeled vehicles (system weight not much over 20 tons.) Furthermore, few technologists are convinced that, even in 15 years, it will be possible to create such a new family and provide it with (armor) protection equivalent to what gives today's heavy elements their central tactical role.

There are many skeptics when it comes to providing the new class of vehicles with “electric” or improved reactive armor. Similarly, there are severe doubts about active kinds of protection which attempt to intercept incoming missiles in a soft- or hard-kill mode. Critical arguments are that advanced reactive or active protection is quite expensive, relatively easy to saturate with multiple hits (machine cannon!) and hence not cost-effective (Hilmes 1999, pp. 154-163.) A system enhancing *situational*

[1] This critical review of U.S. Army equipment could have been written before the invasion of Iraq and a version actually was, as an armchair evaluation (Unterseher 2000.) It is unfortunate that full-scale wars are required in order to arrive at conclusions that are not much more than trivial.

awareness by integrating all available sensor information would be nice to have, but cannot serve as a substitute for solid armor protection. In the final analysis, heavier multi-layered armor developed since the 1970s is indispensable.

A soft skin vulnerability is evident with the HMMWV (Hummer), a vehicle originally intended for liaison purposes that is now extensively used for patrol missions in (semi-) hostile territory. This vehicle's survivability is a function of its agility and relative compactness. It would be greatly enhanced, however, if there was at least a modicum of armor protection (especially against mines and small arms, which represent the bulk of weapons in modern times.) Add-on armor may not be sufficient and the Swiss and Danish examples of protected HMMWVs are not fully convincing. The vehicle has become clumsier and still lacks mine protection. The U.S. Marines' experimental armored reconnaissance car (Shadow) may be a better development for all kinds of light forces applications. The Shadow weighs about the same as the HMMWV (up to 5 metric tons), has integral armor and a (German-designed) diesel-electric drive.

Saving an idea

It is, of course, not General Shinseki who needs to be saved, but the essence of his vision. Would it not be appealing to have a ground-mobile force whose armored core relies on just one basic platform that greatly enhances tactical co-ordination along with logistical support and which, as a wheeled system of considerable survivability, moves faster over longer distances than heavy, tracked elements, and lends itself to relatively easy strategic transport?

The fact that the first, very optimistic, attempt to reach such a solution has failed, or is about to fail, should not discourage other similarly directed approaches. It is perfectly conceivable that the essence of General Shinseki's vision can be saved, if…

- the envisaged restriction on the system's weight is lifted up to a ceiling that still permits the use of wheeled running gear and,
- a holistic view of the vehicle's tactical and organizational context serves as basis for a fresh design and the systematic selection of adequate modern (but not over-sophisticated) technologies.

On the question of weight and mobility: A future wheeled combat system weighing about 50% more than the one originally envisioned by the U.S. Army would still weigh only half as much as an Abrams. Its strategic mobility would be less than that of lighter wheeled systems, but still much greater than an MBT. As for operational mobility, which is particularly important for peacemaking and peace support, there is almost no loss in comparison with lighter wheeled armor.

The increase in weight substantially facilitates the designer's task of finding a viable solution for the vehicle's basic (armor) protection. At the same time, it hampers the vehicle’s tactical mobility (Ogorkiewicz, pp. 9-11.) Therefore the designer has to pay special attention to preventing the system's ground pressure from becoming unacceptably high. This calls for the utilization of modern technologies to optimize automotive performance, principally by fine-tuning the traction of each wheel and making use of adjustable tire pressure. If this approach does not suffice, perhaps the system's weight can be varied with terrain conditions (modular armor) or, more radically, the designer can aim for a different division of labor using lighter, agile elements (Shadow class) for a set of tasks over soft ground.

On the question of tactical role and adequate design: Commanding a battalion with 58 MBTs or MICVs (4 companies with 14 each, plus 2 for leader and deputy) constitutes quite a challenge. There is widespread agreement that the standard tactical entity should not be any larger. Since practically all modern war scenarios require that tanks and armored infantry carriers act closely together, the two different elements have to be integrated organizationally. If this is done by simply adding companies from the complementary arm on to a battalion, the resulting force would be far too clumsy. Rather, it has to be done by routinely mixing, and re-mixing, elements of armor and mechanized infantry within the scope of a battalion. Re-mixing is often necessary, because in the course of a dynamically evolving encounter, the happy mix of yesterday may suddenly become an unhappy one. Because of such frequent reshuffling, human interaction and bonding, necessary for flexible co-operation, may suffer with serious consequences in and among tactical units (Simpkin, pp. 87-100.)

Why not take Shinseki's idea of a family of vehicles based on a single platform and instead create a “hybrid” tank which incorporates two key elements, namely armor and infantry, in the same vehicle? There would be no more unhappy mixes, since reshuffling would no longer be required. Besides, there would no longer be a discrepancy in armor protection between the heavy tank and the lighter MICV, that has tied the former to the latter, depriving it of tactical options. And, of course, there will be considerable logistical advantage in such a one-platform solution.

However, there are design strings attached. The idea of a hybrid tank can, in this context, only be turned into a viable solution if two caveats are obeyed:

- The main armament (anti-tank/helicopter, multi-purpose) should only weigh a small fraction of what modern tanks are equipped with. Otherwise, it will not be possible to provide enough armor for the protection of a wheeled vehicle which has particular weight restrictions. The solution to this problem lies not only in the application of alternative technologies, but also in holistic insight. There has been an increase in the effectiveness of indirect fire, networked with frontline units, that greatly reduces the requirement for MBTs to deal with tank-like targets over longer distances. This, combined with the fact that all vehicles in the battalion do have the same type of “main armament,” allows for a reduced volume of fire by the individual vehicle.

- Special precautions have to be taken to better protect the mounted infantry. The fact that the hybrid system may get involved in duels with tanks could endanger the lives of the infantry if they don’t dismount in time. At the system level, this problem can be solved by not putting too many “eggs in the basket.” The permanent crew should be reduced to 2 and the infantry to 4. This formula of 2+4 compares with 4 in the Abrams and 3+6 in the Bradley.

Designing SAM[2]

Guidelines

- For obvious reasons the vehicle should be compact, but should have enough inside space for a layered, voluminous armor. To reconcile these contrary demands, all vital sub-components –- the human complement, engine, transmission, fuel storage, steering gear, and armament including ammunition –- should be as small as tactically acceptable and technically possible. There should also be stringent weight restrictions on all non-armor parts.

- In order to minimize essential armor needs, and to facilitate communication, the human complement should sit low and at the same level in a specially protected, undivided capsule (the turret is unmanned and without a basket.) All outside elements not directly required for protection of crew and mounted infantry would get lighter armor.

- Tactical mobility, as argued, requires an especially ingenious design effort. Other than the option of variable combat weight through modular armor (which could be risky), there are other features worth integrating into the design. These include turning on the spot, variable ground clearance and tire pressure, as well as the fine-tuning of traction.

- Modern engine technology should not be exploited to provide drastically higher acceleration rates, but rather be used to produce more compact and less thirsty engines. Otherwise, it will be impossible to reach the goal of having a well-protected, lighter, and more compact vehicle. (The ability to better accelerate, as a result of a high power-to-weight ratio, is not a sufficient substitute for armor protection and compactness of a combat vehicle.)

The infantry in the "hybrid" would give the battalion a dismounted force nearly as strong as an infantry-heavy mix consisting of 3 companies with Bradley and 1 with Abrams. If, as critics say, 4 infantry men per system are not enough to form a viable tactical entity, there can be a close teaming of vehicles (two pairs per platoon.)

> *At the individual system level, the reduction of the complement has the advantage of supporting a compact design which enhances its survivability by minimizing its likelihood of getting hit and by having more armor weight per surface area.*

The notion that high-tech components are capable of solving all design dilemmas, should be rejected and a high degree of selectivity should be the rule in choosing

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[2] SAM stands for ***S****hinseki* ***A****ll-purpose* ***M****emorial* tank. Its design occasionally borders on squaring the circle.

system sub-components. In some areas advanced technology appears to be indispensable especially with respect to the vehicle's armament (including missile guidance) and to the observation and the sensor data processing complex.

To complicate matters further, at least some built-in redundancy (most importantly with regards to the sensors, but also with regards to propulsion and power train) is needed to enhance the system's survivability. This requirement may keep the designer from rendering the system "over-compact." In any case it constitutes a considerable challenge.

Characteristics

Name	SAM ("Sammy" among friends)
Function	Dual (mech. infantry / LOS fire)
Complement, number	2+4
Weight (combat loaded)	
- without skirts and side-armor panels (kg)	27,500
- with skirts and side-armor panels (kg)	32,500

Dimensions:

Length (m)	5.75
Width	
- without add-on armor (m)	2.85
- with add-on armor (m)	3.15
Height (normal ground clearance)	
- overall – to mast top, extended (m)	3.00
- to turret roof (m)	2.25
- to hull top (m)	1.90
Ground clearance, variable	
- normal/up/down (m)	0.40/0.50/0.30

Armament:

- on armored turntable/unmanned turret: 10 standardized, individually (up/down) trainable launchers/containers (elevation: 40° / depression: 10°) with LOSAT (guided kinetic-energy missiles anti-armor/rotorcraft, 1 per container) or unguided artillery rockets (105 mm, 4 per container) or light, short-range, short-barreled mortars for smoke and fragmentation grenades (60 mm/ 9 pairs per container) or a mix of these; reloading through exchange of containers;
- on telescopic observation mast: 2 machine guns (7,62 mm).

Propulsion:

Engine(s), number/ type	2 Diesels/ **H**igh **P**ower **D**ensity
Maximum gross output	2x300 kW
Power transmission	2 generators & 8 electric motors
Producer(s), engines/transmission	MTU/Magnetmotors

Running gear:

Wheels, number X driven	8X8
Steering	
- frontal wheel pair	conventional
- all wheels	skid-steering
Tire	
- size	18X22
- pressure	variable
Suspension	independent, trailing arm
Springs	hydro-pneumatic
Wheel travel	
- bump (m)	0.20
- rebound (m)	0.20

The second wheel pair can be lifted to make road marches more economical.

Automotive performance:

Gross kW/hp per ton (maximum weight)	18,5/25
Maximum road speed (km/h)	100
Range on roads (km)	1000

Description

Vehicle's distinguishing features:

Very compact, low silhouette, but high axis of observation thanks to (lightly armored) telescopic mast in the middle of the unmanned turret. Relatively large distance between first and second wheel pair, smaller between the other ones. Forward two thirds of the hull: wedge-shaped, rear third: box-like. V-shaped bottom and special armor to enhance mine protection. Skirts extending over the wheel pairs 2, 3 and 4. Add-on armor to protect the rearward “box”. Considerable space for layered armor in front of the permanent crew.

One set of engine/generator on each side – in the armored space above the third and fourth wheel pair (redundancy!). Weight-saving through the combination of compact and economical HPD (High Power Density) engines with an electric (non-mechanical) transmission, which is also good for the fine-tuning of traction. In addition: weight-saving through the reduction of the steering gear (only for the front wheels.)

Skid-steering for turning on the spot (like a tracked vehicle.) Fuel storage in lightly protected tanks attached to the multi-layered ramp in the rear, and in parts of the bottom. Redundant, all-weather capable means of observation and target acquisition at the telescopic mast and the crew stations. Unmanned turret over the rear third with its armored turntable serving as additional protection against top attack.

Summary description of the SAM combat vehicle: *Considerable, versatile firepower (kinetic energy and fragmentation) without the weight penalty of a main gun system and its special loading machinery. Slightly more than half the weight of an Abrams – and about 60% of the surface area. Designed to have fewer "bullet traps" than the tank. Accordingly a high degree of crew protection. Better strategic mobility. Superior operational mobility -- good for long and swift marches*. *Acceptable tactical mobility.*

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Wheels or Tracks? On the 'Lightness' of Military Expeditions

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Lutz Unterseher
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1. Shinseki's Vision

Most armies with fighting experience in World War II drew the lesson that in future ground combat the hard currency of power would be medium to heavy tanks - accompanied by tracked platforms carrying infantry and artillery. Wheeled armored vehicles, if used at all, would be confined to the roles of light reconnaissance and armed area control. Among the armies following this line of thought were both the British and the French, due in part to their long tradition of expeditionary activity. One notable exception to the trend was the Soviet Army.

During the 1950s the Soviets put the bulk of their infantry on wheeled armored carriers. Even after the advent of tracked mechanized infantry fighting vehicles during the 1960s (for instance, the BMP and its forerunner the BTR 50), a large part of the Soviet infantry continued to ride on wheeled platforms. Indeed, two out of four regiments in a motor-rifle division rode on wheels (BTR 60/70/80). In addition there were relatively strong components of armored reconnaissance that to a large extent also had light wheeled vehicles, including the BRDM 1 and 2. The Warsaw Pact's military leaders had two reasons for giving wheeled vehicles a big role. First, they thought that wheeled armored transport would be better than tracked in moving large masses of soldiers over long distances; second, they thought these vehicles could do the job at relatively low cost.[1]

Since the end of the East-West-confrontation, there has been in NATO and in non-aligned countries as well a general drive to develop expeditionary forces in order to deal with regional crises and conflicts. In this context, light ground forces, and especially those riding on wheels, have gained a more prominent role. Underlying this development is the assumption that such light units are more appropriate than the traditional "heavy mix" for patrolling and controlling relatively large stretches of land. They supposedly are well-suited to establishing a sort of "military omnipresence" which is essential to the restoration of law and order in peace support/peace enforcement operations.

More recently, the US Army Chief of Staff, General Eric K. Shinseki, has advanced a vision of future American ground forces that would ride entirely on wheels. Looking perhaps 15 years into the future, General Shinseki foresees even a wheeled main battle tank (MBT), weighing 25 - 30 (metric) tonnes instead of the 60 - 65 t typical of current vintage tracked monsters. This vision relies on future technological breakthroughs to give the light MBT and the wheeled armored vehicles supporting it a level of combat power (including survivability) that will exceed today's standard. In other words, technology is expected not simply to compensate for the weight loss, but actually to over-compensate for it.

General Shinseki's key reason for pursuing the goal of a much lighter mechanized force is a perceived need to substantially improve the Army's capabilities for rapid power projection across strategic distances. All-wheeled forces are supposed to require much less transport capacity than the current track-dominated mix -- not only because the platforms promise to be lighter, but also because their logistical requirements are likely to be less. Complementing the switch to a wheeled force, the US Army also aims to thoroughly streamline its combat support and logistical elements. In light of these complementary initiatives, General Shinseki thinks it will be feasible to deploy a strong U.S. Army combat brigade to anywhere in the world within 96 hours. A full division is supposed to be globally deployable in 120 hours or less; for five divisions -- a very powerful corps -- the deployment goal is 30 days.

While setting a uniquely ambitious goal for rapid deployment, General Shinseki's vision does not at all relax the requirement for combat capability. The wheeled force is to be able to conduct American-style "decisive operations" across the mission spectrum. Thus, the US Army will stick to its prime concern: the ability to prevail quickly in the toughest conceivable warfighting contest. Unlike today's force, however, the proposed one will also lend itself quite easily to "softer" missions -- peace enforcement and peace support. Hence, General Shinseki may be preparing the US Army to undertake operations that in the recent past it would have preferred to leave to its allies.

General Shinseki's vision of a rapidly deployable, multifunctional ground force should grab the attention of armies the world over. The general promises to transcend a dilemma that has befuddled mechanized forces since their inception: deployability and sustainability versus capability. But how realistic is Shinseki's vision of standard light forces that can be entrusted to do almost everything? Perhaps General Shinseki's goal is feasible with regard to projection. But could it be that the forces to be projected will find themselves on arrival unable to do almost anything? In other words, will his vision lead to projection without power?[2]

We will find some relevant answers in a systematic comparison of tracked and wheeled armored vehicles, their technological limits and potentials.

2. A Systematic Comparison

2.1 Mobility

2.1.1 Strategic mobility

Today's tracked armored vehicles weigh between 3.5 and 65 metric tonnes (t). The respective figures for wheeled armor are 3.5 and somewhat over 35 t. An important qualification is that most wheeled types fall into the category of "up to 20 t". Only about 10 percent are heavier. In the case of tracked vehicles, about half of current types are in the lower weight category, whereas the other half consists of heavier machines (mostly between 35 t and 65 t).

In addition to their relative lightness, wheeled vehicles tend to consume significantly less fuel (and other lubricants) than tracked armored vehicles of equal weight. (I will elaborate on this phenomenon below). Their relative "lightness" and reduced logistical needs together give the wheeled family an edge over the tracked in strategic mobility -- meaning the transport of forces over continental and intercontinental distances.

2.1.2 Operational mobility

Operational mobility refers to the ability to swiftly allocate and relocate forces within a theater of crisis or war. The challenge it poses is more on a regional than a continental scale. One factor relevant to operational mobility is the "rolling resistance" of a vehicle traveling on ordinary roads. On roads the rolling resistance of tracked vehicles equals four percent of their weight, on average, while that of their wheeled counterparts (fitted with cross-country tires) equals only 2 percent of their weight. Consequently, wheeled vehicles need less fuel and can cover longer distances by road before they need to be refueled.

This advantage of wheeled vehicles disappears, however, when they move off roads. Then their fuel consumption may be at least as high as that of tracked vehicles (of equal weight). Still, if patrolling and area control missions are emphasized, road travel predominates and, thus, the advantage of fuel economy accrues to the wheeled class. Even in the context of typical warfighting scenarios, off-the-road activities constitute less than 50 percent of overall travel. This is because, within a sizeable theater, many movements have to be devoted to marching the troops to the combat areas in a timely fashion, rather than to maneuvering in the thick of battle.

There are two reasons that forces equipped with wheeled armor are more likely to deploy operationally in a timely fashion:

- First, there are fewer and shorter refueling stops. (The average road range of wheeled vehicles exceeds that of their tracked counterparts by 50 - 100 percent.)
- Second, the average marching speed of wheeled vehicles is, on roads, also 50 - 100 percent higher than that of tracked vehicles.

The fact that wheeled armor can cover longer distances faster than tracked vehicles is complemented by yet another advantage: There is much less fatigue for their occupants because the wheeled platforms do not suffer the vibrations generated by tracks.

In actual practice most armies recognize the overall advantages of wheeled vehicles with respect to operational mobility. Typically, they use wheeled carriers -- "tank trailers" -- for the theater- wide allocation of tracked armor. This measure, which temporarily puts tracked vehicles on wheels, makes sense only as a stopgap; its disadvantages are quite obvious: It is expensive and makes marching columns clumsier and more vulnerable.

2.1.3 Tactical mobility

Tactical mobility is the kind needed when a force is in immediate contact with its adversary. Direct confrontation with an enemy imposes at least two mobility requirements:

- Good off-road mobility is an important precondition of being able to evade enemy action and exploit unexpected avenues of approach.
- Agility -- a combination of high speed, good acceleration, and the ability to "zig-zag"--is also key to being able to respond flexibly to rapidly changing opportunities and challenges.

Relevant to off-road mobility, wheeled vehicles tend to have a ground pressure considerably higher than that of their tracked counterparts. The Mean Maximum Pressure (MMP), which is the average peak pressure under the tires of wheeled vehicles or under the road wheels of tracked vehicles, varies between 200 to 270 kN/m2 for the latter and 300 to 450 kN/m2 for the former. This implies inferior performance for wheeled vehicles on soft ground. There is at least one notable exception, however. The French Panhard VBL M-11 (a 4 x 4 vehicle weighing 3.55 t) has an MMP of only 220 kN/m2. In this case, a very light wheeled armored vehicle achieves an MMP in the range of tracked vehicles.

Generally speaking, the ground pressure of wheeled vehicles rises significantly with the platform's weight. In the case of tracked vehicles this correlation is not as evident. In light of this, the renowned British tank expert Ogorkiewicz has argued to abandon concepts of wheeled combat vehicles weighing significantly over 22 - 23 t. Even a multi-wheeled configuration (8 x 8 -- that is, eight powered wheels) with variable tire pressure can not solve the problem -- resulting only in a very complex, hence expensive, design.

This is a principal matter: It is difficult, if not hopeless, to conceive of technological solutions that could radically solve the problem of wheeled armor's relatively high ground pressure. (And we certainly should not contemplate resurrecting the failed "solution" attempted during the 1920s and 1930s, which was to equip wheeled vehicles with auxiliary tracks.)

Although wheeled armored vehicles cannot escape their principal dilemma, there have been some interesting and worthwhile examples of such platforms in the 20 - 30 t weight range. One is the South African mechanized howitzer, RHINO, with a weight as high as 36 t. Several other vehicles of interest, mostly in the experimental or blueprint stage, may achieve around 30 t -- for example, the new British/Dutch/German infantry carrier. But the willingness of advanced militaries to invest in such vehicles does not mean that Ogorkiewicz' concerns are being over-turned. These programs do not indicate a belief that wheeled armored vehicles could generally be heavier than he argues and still exhibit good cross-country performance. Instead, in most cases, the fielding of heavier wheeled vehicles reflects special, limited circumstances or goals.

-- In two cases -- the South African RHINO and the Czech/Slovak DIANA/SUZANA -- the vehicles in question are mechanized artillery. For these, tactical mobility is not a high priority. They are wheeled because the resulting operational mobility facilitates the flexible allocation of fire -- a key concern for artillery.

-- In the cases of France, Germany, and some other nations, military planners and designers appear to have deliberately down-rated soft-terrain capabilities. This probably has to do with increased emphasis on peace support and peace enforcement missions, which also put a premium on operational mobility for vehicles of relatively high payload.

Turning to the question of agility: Wheeled armored vehicles tend to excel in speed -- on the road, of course, but also in open terrain, if it is fairly negotiable. When it comes to zig-zagging and acceleration, the advantage also seems to go to wheeled armor. It is true that most tracked vehicles can pivot in place, while wheeled vehicles cannot (except for those with brake-steering). Otherwise, however, wheeled vehicles are more easily steered and their running gear is more responsive. Compared to a tracked counterpart of equivalent weight and engine output, we can expect a wheeled platform to have not only higher speed, but also better acceleration. Interestingly, these advantages are especially pronounced with respect to relatively light armored vehicles. It is plausible that high agility is associated with "smallness" and "lightness."

Tactical mobility has another important precondition: protection. As one legendary expert, General Israel Tal, has argued: Without proper protection even the most agile and cross-country capable vehicle could not move forward in harm's way. We will deal with protection and survivability in the following section. Suffice to say for now that there is a dialectic interplay between tactical mobility (in the narrow sense) and protection that is relevant to the challenge of moving under fire.

2.2 Survivability and protection

If strategic and operational mobility contribute to the capacity to locally overwhelm an opponent then they certainly also contribute to the survivability of the superior force. The same can be said of tactical mobility: as evasive tactics tend to neutralize the impact of hostile action, they indirectly contribute to survivability. Survivability is further enhanced if the weaponry of the platforms in question makes it possible to fire from detached positions -- so that the platforms cannot be easily detected or shot at. All these systematic interactions are important, but the discussion of survivability usually centers on protection. Of course, protection itself is a complex matter. It can be achieved through active and passive measures as well as by the reduction of a vehicle's signature ("stealth").

2.2.1 Active protection

The active protection of armored vehicles was already being pioneered by the Soviet Army in the 1970s. It was regarded as necessary to compensate for perceived weaknesses in the armor of Soviet main battle tanks. Although the work started more than two decades ago, systems ready for field use did not appear before the 1990s.

Active protection involves soft- and hard-kill techniques. Soft-kill methods aim to divert incoming guided missiles to a non-lethal path using, for instance, anti-laser smoke or infrared jammers against an anti-tank-guided weapon's guiding system. Hard-kill methods aim to destroy guided and non-guided missiles, including shoulder-fired rockets, close to their target. A typical hard-kill technique employs a radar-controlled array of small fragmentation-grenade launchers.

The implementation of such systems is not "design-dependent" -- that is, it does not matter whether they are mounted on a tracked or a wheeled vehicle. However, in the case of hard-kill systems, which weigh considerably more than soft-kill ones, it is advisable to put them on vehicles heavier than 25 t. Only above 25 t does their weight, which is more than 1 t, become negligible. Interestingly, the advent of such techniques has already provoked the development of effective counter-countermeasures. Anti-tank missiles are being made "stealthier" and the Russian Army has been field-testing a tank destroyer firing two missiles in a very short sequence (for defense saturation).

In light of the techniques developed so far -- and there are no fundamentally different approaches in sight -- active protection suffers some inherent or principal problems in compensating for some increasingly important armor vulnerabilities. There is no recipe for dealing with high-velocity armor-piercing rods fired from heavy tank guns. Nor is there anything these active systems can do to defeat machine cannon, whose caliber and role has been increasing in modern armies. This is because the respective projectiles are simply too fast, too powerful and, in the case of machine cannon, too numerous.

2.2.2 Passive protection

When we consider the full spectrum of threats to vehicles there seems to be no viable alternative to armor protection proper. And since the 1970s there have been quite a few innovations in this field. First, the development of Chobham (sandwiched) armor in Britain and, soon after, the evolution of "reactive" armor in the USSR and Israel.

Reactive armor can be added to a vehicle's armored skin. It consists of explosive elements designed to neutralize incoming (guided or unguided) missiles equipped with shaped charges. Currently there is work in progress to even deal with kinetic energy projectiles (rod penetrators fired from guns). These cannot be neutralized, but they probably can be rendered somewhat less harmful.[3] For reactive armor to be optimally effective a rather solid embedding is needed, which rules out vehicles much below 30 t. And most experts agree that, in addition to reactive armor's limitations with regard to kinetic-energy projectiles, there remains considerable vulnerability to tandem charges and saturation attacks. In sum, reactive armor can only be an add-on, applied temporarily in high-threat scenarios and in situations where the weight of the respective vehicles does not matter too much.

In the end what counts is the strength of a vehicle's skin. And, indeed, there continues to be a direct correlation between volume and weight of armor on the one hand and the level of direct protection on the other. At present, there are no known technologies that promise a realistic alternative within the next two decades.

British tank designers have been hoping to develop a future MBT (project MODIFIER) with a weight of less than 50 t (and probably only 40 t) but with considerably better protection, firepower, and automotive characteristics than current 65 t monsters. However, the leading German tank expert Rolf Hilmes, estimates that if the British stick to their specifications, they will end up with a 70 - 75 t vehicle. By contrast, Israeli tank designers accept an MBT concept implying a weight of well over 60 t. They place special emphasis on all-round protection because they are planning not only for warfighting scenarios, but also for peace enforcement and counter-insurgency contingencies, which are more likely to expose vehicles to threats from all sides. This is one reason that the MERKAVA-series tanks have a frontal power pack; it allows for additional armor for flank and rear protection.

In Germany the cautious hope is that the future generation of main battle tanks can be confined to a weight not much more than 50 t. Unlike the British, German expectations are rather modest: The Germans are aiming for some improvements in armor protection, greater improvements in firepower, but no advance in tactical mobility over the LEOPARD II. It is noteworthy that the Germans are also planning for a new mechanized infantry combat vehicle (MICV) that is supposed to be fielded from 2008 onwards; considerably earlier than the next generation MBT. The vehicle is being conceived to have adjustable armor with modular packs to be added according to threat. Minimum weight is to be 32 t and maximum weight in access of 40 t which makes riding on tracks imperative. With the addition of active protection measures this vehicle is expected to have almost the protection level of an MBT; a prospect that is disputed by a number of German armor experts. In the view of these critics sufficient protection against mines, shoulder-fired (non-guided) missiles, and machine cannon of medium caliber (30 - 40 mm) implies a MICV weighing nearly 50 t or more.

Of course, this level of protection is simply not available to wheeled armored vehicles, due to weight limitations. The South African 28 t ROOIKAT (with a crew of four and, therefore, much more compact than the future German MICV with 10 or 11 occupants) is frontally protected only against 23 mm-machine weapons! It is unrealistic to expect wheeled armored transport vehicles of 20 - 25 t to have protection against anything more powerful than infantry weapons up to heavy machine guns -- 12.7 mm to 14.5 mm -- (with protection against the latter only in the frontal arc.) Paradoxically, almost the same level of armor protection is possible in the weight class below 10 t. The Swiss EAGLE I of 4.8 t (an armored HUMMER variant) is proof against 7.62 mm hard-core bullets fired from 100 m, and the German-Dutch FENNEK (9 - 10 t) appears to be frontally protected against heavy machine guns. The reason is that these vehicles are far more compact than the armored "buses" of 20 t or more, due to smaller crews and a less voluminous running gear (heavier wheeled armored vehicles need 6 x 6 or 8 x 8 configurations, while lighter ones can do with 4 x 4.)[4]

Six-by-six and eight-by-eight configurations do have an advantage, however: they are somewhat more robust with regard to mine damage. If one or two tires are destroyed the vehicle can still limp back to base. This would be impossible for a 4 x 4 vehicle. (In the case of a tracked vehicle, mine damage to a track also incurs instant immobilization.) Modern sensor-triggered mines are not exclusively directed against tracks or wheels, however, but against the whole bottom of a vehicle. Relying on clever design, some relatively small and light armored wheeled vehicles can achieve an "under-belly" protection level superior to that of much larger and heavier vehicles. A good example is the new South African-inspired German personnel carrier (ATF 2). It carries 5 - 6 occupants and weighs 8 t, and is reported to have substantially better mine protection than the much larger FUCHS (6 x 6) with its crew of 12 and weight of nearly 20 t.

2.2.3 Affecting the signature

If one vehicle is more compact than another, its chances of not being seen and, if seen, not being hit are greater.[5] In the past, wheeled armored vehicles - especially those with a multi-wheel, rigid beam-axle running gear - tended to be considerably less compact and, in particular, significantly higher than tracked vehicles of similar weight and purpose. This has changed significantly. Due to the introduction of advanced running-gear features (such as power trains with H-configuration and trailing-arm suspension) the difference in compactness and height has been reduced. However, with the advent of diesel-electric drive systems the potential exists for making tracked vehicles even more compact.

Whereas in respect to signature wheeled and tracked vehicles will be almost on a par, there is another aspect in which the former will always be superior to the latter: Due to much reduced friction and rolling resistance the acoustic signature of wheeled vehicles is much smaller.

2.3 Firepower

Some wheeled armored vehicles in the 25 - 30 t class are equipped with 105 mm guns -- for instance, the Italian CENTAURO and a variant of the ROOIKAT. And this arrangement works. A German experimental wheeled vehicle weighing slightly over 30 t is reported to have been successfully equipped with a 120 mm gun! However, in this case, doubts about the platform's stability are unresolved. This indicates that we may be reaching a design limit. In this light, the prospect of mounting the next generation powder gun (140 mm) on a wheeled vehicle should be regarded as totally illusory. Given the firing impact of this gun and the armored volume needed, the platform may have to weigh 50 t or more.

Much hope is being invested in the development of powerful electromagnetic guns, with efforts underway in a number of countries including Britain, Germany and the United States. Such weapons (of the "rail"-gun or "coil"-gun approach) could be lighter than contemporary powder guns and convey much less impact to the firing platform. But the related facilities for storing and generating energy are estimated to have a volume in excess of 5 cubic meters (without high performance cooling and other periphery). For comparison: 32 rounds of 140 mm ammunition need about 3 m3. Thus, all told, it is not likely that an electromagnetic-gun tank could be very compact or particularly light. Lightness could only be achieved if one accepts unarmored volume. It is presently impossible to confidently estimate the final weight these developmental systems will achieve. Nonetheless, it is difficult to imagine the eventual product being light enough to ride on wheels.

The firepower story is different for mechanized artillery platforms, however. As noted above, there presently are two examples of series-produced and successfully-fielded wheeled armored howitzers (152/155 mm). Firing such heavy weapons does not cause serious problems since this is not being done on the move, but from a halt position (and, if need be, with the aid of hydraulic stabilizers). Of course, the tactical mobility of such vehicles is quite limited. However, because firing takes place at stand-off distances, this handicap has been acceptable. The same applies to armor protection. Its relative weakness may also be justifiable because direct enemy contact is normally avoided and avoidable. (It would be advisable, however, to employ some add-on elements of reactive armor to protect against top attack by indirect fire.)

A final point: although wheeled armored carriers are not really suited for being equipped with very powerful weapons for direct fire, they might be able to do a better job than their tracked counterparts when equipped with lighter weapons, such as machine cannon and recoil-free missile launchers. This is because the running gear of wheeled vehicles has a "pre-stabilizing", softening effect. Firing lighter weapons on the move should normally be easier from a wheeled platform than a tracked one.

2.4 Costs

Wheeled armored vehicles used to be cheaper than their tracked counterparts. They were simpler and made more use of relatively inexpensive parts or sub-systems (such as engines and tires) from large-series civilian production. Things have changed. Wheeled armored vehicles, especially the large, multi-wheeled ones, have become more sophisticated and "militarized". As a result, the former advantage with respect to procurement costs has disappeared -- with the notable exception of some very light and compact wheeled armored carriers.

Wheeled vehicles enjoy another cost advantage, however: They tend to be less expensive to operate. As noted above, they travel farther than tracked vehicles for the same quantity of fuel. And maintenance requirements also are less burdensome -- provided that most of the vehicles' travel is on roads and not over soft or rugged ground.

3. Composition of Future Intervention Forces

In light of the previous considerations, we can ask: what mix of platforms would best serve the purposes of the ground-mobile element of future intervention forces? To answer this question even minimally we must first specify the military functions that the force will perform, which derive from its likely missions. The present interest in developing a "broad spectrum" force implies a roster of activities or functions that encompasses those relevant to traditional warfighting as well as those that are key to peace missions. In brief overview, the likely functions of the intervention force would include:

a) attack or counter-attack on centers of gravity,

b) extrication of friendly forces under optimal protection,

c) the beefing-up of escorts that are marching with humanitarian convoys through high-threat areas,

d) containing and resolving pockets of resistance in the context of peace enforcement,

e) the routine escort of humanitarian convoys,

f) the routine protection of humanitarian sanctuaries,

g) the beefing-up of sanctuary defense,

h) cavalry screens (to cover the movement of other forces), delaying actions, and pursuit,

i) general reconnaissance,

j) target acquisition and designation for indirect fire,

k) protection of secondary axes and the conduct of initial defense,

l) area control and demonstrations of interest,

m) urban warfare,

n) indirect fire to assist in a), g) and k) as well as for follow-on-forces attack and to stop enemy breakthroughs.

This set of activities and functions would be optimally covered by having three families of vehicles:

-- A heavy family that would be mainly in charge of a), b), c), and d) -- and, to a lesser extent, g) as well as m). Its vehicles should be relatively heavy (around 50 t) and, consequently, tracked. Typical examples would be a main battle tank utilizing new technology and a MICV with especially good protection.

-- The medium family might consist of only one basic wheeled platform (8 x 8) whose different variants (weighing 25 - 35 t) would carry heavy tube artillery, a multiple-launch rocket system, and/or a fiber-optically guided missile array. Its main function would be n), of course. In performing this function it would assist in a), g), k) as well as in follow-on forces attack and in stopping enemy breakthroughs. Emphasis would be placed on ensuring optimal fire allocation, which requires good operational mobility.

-- The light family (4 x 4) would have relatively many members. There should be special versions for reconnaissance (equipped with machine cannon), infantry transport, an anti-tank missile system, shorter-range indirect fire (mortar), and an air defense missile system. All vehicles of this class should be very compact and relatively light (5 - 9 t). They should have acceptable ground pressure (to allow movement over soft ground) and a high degree of agility. Compactness and agility would enhance their survivability. This would be combined with unrivaled operational and strategic mobility. The main functions to be performed by the light family are e), f), h), i), j), k), l); secondarily, it would serve m) as well.

Cautionary note: The variables "low weight" and "compactness" imply that the infantry carrier belonging to the light family cannot have more than 5 to 7 occupants. This would suffice for patrolling missions, but in a warfighting scenario the vehicle's crew may be too small to form a viable tactical entity. However, the currently common practice of loading 10, 12, or even more soldiers into a large 15 - 25 t wheeled carrier puts "too many eggs in one basket". This is especially worrisome because large multi-wheeled vehicles are particularly vulnerable.[6] For this reason, the small-crew/compact-vehicle approach demands further study. One possibility would be to team pairs of vehicles closely together.

One system obvious by its absence in this schema is an Armored Gun System (AGS). As already mentioned, relatively well-armed gun carriers are available in the 20 - 30 t class of wheeled vehicles. However, for reasons explored above, the survivability of these platforms in a tank role has to be rated rather low -- especially if an AGS is expected to confront a "real" main battle tank. The same proviso applies to tracked tanks in this weight class. A small, agile, and compact wheeled missile carrier (probably with LOSAT technology) is likely to do a better job.

In conclusion, if a ground force is to optimally execute a broad spectrum of activities, while also achieving a relatively high degree of strategic and operational mobility, then it should have a differentiated mix of heavy and lighter forces. General Shinseki's vision of a capable full-spectrum all-wheeled ground force is not likely to be realized in the time-frame imagined, ie. 15 years. The present trend of technological development offers little hope for the emergence anytime soon of a medium-weight wheeled vehicle with sufficient protection to confidently undertake the most demanding and dangerous of combat missions.

The alternative concept of a heavy-medium-light mix, although at odds with the General's vision, would still enhance strategic mobility very substantially. In some respects, it might achieve more in this regard than Shinseki's model. The bulk of the forces would be in the very light class - ideally suited for long-distance, rapid deployment. Along with the medium-weight assets of indirect fire they could be used to quickly stabilize a situation. Of course, when the going gets tough, the heavy element becomes indispensable. But it might arrive somewhat later without compromising the campaign, as the historical experience of the Second Gulf War shows. There is no principal reason why intervention forces should not travel in batches.

Notes

1. The Soviet pattern was (or had to be) copied by the satellite armies. Socialist Czechoslovakia went so far as to mount even a heavy howitzer on a wheeled armored platform.

2. Although beyond the scope of this paper, it would be interesting to take a closer analytical look at the combination of "right time and location - wrong, but abundant force". This is beyond the scope of this paper, however.

3. The idea is to rapidly accelerate metal plates (by explosives or electromagnetically) in the direction of the in-coming projectiles. Thereby passive armor becomes nearly active. At the moment it is an open question whether or not this approach is really promising.

4. Wheeled armored vehicles in the 15 - 25 t bracket are often used for infantry transport.

5. While compactness is helpful, "over-compactness" is not. As some negative Soviet experience shows: drastic reduction in size of a vehicle is likely to result in insufficient sub-system redundancy -- hence vulnerability.

6.In the context of modern non-linear battlefield scenarios, and especially when troops are engaging in peace enforcement, threats are likely to come from all sides and may not wait until the unit has arrived "at the front". Bulky vehicles have become increasingly vulnerable - not only when they get into a jam, but also on operational marches.

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