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The Impact of Equipment Availability and Reliability on Mission Outcomes

An Initial Look

CHARLES T. KELLEY

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PREFACE

This documented briefing describes an initial effort to understand analytically how start-of-mission availability and during-mission reliability of Army equipment affect ground combat capability and to assess consequent implications for current and future forces. Combat results were simulated using the JANUS model and scenarios available from prior research. The principal scenario for the analysis was a forced entry by U.S. forces into rough and heavily foliated terrain to neutralize Red forces and stop ethnic cleansing. A second scenario considered an offensive mission in more open terrain. The briefing then draws upon broader reasoning and approximate analysis to suggest tentative conclusions, and it recommends features of more detailed work.

This research should interest those charged with logistics support of the Army's legacy forces, those engaged in ensuring that legacy forces remain capable until they are phased out, and those involved in developing the Army's Objective Force, including its organizational structure and equipment requirements.

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SUMMARY

Two important measures of Army readiness are the availability of equipment for use at the beginning of a combat mission ("start-of-mission capability") and the reliability of that equipment over the course of the mission ("during-mission reliability"). While the usefulness of these measures is widely recognized, few attempts have been made to quantify their impact on combat capability.

A better understanding of the relationship of equipment availability and reliability to combat capability can help the Army address both current and future force needs. Army planners need to understand how current equipment availability and reliability rates are affecting combat capabilities, and how those capabilities might be impacted due to equipment age and/or rebuilding. Those involved in the design and development of future forces need to understand how to achieve the greatest leverage in these systems, e.g., whether through significant improvements in equipment reliability or investments in other system-enhancing characteristics, such as robotics.

In this documented briefing we describe an initial effort to quantify the effects of start-of-mission availability and during-mission reliability of Army ground equipment on combat capability. This "first look" analysis used JANUS, a force-on-force simulation model, to examine four issues relevant to current and future forces.

For the current force:

- How do changes in equipment availability and/or reliability affect combat results?
- How does equipment degradation due to age affect combat capability?
- To what degree could the combat capability of current systems be enhanced through rebuilding to mitigate the effects of aging?

For the Objective Force:

- How might a very significant improvement in equipment supportability affect combat capability relative to other system-enhancing characteristics, such as robotics?

Our main scenario for analysis involved a small-scale contingency (SSC) with a U.S. brigade-sized force on the offense against a comparably-sized, but less effective, adversary. The principal scenario takes place on heavily wooded terrain (based on digital terrain data from Kosovo). For purposes of comparison, we also considered a second scenario in more open terrain.

For the current force, the U.S. unit is a heavy brigade with more than 400 pieces of heavy equipment, including three predominant systems—referred to here as the “Big 3”—54 M1A1s, 159 M2A2s, and 45 M2A3s. In JANUS, these U.S. systems achieved nearly 90 percent of the kills and suffered about 70 percent of the casualties. For the Objective Force, the U.S. unit is a brigade combat team (BCT) or Unit of Action (UA).

We used data collected at the National Training Center (NTC) in order to explicitly model equipment availability and/or reliability at the start of the operation; after a road march of 0, 50, or 100 kilometers; and at the time of shots during the engagement.

Initial Equipment Availability Has a Moderate Effect on Combat Outcomes

To understand the sensitivity of combat results to different levels of equipment availability, we arbitrarily decreased the availability of “Big 3” systems from 100 to 40 percent in steps of ten percentage points. Our analysis found that varying the level of initial equipment availability had a moderate effect on combat outcomes. We measured this effect using the loss exchange ratio, which refers to the total number of enemy losses divided by the total number of U.S. losses.

We found that as the availability of equipment decreases, the loss exchange ratio decreases moderately. A second scenario in more open terrain yielded similar results. But while we found that equipment availability has a moderate effect on combat outcomes, we did not see a catastrophic fall-off in capability. In other words, the simulation showed no clear threshold beyond which a force would not be mission-capable. The lack of such a fall-off in the simulation could be at least partially the

result of the model construct, however, since it does not account for human behavior or organizational network effects.

Some Initial Availability and Engagement Failures Have a Significant Adverse Impact

While equipment availability had a relatively modest effect on the loss exchange ratio, availability and reliability failures were found to have significant adverse impacts on other measures of effectiveness, particularly the number of vehicles available for a second engagement. Figure S.1 shows the loss exchange ratio, the number of enemy units killed, and the number of U.S. Big 3 vehicles available at the end of the combat engagement over a base case and three alternative scenarios. The base case uses 100 percent initial equipment availability and reliability, while all of the alternatives use current equipment availability and reliability data derived from NTC experience, and each progressively

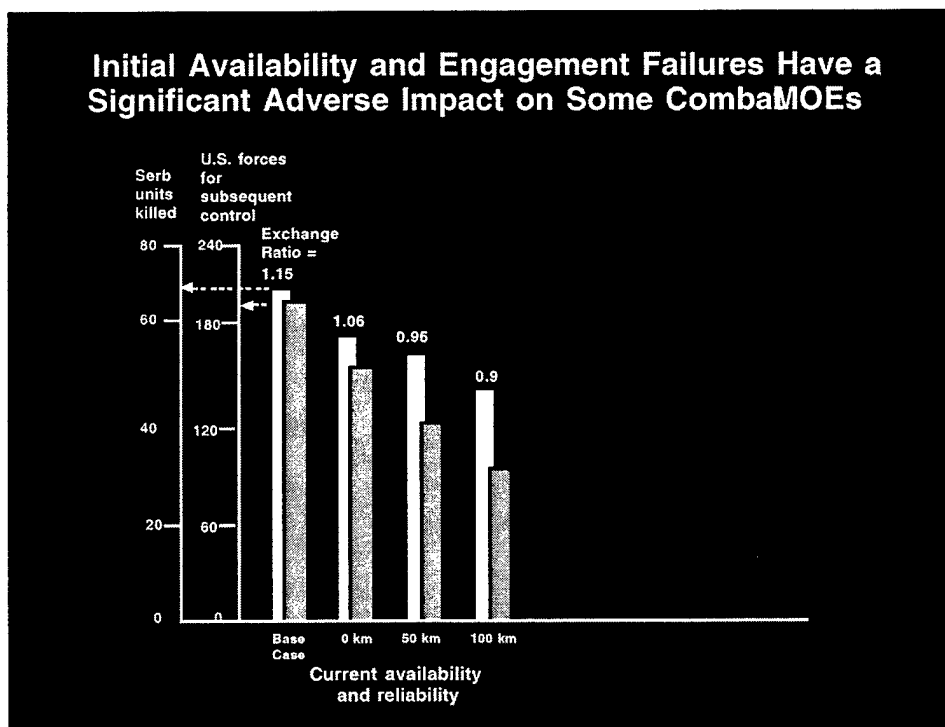


Figure S.1—Impact of Availability and Reliability Failures on Combat Measures of Effectiveness (MOEs)

illustrates the effects of distance traveled (0, 50, or 100 km) before the engagement commences. The loss exchange ratio is indicated by the number on top of each bar, while the upper dashed line indicates the number of enemy platforms killed and the lower dashed line indicates the size of the U.S. force immediately at the end of the engagement, as measured by the number of active Big 3 vehicles.

As indicated by the figure, shifting from the base case to cases using an estimate of current equipment supportability shows a significant degradation in the combat performance of the U.S. heavy brigade. This degradation becomes more pronounced the farther the distance traveled. For example, for the 100-km road march, the size of the U.S. force at the end of combat drops to about 100 from about 200 Big 3 vehicles in the base case. Such a significant drop-off in availability could create a high level of risk, potentially leaving the force with low readiness for an immediate second engagement.

Capability Degrades Further With Equipment Age

Combat capability was found to degrade further as reliability decreases with equipment age. In the simulation, we assumed that from 2000 to 2015, availability would remain at current rates while reliability would decrease by about 4 percent a year, which is approximately the rate at which M1 reliability has been shown to decrease during the first 14 years of its operation.

The resulting analysis showed that combat capability of the force degrades as the force ages. In the worst case, the loss exchange ratio fell from 1.15 in the base case to 0.87, while the number of enemy elements killed dropped from 70 to 45, and the size of the Big 3 occupying force fell to 75 vehicles, only about a third as large as the 205 remaining in the base case.

Rebuilding Equipment Can Substantially Increase Equipment Availability and Reliability

Further analysis showed that rebuilding equipment can substantially increase availability. Our analysis showed that rebuilding equipment can more than maintain current combat capability. We modeled the results of 2015 reliability after a rebuild of Big 3 equipment to M1A2 availability

and reliability levels. The analysis found that the capability of the rebuilt equipment in 2015 more than matches the capability of current equipment in 2000, if the enemy does not also make comparable improvements.

Technologies May Have Greater Benefit to Future Systems Than Improvements in Reliability, If Costs Are Not an Issue

To evaluate BCT issues for the Objective Force, we used a series of alternative BCT configurations developed as part of an earlier RAND Arroyo Center study for the Army Science Board (ASB). Our analysis used the same Kosovo scenario but replaced the M1, M2, and HMMWV with the Future Combat System (FCS) and included an upgraded enemy threat. We examined the performance of five BCT configurations as defined in the ASB study. These ranged from a "vanilla" configuration, with standard versions of the 20-ton Light Armored Vehicle (LAV) with Level III protection, to alternative configurations, each of which adds increasingly sophisticated technologies, such as robotic vehicles for reconnaissance; notional miniature line-of-sight anti-tank (LOSAT) missiles and a machine gun; "Quickdraw" to detect muzzle flash and immediately return fire; and an active protection system (APS) for combat vehicles.

The analysis indicated that the combat capability enhancements produce much greater leverage than do improvements to supportability alone. Figure S.2 illustrates the results.

The capabilities possible through improved availability and reliability are indicated by the lower and higher dots to the left of the diagram. The lower dot indicates the loss exchange ratio for a vanilla BCT with FCSs that have the same availability and reliability as today's M1A1, while the higher dot indicates the loss exchange ratio for a vanilla BCT with FCSs that are significantly more reliable than today's M1A1s.

While higher availability and reliability led to an improved loss exchange rate in the simulation, much greater gains were found to be possible through the addition of technology, as indicated by the step-like lines extending across the figure. The dashed line represents the kills of manned and robotic vehicles, while the solid line represents the kills of manned vehicles only.

In One Engagement, Some Combat Capability Enhancements Produce Much Greater Leverage Than Supportability Improvement

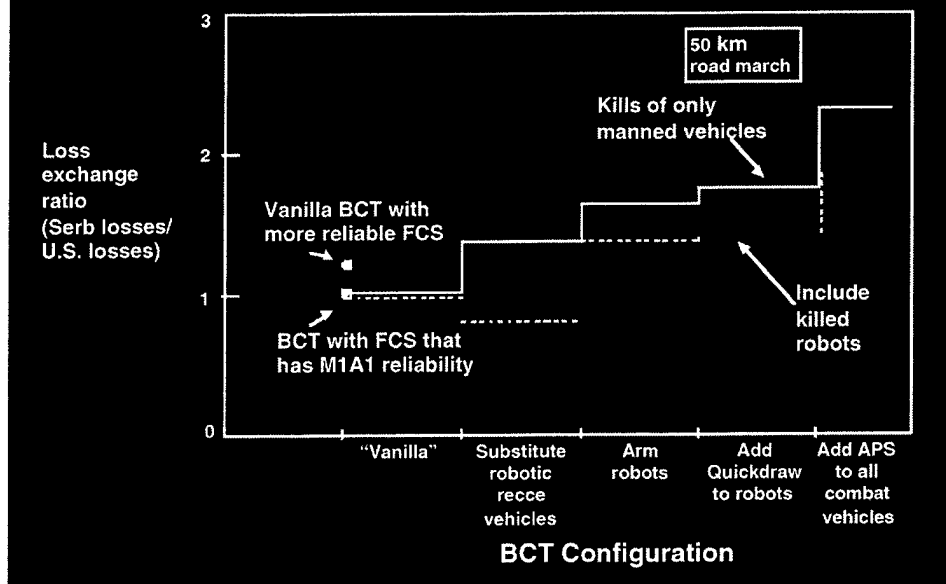


Figure S.2—Effect of Reliability and Technological Advances on Combat Capability

By including all improvements to the vanilla BCT, the loss exchange ratio increases to about 2.0 (2.4 for manned vehicles only) compared to a loss exchange ratio of about 1.0 for the vanilla BCT with M1A1-like supportability. When only manned vehicles are considered, except for the addition of Quickdraw, the technologies improve the loss exchange rate by a greater amount than the improvement to reliability alone. When both manned and unmanned vehicles are considered, there is a decrease in loss exchange ratio when only robots are added to the force, indicating that they are being killed at a faster rate than were the manned vehicles they replaced.

Although these results suggest that performance-enhancing improvements are more valuable than this level of supportability improvements for one engagement, it must be remembered that no account was taken of the costs of achieving either improved supportability or the technological advances in performance. Nor did the analysis

evaluate the likelihood of achieving improved supportability or the technological advances that were modeled.

CONCLUSIONS

We found that JANUS was a useful tool for analyzing some of the implications of equipment availability and reliability on ground combat outcomes. However, future analyses should explore additional approaches, including the potential for a catastrophic fall-off in combat effectiveness due to equipment unavailability, the effects of availability and reliability over a series of engagements, and the cost-effectiveness of reliability and other system-enhancing improvements.

ACKNOWLEDGMENTS

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**The Impacts of Equipment Availability and
Reliability on Mission Outcomes:
An Initial Look**

This documented briefing describes an initial effort to quantify the effects of start-of-mission availability and during-mission reliability of Army ground equipment on ground combat capability. It is part of a research project, titled Estimating Mission Reliability and Its Effects for Future Forces, being conducted within the RAND Arroyo Center's Military Logistics Program for the Assistant Secretary of the Army for Acquisition, Logistics, and Technology. The overall project is examining the effects of aging equipment with regard to failure rates, the mitigation of these effects through recapitalization, and how equipment sustainment requirements should be defined for Objective Force systems.

Objective

Gain insights into the effects of equipment availability and reliability on combat capability and the resulting implications for the Army's transformation

The purpose of the study reported here was, through a first-cut analysis, to understand better the effects of equipment availability and reliability on combat capability, and to assess potential implications for the Army's transformation.

Research Issues

Legacy Force

- How does equipment availability and reliability affect a unit's combat capability?
- How much does combat capability decline as equipment ages?
- What is the potential contribution from rebuilding equipment?

Objective Force

- What are the relative contributions of improved equipment supportability and other combat-enhancing system characteristics?

We considered a number of research issues for both the Army's Legacy and Objective Forces.

With regard to the Legacy Force, we addressed:

- The sensitivity of simulated combat results and residual combat capability to changes in equipment availability and reliability,
- The sensitivity of combat capability to equipment degradation with age, and,
- The potential combat-capability benefit from rebuilding legacy equipment to mitigate degradation from equipment aging.

With regard to the Objective Force, we addressed the impact that a very significant improvement in equipment supportability might have on combat capability relative to the impact that other combat-enhancing system characteristics, such as robotics, might have.

Briefing Outline

- ✓ • Methodological Approach
 - Legacy Force Issues
 - Objective Force Issues
 - Summary and Conclusions

The briefing is divided into four parts. First, we describe the analytic approach. Next, separately, we provide preliminary results and consequent insights with regard to the Legacy and Objective Force research questions. Finally, we summarize findings and tentative conclusions.

Definitions

- **Start-of-mission availability:** Percent of equipment that, at the beginning of a mission involving maneuver and combat, can be used
- **During-mission reliability:** Percent of equipment that operates effectively in the course of the mission

Note: Both depend on "reliability" in a broad sense

Throughout the course of this documented briefing we will use the terms *start-of-mission availability* and *during-mission reliability*, or *availability* and *reliability* in shorthand.

Start-of-mission availability is the fraction of deployed equipment that is ready for use at the beginning of a mission. During-mission reliability is the fraction of equipment that began the mission and is still operative as of a given time into the operation. Later we describe the data sources that we used to calculate start-of-mission availability and during-mission reliability.

Scenarios for Our First Look

- **Need to consider tactical-level building-block missions of importance in current international security environment**
- **Choice: Brigade-sized offensive operations against comparably sized adversary**
 - **Early offense against defender in rough, heavily foliated terrain**
 - **Early offense against defender in more open terrain**

For this first examination of the combat implications of ground force supportability issues, we considered scenarios that are of importance in the current security environment.

We chose a small-scale contingency (SSC) with a U.S. brigade-sized force on the offense against a comparably sized but less effective adversary.

The principal scenario involved combat in a rough, heavily foliated terrain. For comparison purposes we also briefly considered a scenario in more open terrain.

Primary Scenario Based on SSC That Takes Place in Kosovo



Scenarios

- Early offensive to halt ethnic cleansing in rough, foliated terrain
- Offensive against defender in more open terrain

Observations

- Both involve "new" tactical operations with small forces
- Terrain varies considerably
- The scenarios should stimulate and suggest, but are, of course, very particular cases

For this initial attempt to understand the implications of ground force equipment supportability characteristics for combat results, we employed a building-block scenario featuring a single heavy brigade combat team (BCT) that was used in a recent RAND Arroyo Center study.¹ The scenario involved a U.S. forced entry into rough, heavily wooded terrain (based on digital terrain data from Kosovo). The U.S. military might have faced such a challenge in the actual Kosovo war had a decision been made to employ U.S. ground forces.

The U.S. ground force mission is to establish a lodgment or foothold in territory held by the enemy of roughly 40 km by 40 km. Establishment of the lodgment would result in control of a considerable amount of territory, thereby protecting the civilian population in that area. It would also secure an entry point for follow-on forces should they be required. Finally, U.S. forces engage regular-army Red forces supporting the ethnic cleansing. The entry of the U.S. force in this

¹John Matsumura et al., *Exploring Advanced Technologies for the Future Combat Systems Program*, Santa Monica, CA: RAND, MR-1332-A, 2002.

scenario is opposed by four Red reinforced company-sized "battle groups" shown as ovals on the map. Each battle group consists of an infantry company, one or two platoons of tanks, three or four artillery pieces, a few mortars, and anti-aircraft guns and shoulder-fired missiles.

The arrows at the top of the map indicate other Red forces that are attempting to reinforce the four battle groups. However, in the scenario that we investigated, these reinforcing units do not arrive in time to engage the U.S. BCT.

The JANUS model, a force-on-force simulation, was used to simulate combat. The previous study using this scenario concluded that the BCT could accomplish its mission of establishing a lodgment, but under most circumstances U.S. casualties would be heavy because the terrain and foliage were conducive to the Red defenders lying in ambush. Such conditions reduced the benefit of U.S. advantages in sensors and weapons.

Scenario Orders of Battle

U.S. Heavy Brigade Combat Team (416 shooters)

54 M1A1s
159 M2A2s
45 M2A3s

} 258 "Big 3"

Plus scouts, artillery and other support

Red Battle Groups (488 shooters)

48 BTR-60s

32 T-72s

Plus infantry teams, artillery and other support

This chart summarizes the U.S. and Red orders of battle.

The U.S. BCT is a "heavy" brigade with over 250 heavy pieces of equipment such as Abrams tanks and Bradley fighting vehicles. The BCT has a total of 416 firing platforms or "shooters," consisting of several different types of systems. However, the principal systems were 54 M1A1s, 159 M2A2s, and 45 M2A3s. As a shorthand, we called these systems the "Big 3." We learned, after running JANUS, that Big 3 systems achieved nearly 90 percent of the U.S. kills and suffered about 70 percent of the casualties. The U.S. heavy BCT has, including support, about 4,500 personnel.

The four Red battle groups had 488 shooters, but unlike the U.S. force, the kills and casualties as determined by JANUS were spread asymmetrically across the force, with the BTR-60s and T-72s achieving the majority of kills and the dismounted infantry teams suffering the majority of the casualties.²

The capabilities of these systems were assumed to be consistent with those of similar Russian equipment.

²JANUS did not track individual soldiers in the scenario. The Red infantry were organized into teams equipped with anti-tank weapons and heavy machine guns. The teams were tracked in JANUS.

Methodology Overview

Assembly Area



- Fraction of equipment available to move from assembly area is taken from NTC data

Road March



- Breakdown of equipment on road march from NTC data

Combat



- Breakdown of equipment during combat phase from NTC data
- Combat results from JANUS model

This slide presents an overview of the methodology that we used. We begin with the U.S. heavy BCT leaving its assembly area in order to proceed to meet and engage the enemy. Some of the equipment will be unable to leave the assembly area because it is broken and has not yet been repaired. The fraction of the equipment that is available to leave the assembly area is obtained from National Training Center (NTC) data.

The unit then conducts a road march from the assembly area to the combat zone. Some equipment will break down on the road march according to $P_{\text{breakdown}} = 1 - e^{-R/MK_{\text{mBF}}}$, where P is the probability of breakdown, R is the distance of the road march, and MK_{mBF} is the mean kilometers traveled between failure. The value of MK_{mBF} is obtained from NTC data.

Finally, as the unit engages the enemy force in combat, additional equipment breakdowns can occur. We used the same formula as was used to calculate the probability of breakdown during the road march. Here, though, the calculation was accomplished within the JANUS combat model in a way that we will describe shortly.

Equipment Breakdown was Modeled at Three Points

- **At start of operation (availability = .74)**
- **After road march of 0, 50, or 100 km (using 279 MKmBF)**
- **At time of shots during engagement (again using 279 MKmBF)**

To evaluate the effects of equipment availability and reliability on combat results, we used availability and reliability data collected at the NTC.³ We simulated only the effects of availability and reliability for Big 3 equipment because, as mentioned previously, that equipment accounted for the vast majority of kills achieved and casualties suffered by the U.S. force. For simplicity, we used the average availability of the M1A1 (74 percent) as representative of the initial availability of Big 3 equipment for missions. The 26 percent nonavailability at the NTC was due to equipment failures in the course of mission preparation.

One of the factors that we varied was the distance that the U.S. BCT traveled (0, 50, 100 km) in the mission before combat began. Equipment operating status was then checked at the beginning of combat assuming a MKmBF of 279 km.

³Equipment availability and reliability was calculated from NTC Observer-Controller daily equipment status reports for rotations 99-08 through 01-10 and NTC Materiel Management Center Rotational Usage reports. See Eric Peltz, "The Effects of Equipment Age: A Study of M1 Tanks," RAND, unpublished.

The engagement duration was fixed for each JANUS run at 270 minutes. Typically, Blue moved about 20 km. Big 3 equipment operational status was checked before each shot was attempted and was based on the distance traveled since the last shot or, if no previous shot had been taken, based on the distance the vehicle traveled from the start of the engagement.

RAND's Unix-Based Version of JANUS: The Army Standard for Training and Analysis

- **Air-land combat**
- **Uses NIMA digital terrain and features data**
- **Entity level portrayal**
- **Stochastic portrayal using Monte-Carlo generation**
- **Interactive gaming capability**
- **Closed environment**

To simulate combat, we used the RAND-modified version of the JANUS combat model.⁴ JANUS—developed originally at Livermore National Laboratory—can model ground-to-ground, air-to-ground, and ground-to-air combat, although in this analysis only ground forces were involved, except for some unmanned aerial vehicles (UAVs) that were used for reconnaissance purposes in support of the U.S. heavy brigade. Terrain and features data come from a National Imagery and Mapping Agency (NIMA) database. Force elements are represented at the level of individual entities (e.g., tanks and dismounted infantrymen). Combat outcomes are determined stochastically using Monte-Carlo methods to determine the outcomes of combat activities such as target detection, projectile hit, and target kill.

JANUS can be used in an interactive gaming mode or in an automatic run mode. In the automatic run mode, force movement plans that cover the complete duration of the engagement are provided as scripted input. These plans are the products of tactical and gaming

⁴For a description of the JANUS model, see Appendix B in John Matsumura et al., *Lightning Over Water*, Santa Monica, CA: RAND, MR-1196-A/OSD, 2000.

experts, who carefully “choreograph” movement and action at the entity level to produce reasonable, doctrinally based action by both sides. For this study, we used the automatic run mode.⁵

As an entity-level simulation, JANUS has typically been used to model operations of brigade size and below in single engagements usually lasting a few hours.

Neither the standard nor usual RAND-modified versions of JANUS have incorporated equipment failure (as opposed to combat damage and kills) and repair. While availability can be played by modifying the starting position, it is typically not considered. In short, JANUS is traditionally used to model combat effects, with little interest in the interaction of logistics and readiness effects on combat outcomes.

⁵Care is necessary because if a parameter is changed enough, the corresponding change in the real world would cause a change of tactics.

We Modified JANUS For This Study

- **Availability and reliability determined probabilistically**
- **Equipment availability is considered at the beginning of a tactical operation or mission**
- **Equipment intra-mission reliability is considered during the operation, with maneuver and engagement**
 - **Determined before a shot is taken**
 - **Based on distance traveled since last shot or beginning of engagement**

For the purposes of this study, we modified JANUS using simple methods to capture some of the effects of equipment supportability on combat results. The intent was not to create a new, validated module for standard use, but rather to have a tool with which to gain insight and assess the potential value of more refined studies.

First, we modified JANUS to take into account equipment availability before the engagement begins. Based on an availability parameter, the model determines probabilistically whether each individual piece of equipment is available to participate in the scenario. Then we introduced the effects of a precombat road march, which further degrades initial engagement levels as described earlier.

Equipment failures are also considered during combat. For ease of adding a reliability effect to the model in a first-cut calculation, we elected to program reliability “checks” using what we expected to be a frequent event already played in the model—the act of firing.

When a platform is about to fire, the simulation checked whether it is operational. If JANUS determines that the platform is still operational,

the shot is taken; otherwise, the shot is not taken. At the time of failure, platforms become immobilized. In effect, a platform either is fully mission capable or suffers "total failure." Operational status is calculated based on the distance traveled from when the platform last fired a shot or, if it is the first shot, based on the distance the platform traveled from the beginning of the engagement. These operational failures thus represent a failure that occurred between the previous check (or start of the engagement) and the firing event.

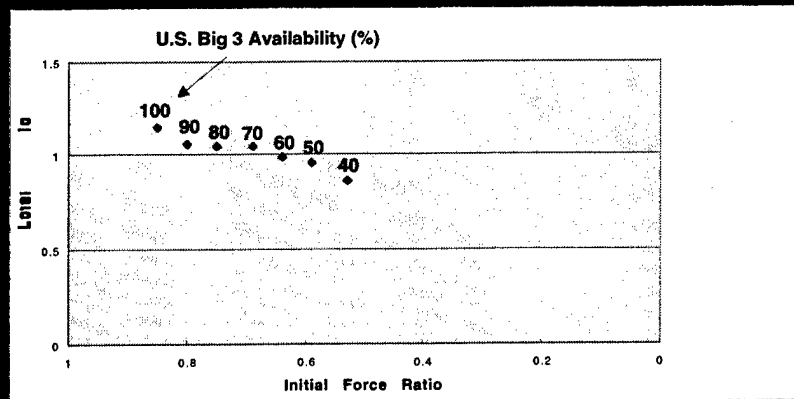
This method of determining equipment reliability probably undercounts the occurrence of failures during engagements, because not all platforms fired and activities beside movement can cause failures. Nonetheless, we believe the methodology is a reasonable first cut.

Briefing Outline

- Methodological Approach
- ✓ • Legacy Force Issues
 - Engagement outcomes affected by equipment
 - availability and reliability
 - aging
 - rebuild
- Objective Force Issues
- Summary and Conclusions

We now address the three legacy force issues: the effects on simulated combat results of equipment availability and reliability, equipment reliability degradation with age, and the improvement of equipment supportability through rebuild programs.

Equipment Availability Has a Modest Effect on Combat Outcome in This Scenario



Our first task was to understand the effect of equipment availability on scenario results parametrically. To do so, we determined the effect of the number of weapon systems available, or the force ratio, on the engagement outcome. The measure of effectiveness that we used is the loss exchange ratio, which is defined as the total number of Red losses divided by the total number of U.S. losses.⁶ Equipment availability for the Big 3 force elements⁷ was varied from 100 to 40 percent in decreasing steps of ten percentage points.⁸ The loss exchange ratio is

⁶Note that the loss exchange ratio is only slightly larger than unity even when 100 percent of the U.S. force is available. Although the U.S. force has significant item-for-item advantages, it is operating at a disadvantage because the adversary is able to use foliage and terrain.

⁷Although JANUS was modified to take into account the availability and reliability of both sides' equipment, we only considered the effects on U.S. equipment for this study. In addition, because the Big 3 achieved the vast majority of kills and suffered the vast majority of casualties for the U.S. forces, the availability and reliability of only the Big 3 elements were varied. A more complete study would have taken into account the availability of both U.S. and enemy equipment.

⁸For this particular part of the study we did not include the possible effects of equipment reliability during the engagement.

plotted as a function of the force ratio (defined as the initial number of all U.S. equipment entities divided by the initial number of all Red shooters). A quality adjusted force ratio would be much more advantageous to the United States—perhaps by a factor of 2 to 3—but the unadjusted force ratio is more readily calculated from the data. The JANUS model was run 30 times for each case and the results of the individual runs were averaged to obtain the values for the points shown on the graph.

As the availability of the U.S. force decreases, the loss exchange ratio decreases moderately. In other words, the number of available force elements makes a difference on the combat outcome but there was not a catastrophic falloff in capability, as measured by the loss exchange ratio, as the number of Big 3 elements decreased in this scenario.

Initially, we were interested in whether with the JANUS simulation we might see a catastrophic falloff or at least a significant “knee in the curve.” Whether a supportability requirement should be a KPP⁹ has been an important issue in the Army over the last couple of years. Having a clear threshold beyond which a force would not be mission capable would enhance the justification for making a supportability requirement a KPP and would ease the task of establishing a justifiable threshold.

However, the lack of such a falloff in the simulation could be a result of the model construct. This is because organizational network effects and human behavior are not accounted for. Organizational structure and command and control implications are not played in JANUS. That is, each vehicle is just part of a battalion and not a company, platoon, or section. In real situations, a tank crew, for example, would be responding to the commands of its platoon leader, who would be responding to the commands of his company commander, who would be responding to the commands of his battalion commander. At a certain level of losses at each echelon of command, the leader may elect to change the course of action or request a changed course of action

⁹Key performance parameters. KPPs are specified for a system in development and are required to be achieved.

based upon perceived capability. Or if a platoon was conducting an assault of a position, and two tanks were taken out, would the crews of the remaining two continue pushing forward? If a platoon leader's tank is taken out, what would happen? As currently programmed, JANUS does not have the dynamics for automated simulations to accommodate such effects (although they could be played in man-in-the-loop runs based upon expert judgment).

From the results shown on this chart, we cannot prove a threshold effect in combat capability based upon the availability of equipment using JANUS.

How Do JANUS Results Compare with Lanchester's Model of Combat?

- Most widely known mathematical model of combat was developed by Lanchester
- One form of the Lanchester equation

$$ER = ER_{FR=1} \cdot FR^\gamma$$

Where ER = exchange ratio and
FR = force ratio

- $\gamma = 0$ represents "ancient warfare" (linear law)
- $\gamma = 1$ represents "modern warfare" (square law)

These results raise this question: How do they compare with results generated by other models of warfare?

It would be interesting to compare results with other detailed simulation and history, but in our short-duration study, we turned to Lanchester's theory of combat.¹⁰ Lanchester's theory of combat is arguably the most widely known and used mathematical model of combat. Lanchester derived two laws of combat: the linear law and the square law. The linear law represents, in his words, ancient warfare where no matter how much one side might outnumber the other, only equal numbers of combatants can engage. The square law represents modern warfare, Lanchester argued, fought with long-range weapons that essentially enable all of the firepower of one side to be

¹⁰F. W. Lanchester, *Aircraft in Warfare: The Dawn of the Fourth Arm*, London: Constable and Company Limited, 1916. See also National Research Council, *Modeling and Simulation: Becoming a 21st Century Force*, Vol. 9 of Technology for the United States Navy and Marine Corps: 2000–2035, 1997; James Taylor, *Force on Force Attrition Modeling*, Alexandria, VA: Military Operations Research Society, 1980; and Jerome Bracken et al. (ed.), *Warfare Modeling*, Alexandria, VA: Military Operations Research Society, 1995.

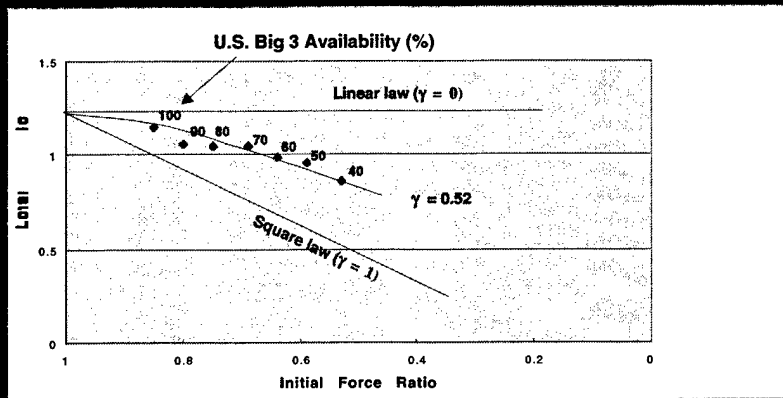
concentrated against the other, regardless of how the two force sizes compare, and vice versa. In the limit, any weapon system on one side can engage any target on the other side. Other observers describe the differences as being more of aimed versus unaimed fire. Still others disparage the simple descriptions and argue that a power law is reasonable but would reflect the average result over time of search for engagements, search during engagements, firing rate, etc. The point here is that the "law" that governs a battle will depend on details that have little to do with the more simplistic rationalizations usually given for linear- and square-law versions. Nonetheless, it will typically be the case that in a class of more or less symmetrical battle, the net attrition rate will most likely be described with a "generalized" Lanchester law with a suitable exponent between that for the linear and square laws.

A simple form of a generalized Lanchester equation of combat is shown on the chart,¹¹ where ER is the loss exchange ratio, FR is the initial force ratio, and γ is a parameter that indicates the extent to which each side can concentrate its firepower on the other. When $\gamma = 0$, the conditions of ancient warfare hold (Lanchester linear law), and when $\gamma = 1$, the theory of "extreme" modern warfare holds (the square law). Many authors have noted that both historical and simulation data often correspond to something intermediate.

We fit the generalized Lanchester equation to the data points shown in the previous slide using the method of least squares. The result of the fit is shown on the next slide.

¹¹C. T. Kelley, Jr., et al., *Quality-Quantity Tradeoffs: A Historical Analysis of Air Combat*, Santa Monica, CA: RAND, R-1976-AF, April 1977.

Comparison with Lanchester Theory



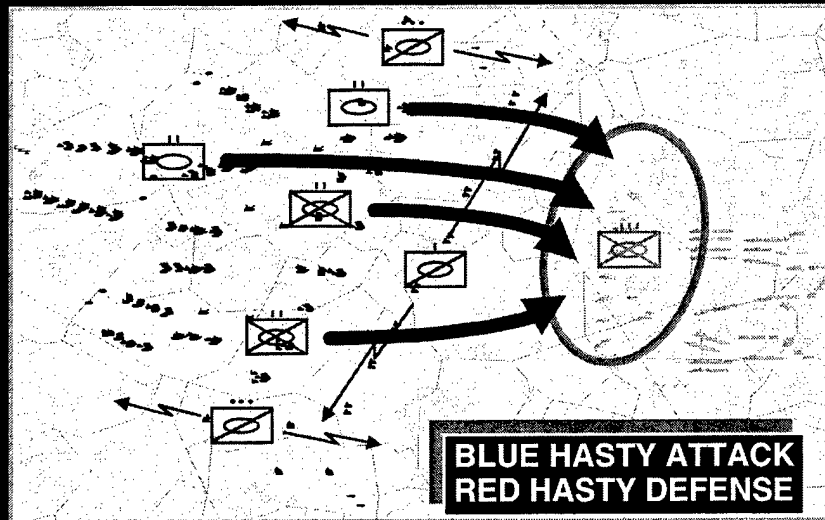
The best fit of the generalized Lanchester equation for the JANUS results shown on the previous chart is depicted by the curve labeled with $\gamma = 0.52$, the curve's firepower concentration parameter. Also shown are two straight lines that represent how combat outcomes would have changed with availability if the linear law ($\gamma = 0$) held (loss exchange ratio is independent of the initial force ratio) and if the square law ($\gamma = 1$) held.

The JANUS results for the Kosovo scenario exhibit behavior roughly halfway between the linear and the square laws.¹² In terms of the Lanchester theory, the JANUS results for the scenario being investigated appear reasonable. That is, a moderate degree of firepower concentration or aimed fire is possible. If the results had exhibited a trend more in line with the square law, the effects of

¹²Because the Big 3 accounted for most of the kills achieved and the casualties suffered by the U.S. force, we also calculated the force ratio assuming that the size of the U.S. force was due only to the Big 3 vehicles. In that case, the curve fitting resulted in $\gamma = 0.28$, which represented less of an effect of force size on combat results than when all U.S. shooters were included in the force ratio calculation.

equipment availability on combat results would have been greater than what we observed here. Before turning to a discussion of the scenario results using actual equipment availability and reliability data, we examine a second scenario to see if the results presented in this slide appear there also.

We Used a Second Scenario to Assess the Broader Applicability of the Kosovo Scenario Results



The second scenario takes place in more open terrain, typical of northern Europe, that is conducive to armored warfare and in which U.S. forces should benefit from advantages in sensor and weapon range. A U.S. heavy BCT, conducting a movement-to-contact mission, meets a Red armor-heavy regiment conducting a similar mission.¹³ The Red unit is attempting to seize terrain, consolidate its position, and then negotiate from a position of strength. The mission of the U.S. heavy BCT is to intercept and block the Red force. The meeting engagement turns into a U.S. hasty attack on the Red hasty defense. The scenario takes place in a mixed-terrain environment typical of Poland and northern Germany (neither excessively flat nor excessively devoid of foliage). Once the forward security elements for each side detect each other, the Red force prepares to conduct a hasty defense on dominant terrain overlooking a five-kilometer-wide valley. The U.S. force then attacks.

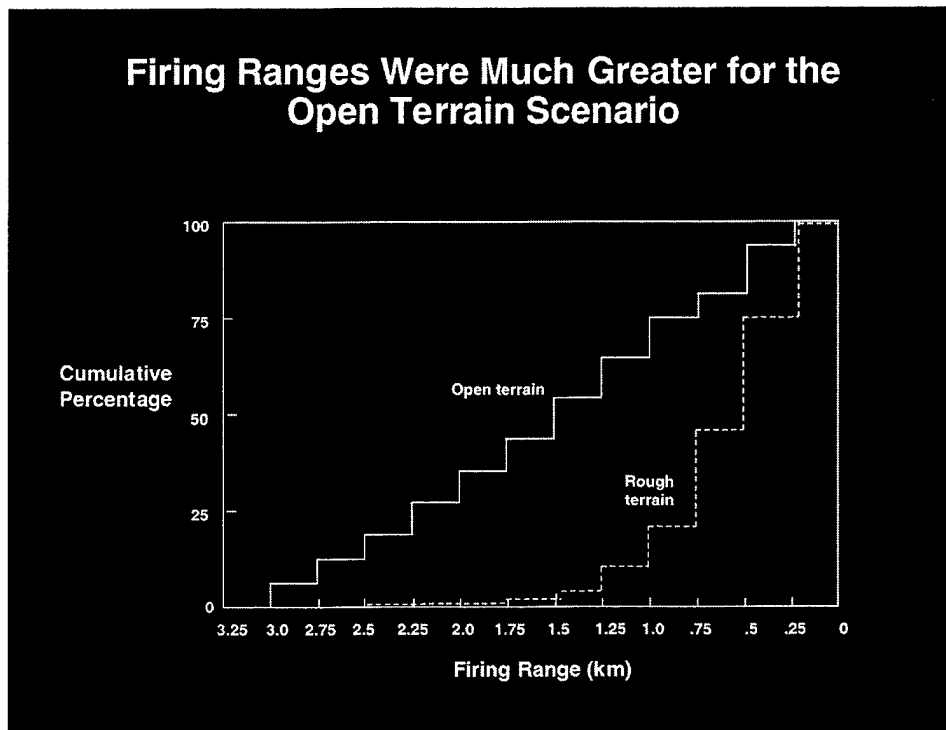
As with the previous scenario, we used JANUS to simulate the operation. We varied the availability of the U.S. brigade's Big 3

¹³Gary McLeod et al., "Analytical Support to MTI Requirements and Analysis Study," RAND, unpublished.

equipment and fit the generalized Lanchester equation to the results as we did for the Kosovo scenario. We found that $\gamma = 0.6$, which is quite close to the same value as we found for the Kosovo scenario.

Although we have not done a definitive investigation to pin down the reason for the difference in the firepower concentration parameters for the two scenarios, we suspect that it is due to the difference in terrain between the two cases. If terrain is less of a constraint in detecting and firing at opponents, the effects on engagement outcome of varying the number of shooters in terms of the loss exchange ratio should be greater (i.e., a larger value of γ would be found). If terrain is less of a constraint in detecting and firing at opponents, we would also expect that in general the distances between shooter and target should be greater. In addition, each target should be targeted by a greater number of systems due to improved line-of-sight opportunities for direct-fire weapons and less impeding terrain for indirect-fire weapons. To evaluate the first hypothesis with regard to firing ranges, we compared the firing ranges between shooter and target for the two scenarios.

Firing Ranges Were Much Greater for the Open Terrain Scenario



The graph shows the cumulative percentage of firings for U.S. direct-fire weapons that occurred between U.S. shooters and enemy targets as a function of the range or distance between the shooter and the target. The firing ranges, taken from JANUS, are aggregated in increments of 0.25 km. As the graph shows, the ranges of shots taken in the open terrain are considerably greater than the ranges of shots that occurred in the rough terrain. For the open-terrain scenario, 50 percent of the weapon firings occurred at distances greater than 1.25 km from the target, whereas for the rough-terrain scenario, the corresponding distance is only about 0.75 km.

It seems intuitive that as average firing range increases, the effects of weapon system availability will also increase in terms of the loss exchange ratio because results will depend more directly on the number of shooters. The data from the two scenarios support that notion. Nonetheless, we also conclude from the rather close agreement of the two γ values derived from the open-terrain and rough-terrain scenarios that the rough-terrain scenario results are not unrepresentative of armored ground combat results in many situations. We posit, however, that the more open and flat the terrain, the higher the firepower concentration parameter, with desert warfare most likely having the highest value.

**Base Case Results:
100% Availability and 100% Reliability
(30 iterations)**

- How does U.S. force perform relative to Red force?

Loss exchange ratio (Red losses/U.S. losses) = 1.15

- How well does U.S. force defeat Red forces?

Red elements killed = 70

- To what extent does U.S. force control contested area?

Size of U.S. occupying force* = 205

* numbers of active M1 and M2 vehicles at end of engagement

We used three measures of effectiveness (MOEs) to describe the effects of equipment initial availability and reliability on combat outcomes. The first MOE describes the performance of the U.S. force relative to that of the Serbian force and is the loss exchange ratio discussed earlier. The loss exchange ratio (LER) is defined as Red force elements killed divided by U.S. force elements killed. Obviously, it is in the U.S. interest to have a high LER value. The value shown here indicates rough parity between the two sides. The principal reason why the LER is not more favorable to the U.S. force is that the Red force is taking full advantage of terrain and foliage cover to set up ambush positions. LER, along with the initial force ratio, measures how the forces are being drawn down relative to one another. For the situation that we are examining, both the initial force ratio and the LER are close to unity. That means that if successive engagements were to occur under similar conditions, the two opposing forces would decline in size at about the same rate—not a good result for the U.S. side.

The second MOE describes the extent to which the U.S. force defeats the Red force and is the number of individual Red force elements

killed. In the base case, 70 Red force elements were killed out of an initial number of 488 force elements.

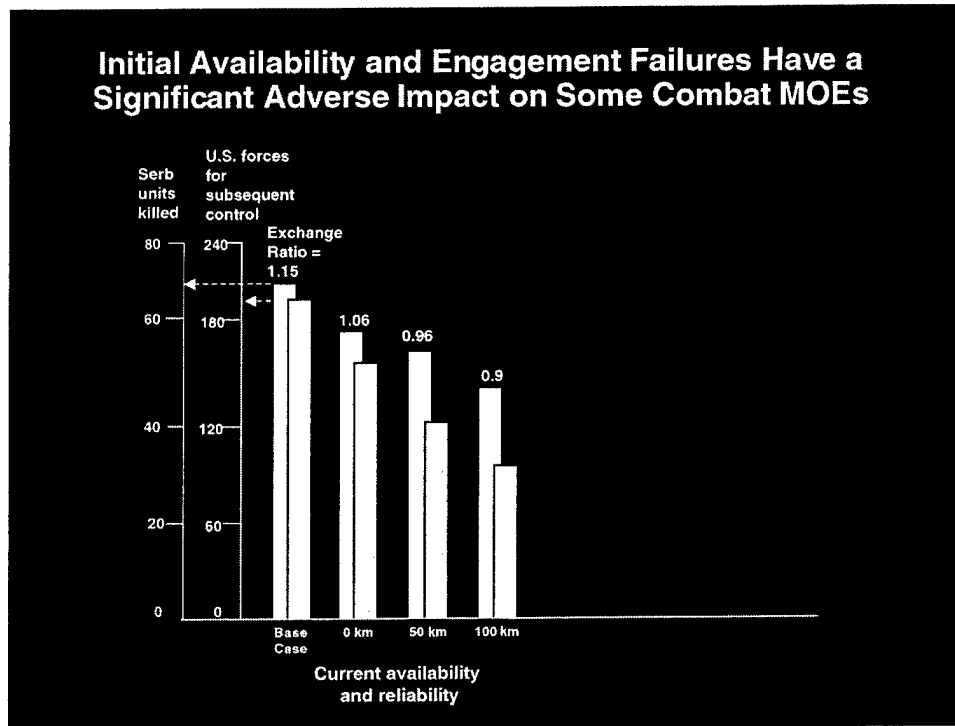
The third MOE represents the extent to which the U.S. force controls the contested area and is the number of active Big 3 vehicles at the end of the engagement.^{14, 15} This MOE also serves as an indicator of the size of the U.S. force (as measured by the number of Big 3 vehicles) that is available to begin a second engagement immediately after the first one ends. This would be important in the face of an immediate counterattack. In the base case, 205 Big 3 vehicles are available for controlling the contested area out of an initial number of 258 vehicles. Of course, as time passes the position of U.S. forces would improve as vehicles are repaired or replaced.

The values of the three MOEs for the base case, where equipment initial availability and reliability equal 100 percent, are shown.

¹⁴Active vehicles are all those vehicles that have survived and are operational at the end of the engagement.

¹⁵For controlling territory after a combat engagement, "number of personnel" may be a better MOE. We are not using JANUS to keep track of personnel counts in this study.

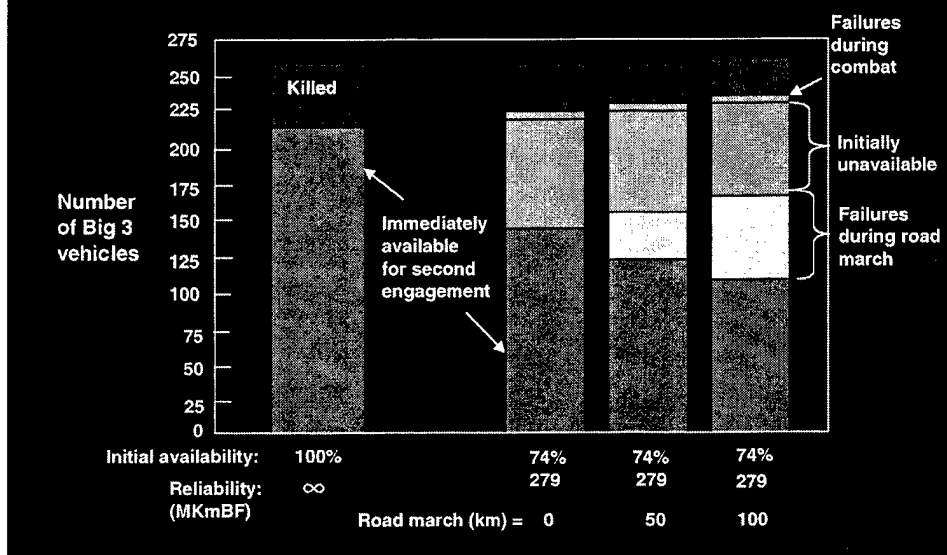
Initial Availability and Engagement Failures Have a Significant Adverse Impact on Some Combat MOEs



This chart shows the three MOEs for the base case (far left pair of bars) and for three cases using current equipment availability and reliability data. What distinguishes the three cases is the distance traveled by the U.S. heavy BCT before the start of combat: 0, 50, or 100 kilometers. The longer the road march, the more vehicles break down and thus the fewer the number of vehicles that can engage in combat. The loss exchange ratio is indicated by the number on top of each bar. The upper dashed line indicates the number of Serbian platforms killed, and the lower dashed line indicates the size of the U.S. occupying force immediately at the end of the engagement as measured by the number of active Big 3 vehicles.

As the chart shows, shifting from the base case to cases using an estimate of current equipment supportability shows a significant degradation in the combat performance of the U.S. heavy BCT, especially with regard to the size of the U.S. occupying force at the end of combat, which drops from about 200 Big 3 vehicles in the base case to about 100, for the 100-km road march case, potentially creating a high level of risk. As the situation becomes more demanding in terms of supportability, the effect grows dramatically.

Combining Equipment Failure With a Stressing Combat Scenario Can Leave a Force with Very Low Readiness for an Immediate Second Engagement



This chart compares the details of the Big 3 outcomes for the base case (100 percent availability and reliability) and for the three cases when current availability and reliability factors are used and the unit travels 0, 50, and 100 km before the beginning of combat.¹⁶

For the base case at the end of the engagement, about 45 Big 3 vehicles have been killed and about 215 are active and immediately available for a second engagement, if needed.

In contrast, for the three cases when current availability and reliability factors are taken into account and combat is preceded by a road march of varying length, only about 100–150 Big 3 vehicles are available. In the worst case (100-km road march) about 70 vehicles were determined to be unavailable prior to the road march, about 60 vehicles were determined to fail during the road march, 30 were killed during the engagement, and only two failed during combat. In this case, only about 100 active vehicles are immediately available for a second engagement.

¹⁶Because the equipment availability and reliability for the base case was 100 percent, distance traveled before the start of the engagement has no effect on the base case results.

While the failures during the road march may be overestimated, the number of vehicles determined to fail during combat is probably underestimated because JANUS checks on vehicle reliability only when a shot is taken and only based upon movement. If reliability were checked on the basis of other vehicle activities, the number of vehicle failures during the engagement would probably increase. In the end, however, while the mix of when vehicles are determined to be unreliable might change, the overall total might not be significantly different. In effect, the methods used in this analysis probably "shift" some engagement-oriented failures to the road march.

We now turn to an explanation as to why so few vehicles were found to fail during combat.

Why Were So Few Vehicles Deemed Unreliable During Combat?

- Reliability checked when a shot is about to be taken
- Only about 17% of available vehicles attempt a shot
 $134 \text{ vehicles} \times 0.17 = 23 \text{ vehicles}$
- Unreliability determined by distance traveled (about 20 km) and MKmBF (279 km, in this case)
 $23 \text{ vehicles} \times (1 - \exp(-20/279)) = 1.6 \text{ unreliable vehicles}$

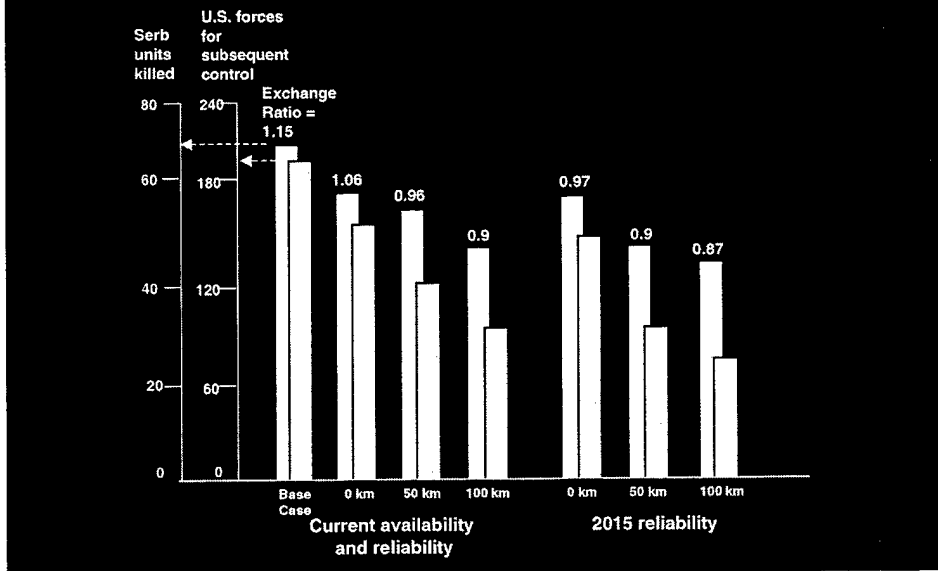
A detailed examination of the JANUS output showed that only a small percentage, about 17 percent, of the Big 3 vehicles actually took a shot.¹⁷ The relatively small number of vehicles taking a shot is due to two reasons: (1) many of the U.S. vehicles are killed before they detect the enemy shooter, and (2) many of the trailing U.S. vehicles never get into the fight. After taking into account the initial unavailability of vehicles and failures from the road march, only 134 Big 3 vehicles began the engagement. The resulting number of vehicles that took a shot was just 23. The average distance traveled before these shots was about 20 km, resulting in an average of less than two vehicles that were determined to become not mission capable due to equipment failure during the combat phase of the scenario.

We mentioned earlier that our method of calculating the number of unreliable vehicles during combat probably underestimates that effect. If all vehicles had been checked for reliability and not just those that had attempted to fire a shot, then we estimate that perhaps as many as

¹⁷However, of the vehicles that did shoot, many took multiple shots.

up to nine vehicles might have been judged to be unreliable based on the average distance traveled. Although this value is significantly larger than the 1.6 vehicles calculated in JANUS, it is small compared to the number of vehicles lost for other reasons.

**Capability Degrades Further As Reliability Decreases with Equipment Age
(Initial availability assumed constant over time period)**



Here we examine the implications of aging equipment for combat performance. In other Arroyo Center work,¹⁸ it has been estimated that M1 reliability decreases at a rate of 4 percent per year over the first 14 years of life. We assumed that reliability would continue to decrease by 4 percent per year from 2000 to 2015. Then the reliability would be 151 MKmBF, in contrast to the current value of 274 MKmBF.

The three rightmost sets of bars were calculated using the degraded reliability factor due to equipment aging. However, we assumed that equipment availability would remain the same as it is currently. That assumption may overstate Big 3 equipment availability by the year 2015. On the other hand, if availability were allowed to degrade at the same rate as reliability, then the availability would be less than 50 percent, which would be an intolerable readiness level for the force. We assumed that such a degradation would not be allowed to happen. Rather, additional resources could be employed to maintain initial availability. Further, the sensitivity analysis of availability versus the

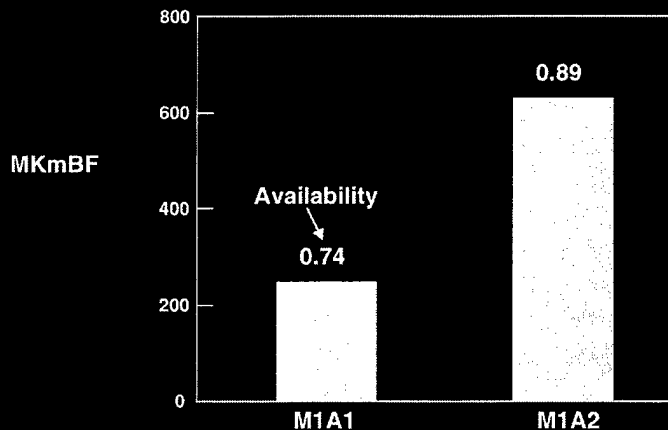
¹⁸Eric Peltz et al., "The Effects of Equipment Age on Mission Critical Failure Rates: A Study of M1 Tanks," RAND, unpublished.

loss exchange rate provides insight into how changes in availability affect combat outcomes.

As the chart shows, the combat capability of the force degrades further as the force ages and reliability degrades. In the worst case, indicated by the rightmost set of bars, the exchange ratio falls to 0.87, the number of Red elements killed drops to about 45 (out of an initial number of 488 Red elements), and the size of the Big 3 occupying force is only about 75 vehicles (out of an original Big 3 force size of 258 vehicles), only about one-third as large as for the base case.

How might capability improve if M1A1s are rebuilt to improve their availability and reliability?

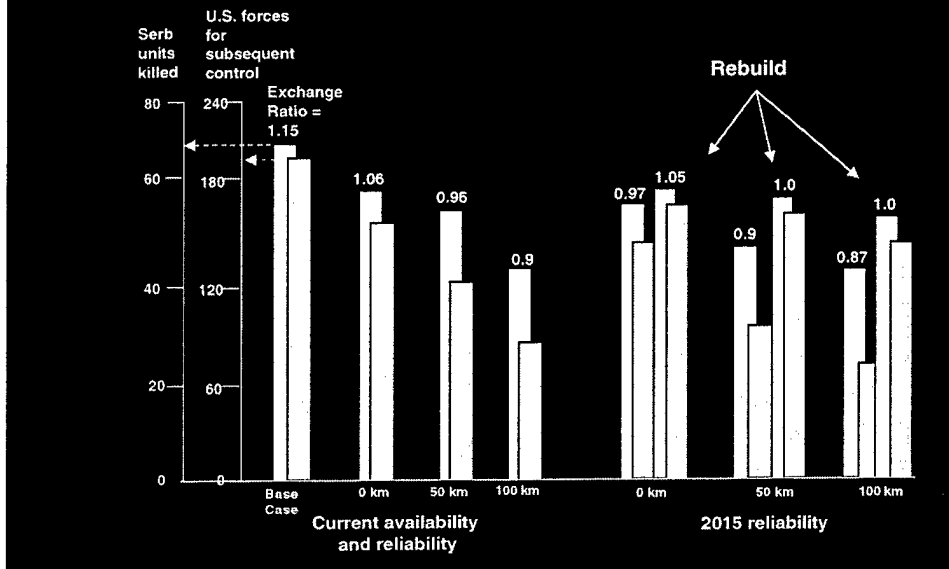
Rebuilding Equipment Can Substantially Increase the MKmBF and Availability



The Army has undertaken a program to rebuild and upgrade the M1 tank fleet. Rebuilding equipment can have a significant effect on equipment availability and reliability, as shown in the chart. At the NTC in fiscal year 2001, the availability of relatively new M1A2s was found to be 89 percent versus the M1A1's 74 percent, and the reliability increased to 620 MKmBF from 279 MKmBF.¹⁹ Analysis of the data suggests that the major difference in the availability and reliability numbers resulted from differences in failures of components common between the two variants (e.g., hydraulic lines and roadwheel arms) and not from the enhancements unique to the M1A2. M1A2s are rebuilt M1 tanks with upgrades in selected areas such as fire control. In the analysis that follows, we assume that the M1A2 availability and reliability numbers are representative of those for all rebuilt Big 3 vehicles.

¹⁹NTC observer-controller daily equipment status reports for rotations 99-08 through 01-10.

Rebuilding Equipment More Than Maintains Current Capability Into the Future If Enemy Doesn't Upgrade



The three sets of bars labeled "rebuild" on the right side of the chart are the JANUS results when the Big 3 equipment is rebuilt to M1A2 availability and reliability levels.²⁰ We assumed that the equipment was rebuilt in 2000 and applied a 4 percent degradation in reliability per year, as we did previously with the M1A1 data. As before, we did not degrade equipment availability.

If we compare the sets of bars for the rebuilt equipment in 2015 with the sets of bars for current availability and reliability in 2000, we see that the capability of the rebuilt equipment in 2015 more than matches the capability of the current equipment in 2000. Thus, rebuilding the Big 3 equipment to the M1A2 standard maintains the current combat capability into the future. Note that this only considers the M1A1 at the higher availability and reliability associated with new M1A2s and not the upgraded capabilities of the M1A2.

²⁰ The results do not take into account any upgrading of performance other than improved availability and reliability.

Briefing Outline

- Methodological Approach
- Legacy Force Issues
- ✓ • Objective Force Issues
 - Contributions of supportability and other BCT characteristics
- Summary and Conclusions

We now address the issue of the relative contributions of equipment supportability and other performance-enhancing characteristics for the Objective Force's BCT, which is currently being called the Unit of Action.

Objective Force Evaluation

- Same Kosovo scenario
- Threat upgraded
 - FLIR
 - Better tank armament
 - Upgraded anti-tank weapons
- FCS (LAV) replaces the M1, M2 and HMMWV
- BCT configurations were developed for an ASB study
 - “Vanilla”
 - Substitute robotic vehicles for some FCSs
 - Arm robotic vehicles
 - Add “Quickdraw” to armed robotic vehicles
 - Add active protection system (APS) to all combat vehicles

Our analysis of Objective Force BCT supportability issues is based on an earlier RAND Arroyo Center study for the Army Science Board (ASB). That study examined the role that the BCT might play in providing rapid reaction capabilities.²¹ The primary BCT combat vehicle is the Future Combat System (FCS). In the study for the ASB, the basic FCS vehicle was represented by an improved version of the Light Armored Vehicle (LAV). Various versions of the LAV replaced the heavy brigade’s M1s, M2s, and scout vehicles on a one-for-one basis. Additionally, the overall number of vehicles in the BCT was kept the same as that of the heavy brigade. For this examination, we used the Kosovo scenario.

We examined the performance of five BCT configurations as they were defined in the study for the ASB. The first BCT configuration (what was called the “vanilla” configuration) has standard versions of the 20-ton LAV vehicle with Level III protection.²² In the analysis for the

²¹John Matsumura et al., *Exploring Advanced Technologies for the Future Combat Systems Program*, Santa Monica, CA: RAND, MR-1332-A, 2002.

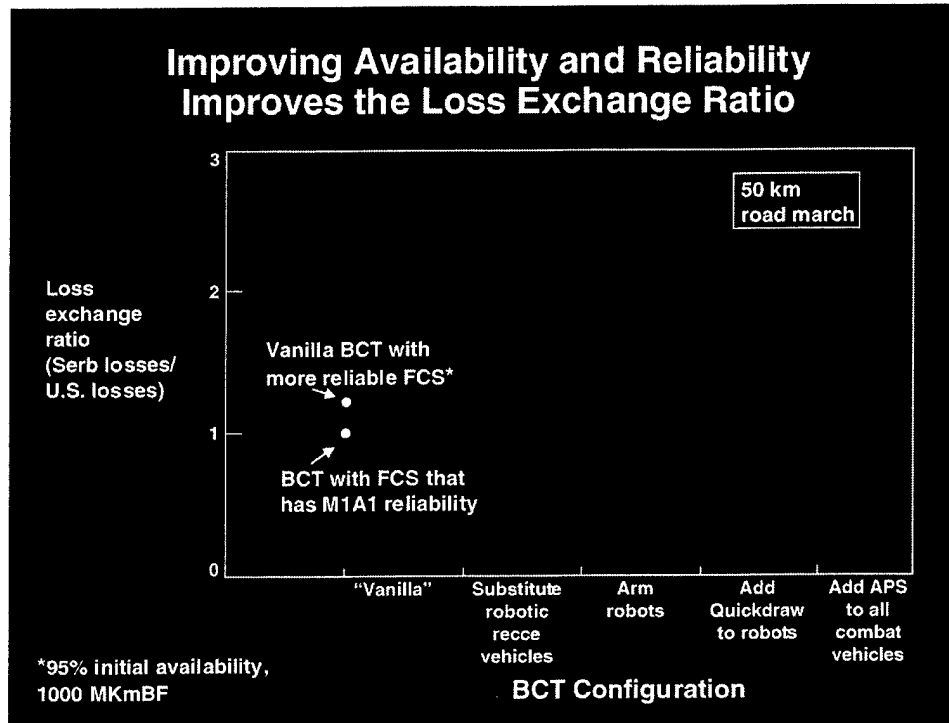
²²Level III protection means protection from a 30mm round fired at the front, back, and two sides.

ASB, it was found that the LAVs performing the reconnaissance role suffered high losses, so the second BCT configuration employed robotic vehicles in the reconnaissance mission, replacing manned systems on a one-for-one basis. The third configuration armed the robotic vehicles with four notional mini-LOSAT²³ missiles and a machine gun. The fourth configuration equipped the armed robotic reconnaissance vehicles with "Quickdraw," which detects muzzle flash and immediately returns fire. Each robotic vehicle has four Javelin missiles and a machine gun for that purpose. The fifth BCT configuration adds an active protection system (APS) to all combat vehicles.²⁴

²³Line of sight anti-tank.

²⁴The APS consists of a single launcher with 360° coverage for 12 shots with a probability of engagement of 0.9 and a hardness of 0.9 with a one second recovery rate. It is assumed to be ineffective against 125mm KEP rounds.

Improving Availability and Reliability Improves the Loss Exchange Ratio

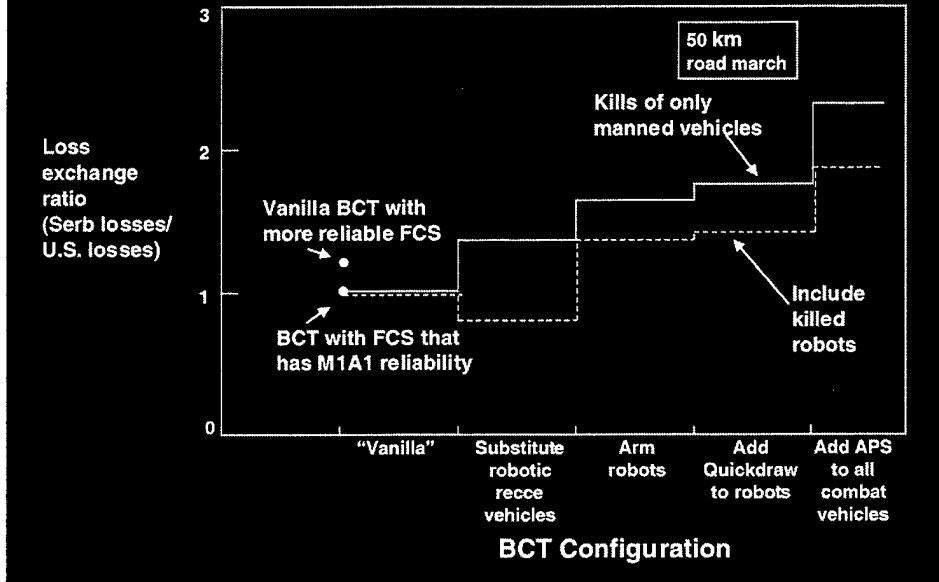


This slide shows the effects of varying FCS availability and reliability versus the other performance-enhancing capabilities that we described. The MOE that we display is the loss exchange ratio. Along the bottom of the graph we list the five BCT configurations that we considered. In all cases, the BCT traveled 50 km before beginning the engagement.

The upper dot indicates the loss exchange ratio for a vanilla BCT with FCSs that are significantly more reliable than today's M1A1s. The FCS is assumed to have 95 percent initial availability and 1,000 MKmBF. The lower dot indicates the loss exchange ratio for a vanilla BCT with FCSs that have the same availability and reliability as today's M1A1. The higher availability and reliability leads to an improved loss exchange rate.

The next slide shows the MOE values for other BCT configurations.

In One Engagement, Some Combat Capability Enhancements Produce Much Greater Leverage Than Supportability Improvement



The step-like line indicates the results when we: add robotic reconnaissance vehicles that replace manned reconnaissance vehicles, arm the robotic reconnaissance vehicles, equip the armed reconnaissance vehicles with Quickdraw, and, finally, add an APS to *all* combat vehicles. The dashed line represents the kills of manned and robotic vehicles, and the solid line represents the kills of only the manned vehicles.

Including all the added improvements to the vanilla BCT, the loss exchange ratio increases to about 2.0 (2.4 for manned vehicles only) compared to a loss exchange ratio of about 1.0 for the vanilla BCT with M1A1-like supportability, depending upon whether robotic vehicle kills are included. All cases represented by the step-like line have an FCS reliability equal to the M1A1's reliability.

When only manned vehicles are considered, except for the addition of Quickdraw, the technologies improved the loss exchange rate by a greater amount than the improvement in reliability (compare each step increase with the difference between the two point values for the

"vanilla" BCT). When both manned and unmanned vehicles are considered, there is a decrease in loss exchange ratio when only the robots are added to the force, indicating that they are being killed at a faster rate than were the manned vehicles that they replaced. However, if the full range of improvements are considered, the loss exchange ratio climbs to about 2.0, a significant improvement compared to the "vanilla BCT with more reliable FCS" case. This suggests that such performance-enhancing improvements are more valuable than this level of supportability improvement, for one engagement. However, two caveats are in order. First, no account is taken of the costs of achieving either improved supportability or the technological advances in performance. Many reliability and maintainability experts believe that using state-of-the-art design practices could lead to much better supportability with limited change in investment cost. Thus, it can most likely be pursued without requiring a tradeoff against these types of performance enhancements (unless such enhancements create supportability difficulties, which could be the case with immature technology). Second, no account is taken of the likelihood of achieving improved supportability or the technological advances that were modeled.

Finally, the scenario that we used is probably biased in favor of the technological advances. The duration of the scenario is short—270 minutes—and the effects of having unavailable equipment would be greater if we had used engagements of longer duration or if we had measured the effects of reliability over a series of engagements that had occurred one after the other.

Briefing Outline

- Methodological Approach
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- ✓ • Summary and Conclusions

We now provide a brief summary and draw some tentative conclusions.

Summary of Findings

- For the scenario used, equipment availability has a moderate effect on combat outcome in one engagement
- Against a moderately capable enemy, rebuilding equipment sufficiently maintained capability as equipment aged and reliability degraded
- Technology-driven combat capability improvements created greater leverage than improved supportability for one engagement

We found, using the JANUS model and applying it to a Kosovo scenario, that equipment availability had a moderate effect on combat outcomes. In terms of the Lanchester theory, the JANUS results for the Kosovo scenario appear reasonable in that results exhibit behavior about midway between the Lanchester linear and square laws. The firepower concentration factor derived in the two scenarios could be used to explore further supportability effects using non-simulation-based models.

Rebuilding legacy equipment so as to improve its availability and reliability more than maintains its current combat performance for the specific scenario used in this analysis. However, rebuilding equipment might have been shown to be not sufficient if a future enemy upgrades its equipment. We might also have to consider upgrading U.S. equipment.

For the objective force used in this scenario, enhancing combat performance through the incorporation of advanced technologies produced a greater improvement, in terms of just one engagement, than increasing the equipment availability and reliability improvements that were modeled. Scenarios with longer or multiple engagements might

yield a different result. In fact, in the Kosovo scenario cases with road marches, the force would have to be assumed to be combat ineffective at the end of the engagements, when current M1A1 availability and reliability are assumed. The unit would probably have had trouble in the face of an immediate counterattack or would have a significant delay before being ready for further offensive operations. So even though technological improvements may be more beneficial in some situations for one engagement, improved supportability may be essential for sustained, high-intensity operations with high operating tempo and a capable enemy.

Conclusions

- **JANUS is a useful tool for measuring some of the combat implications of equipment availability and reliability**

- **However, there is a need to consider**
 - **Threshold effects**
 - **Alternative methods for calculating reliability during the combat phase**
 - **Successive engagements**

- **Include costs in future analysis**

On the basis of the results of this analysis, we found that JANUS was a useful tool for analyzing some of the implications of equipment availability and reliability for ground combat outcomes. We were able to measure the effects of start-of-mission availability and during-mission reliability. We were also able to compare the effectiveness of improving equipment availability and reliability with other combat-enhancing measures for the next-generation force.

However, JANUS also has some limitations. We did not observe a catastrophic falloff in combat effectiveness or a significant "knee in the curve" as the number of systems declined because of the unavailability of those systems. Yet we expect that such catastrophic falloffs exist in the real world. For example, if the capability to perform a mission is already marginal, a commander might call it off if too many major systems are lost beforehand. As another example, a mission might be aborted by a commander if, in the course of pursuing it, the unit took random losses because of unreliability and was concerned about suffering excessive casualties. These and other aspects of catastrophic drop in capability due to availability and reliability effects need to be captured.

In this study, we implemented one approach for calculating equipment unreliability during the course of an engagement based on when a shot was attempted. That approach understates the effect. Although the understatement does not materially affect the findings of this study, other, more realistic approaches should be explored.

The effects of problems of availability and reliability can become very significant if they are allowed to accumulate over a series of engagements. Obviously, actions can be taken between engagements to repair broken equipment, depending upon the resources and amount of time available between engagements. JANUS models combat for a single engagement. Some other analytic tool is probably necessary—perhaps in conjunction with JANUS or a JANUS-like model—to capture the effects of availability and reliability over a series of successive engagements and perhaps even over a campaign.

Finally, it is important to include costs in a future analysis of reliability improvements. Depending upon their costs, reliability improvements might look quite attractive on a cost-effectiveness basis—at least for contexts that stress reliability, as, for example, do those involving long road marches, successive engagements, or the need to control large areas with small forces.



OBJECTIVE ANALYSIS.
EFFECTIVE SOLUTIONS

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