Force Multiplying Technologies for Logistics Support to Military Operations

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Preface

Logistics provides the backbone for Army combat operations. Without fuel, ammunition, water, rations, and other supplies, the Army would grind to a halt. This fact is frequently acknowledged in conversation but not as often rewarded in the allocation of resources necessary to carry out logistics functions. In 1997, I was asked to chair the Committee to Perform a Technical Assessment Focused on Logistics Support Requirements for Future Army Combat Systems. That committee authored the report *Reducing the Logistics Burden for the Army After Next: Doing More with Less*.[1] The charge to the 1999 committee was similar to the charge to the authoring committee of this report, the Committee on Force Multiplying Technologies for Logistics Support to Military Operations—examine logistics burdens and identify where technology, operating adjustments, and efficiencies might offer opportunities for improvements. In 1999, the committee found that there were several areas in which logistics burdens could be reduced through the use of emerging technologies. It also identified ways for Army logistics to be better supported in its analytical efforts. Some of the committee's recommendations were adopted, especially with respect to weapon systems reliability. Other recommendations, however, were either put into the "too hard box" or the "awaiting funding drawer." Now, 15 years later, many of the findings and recommendations of this report follow in the footsteps of the earlier report.

This committee is concerned that logistics activities within the Army do not receive the attention necessary to ensure the effective sustainment of operational forces on the battlefield over the long term. Because the logistics community has worked tirelessly to ensure that soldiers get what they need when they need it, the assumption is frequently made that these activities are being performed in the most efficient manner, and at the least fiscal and personal cost. In research and development, analyses, exercises, and planning, logistics challenges are often minimized, or the need to come to grips with them is postponed until another day. A recent study by the Joint and Coalition Operational Analysis division, a part of the Joint Staff J-7, identified "enduring lessons" from the past decade of military operations.[2] Although many of the lessons from that study touched on issues raised in this report, the analysis did not address any specific logistics topics, even though a substantial number of the challenges faced over this last decade involved the sustainment of the force. It is time to give appropriate attention to logistics.

The National Research Council assembled an outstanding group of experts to carry out this study. It brought together scientists, engineers, policymakers, analysts, and logisticians. The members brought their exceptional expertise and years of experience to the study. I would like to express my personal appreciation to GEN (ret.) Leon Salomon, a former Army G-4 and former commander of the Army Material Command, and also a member of the 1999 committee that authored *Reducing the Logistics Burden for the Army After Next: Doing More with Less*. GEN Salomon served as chair of this committee when I was not available. I would also like to express my personal appreciation to the other members of the committee for their professionalism, willingness to operate in a collaborative environment during difficult discussions, and to continuously focus their efforts on providing the most useful study possible to the United States Army.

[1] National Research Council, *Reducing the Logistics Burden for the Army After Next: Doing More with Less*, National Academy Press, Washington, D.C., 1999.

[2] Joint and Coalition Operational Analysis, *Decade of War, Volume 1: Enduring Lessons from the Past Decade of Operations*, June 15, 2012, http://blogs.defensenews.com/saxotech-access/pdfs/decade-of-war-lessons-learned.pdf.

The committee very much appreciated the efforts made by organizations to provide the information that was requested and to share their insights into the challenges that they and the Army face. The committee expresses its appreciation to all of those who took time out of their busy schedules to meet with the committee as a whole or with individual members. Their dedication to mission accomplishment was evident. A list of the majority of people and organizations contacted by the committee is given in Table 1-1, and a more detailed listing is in Appendix A. At the request of some interviewees, their names were not included on this list.

This study was directed to be unclassified, and as a result, some information identified as "For Official Use Only" was not provided to the committee. This may have resulted in small gaps in the study coverage.

In its deliberations the committee examined the potential for developing a strawman research and development (R&D) strategy for logistics and logistics-related actions, but quickly learned that the absence of information needed and the complexities of integrating such a strategy across all Army elements would make such development infeasible. A strategy begins with a clear definition of the mission and goals to be achieved. It was clear to the committee that the Army is in a period of great transition and is seeking, through organizations such as the Army Capabilities Integration Center, to better define how the Army will doctrinally and organizationally meet future challenges and how a new force will be equipped. Logistics burdens follow equipment choices and tactical demands, strategies employed and missions assigned to the Army. Much is said about the Army becoming expeditionary, yet much of the large forward operating base memory still drives planning. Development of a strategy for science and technology and R&D affecting logistics will require agreement on the tradeoffs among operational capabilities, logistics demands, and personnel requirements in programs far outside the purview of the G-4. While the committee determined that development of forward looking logistics R&D strategy would be infeasible (especially considering that none currently exists), it did provide advice in Chapter 9 as to the collaborative development of such a strategy by the Army staff as a whole.

The committee would like to express its sincere thanks to our study director, Mr. James Myska. His tireless efforts to provide the committee the information it requested, identify opportunities to expand the horizons of the committee, and, of critical importance, shepherd final writing of the report merits the highest levels of praise. The committee also expresses its appreciation to Mr. Bruce Braun, BAST director, Ms. Deana Sparger, and Ms. Nia Johnson for their assistance to the committee throughout its life.

Finally, the committee would like to pay special tribute to LTG Ray Mason, the Army G4 at the inception of the study, for his willingness to undertake this study and to share his personal views on logistics with the committee. His dedication to the improvement of Army logistics will make a difference to the Army as a whole in the years ahead.

Gerald E. Galloway, *Chair*
Committee on Force Multiplying Technologies for
Logistics Support to Military Operations

Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Claude M. Bolton, Jr, Claude Bolton & Associates, LLC;
Lillian C. Borrone, NAE, Eno Center for Transportation;
W. Peter Cherry, NAE, Independent consultant;
Walt DeGrange, CANA Advisors, LLC;
Mitra Dutta, University of Illinois at Chicago;
Kathleen Gainey, Cypress International, Inc.;
Mary L. Good, NAE, University of Arkansas at Little Rock;
Michael R. Johnson, NAE, University of Arkansas;
David M. Maddox, NAE, Independent consultant;
M. Frank Rose, Radiance Technologies; and
Robert G. Traver, Villanova University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Claude F. Christianson, independent consultant. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Abbreviations and Acronyms

A2/AD	anti-access/area denial
AESIP	Army Enterprise Systems Integration Program
AFSB	Afloat Forward Staging Base
AGC	Army Geospatial Center
AMAS	Autonomous Mobility Appliqué System
AMC	Army Materiel Command
ARES	Aerial Reconfigurable Embedded System
ASL	Authorized Stockage List
CAMEX	computer aided map exercise
CASCOM	Combined Arms Support Command
CAST	Convoy Active Safety Technology
CBM	condition-based maintenance
CBM+	condition-based maintenance-plus
CBRNE	chemical, biological, radiological, nuclear, and explosives
DARPA	Defense Advanced Research Projects Agency
DE	directed energy
DLR	depot level reparable
DoD	Department of Defense
ELCAS-M	elevated causeway system-modular
ERP	enterprise resource planning
ESC	Expeditionary Support Command
FIB	fires brigade
GCSS-Army	Global Combat Support System-Army
GPH	gallons per hour
HBCT	heavy brigade combat team
HEL-MD	High Energy Laser Mobile Demonstrator
ICAAPS	Intelligent Collaborative Aging Aircraft Spare Parts Support project
INLS	Improves Navy Lighterage System
ISPDS	Integrated Soldier Power and Data System
IT	information technology
ITEP	Improved Turbine Engine Program
JHSV	Joint High Speed Vessel
JLOTS	Joint Logistics Over-the-Shore
JOEI	Joint Operational Energy Initiative
JPADS	Joint Precision Airdrop System

LCAC	Landing Craft Air Cushion
LCM	Landing Craft, Mechanized
LCMS	Lightweight Modular Causeway System
LCU	Landing Craft, Utility
LMP	Logistics Modernization Program
LMSR	Large, Medium-speed, Roll-on/Roll-off Ship
LOC	line of communication
LOTS	logistics over-the-shore
MASMC	Mobile Aircraft Sustainment Maintenance Capability
MBF	mission-based forecasting
MLP	Mobile Landing Platform
mpg	miles per gallon
MRE	meal-ready-to-eat
MSV	Maneuver Support Vessel
NDU	National Defense University
NRC	National Research Council
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OR	operations research
ORSA	operations research/systems analysts
PV	photovoltaic
R&D	research and development
RBS	readiness-based sparing
RCM	reliability-centered maintenance
RFID	radio frequency identification
ROWPU	reverse osmosis water purification unit
S&T	science and technology
SARTRE	Safe Road Trains for the Environment
SMR	small modular reactor
SMSS	Squad Mission Support System
SOCOM	Special Operations Command
SOF	special operations forces
SOFC	solid oxide fuel cell
SRL	sustainment readiness level
SSA	Supply Support Activity
SSC	Ship-to-Shore Connector
T&E	test and evaluation
TARDEC	U.S. Army Tank Automotive Research, Development and Engineering Center
TOC	theory of constraints
TRAC	U.S. Army Training and Doctrine Command Analysis Center
TRADOC	U.S. Army Training and Doctrine Command
TRANSCOM	U.S. Transportation Command
TRL	technology readiness level

Summary

MILITARY LOGISTICS

The mission of the United States Army is "to fight and win our nation's wars by providing prompt, sustained land dominance across the full range of military operations and spectrum of conflict in support of combatant commanders."[1] Accomplishing this mission rests on the ability of the Army to equip and move its forces to the battle and sustain them while they are engaged. This is Army logistics.

Technology has enabled military forces to become far more effective and lethal than they ever were in the past, but these improvements have come at a cost. Much of the equipment is heavier and more complex and requires more support than similar systems in the past. The pace of battle has dramatically accelerated, and deployment times for the engaged forces have been reduced. The U.S. military must be prepared to fight anywhere on the globe and, in an era of coalition warfare, to logistically support its allies. While aircraft can move large amounts of supplies, the vast majority must be carried on ocean-going vessels and unloaded at ports that may be at a great distance from the battlefield. As the wars in Afghanistan and Iraq have shown, the costs of convoying vast quantities of supplies is tallied not only in economic terms but also in terms of lives lost in the movement of the materiel. As the ability of potential enemies to interdict movement to the battlefield and interdict movements in the battlespace increases, the challenge of logistics grows even larger.

For the past 13 years, the Army has been engaged in a hybrid warfare scenario. In Iraq, the conflict began with near-conventional warfare, moved to fierce fighting in an urban environment, and then engaged in efforts to provide stability to a nation in turmoil. In Afghanistan, conventional conflict was mostly bypassed as entering forces began warfare in urban environments and then took on stability operations. In both cases, logistics began with support of frontline military operations and transitioned over time to a logistics structure that closely paralleled, in many respects, the massive system that existed to support U.S. forces in Europe during the Cold War and coalition forces during the war in Vietnam. A significant part of U.S. and coalition forces was committed to supporting logistics and those who were providing logistics.

The wars in Afghanistan and Iraq have been unlike those that occurred under more conventional circumstances. While the initial phase of Operation Iraqi Freedom was more conventional (i.e., units in formations engaging other military units over several weeks), the remainder of the war became a mix of asymmetrical unconventional war and short periods of conventional urban warfare. The war in Afghanistan has been unconventional since its beginning and provided few opportunities for formations to engage in combat of the kind that has occurred in the past. Over time, the sustainment for U.S. forces fighting these exceptionally long wars came to reflect the logistics support conditions, and their support bases were structured much like those, found in the United States or a partner country outside combat zones. In both cases, the lines of supply, both air and land, were extensive and involved heavy support from contractor personnel.

U.S. forces were used in roles they were not equipped or trained for in both Operation Enduring Freedom and Operation Iraqi Freedom (e.g., artillery and other units were carrying out transportation security missions), and the nature of the operations over time involved individual battles, each battle having a different supply character. It is difficult to develop insight into what future logistics burdens

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[1] U.S. Army mission information available at http://cloud.cio.gov/profile/us-army, accessed August 28, 2014.

might be based on what has occurred over the past 13 years. It is clear that there was a continuous, heavy logistics burden on the system in both Iraq and Afghanistan, but whether the demands from these wars will be seen again in future wars in other geographic locations is hard to say.

As a result, in 2008 the Combined Arms Support Command conducted a Computer Assisted Map Experiment (CAMEX 2008) using a scenario developed for the purpose of testing future operational and sustainment concepts and equipment (CASCOM, 2008). CAMEX 2008 represented the Combined Arms Support Command's assessment of the operational challenges of routine sustainment for the force in 2016 and identified daily resupply needs for a heavy brigade combat team (HBCT) and a fires brigade (FIB). The distribution lines of communications in CAMEX 2008 ran from the aerial port of debarkation to the brigade support area and then to the forward support company in the HBCT and FIB. Of the projected major requirements for the combination of the HBCT and FIB, 90 percent of the demand by tonnage was for fuel, ammunition, and water. Although repair parts and batteries were of great importance for operational assurance, they constituted less than 0.1 percent of the demand. These data are presented for illustrative purposes in Table S-1. Any variations from the conditions set out in the planning scenario used in CAMEX 2008 would result in different data. For instance, since CAMEX 2008, the HBCT has been reorganized to include an additional maneuver battalion. This will affect the sustainment requirements. The committee does not believe, however, that the fact that fuel, water, and ammunition dominate the logistics demands would change.

As the Army moves into the next decades, it will likely be dealing with conflicts different from those it has fought since 9/11 and those considered in CAMEX. Both the Marine Corps and the Army now speak in terms of expeditionary missions and expeditionary forces. Getting to the battle site as

TABLE S-1 Daily Resupply Requirements for a FIB and HBCT from CAMEX 2008 (tons)

Supply Class	Description	FIB	HBCT	Subtotal
Class I	Rations	12.08	23.20	35.28
Class II	Clothing and textile	2.36	4.53	6.88
Class III	Package petroleum	1.11	2.14	3.25
Class III	Fuel	121.61	338.24	459.85
Class IV	Barrier materials	3.33	6.40	9.72
Class IV	Construction materials	2.84	5.45	8.29
Class V	Ammunition	175.93	45.24	221.18
Class VI	Personal demand	0.51	0.98	1.48
Class VII	End items	6.22	11.95	18.17
Class VIII	Medical supplies	0.21	0.41	0.62
Class IX	Repair parts/batteries	3.22	6.18	9.40
Ice		6.35	12.20	18.55
Mail		1.66	3.20	4.86
Water		126.72	243.38	370.10
Total		464.15	703.47	1,167.63
Delivered by GLOC, class IIIB, class I (water) and ice		254.68	593.81	848.49
Delivered by air		209.47	109.66	319.13

NOTE: CAMEX, Computer Assisted Map Experiment; FIB, fires brigade; GLOC, ground lines of communication; HBCT, heavy brigade combat team.
SOURCE: CASCOM (2008).

quickly as possible and concluding whatever mission is assigned to the Army as fast as possible is paramount. This new approach is made all the more difficult by the global nature of the conflicts and potential conflicts that have emerged. The distances involved in Pacific operations are extraordinary and will stress every facet of logistics for all services. At the same time, force structure and resources are being reduced, and there is little certainty as to how far the tightening and resource reductions will go. It is a matter of having to do more with less. But no matter how the nature of battle develops, logistics will remain a key factor.

EXAMINING ARMY LOGISTICS

This report responds to a request from the U.S. Army G-4, Logistics, which asked the National Research Council (NRC) to explore Army logistics in a global, complex environment that includes the increasing use of anti-access and area-denial tactics and technologies by potential adversaries. The NRC was asked to describe new technologies and systems that would reduce the demand for logistics—the tonnages referred to above—and meet the demand at the point of need, make maintenance more efficient, improve inter- and intratheater mobility, and improve near-real-time, in-transit visibility. The NRC was also asked to explore options for the Army to operate with the other Services and improve its support of Special Operations Forces (SOF). Finally, the NRC was to provide a logistics-centric research and development (R&D) investment strategy and illustrative examples of how improved logistics could look in the future. In response to this request, the NRC Board on Army Science and Technology established the Committee on Force Multiplying Technologies for Logistics Support to Military Operations.

The committee examined the technologies, the organizational efficiencies, and adjustments in human capital that potentially would have the most impact on logistics operations. It met with members of the R&D community and civilian and military operational and logistics practitioners from the Services, joint organizations, and industry.

ENHANCING ARMY LOGISTICS

The Army is moving into a new, more austere and more joint environment and must develop its equipment and prepare its personnel, force structure, decision making, and concepts of operation for a more expeditionary approach, one with a reduced logistics footprint. Unfortunately, there is no single solution to the logistics challenge. Reducing the footprint will require efforts in every area in which the Army is engaged, and success will result from full engagement with this challenge across the Army, not just in the logistics community.

This engagement will begin efforts to reduce the bulk and weight of Army logistics (e.g., ammunition, fuel, and water). It will seek methods to increase the reliability and reduce the maintenance requirements of equipment in the hands of our soldiers. It will require more efficient management approaches and permit those in the field to be part of logistics processes. It will seek to let soldiers in the field know where their supplies and repair parts are in the pipeline. It will address the need to link operational requirements for new systems with the logistics loads they create and the life-cycle costs they must pay. Recognizing that every new burden added to the system adds force structure and the requirement for logistics to support that structure, it will consider the personnel and system risks that develop from such actions.

The committee provides recommendations on areas in which burden-reducing R&D efforts should be focused, identifies areas in which logistics efficiencies could be obtained, and reviews the status of the Army's role within the joint logistics effort. Although Table S-2 lists items related to reducing the burden, other science and technology (S&T) or R&D work may be needed to address areas like decision support, cultural changes, etc.

TABLE S-2 Road Map and Areas to Focus Logistics S&T and R&D Efforts

Technology Development Area	Research Area	Logistics Area	Goal
High Priority—High Return and Recognized Feasibility			
Adaptive Engine Technology Development	Accelerate the Improved Turbine Engine Program	Fuel and Power	Reduce fuel requirements
Alternative engine for the M1 Abrams tank	Investigate alternative engines or techniques to improve efficiency	Fuel and Power	Reduce fuel requirements
Autonomous re-supply convoys	Refine technologies to provide reasonable cost autonomous leader-follower convoy vehicles for non-tactical movement	Mobility	Reduce troop and equipment risk and burden in convoy operations
Small unit water supply	Accelerate R&D and fielding of platoon and squad water sets	Water	Provide point of need water supply
Micro-grids and smart-grids	Accelerate R&D and fielding	Fuel and Power	Maximize energy efficiency
Low Ammo Demand Weapon System	Accelerate R&D and fielding of High Energy Laser–Mobile Demonstrator (HEL-MD).	Ammunition	Reduce Ammunition Demand
Unmanned aircraft and precision parachute resupply	Refine technologies to support cost efficient aerial supply operations	Mobility	Remove dependency on ground vehicles in critical areas
Improved sea mobility	Complete and deploy Maneuver Support Vessel (MSV)-Light; develop MSV-Medium and Heavy concurrently	Mobility	Improve sea-borne Army logistics support
High Priority—High Return, but Requires R&D or Feasibility of Immediate Use in Question			
Water from Diesel Exhaust	Explore technologies to obtain potable or non-potable water from diesel exhaust with small impact to weight, power, and cost of systems incorporating the technology; taste is a major barrier to acceptance	Water	Develop alternative water sources
Additive manufacturing	Monitor industry; continue Army field evaluation	Maintenance	Improve supply of critical items

Radionuclide power sources	Sponsor R&D in the development of small radionuclide power sources	Fuel and Power	Reduce battery weight
Medium Priority—Large Return; Longer Time to Fielding			
Hybrid technology to power vehicles	Investigate existing commercial hybrid and electric technology	Fuel and Power	Reduce fuel requirements
Base area power generation small modular reactors	Monitor Department of Energy and research for power production	Fuel and Power	Reduce fuel requirements (generators);provide significant base camp power source
Alternative battery types that produce more power and are rechargeable	Investigate lithium-air batteries for application in the Army	Fuel and Power	Reduce battery weight
State of charge indicators to batteries so soldiers do not discard usable batteries because they do not know how much charge remains	Integration of small, rugged, reliable state of charge indicators on batteries soldiers carry	Fuel and Power	Reduce battery weight
Ammunition consumption	Improve ammunition lethality and effectiveness	Ammunition	Increase small caliber ammunition effectiveness
Reduce ammunition weight	Investigate caseless, polymer cased, or case telescoped small-caliber ammunition	Ammunition	Decrease weight of small caliber ammunition
Innovative packing to reduce volume and weight	Investigate replacing conventional packing materials	Ammunition	Ammunition packaging
Shipboard desalination	Investigate converting existing tanker for providing desalination of seawater to produce bulk potable water	Water	Develop alternative water sources
On-board auxiliary power units (APUs) to produce electricity	Determine if fuel cell based systems are technically feasible to operate as APUs	Fuel and Power	Reduce fuel requirements

KEY FINDINGS AND RECOMMENDATIONS

The committee's overall priorities are set out in the Key Recommendations, which represent the committee's identification of the actions that it believes need to be taken to reduce the logistics burden and improve the efficiency of Army logistics. The first Key Recommendation carries the highest priority. The subsequent Key Recommendations follow the structure of the report and are essentially equally important. They address technologies, operating procedures to include resourcing, decision-making, education, joint and special operations support. If there is going to be substantive improvement in the logistics system the Army relies on for its sustainment, all of the Key Findings accompanying these recommendations must be recognized and all of the Key Recommendations addressed. They are substantively intertwined.

Key Findings and Recommendations either rest on one or more underlying findings and recommendations in the report body or represent a finding and recommendation drawn from the substance of the report or a section as a whole. Where the former is the case, the pertinent findings and recommendations are noted in brackets.

The committee's priorities for R&D investments are given in Tables S-2 and 9-1 and represent the professional judgment of the committee in assessing the technologies behind the technology-based recommendations in the report. High-priority investment areas represent a coalescence of a promise of a substantial reduction in logistics burden and/or a reduction in resource demands and a committee judgment that the programs are achievable within the next decade or sooner and meet an immediate operational need identified by the Army. However, these priorities are closely tied to the force structure the Army chooses or is directed to implement.

General

Key Finding 1. Logistics activities within the Army do not receive the attention necessary to ensure the effective sustainment of operational forces on the battlefield over the long term. This is because, unlike things that directly affect combat effectiveness, it is difficult to understand the ultimate impact of logistics activities on Army capability. In R&D, analyses, exercises, and planning, logistics challenges are often minimized or postponed to be addressed another day. As a result, when systems are developed or plans are executed, the logistics enterprise is placed in a catch-up position, significantly reducing its ability to support the ongoing operations. Capability requirements, along with off-the-shelf solutions that create logistics burdens, are outpacing the development and fielding of burden-reducing logistics and logistics-related technologies.

Key Recommendation 1. Senior Army leadership should ensure that adequate resources and priorities are given to logistics activities across the spectrum of Army activities, including research and development, analytical support, force structure, military education, and operational planning.

Water

Key Finding 2. As a matter of doctrine, bottled water is used in the initial stages of operations until the bulk purification, storage, and distribution of water can be established. The use of bottled water weighs heavily on the logistics systems, puts soldiers and civilians at risk to deliver it, and generates a significant waste burden. Because of the availability of contractor-provided bottled water in Iraq and Afghanistan, earlier peacekeeping missions, and humanitarian assistance and disaster relief missions, the Army reduced its organic active force capability to provide water at the point of need and is now heavily reliant on the use of bottled water.

Key Recommendation 2. The Army should rely on its existing water technologies, and adopt or develop appropriate additional technologies, to satisfy water demand at the point of need and limit the use of bottled water except where the situation dictates its use e.g. for humanitarian assistance and disaster relief operations.

Fuel and Energy

Key Finding 3. Emerging technologies such as the improved turbine engine program and high-efficiency drive systems would provide significant reductions in fuel demand for aircraft, the M1 Abrams, and the M2 Bradley and increases in system efficiencies. Selective use of hybrid and electric vehicles in rear areas would reduce fuel demands. Use of high-efficiency auxiliary power units could not only reduce fuel demands but could also enable use of electric systems in vehicle design. Advancements in fuel cell design, micro- and smart-grid employment, and battery efficiency would similarly reduce the demand for fuel. Use of small modular nuclear reactors in rear areas could provide large-scale power sources. [This is based on Findings 3-12, 3-14, 3-15, 3-16, 3-17, 3-19, and 3-22.]

Key Recommendation 3. The Army should strongly support continued development and fielding of a portfolio of promising technologies to reduce fuel and energy demand, including acceleration of the improved turbine engine program and more fuel-efficient engines for the M1 Abrams and the M2 Bradley or their replacements, recognizing that it will take success in several areas to reduce the overall demand. [This is based on Recommendations 3-12 and 3-14.]

Ammunition

Key Finding 4. Precision munitions potentially offer significant reductions in required munition expenditures and qualitative improvements in effectiveness, thereby reducing ammunition demand and its logistics burden. The additional costs of precision munitions must be weighed against the total costs of employing nonprecision munitions in the aggregate, from the ammunition plant to the target. Similarly, initial tests of directed energy weapons have indicated both their effectiveness and the reduction in logistics support required for their employment. [This is based on Findings 3-25 and 3-27.]

Key Recommendation 4. The Army should adopt the use of precision munitions as widely as practical within mission requirements, and should use directed-energy weapons systems if ongoing tests are successful. [This is based on Recommendations 3-21 and 3-23.]

Key Finding 5. The planning of Army production, transportation, maintenance, storage, and expenditure of ammunition are carried out as relatively independent activities that have successfully supported military operations and has improved the efficiency of several elements of the ammunition supply chain. However, there is no indication that the Army is taking advantage of usage data from the past 25 years, experience from changes in weapons technology over past decades, or future opportunities that may exist to lessen the ammunition burden. There has been no significant effort to examine ammunition as a system or which ammunition mixes will provide the optimum combination of fires effectiveness and logistics burden minimization. The recent "Improve/Lean & Control Phases (Combined) Gate Review" by the Program Executive Office Ammunition could provide the baseline for the development of the optimum mix of weapons system effectiveness and logistics burden reduction.[2]

[2] Improve/Lean & Control Phases (Combined) Gate Review, September 12, 2012. Provided by Chris J. Grassano, Deputy Program Executive Officer Ammunition to Leon Salomon, committee member, by e-mail on May 16, 2014.

Key Recommendation 5. As one of the largest logistics burdens faced by the Army, it is imperative that the Army maintain cognizance over all aspects of the ammunition supply chain and identify steps that could be taken to ensure the effectiveness of the support provided to combat units and the potential for reductions in the ammunition tonnages that needs to be moved in battle situations. The Army should conduct a comprehensive analysis of the ammunition system with a view toward linking analysis of battlefield experience with the operations of the system as a whole.

Soldier Systems

Key Finding 6. Over the past decade, the effectiveness of the individual soldier has been increased by on-person combat support systems. However, at the same time, the weight the soldier must carry has increased. Technologies for effectively meeting power demands for individual soldiers are emerging and offer the potential to reduce soldier load and increase soldier trust in the power reliability of carried systems. [This is based on Findings 3-28, 3-29, 3-30, 3-31, 3-32, 3-34, and 3-35.]

Key Recommendation 6. The portfolio of projects under way to reduce the weight of power supplies for an individual soldier should be given emphasis, and the resulting equipment should be fielded as soon as possible. [This is based on Recommendations 3-25, 3-26, 3-27, 3-29, and 3-30.]

Mobility

Key Finding 7. The Army will be dependent on its organic watercraft capabilities for much of its intratheater transportation in many areas of the world. The age and capabilities of the watercraft currently in the inventory will limit such support. They are slow, have insufficient capacity, are too few in number, are highly sensitive to sea state, and could be impediments to efficient and effective logistics in the Asia-Pacific theater. [This is based on Findings 4-2 and 4-4.]

Key Recommendation 7. The Army should maintain priority support for the acquisition of the Maneuver Support Vessel (MSV) (Light) and concurrent development of the MSV (Medium) and the MSV (Heavy). It should also consider the acquisition of the Ship-to-Shore Connector vessel under the Navy program. [This is based on Recommendations 4-2 and 4-3.]

Key Finding 8. Autonomous vehicle technologies offer a significant opportunity to automate military operations in an effort to improve logistics operations. Unmanned and remote-controlled helicopters and precision air drop systems can significantly reduce the demand for ground-based resupply of forward areas in high-risk or limited-access situations. Resupply operations over the last tactical mile could be efficiently performed by autonomous vehicles to reduce the risks to supply vehicle operators and lighten the load that small units currently must carry. Autonomous vehicles are ready to be deployed in constrained settings with limited obstacles and established routes. They are not yet ready to deploy in operational settings with rough terrain or unpredictable routes. Unmanned and remote-controlled helicopters have been effectively employed by the Marine Corps for resupply in Afghanistan on a test basis, and development continues. [This is based on Findings 4-9, 4-11, 4-12, and 4-13.]

Key Recommendation 8. Autonomous vehicle technologies should be implemented in phases, starting with what is possible now using semiautonomous technologies, such as leader-follower, so that incremental improvements to logistics can be realized as the technology matures. Research and development should be continued to develop these technologies for use in challenging, unpredictable environments that are currently beyond the capabilities of these technologies. The Army should work with the Marine Corps to combine research and development efforts to develop a common autonomous aerial support capability for logistics. The Army should continue to support rapid development and fielding of precision airdrop for sustainment to forward areas and pursue a helicopter-borne Joint Precision Airdrop System capability to expand its overall sustainment options and capabilities. [This is based on Recommendations 4-7, 4-10, and 4-11.]

Additive Manufacturing

Key Finding 9. Additive manufacturing provides an emerging capability to produce components in support of Army logistics system needs at the point of need and to improve the responsiveness of the Army maintenance system. Present additive manufacturing efforts are ongoing across the Army and are close to the state of the art. However, additional development is required to (1) fully realize the benefits of additive manufacturing and (2) make it widely useful forward of fixed facilities, such as depots, given the current heavy power demands and challenges in base material management and standard setting. [This is based on Findings 5-1 and 5-2.]

Key Recommendation 9. The Army should leverage the industry investments in additive manufacturing and support technology areas that map to the Army's specific needs and implementation constraints. The Army should support standards development that would form the basis for qualifying components produced by additive manufacturing. [This is based on Recommendations 5-1 and 5-2.]

Logistics Enterprise Information System

Key Finding 10. The Army Logistics Enterprise System, which includes the Army Enterprise Systems Integration Program Hub, the Global Combat Support System-Army (GCSS-A), and the Logistics Modernization Program (LMP), is a viable approach to support efficient and effective logistics for the Army. The Army has expended considerable resources on implementing what may be the largest enterprise resource planning system ever. The other Services have a mixed record of success in implementing such systems. Successful implementation of the program will require strong and continuous support and an understanding by Army leadership of the challenges and opportunities that the continuously evolving systems will face. In addition to the ever-present technical issues that will develop, there will be a need to develop new decision support tools and applications that can utilize GCSS-A and LMP data and to pay attention to cybersecurity issues as the threats evolve. [This is based on Findings 6-1, 6-2, 6-3, and 6-4.]

Key Recommendation 10. To ensure that the Army Logistics Enterprise Systems is fully implemented and operated efficiently over its life, the Army should provide constant resource and organizational support for the Army Enterprise Systems Integration Program, the Global Combat Support System-Army, and the Logistics Modernization Program, even after full implementation of the initial systems and related tools and applications. Without such support, the overall system will rapidly atrophy. [This is based on Recommendation 6-2.]

Key Finding 11. The U.S. Army logistics network has made considerable progress in improving in-transit visibility to the supply support activity and the unit motor pool. Estimated shipping dates and advanced shipping notices are routinely provided, which has improved availability and readiness. More confidence in the system might be realized by also letting the end user/soldier know about the availability of the item he or she requested from the supply system. The benefit of this would be a reduction in the current practice of placing redundant orders due to a lack of confidence in the supply system.

Key Recommendation 11. Using the capabilities of Global Combat Support System-Army and the Logistics Modernization Program, the Army, in conjunction with industry, should compare the costs and benefits of extending the in-transit visibility to the end user/individual soldier to those of the current systems. [This is based on Recommendation 6-5.]

Logistics Decision Support

Key Finding 12. Modeling and simulation and systems analysis capabilities in support of Army logistics are insufficient to evaluate, compare, and contrast various S&T initiatives and their respective impacts on both the force structure alternatives currently under consideration and the outcomes across the spectrum of operations. (This same condition was identified in the 1999 NRC report *Reducing the Logistics Burden for the Army After Next.* (NRC, 1999)) When systems are being developed, the results of logistics analyses are not quantified in terms of warfighting effects or the impact they might have on the logistics system as a whole (e.g., adding fuel capacity to a vehicle family may result in a need for additional fuel transport vehicles, with the accompanying additions to force structure). As a result, logistics systems and logistics requirements do not fare well when competing with other types of systems or subsystems. Because logistics decisions are complex and often mostly subjective and because they have great impacts on life-cycle cost, investment in decision support systems for logistics could result in significant savings over a system's life cycle. The Army's ability to perform informed logistic studies and analyses has eroded over the past two decades to the point where there is little intrinsic capability left to conduct these analyses. [This is based on Findings 6-15, 6-16, 6-17, 6-18, and 6-19.]

Key Recommendation 12. The Army should revitalize its logistics analysis capability by acquiring the necessary tools and qualified military and civilian analysts in quantities commensurate with the number and impact of logistics decisions that need to be made. Modeling, simulation, and analysis tools need to be improved to explicitly include logistics factors. [This is based on Recommendations 6-14 and 6-16.]

Use of Contractors and the Army Reserve

Key Finding 13. Contractors and the Army Reserve represent important elements of the Army and joint logistics team and, given the reductions in active military force structure, must be considered an essential component in the planning and execution of operations. They possess unique knowledge of the functions they may be called on to carry out and, in the case of contractors, on-the-ground experience in potential areas of operations. At present, they are excluded from participation in contingency planning until contracted or invited to do so. [This is based on Findings 7-1, 7-2, and 7-4.]

Key Recommendation 13. Both Army and combatant command leaders should integrate contractors and the Army Reserve into their contingency planning process from the beginning and on a continuous basis. Planners in both the Army and combatant commands should be schooled in the capabilities of contractor organizations and the Army Reserve to assist in contingency planning. For contractors, this may require establishing ongoing contracts for the support of specific combatant commands or regions so they can engage in planning processes within the combatant commands. [This is based on Recommendations 7-1, 7-2, and 7-4.]

Key Finding 14. Guidelines for support of military operations over time by contractors are frequently formulated on the fly as operations evolve. This results in inconsistencies in the provision of services, competition among units and services, and a lack of attention to both potential support costs and the logistical burdens that are created. The necessity for these guidelines prior to the start of operations was a lesson learned in Vietnam. [This is based on Finding 7-3.]

Key Recommendation 14. Army leadership, in coordination with its sister Services, the Joint Staff, and combatant commanders, should establish guidelines for the support to be provided for contingency operations over time as the mission and needs develop. [This is based on Recommendation 7-3.]

Joint Logistics

Key Finding 15. Given the resource constraints that face today's armed forces and the necessity to develop an effective joint fighting force, jointness in logistics is an imperative. The committee recognizes that transformation takes time and that moving to joint logistics represents a significant change in culture. However, it has been over a decade since the military community began serious discussions of joint logistics and nearly 5 years since the Joint Staff articulated a vision for integrated logistics, and signs of progress are limited. The committee, during its review and its interviews with senior logistics personnel, both retired and active, could not find strong evidence that the Army and the joint community were actively involved in implementing a joint logistics effort. There remains a strong belief among the leadership of the Services that their Title X responsibilities trump the authorities of the Secretary of Defense and the combatant commanders to require the conduct of joint logistics operations. There was clear articulation that, absent directives from the Secretary of Defense, the services will not move rapidly to embrace joint logistics activities or aspects of joint operational activities. It is this committee's opinion that the trump card for jointness should be held by the combatant commander since the execution of the strategy is the combatant commander's responsibility.

Key Recommendation 15. Wherever possible and appropriate, the Army should strongly support and become a part of joint logistics and related research and development activities. As a starting point, the Army should review the status of implementation of Appendix B of the *Joint Concept*, *Key Indicators of the Military Problem*, along with the operational issues described in 2011 by the G-4 of the Army.

Logistics Support of Special Operations

Key Finding 16. Based on lessons learned from Operation Iraqi Freedom and Operation Enduring Freedom, the Army's new thrust to become more expeditionary, and the additional focus on geopolitical areas beyond the Middle East, an extraordinary opportunity has arisen for the Army and Special Operations Command to jointly revisit and redefine their working relationships in the areas of logistics and sustainment for their mutual benefit. [This is based on Findings 8-1 and 8-3.]

Key Recommendation 16. The Army G-4 should initiate discussions with Special Operations Command (SOCOM) to revisit existing logistics and sustainment support policies, agreements, and capabilities (including linked databases) with the stated objective of revising them for their mutual benefit. In parallel, the Army G-4, working in conjunction with the individual geographic combatant commands and SOCOM, should determine the feasibility and acceptability of designating each Theater Army as the primary logistics and sustainment support organization for special operations forces in each geographic combatant command's area of responsibility. [This is based on Recommendations 8-1, 8-3, and 8-4.]

Taking Advantage of Technology Innovation

Key Finding 17. Joint, interagency, intergovernmental, multinational, nongovernmental, and commercial organizations remain heavily involved in material development and technology innovation in areas directly relevant to Army logistics operations and sustainment goals. (1) Continuous monitoring of these efforts outside the Army and (2) collaborative efforts with other organizations offer opportunities for reductions in military expenditures for needed technologies and the early acquisition of systems that have been proven in the private sector. [This is based on Finding 8-4.]

Key Recommendation 17. In carrying out its material development programs, the Army should continue and, where appropriate, increase close collaboration with joint, interagency, intergovernmental, multinational, nongovernmental, and commercial organizations in science and technology areas where these organizations are pursuing programs similar to those required by the Army. The Army should avoid duplication of efforts underway in other sectors wherever possible. [This is based on Recommendation 8-5.]

Logistics Science and Technology and R&D Strategy

Key Finding 18. There is no explicit strategy for Army investment in logistics and related goals, such as a 25 percent reduction in fuel consumption for a given system. Such a strategy is needed to guide efforts to reduce logistics requirements and to guide the non-logistics material development efforts that increase the logistics burden of the Army in the field. Without such a strategy and goals, the Army G-4 and the Army sustainment community are unable to effectively influence critical decisions in S&T and R&D. In addition, there is no explicit effort by the Army logistics community to closely monitor the S&T and R&D activities of the other elements of the Department of Defense or the defense industry to capitalize on S&T and R&D successes in those organizations and to integrate their new capabilities into consideration of a future joint logistics environment. [This is based on Findings 9-1 and 9-2.]

Key Recommendation 18. The Army, through the G-4 and with the support of the Combined Arms Support Command, should develop, staff, publish, and annually update an Army Logistics Science and Technology (S&T) and Research and Development (R&D) Strategy that clearly defines the long-range objectives for Army logistics, the programs that influence the attainment of these objectives, and the actions that will be taken to ensure the close integration of Army logistics enhancement activities with those of the joint and Department of Defense community and related industry. The Army Logistics S&T and R&D Strategy should include specific burden reduction goals, such as a 25 percent reduction in fuel consumption for a given system. Development of the Army Logistics S&T and R&D Strategy should be followed by development within the entire R&D community of a roadmap specifying the responsibilities and actions that need to be taken to ensure accomplishment of the objectives of the strategy. [This is based on Recommendations 9-1 and 9-2.]

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CASCOM (Combined Arms Support Command). 2008. Air-Ground Distribution Computer Assisted Map Exercise (CAMEX) Experiment Report. Fort Lee, Va.: U.S. Army Combined Arms Support Command.

NRC (National Research Council). 1999. Reducing the Logistics Burden for the Army After Next: Doing More with Less. Washington, D.C.: National Academy Press.

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Introduction

LOGISTICS AS A KEY BATTLEFIELD ELEMENT

> Continuing to regard logistics as the secondary "tail" to warfighter doctrine, training and armament will have unacceptable consequences in the 21st century battlespace resulting in decreased ability to achieve national security objectives and cost (DSB, 1998a).

History

The mission of the U.S. Army is "to fight and win our nation's wars by providing prompt, sustained land dominance across the full range of military operations and spectrum of conflict in support of combatant commanders."[1] Accomplishing this mission rests on the ability of the Army to move its forces to the battle and sustain them while they are engaged. This is Army logistics.

At the end of the Second World War, the director of the Service, Supply, and Procurement Division of the War Department General Staff, after conducting logistics operations in that war, reported, "Wars cannot be won without logistics superiority. . . . Military effectiveness must govern, but logistics supportability is the first prerequisite" (CMH, 1993, p. 252). The director's words echoed those of military commanders as far back as Alexander the Great and leaders who followed Alexander in the execution of warfare up through the present.

Typically, as wars end and the size of the armed forces is reduced, great emphasis is placed on increasing the tooth to tail ratio—that is, the number of personnel and resources involved in direct combat operations relative to that of those carrying out support functions. This is done under the assumption that improvements in technology can reduce the amount of support required and that logistics missions can be shifted from the active Army to reserve components or contractor organizations and called on to respond when they are needed. The post-Second World War report cited above pointed out, however, that "the logistic organization with which we will fight must be in being and capable of immediate expansion" (CMH, 1993, p. 252).

Technology has enabled military forces to become far more effective and lethal than ever, but these improvements have come at a cost. The price paid for this increased effectiveness and lethality is that much of the equipment is heavier and more complex than its predecessors and requires more support than the systems they replace. The pace of battle has dramatically accelerated and deployment times for the engaged forces have been reduced. The U.S. military must be prepared to fight anywhere on the globe and, in an era of coalition warfare, to frequently logistically support its allies. While aircraft can move large amounts of supplies, the vast majority must be carried on ocean-going vessels and unloaded at ports that may be at a great distance from the battlefield. As the wars in Afghanistan and Iraq have shown, the costs of convoying vast quantities of supplies is tallied not only in economic terms but also in terms of lives lost in the movement of the materiel.

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[1] U.S. Army mission information available at Cloud.cio.gov, "U.S. Army," http://cloud.cio.gov/profile/us-army, accessed August 28, 2014.

There is also a significant history of soldier distrust in the logistics system. This manifests in the placing of multiple orders for the same item to ensure it is received, over-ordering of supplies to make sure something is on hand if needed, and the accumulation of "iron mountains" prior to the commencement of operations. Whether at the field Army level or the squad level, battlefield commanders do not want to commit forces unless they are convinced the resources required are available at the start of the battle and that they will be resupplied as needed during the course of the engagement. There must be absolute trust in the logistics system. Supplies and support must be there when they are needed.

Warfare Today

The 1990-1991 war in the Middle East (Operation Desert Storm) was conducted within a limited time and under circumstances that permitted the U.S. forces to build up their logistics base prior commencing operations against the enemy. The air portion of the war lasted for 5 weeks and the ground portion for 100 hours. Upon the conclusion of the operation, U.S. forces returned to their stations in Europe, the United States, and other locations, and much of the materiel taken to the theater was retrograded the United States or Europe. The entire operation was essentially completed in 10 months. Because logistics facilities were relatively close to the battlefield, and friendly forces controlled the areas around supply routes, the logistics challenge, while difficult, was effectively managed.

U.S. support of peacekeeping operations in Bosnia-Herzegovina required the deployment of U.S. forces from Europe and the United States and initially logistics support by military elements. As it became obvious that the forces would remain in position for an extended period, contractors were brought on board to replace the military logistics providers and to provide the basic logistics functions for the peacekeeping elements under a program known as the Logistics Civil Augmentation Program. Both the mission in Bosnia-Herzegovina and its Logistics Civil Augmentation Program support continue to this day.

Since 2001, the United States has been engaged in warfare in the Middle East and Southwest Asia that has shifted the operational focus from quickly winning a battle to initially defeating a hostile enemy and then restoring peace to two nations caught in the middle of sectarian and ethnic violence. The initial combat operations during Operation Iraqi Freedom were followed by over 7 years of small and large military operations that sought to bring peace to the diverse population of Iraq. The longer U.S. forces remained in the country, the larger the logistics footprint became as demands increased and expeditionary base camps were expanded to approach the size of installations in the United States. Accordingly, logistics resupply convoys became targets for the enemy. Although in the early days of operations in Afghanistan the logistics footprint was relatively small, when troop levels were increased beginning in 2009, the logistics situation in Afghanistan began to parallel the situation that had developed in Iraq. Unfortunately, because of the distances involved in the ever-changing relationship with Pakistan, ground supply lines were and remain very hazardous. It became apparent that the greater the amount of materiel that had to be delivered to the front, the more people would be wounded or killed doing so. Reducing logistics demand became imperative as a way to save lives. During the operations in both countries, logistics was provided by a combination of military forces and support from contractors, with larger bases being operated by contractor elements. At one point there were 160,000 contractors providing logistics support in Iraq and Afghanistan (U.S. Army, 2007).

During Desert Storm, Operation Iraqi Freedom, Operation Enduring Freedom, and the numerous smaller combat and humanitarian military operations that have taken place in recent history, contractors have provided high-level technical logistical support for some weapons systems, replacing military elements that in the past would have provided the support. The nation's reserve components have also been called up to provide essential support in selected mission areas.

Future Logistics

With the end of Operation Enduring Freedom and Operation Iraqi Freedom, the nation has begun to define what its military posture will be in the future. According to the Department of Defense (DoD) 2014 Quadrennial Review, as the nation moves through the immediate future,

> The U.S. Armed Forces will be capable of simultaneously defending the homeland; conducting sustained, distributed counterterrorist operations; and in multiple regions, deterring aggression and assuring allies through forward presence and engagement. If deterrence fails at any given time, U.S. forces will be capable of defeating a regional adversary in a large-scale multi-phased campaign, and denying the objectives of—or imposing unacceptable costs on—a second aggressor in another region. (DoD, 2014, p. VI)

The review also directs a rebalancing of U.S. forces to the Asia-Pacific region in order to preserve peace and regional stability. Such a rebalancing significantly increases the distances involved in deploying and sustaining Army forces that might be required to operate in that region, introducing significant challenges into the logistics picture.[2]

In carrying out its operations, the U.S. military must project and sustain military presence despite an increasingly capable adversary who will employ weapons or other technologies that can be used to deny access to, or freedom of action within, an operational area. Emerging trends in the operating environment and enemy adoption of anti-access and area-denial strategies pose challenges to ensuring access. This challenge has already been under consideration for a while. The 2010 Quadrennial Defense Review stated that U.S. forces must be able to project power into regions with anti-access challenges in order to "deter, defend against, and defeat aggression by potentially hostile nation states" (DoD, 2010, p. 31). Anti-access refers to actions and capabilities, usually employed at long range, that are designed to prevent access to an operational area. Area denial refers to actions and capabilities, usually employed at shorter range, that are meant not to prevent access to an operational area, but rather to limit freedom of action within such an area. In the *Joint Operational Access Concept*, the Chairman of the Joint Chiefs of Staff proposes a concept for how Joint forces will be employed to achieve operational access in the face of armed opposition (DoD, 2012a). This document defines operational access as "the ability to project military force into an operational area with sufficient freedom of action to accomplish the mission" (DoD, 2012a, p. i). The basic premise of the *Joint Operational Access Concept* is that Joint forces will leverage cross-domain synergy to provide freedom of action and a greater degree of integration, in particular at lower echelons, in order to exploit fleeting opportunities for disrupting the enemy (DoD, 2012a).[3]

This vision of future military posture and the challenges facing future military operations is being articulated and grappled with at a time of deep cuts in defense spending, with the Army being hit especially hard. As troops are withdrawn from Afghanistan, the Army is resetting its structure to deal with future missions and a probable significant reduction in force size. Yet, the Army must be prepared to engage in a wide range of future conflicts, ranging from contingency operations against proxy groups engaging in asymmetric warfare to a conflict against a peer state that possesses weapons of mass destruction and/or technologically advanced anti-access and area-denial capabilities. The new Army operational concept envisions conducting expeditionary operations by initially deploying multiple small

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[2] According to the Defense Strategic Guidance 2012, *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense,* "U.S. economic and security interests are inextricably linked to developments in the arc extending from the Western Pacific and East Asia into the Indian Ocean region and South Asia, creating a mix of evolving challenges and opportunities" (DoD, 2012b). The U.S. military will continue contributions to rebalance to the Asia-Pacific region to preserve peace and stability, which will include maintaining a robust footprint in Northeast Asia, enhancing a presence in Southeast Asia, investing in long-term strategic partnership, and expanding coordination with emerging partners throughout the region.

[3] Cross-domain synergy is defined as "the complementary vice merely additive employment of capabilities across domains in time and space" (JCS, 2012, p. 7).

Army combat units to dispersed locations and having them conduct interdependent operations to facilitate the arrival of follow-on forces. The Army must also be in a position to support Special Operations Forces (SOF) operating in the same areas as Army forces, to function in an environment of increasingly Joint operations with its sister Services, and to operate effectively with international coalition partners. Moreover, the Army must be prepared to support this broad range of possibilities logistically. In an effort to ensure that the Army is able to provide the combat forces that will be required, the size of the logistics force is under scrutiny at the same time as the demand for highly responsive logistics support is increasing.

This study is focused in on determining what emerging technologies and operational capabilities might enable the U.S. Army, operating as part of a multiservice or coalition armed force and tasked to provide support to others, to reduce its logistics demands and logistics force structure.

PREVIOUS STUDIES OF LOGISTICS

Military logistics is a well-studied subject. After each conflict, after-action reports are developed, submitted to the appropriate authorities, and considered in actions that are planned, and sometimes carried out, to restructure forces to deal with future conflicts. The post-Second World War review of logistics identified actions that needed to be taken to improve the efficiency of the logistics effort. Some of these actions were accomplished. Many were not and had to be resurrected at the start of the Korean War. Lessons from the Korean War provided the basis for initial logistics operations during the Vietnam War, but because of the length of the Vietnam War, combat logistic s were replaced by base-focused logistics structures and sustainment demands that reflected a standard of living that soldiers would expect on and around bases outside the theater of operations. By the end of the war in Vietnam, a significant part of the effort involved operations and security of the bases that had been established. Many lessons were later learned in Desert Storm and the buildup to it, Desert Shield, and transmitted to those who were structuring the Army of the future. A constant emphasis in all of the logistics reports resulting from these experiences was the need for increased efficiency, asset visibility, and demand reduction—that is, reducing the weight and volume of supplies needed within the theater.

In 1997, the Department of the Army asked the National Research Council (NRC) to conduct a multidisciplinary study of long-term Army science and technology investments that would have the greatest impact on reducing the logistics burden for the future Army, known at that time as the "Army After Next" (NRC, 1999). In its 1999 report, the NRC study committee determined that the logistics burdens of fuel and ammunition would overshadow all other logistics demands and recommended that effort be focused on

> Reducing fuel demand; increasing fuel energy density; improving energy systems and energy management; reducing the weight of vehicles and ammunition; reducing the number of rounds per target; increasing system reliability; lightening soldier systems and increasing soldier effectiveness; and optimizing system designs. (NRC, 1999, p. 2)

The report also recommended that the Army should

> Develop the necessary modeling and simulation tools for conducting logistics trade-off analyses at all levels of design, from small-scale components to fully integrated systems. (NRC, 1999, p. 13)

The committee found that

> Reliability considerations (including reliability, availability, maintainability, and durability) have been routinely sacrificed for other performance characteristics and that to reduce logistics demand reliability must be treated on an equal basis with lethality, survivability, and mobility in the design process. (NRC, 1999, p. 161)

While the 1999 NRC committee was conducting its review, the Defense Science Board conducted a summer study of logistics and services and reported that

> Transformation of the military logistics system is not deterred by knowledge of what to do, not primarily a structural issue, nor is it limited by lack of people, technology or resources. Instead, the most significant barrier to logistics change to meet 21st century needs is the lack of an overall business and information systems architecture focal point—a "champion" in the Arthurian sense. (DSB, 1998b)

STATEMENT OF TASK

The Committee on Force Multiplying Technologies for Logistics Support to Military Operations was formed in November 2013. The committee was tasked with conducting a multidisciplinary study to explore capabilities and technologies that can be used to perform distributed operations and meet sustainment requirements in the Army through 2020 and beyond in support of the Joint Force Commander. It was also to describe systems and operational concepts that will reduce the need for logistics support by exploring technologies that reduce or eliminate the challenges of storing, transporting, maintaining, distributing, or returning sustainment and transforming or reducing waste in forward areas or in mature base camps. The committee was asked to

- Explore options that could enable support to units operating in a global, complex environment in response to emerging anti-access and area-denial security challenges with a focus on the Asia and Pacific as well as support to dispersed special operations units.
- Describe technology and advanced systems solutions that: reduce drivers for logistics requirements, particularly power and energy, maintenance, fuel and water by fundamentally changing the demand characteristics of the force and increasing capabilities that will allow demand to be satisfied at the point of need; improve intra-theater mobility and distribution; improve near real time visibility of logistics information. Identify S&T initiatives to predict and resolve equipment faults and failures to reduce life cycle sustainment costs.
- Describe solutions to logistics challenges that contribute to the integration and execution of Army logistics capabilities that improve responsiveness, agility, flexibility, and precision within a Joint concept of employment, to include optimization of SOF and conventional force interdependence within the areas of strategy, policy and concepts.
- Recommend a logistics-centric R&D investment strategy that includes a framework, specific research objectives and a roadmap to achieve the previously-described objectives.
- Develop 2-3 illustrative examples to support and validate the concepts described in the committee's report; the examples shall provide an operationally-focused assessment of the military value provided through solutions addressed in the concepts.

See Appendix C for the statement of task and the sponsor-provided context that guided the committee's approach to this study.

OVERVIEW OF COMMITTEE ACTIVITIES AND APPROACH

The committee began its activity on November 12, 2013, when it met at the Pentagon with the study sponsor, LTG Raymond V. Mason, Army Deputy Chief of Staff, G4/Logistics. During its first meeting, the committee had the opportunity to meet with G4 staff and representatives of Army and DoD agencies involved in logistics. The committee held two additional data-gathering meetings, which included sessions in Washington, D.C.; Aberdeen, Maryland; Fort Lee, Virginia; and Fort Belvoir, Virginia, as well as several teleconferences with experts afield. A fourth meeting was held in Irvine, California, to deliberate and conduct report drafting activities. A fifth and final meeting was held in May 2014 in Washington, D.C., to continue the writing of the report.

During the conduct of the study the committee met with representatives of the Department of the Army and other defense agencies. Members of the committee also contacted individuals and agencies doing research in their fields of interest. A complete list of individuals and organizations contacted is found in Appendix A. Following is a list of the organizations contacted by the committee.

Army organizations:

- 404th Army Field Support Brigade
- Army Enterprise Systems Integration Program
- Army Materiel Command
- Assistant Secretary of the Army for Acquisition, Logistics, and Technology
- Center for Army Analysis
- Combined Arms Support Command
- Construction Engineering Research Lab, U.S. Army Engineer Research and Development Center
- G-4 staff
- Program Executive Office Ammunition
- Program Executive Office Enterprise Information Systems
- Rapid Equipping Force
- U.S. Army Armament Research, Development and Engineering Center
- U.S. Army Aviation and Missile Research, Development and Engineering Center
- U.S. Army Communications-Electronics Command
- U.S. Army Communications-Electronics Research, Development and Engineering Center
- U.S. Army Engineer Research and Development Center
- U.S. Army Edgewood Chemical Biological Center
- U.S. Army Deputy Chief of Staff G-3-5-7
- U.S. Army Logistics Innovation Agency
- U.S. Army Logistics University
- U.S. Army Maneuver Center of Excellence
- U.S. Army Materiel Command
- U.S. Army Materiel Systems Analysis Activity
- U.S. Army Natick Soldier Research, Development and Engineering Center
- U.S. Army Pacific Command
- U.S. Army Public Health Command
- U.S. Army Research, Development and Engineering Command
- U.S. Army Reserve Command
- U.S. Army Space and Missile Defense Command/Army Forces Strategic Command
- U.S. Army Sustainment Command
- U.S. Army Sustainment Center of Excellence (Watercraft)
- U.S. Army Tank Automotive Research, Development, and Engineering Center
- U.S. Army Training and Doctrine Command Analysis Center – Fort Lee
- U.S. Army Transportation School

Other DoD organizations:

- Assistant Secretary of Defense for Operational Energy Plans and Programs
- Defense Advanced Research Projects Agency, Tactical Technology Office
- Defense Logistics Agency
- Joint Munitions Command
- Joint Munitions and Lethality Life Cycle Command
- National Defense University
- Naval Postgraduate School
- U.S. Marine Corps
- U.S. Special Operations Command
- U.S. Transportation Command

Non-government organizations:

- Advanced Turbine Engine Company, LLC
- Coca Cola
- Draper Labs
- DynCorp International, LLC
- Fluor Corporation
- Liedos, Inc.
- Massachusetts Institute of Technology
- North Carolina State University
- Quantum Research International
- Rensselaer Polytechnic Institute
- SAS Federal

The study effort was guided by the parameters of the tasks defined by the study sponsor. In this regard, the committee focused its efforts on identifying both technology approaches that would assist in reducing battlefield logistics demands and organizational and operational process improvements whose implementation would improve the efficiency and effectiveness of logistics.

In carrying out the study, the committee did not emphasize logistics issues dealing with the individual soldier because the 2013 NRC report *Making the Soldier Decisive on Future Battlefields* (NRC, 2013) had already addressed the individual soldier in depth, nor did the committee review the logistics organization of the DoD and its combatant commands level unless they directly affected Army logistics activities. Moreover, several recent Defense Science Board studies have examined logistics issues at the higher levels. This study focuses on those areas where the committee believes the most progress can be made and only briefly touches on activities that were seen to have marginal potential. While the committee gathered a large amount of information, the report does not discuss all of the programs and initiatives the committee learned about. Rather, it focuses on how the Army can proceed from the current baseline. The committee did not develop a logistics investment strategy as called for in the statement of task. The assumption was that the G-4 had a current strategy that could be used as a basis for the committee to develop one that would include potential new investments. Part way through data gathering the committee learned that such a strategy does not exist. The programs that impact logistics are spread across the Army in many programs, many of which are outside the purview of the G-4. For example, the Assistant Secretary of the Army (Acquisition, Logistics, and Technology) has a 30-year strategic research and development (R&D) plan that includes programs that will impact logistics, and would be an important part of developing a logistics R&D strategy. Developing a credible strategy will require careful coordination with other staff elements and Program Executive Offices that have responsibility for programs that have impact logistics, and for significant analysis of these programs. The committee was not structured to carry out such an analysis and was not given access to information concerning potential force structuring and contingency scenarios or other data with the level of resolution required for such an analysis. To best assist the G-4 in developing a strategy, the committee focused on identifying areas of greatest payoff for the Army and in offering advice as to how such a strategy should be developed (a roadmap, in Tables S-2 and 9-1).

OVERVIEW OF REPORT

The report is organized into three basic parts. The first part, Chapter 2, provides background information on logistics operations; the interface between the Army, the SOF, and the other Services and Joint activities. The second part, Chapters 3-8, describes methods for reducing demand through potential technological and process improvements in logistics operations and support that would enable logistics activities to be more efficient and effective. The report concludes with Chapters 9-11, the third part. Chapter 9 offers a strategy that identifies investments that the committee believes should be made in programs that would improve logistics efficiency or reduce the demand for logistics. In Chapter 10 the committee discusses three scenarios that illustrate what might take place should the committee's recommendations and approaches be accepted, and in Chapter 11 the committee summarizes its findings and recommendations. The committee's general priorities are laid out in two places. The committee's opinions on priorities for R&D investments are given in Tables S-2 and 9-1. The committee's broader priorities are set out in the Key Findings and Recommendations, in the Summary and in Chapter 11.

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2

The Current Logistics Picture

ORGANIZATION AND RESPONSIBILITIES

While the mission of the U.S. Army is "to fight and win our Nation's wars," the organization for carrying out this mission has varied over the 239-year history of the Army.[1] In 1947, following the end of the Second World War, the defense establishment was reorganized: Two cabinet-level departments (War and Navy) became the Department of Defense, headed by a Secretary of Defense who "is the principal assistant to the president in all matters relating to the Department of Defense. Subject to the direction of the President and . . . the National Security Act of 1947. . . [who] has the authority, direction and control over the Department of Defense."[2] The National Security Act of 1947 also established the Departments of the Army, the Air Force, and the Navy, and the Reserve components of the defense establishment. The 1986 Goldwater-Nichols Department of Defense Reorganization Act (Public Law 99-433) standardized many provisions of the earlier acts and provided for uniform statutory authorities for the military departments. The Reserve Officer Personnel Management Act (enacted as Title XVI of Public Law 103-337, the National Defense Authorization Act for Fiscal Year 1995) established the responsibilities of the Reserve components. These laws also established the Joint Chiefs of Staff and the combatant commands,[3] which serve as the operational elements of the department and carry out those missions assigned to them by the Secretary of Defense.

Under Title 10, the Secretaries of the Departments, subject to certain exceptions, shall "assign all forces under their jurisdiction to unified and specified combatant commands. . . " and "subject to the authority, direction, and control of the Secretary of Defense and subject to the authority of commanders of the combatant commands under section 164(c) of [Title 10] "[be] responsible for the administration and support of forces assigned by him to a combatant command."[4] In practical terms, the military departments have responsibilities to organize, train, and equip the forces they assign to the combatant commands, subject, however, to the instructions of the Secretary of Defense and, for certain activities, the combatant commanders.[5]

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[1] U.S. Army mission information available at Cloud.cio.gov, "U.S. Army," http://cloud.cio.gov/profile/us-army, accessed August 28, 2014.

[2] Title 10 USC, Chapter 2, Section 113, paragraph b.

[3] The combatant commands are Africa Command, Central Command, European Command, Northern Command, Pacific Command, Southern Command, Special Operations Command, Strategic Command, and Transportation Command.

[4] Title 10 USC, Chapter 6, Section 165, paragraph b.

[5] Title 10 USC, Chapter 303, Section 3013, paragraph b, indicates that "Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (1) Recruiting. (2) Organizing. (3) Supplying. (4) Equipping (including research and development). (5) Training. (6) Servicing. (7) Mobilizing. (8) Demobilizing. (9) Administering (including the morale and welfare of personnel). (10) Maintaining. (11) The construction, outfitting, and repair of military equipment. (12) The construction, maintenance, and repair of buildings, structures, and utilities and the acquisition of real property and interests in real property necessary to carry out the responsibilities specified in this section."

Title 10 also indicates that, "unless otherwise directed by the President or the Secretary of Defense, the authority, direction, and control of the commander of a combatant command with respect to the commands and forces assigned to that command include the command functions of— (A) giving authoritative direction to subordinate commands and forces necessary to carry out missions assigned to the command, including authoritative direction over all aspects of military operations, joint training, *and logistics* [emphasis added]."[6]

LOGISTICS OPERATIONS AND PLAYERS

Today's battlespace logistics operations are typically carried out in a Joint environment under the direction of the combatant commanders. The services normally provide the support required for their forces assigned to the combatant commanders. The Defense Logistics Agency provides "subsistence, bulk fuel, construction and barrier materiel, and medical material . . . spares and reparables for weapons systems . . . [and] manages a global network of distribution depots that receives, stores, and issues a wide range of commodities owned by the Services, General Services Administration, and DLA"(JCS, 2013, p. I-7). The U.S. Transportation Command provides "air, land, and sea transportation, terminal management, and aerial refueling to support the global deployment, employment, sustainment, and redeployment of US forces" (JCS, 2013, p. I-7). Logistics (supplies and service) support is also provided in the theater of operations through contractor logistics support under authorities of the combatant commanders.

The Army's specific logistics responsibilities include supplying, equipping (including necessary research and development), maintaining, outfitting, and repairing military equipment and ammunition needed by and used by the Army and other U.S. and coalition forces as ordered. The Army Material Command has the mission for the Army to "develop and deliver global readiness solutions to sustain Unified Land Operations, anytime, anywhere."[7] Logistics organizations and contractors, within the Army Materiel Command and as part of tactical formations, carry out the logistics missions. The Combined Arms Support Command (CASCOM) of the Army Training and Doctrine Command is responsible for training, educating, and growing adaptive sustainment professionals and developing and integrating innovative Army and Joint sustainment capabilities, concepts, and doctrine to enable unified land operations.[8]

Logistics in Joint and Combined Operations

In the future, U.S. forces must be prepared to conduct a range of military activities, including combat, security, engagement, and relief and reconstruction operations. These will be conducted across multiple domains, including air, land, sea, space, and cyber. It is anticipated that future operating environments will be characterized by increasing uncertainty, rapid change, extreme complexity, and persistent conflict. The Department of Defense (DoD) must be adaptive and agile to meet the diverse needs of the Joint force commanders at the pace at which new threats evolve. An elevated level of Joint supply support will be needed to integrate the capabilities of many new partners while also satisfying the requirements of multiple missions.

The 2014 Quadrennial Defense Review emphasizes the need to rebalance and reform across the defense enterprise to meet the security challenges of the future during a "period of fiscal austerity" (DoD, 2014). The review builds on the National Security Strategy and the 2012 Defense Strategic Guidance

[6] Title 10 USC, Chapter 6, Section 164, paragraph c.

[7] U.S. Army Materiel Command (AMC) information is available at http://www.amc.army.mil, accessed April 27, 2014.

[8] U.S. Army Combined Arms Support Command (CASCOM) information is available at http://www.cascom.army.mil, accessed April 27, 2014.

(DoD, 2012), emphasizing three pillars: protect the homeland, build security globally, and project power and win decisively. To achieve these objectives, the review calls for increased innovation—not just in technology but also with respect to how U.S. forces operate and work with other U.S. departments and agencies and with international partners. Central to this innovation is shaping, preparing, and posturing the Joint force to sustain U.S. leadership in this rapidly changing security environment.

Thus, in the future, it is anticipated that the Army will be operating in a complex, widely distributed, Joint and coalition operational environment. Some thought has already been given to this. The *Capstone Concept for Joint Operations: Joint Forces 2020*, dated September 10, 2012, describes the anticipated future security environment (JCS, 2012). It characterizes this environment as rapidly changing, uncertain, complex, increasingly transparent, and with a range of increasingly capable enemies. The capstone concept articulates a vision of how the future force will operate to protect U.S. national interests. The capstone concept proposes the concept of globally integrated operations, in which Joint Force elements, globally postured, combine quickly with each other and mission partners to integrate capabilities fluidly across domains, echelons, geographic boundaries, and organizational affiliations.

The *Capstone* document envisions the integration of existing and emerging capabilities with new ways of fighting and partnering, and identifies eight key elements of globally integrated operations (JCS, 2012):

- Commitment to mission command;
- Seize, retain, and exploit the initiative;
- Global agility;
- Partnering;
- Flexibility in establishing Joint forces (i.e., mission-based command versus strictly geographically based command);
- Cross-domain synergy;[9]
- Use of flexible, low-signature capabilities (such as cyberspace, space, special operations, global strike, intelligence, surveillance, and reconnaissance); and
- Increasingly discriminate to minimize unintended consequences.

The document identifies implications for Joint Force 2020 tied to key warfighting functions of command and control, intelligence, fires, movement and maneuver, protection, sustainment, and partnership strategies, with partnership strategies being introduced as equivalent to the traditional warfighting functions. In August 2010, recognizing the challenges expected in the future operating environment, the Joint Staff, J-4 published the *Joint Concept for Logistics* (DoD, 2010). This concept document emphasizes the need for increased integration and synchronization of Joint logistics processes within the Joint logistics enterprise in order to provide support for Joint force commanders across a range of military operations.

Special Operations

The U.S. Special Operations Command (SOCOM) was legislated into existence by Congress in 1987 in an attempt to correct some of the deficiencies that became apparent during the failed Iranian hostage rescue attempt of 1980. This legislation directed the secretaries of the military departments to transfer operational control of their existing special operations forces (SOF) from their respective service chiefs to SOCOM. As part of this legislation, Congress also granted SOCOM a number of military department-like authorities, including specific budget authority to develop, acquire, field, and maintain special operations-peculiar capabilities; authority to perform acquisition and procurement activities

[9] Cross-domain synergy is defined as "the complementary vice merely additive employment of capabilities across domains in time and space" (JCS, 2012, p. 7).

(including contracting); and authority to conduct test and evaluation (T&E) activities. Therefore, in addition to being a combatant commander, the commander of SOCOM also functions as both a service chief (i.e., organize, train, and equip SOF) and as the equivalent of the head of a military department, including the functions discussed above.

In the service chief-like role, the SOCOM commander oversees a force composed of the Army Special Operations Command (approximately 26,000 personnel), the Air Force Special Operations Command (approximately 17,000 personnel), the Naval Special Warfare Command (approximately 7,000 personnel), and the Marine Corps Forces Special Operations Command (approximately 3,000 personnel), plus the Joint Special Operations Command, the SOCOM Headquarters organization, the Joint Special Operations University, and the Special Operations Command-Joint Capabilities organization. The mission of the last-named organization, which is to train conventional force and SOF staffs in the proper integration and employment of SOF when combined with conventional forces, was transferred to SOCOM upon the disestablishment of the U.S. Joint Forces Command in 2011.

There are notable differences between the SOCOM commander and a service chief. The reporting chain is different. The SOCOM commander reports directly to the Secretary of Defense and the President of the United States rather than to the secretary of a military department. The SOCOM commander is authorized to approve formal operational requirements (ORs). Following approval, these SOF ORs are submitted to the Joint Requirements Oversight Council for awareness and information, whereas the council is the review and approval authority for ORs from the individual services. Although the SOCOM commander oversees and monitors personnel administration of the special operations force, SOCOM reimburses the respective services for actually paying and managing each service's SOF personnel within their respective service personnel systems. There are also specific agreements, negotiated as part of the original transfer of operational control, with each military department and/or service to provide service common equipment and specific logistics and sustainment support for their respective SOF personnel and units.

As the equivalent of the head of a military department, the SOCOM commander has several important sets of authorities and associated assets to fund, develop, outfit, maintain, and sustain the desired SOF capabilities. These include

- Budget authority, a dedicated funding line, called the Major Force Program (MFP) 11, and a headquarters comptroller staff;
- Acquisition and procurement authorities, a headquarters acquisition staff consisting of an acquisition executive, program executive officers, program managers, logisticians (including a J-4 organization with data links to the respective military department and service databases), and a procurement staff (contracting officers and associated counsel) located at headquarters and in the component commands; and
- T&E authority (it can either perform T&E in-house using SOCOM assets or outsource the T&E to any of the respective Service or DoD T&E activities).

As a designated combatant commander, the SOCOM commander has two main roles according to the Unified Command Plan:

- Synchronizing DoD's planning for global operations against terrorist networks as well as executing global operations against terrorist networks as directed; and
- Providing SOF support to the other combatant commanders in response to their respective formal requests for forces, and also to the U.S. ambassadors and their respective country teams.

Each geographic combatant command has a Theater Special Operations Command (TSOC) component as part of its staff. Once SOF units and capabilities are assigned to a geographic combatant command in response to a request for forces, they become an organizational part of the TSOC, which reports directly to that geographic combatant commander. The requesting combatant commander is then responsible for utilizing them operationally and, among other things, for providing all their associated logistics and sustainment support. Such support requirements can range from situations such as Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), where large numbers of SOF were operating in conjunction with large numbers of conventional forces, to situations where there have been very small numbers of SOF operating in over 70 countries.

ASSESSING THE LOGISTICS BURDEN

The wars in Afghanistan and Iraq have been unlike those that occurred under more conventional circumstances. While the initial phase of OIF was more conventional, that is, units in formations engaging other military units over a several-week period, the remainder of the war became a mix of asymmetrical, unconventional war and short periods of conventional urban warfare. The war in Afghanistan has been unconventional since its beginning and provided few opportunities for formations to engage in combat of the kind that occurred in the past. In both Iraq and Afghanistan, the length of war was exceptional. As a result, over time the support base for much of the U.S. and coalition forces grew to embody logistics support conditions similar to those found in the United States or a partner country away from the combat zone. In both countries, the lines of supply, both air and land, were extensive and involved heavy support from contractor personnel. Box 2-1 discusses base camps in Iraq and Afghanistan.

Because U.S. forces were used in roles they were not equipped or trained for in both OEF and OIF—for example, artillery and other units were carrying out transportation security missions—and the operations over time involved individual battles, with each battle having a different supply character, it is difficult to develop insights into what future logistics burdens might be based on what has occurred over the past 13 years. It is clear that there was a continuous, heavy logistics burden on the system in both Iraq and Afghanistan, but whether or not the demands that characterized these wars will be seen again in future wars is hard to say.

Joint Chiefs of Staff Joint Publication 3-0, *Joint Operations*, defines six phases of military operations and relates these phases to the level of military effort expended in each (Figure 2-1) (JCS, 2011). The greatest amount of effort and the most time are expended in either the domination phase or for activities related to direct combat operations. However, in both OEF and OIF, the majority of the time in which U.S. forces were and continue to be engaged falls into Phase IV or V. Unlike Desert Storm and Desert Shield, during which U.S. forces entered the area of operation, conducted operations, and returned to their base stations, the initial U.S. force buildup for the conduct of the domination operations in OIF and OEF was followed by continuing expansion of the base support activities needed to carry out the subsequent phases. As a result, what began as a domination mission turned into long-term stability operations requiring support more typical of that found in locations where United States has determined that it will have a long-term presence (e.g., Korea, Japan, and Europe during the Cold War). In OIF and OEF, combat operations were and still are being conducted on a daily basis from within a structure that integrates long-term base support operations, host nation support capabilities, and continuous expeditionary military operations.

As with operations in Vietnam, the presence of these large base camp facilities created not only the demand for logistics support of the bases themselves and the forces necessary to secure these bases but also an expectation that deployed elements would receive a higher level of support during military operations than was expected or provided during expeditionary operations such as Operations Desert Storm, Urgent Fury (Grenada), and Just Cause (Panama). As a result, much of the understanding of logistics in support of combat operations by all ranks of today's Army has been conditioned by experiences with a nonstandard, base-centric support activity. Although the supplies required for OIF and

BOX 2-1
Base Camps in Iraq and Afghanistan

Base camps, forward operating bases, and similar facilities have been part of the landscape of OIF and OEF. During OIF, bases developed from initial positions of combat units as they moved into key areas of Iraq following the 2003 invasion by U.S. forces. Once it was determined that the forces would be remaining in the area for a substantial period of time, military construction elements and contractor forces began to convert expeditionary field bases into more static facilities. As the size of the forces increased so did that of the base. As the necessity for increased support grew or standards were improved, the bases also grew in size and complexity. To promote efficiencies, activities were consolidated where possible into larger and larger facilities such as common dining facilities, recreational activities, exchanges, fast food services. As the threat of mortar and rocket attacks on the bases grew, efforts were put into increasing the protection for facilities from such attacks. As it became possible and feasible, for example, as facilities for electric power generation were constructed, the standards at many facilities improved, to include, for instance, air conditioning. By the end of OIF and the peak of OEF, standards at many of these camps and facilities approached those found at some U.S. and overseas military installations. By the end of U.S. activity in OIF, considerable effort and support were focused on the operation and security of the bases as opposed to direct support of combat operations. The combined size of Camp Leatherneck (a U.S. base camp) and Camp Bastion (a U.K. base camp) in Helmand Province, Afghanistan, approached 10 square miles (7,000 acres), and they housed, at their peak, more than 40,000 troops.

FIGURE 2-1-1 Aerial view of the hospital at Bagram Airfield in Afghanistan.
SOURCE: http://www.globalsecurity.org/jhtml/jframe.html#http://www.globalsecurity.org/military/world/afghanistan/images/bagram-hospital_aerial_17oct2002.jpg.

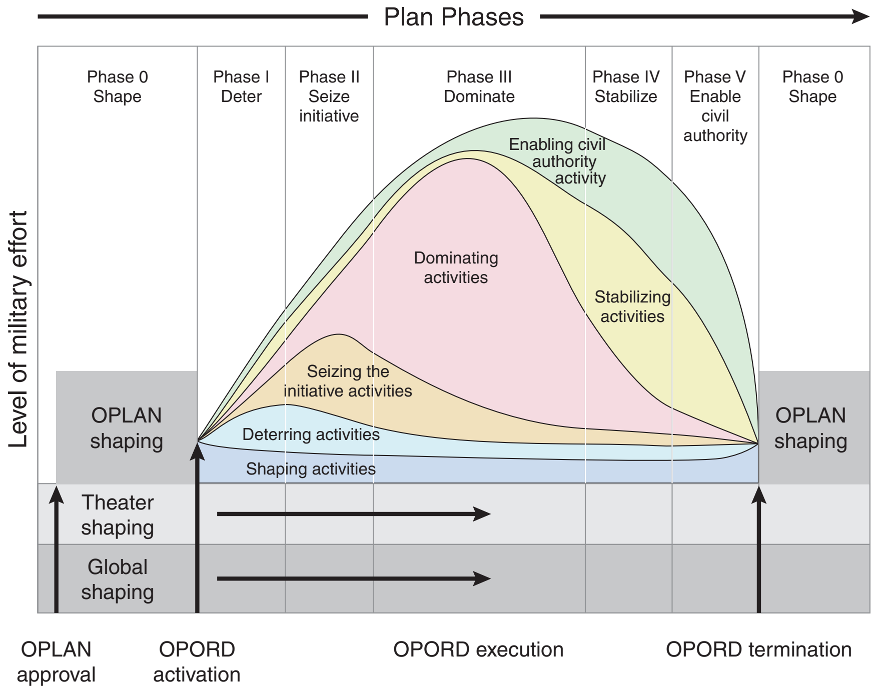

FIGURE 2-1 Phases of a notional operation plan versus level of military effort. OPLAN, operation plan; OPORD, operation order. SOURCE: JCS (2011).

OEF are difficult to quantify, a significant portion of them were and are directly related to the existence of the bases out of which the forces operate as opposed to what would have been needed had the forces been operating in an expeditionary-like environment (e.g., Desert Storm).

Recognizing that planning figures for logistics demands during combat operations could not be tied to the theater demands seen in OIF and OEF, in 2008 CASCOM conducted an air-ground distribution Computer Assisted Map Experiment (CASCOM, 2008). CAMEX 2008 used the Multi-Level One Scenario, which is intended for planning and map experiments. It is a corps-level U.S. Army Training and Doctrine Command standard operational scenario based in the year 2007 and built for the purpose of testing future concepts (e.g., operational or sustainment concepts) and equipment. CAMEX 2008 represents CASCOM's examination of the operational challenges of routine sustainment for the force in 2016. It was used to identify shortfalls in the tactical distribution system by laying out daily resupply tonnages by supply class against the capability of the distribution system to deliver these tonnages to a heavy brigade combat team (HBCT) and a fires brigade (FIB). The distribution lines of communications in CAMEX 2008 ran from the aerial port of debarkation to the brigade support area and then to the forward support company in the HBCT and FIB. Direct distribution and resupply from the aerial port of debarkation to the forward support company was also explored in CAMEX 2008. The CAMEX 2008 report also breaks out the required daily C-130 sustainment sorties for an HBCT and a FIB. Table 2-1 shows the daily resupply requirements for an FIB and an HBCT. Tables 2-2 and 2-3 show the 4-day sustainment requirements for an HBCT and an FIB and shows the proportion of those requirements delivered via ground transport and the proportion by air. Table 2-4 shows the total distribution of sustainment cargo over the course of CAMEX 2008 and the proportion of those requirements that was delivered via ground transport and what proportion by air.

TABLE 2-1 Daily Resupply Requirements for a FIB and HBCT from CAMEX 2008 (tons)

Supply Class	Description	FIB	HBCT	Subtotal
Class I	Rations	12.08	23.20	35.28
Class II	Clothing and textile	2.36	4.53	6.88
Class III	Package petroleum	1.11	2.14	3.25
Class III	Fuel	121.61	338.24	459.85
Class IV	Barrier materials	3.33	6.40	9.72
Class IV	Construction materials	2.84	5.45	8.29
Class V	Ammunition	175.93	45.24	221.18
Class VI	Personal demand	0.51	0.98	1.48
Class VII	End items	6.22	11.95	18.17
Class VIII	Medical supplies	0.21	0.41	0.62
Class IX	Repair parts/batteries	3.22	6.18	9.40
Ice		6.35	12.20	18.55
Mail		1.66	3.20	4.86
Water		126.72	243.38	370.10
	Total	464.15	703.47	1,167.63
Delivered by GLOC, class IIIB, class I (water) and ice		254.68	593.81	848.49
Delivered by air		209.47	109.66	319.13

NOTE: GLOC: ground lines of communication. SOURCE: CASCOM (2008).

TABLE 2-2 Four-Day Sustainment Requirements for an HBCT and How the Required Cargo Was Delivered

	Dry Cargo (tons)	Liquid Cargo (gallons)
Four-day requirement	438.6	363,848 (JP8) 234,580 (water)
Not delivered	0.0	34,362 water
Delivered by air	229.0	43,200 (JP8) 2,878 (water)
Delivered by ground	209.6	354,729 (JP8) 214,467 (water)

SOURCE: CASCOM (2008).

TABLE 2-3 Four-Day Sustainment Requirements for a FIB and How the Required Cargo Was Delivered

	Dry Cargo (tons)	Liquid Cargo (gallons)
Total four-day requirement	837.9	136,204 (JP8) 121,136 (water)
Total not delivered	0.0	18,230 water
Total delivered by air	831.9	26,400 (JP8)
Total delivered by ground	6.0	116,658 (JP8) 103,304 (water)

SOURCE: CASCOM (2008).

TABLE 2-4 Total Sustainment Requirements Over CAMEX 2008 and How Those Requirements Were Delivered

	HBCT			FIB		
	Dry (tons)	JP8 (gal)	Water (gal)	Dry (tons)	JP8 (gal)	Water (gal)
Four-day total	438.6	397,929	233,477	837.9	143,058	121,534
Amount not delivered	0	0	16,132	0	0	18,230
Total delivered	438.6	397,929	217,345	837.9	143,058	103,304
Delivered by air	229.0	43,200	2,878	831.9	26,400	0
Delivered by ground	209.6	354,729	214,467	6.0	116,658	103,304
Percent by ground	47.8	89.1	98.7	0.7	81.5	100
Percent by air	52.2	10.9	1.3	99.3	18.5	0

SOURCE: CASCOM (2008).

It should be noted that the HBCT modeled in CAMEX 2008 consisted of two maneuver battalions. The new HBCT design has three maneuver battalions. This can be expected to affect resupply requirements proportionally. Also, CAMEX 2008 did not provide explicit data on the logistics demand of Army aviation assets. It should also be noted that CAMEX 2008 assumed an already fully deployed force. The picture might be very different if the scenario included deploying the force to the operating theater.

As the Army moves toward 2020, it must either accept the heavy logistics burden shown above for more conventional warfare, assume that future warfare will not require that same amount of support, or take steps to ensure that, no matter the nature of the warfare, logistics requirements are reduced to a practical minimum to enable future forces to be efficiently and effectively supported with the supplies needed to win the wars they must fight.

CHALLENGES

As the Army moves into the next decades, it will likely be dealing with conflicts far different from those it dealt with since 9/11. Both the Marine Corps and the Army now speak in terms of expeditionary missions and expeditionary forces. This is in contrast to the experience in the last decade of conducting operations from fixed, mature bases. Getting to the battle site as quickly as possible and concluding whatever mission is assigned to the Army as fast as possible is paramount. This new approach is made all the more difficult by the global nature of the conflicts and potential conflicts that have emerged. The distances involved in Pacific operations are extraordinary and will stress every facet of logistics for all services. At the same time, force structure and resources are being reduced, and there is little certainty as to how far the tightening and resource reductions will go. It is a matter of having to do more with less.

For the past 13 years, the Army has been engaged in a hybrid warfare scenario. In Iraq the conflict began with nearly conventional warfare, moved to fierce fighting in an urban environment, and then engaged in efforts to provide stability to a nation in turmoil. In Afghanistan, the mass of a conventional conflict was bypassed as entering forces began warfare in urban environments and stability operations. In both cases logistics began with support of frontline military operations and transitioned over time to a logistics structure that closely paralleled, in many respects, the massive system that existed in support of U.S. forces in Europe during the Cold War and coalition forces during the war in Vietnam. A significant part of the U.S. and coalition forces was committed to supporting logistics and supporting those who were providing logistics.

Now, the Army is moving into a new, more austere and more Joint environment and must prepare its personnel, its force structure, its decision-making support, and its concepts of operation for a more expeditionary approach. Logistics must be a central element of this preparation. There is no logistics silver bullet. Success will depend on full use of the potential of numerous technological and organizational opportunities that are now presenting themselves to the Army. The Army must recognize these opportunities and act upon them. This committee is concerned that all too often, logistics is addressed after everything else has been considered.

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3

Reducing the Major Logistics Demands

An analysis in 2003 by the Army Materiel Systems Analysis Activity indicated that, in the initial phase of Operation Iraqi Freedom (OIF), 51.1 percent of the tonnage moved to the theater was accounted for by water and 38.6 percent by bulk fuel. The Army consumed 1.2 million bottles of water per day. There have been on average 1 casualty per 50 supply convoys in Iraq and Afghanistan. Resupply operations have been identified as a significant contributor to casualties in operations in Afghanistan and Iraq.

There are many technologies that could reduce the logistics burden of the Army. This chapter presents a variety of these. It should be noted that many of the technologies discussed in this chapter are not particularly new. The committee is at a loss for the reason that some of them have not yet made it into the field. The implementation of demand-reducing technologies will have second- and third-order effects that would have to be analyzed and modeled to be completely understood. For instance, take a technology that reduces the demand for fuel. That would take trucks, and soldiers, off the road and out of danger. Fewer trucks mean less fuel consumed in transporting fuel. A reduction in the number of trucks would also result in a reduction in maintenance demands. A reduction in the number of personnel required would mean that less sustainment needs to be provided overall (less food, water, power used, etc.). And so on. Some technologies would also introduce logistics demands that might mitigate their benefit to some degree. For example, using additive manufacturing in the field would introduce a maintenance demand for the machines and associated equipment and would introduce a demand for the raw material used in additive manufacturing. Combined Arms Support Command analyses indicate that the largest future demands will continue to be for fuel, ammunition, and water. Other logistics demands of interest to the Army, even though they are not large by tonnage, are maintenance and critical parts and batteries and soldier load.

The committee notes the need to be cautious when introducing new systems and technologies into the field. The Army has had some successes by fielding fairly-mature technologies to gain operational experience. This has allowed technologies to be refined, aided in the development of better capabilities for soldiers, and has even provided soldiers with new capabilities that they would otherwise have had to wait a long time to access. But introducing technologies before they are sufficiently mature can create many problems. One effort to introduce new capabilities to deployed soldiers, the Rapid Fielding Initiative, fast-tracks equipment and systems to deployed soldiers outside of the normal acquisition process.[1] There is anecdotal evidence that this has caused some problems in terms of logistics support. The fast tracking of the procurement system did not allow for proper integrated logistics support planning. Inadequate training, manuals, repair parts, and long-term support resulted in much of this equipment not being deployed properly, only being deployed on a limited basis, or only being used until the unit rotated out of theater but then going unused because the next unit could not operate or maintain the equipment. The committee's findings and recommendations about introducing new systems and technologies should be viewed in light of these two items.

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[1] U.S. Army, "Rapid Fielding Initiative," http://www.army.mil/aps/08/information_papers/prepare/Rapid_Fielding_Initiative.html, accessed October 15, 2014.

In the following sections, the committee touches on actions it believes could make significant impacts on the water, fuel, and ammunition logistics demands. The committee's general priorities for investment in these technologies are presented in Tables S-2 and 9-1. The committee is aware that the technologies it discusses in this chapter span a range of maturities. Some are nearly ready to field, others will take more research and development. Some areas are already under active exploration by the Army. Some are efforts underway by other Services. And some may be novel to the Army. Per its tasking, the committee focused on identifying and describing technologies that could reduce the logistics burden. The committee did not receive the level of information that would be necessary to analyze these technologies, identify technical challenges to their adoption, or assess their maturity. Addressing challenges and maturity would be a complicated task as these will vary depending on the specific setting and operational circumstances. For instance, the technology readiness level (TRL) of a technology for a commercial application might be different from the TRL for a military application, due to the special requirements of military settings. And the TRL of a technology for operation on a mature base might be very different from the TRL of that technology when considering an expeditionary environment.

WATER

Water Requirements

Water is vital to the human body. During the Six-Day War of 1967, Israeli troops, who had adequate field water, suffered minimal casualties from dehydration, whereas Egyptian troops, who experienced severe water rationing, suffered more than 20,000 fatalities from heat stroke (Grandjean, 2005). The quantity of water required by humans depends on a variety of factors, including physical activity, physiology, body weight, ambient temperature, and humidity. There are other water needs of the forward-deployed soldier besides drinking water. These other needs, which can also vary widely depending on temperature, humidity, topography, and activity, include the following:

- Personal hygiene (hand and face washing, sponge baths, teeth brushing, etc.),
- Showers,
- Laundry,
- Food preparation,
- Medical treatment,
- Mortuary affairs,
- Equipment wash down,
- Vehicle maintenance,
- Engineers' requirement (concrete, well drilling, etc.), and
- Equipment coolants.

These various non-drinking-water requirements can be satisfied by water of differing qualities and by different levels of water treatment. The categories of water quality include these:

- Potable water,
- Untreated source water,
- Untreated grey water,
- Treated grey water,
- Untreated black water, and
- Treated black water.

Bottled Water

Satisfying the water demand at the point of need as much as possible would reduce not only the logistics demand, it would also reduce personnel risk. In Iraq, approximately 50 percent of convoy trucks were used to transport bottles of water, amounting to 144 trucks per day.[2]

Historically, during wars, the wide range of water purification and drilling technologies available to the Army has been used to supply local water to soldiers. The availability of contractor-provided bottled water in peacekeeping missions and initial deployments in the Gulf War and in Iraq, and decisions to not deploy organic Army water production capabilities, have made bottled water the principal water source for deployed forces. The use of bottled water has been so great that the Army procured and deployed expeditionary bottling facilities. These facilities used plastic "blanks" that were formed into bottles on-site and then filled with local water.

When given a choice between water provided by organic Army capabilities and bottled water, bottled water becomes a cultural preference that imposes a large logistics burden. Because water has been bottled from local sources, contamination can enter the bottled water. Also, there has been a problem with bottled water being wasted by people throwing away partly full bottles. While there may be many applications such as medical use and emergency storage that merit bottled water, traditional water carrying methods such as canteens and water sacks offer significant advantages for a leaner and more expeditionary Army. There are many sound alternatives to bottled water, starting with the soldiers' canteens and extending to on-site water recovery and purification technologies. Simply eliminating the use of bottled water as a mainstay of sustainment would have a huge positive impact on the Army logistics situation, not to mention saving lives by reducing the number of convoys needed to transport water.

Some solutions to the need for water are available immediately or in the near term. Some are longer-term solutions that will require research and development work. Massive resources have been devoted to bottling water and transporting it to the warfighter. The committee believes this to be unnecessary, a self-inflicted wound, and that there are any number of solutions to the water problems available to the Army now. These range from existing Army capabilities and systems to access and purify water, to mature commercial systems, to systems under development.

Water Technologies, Current and Future

There are many ways to satisfy the water demand at the point of need and reduce the amount of water that has to be moved. Currently, the Army relies on reverse osmosis as a way to purify surface or ground water found in the area.

The existing Army equipment for reverse osmosis appears to meet the Army's company, battalion, brigade, and division water requirements. For water recycling purposes, biofiltration and ultrafiltration methods are effective for pretreating gray water prior to reverse osmosis, which extends the utility of the current reverse osmosis units. Existing reverse osmosis equipment includes the 3,000 gallon per hour (GPH) reverse osmosis water purification unit (ROWPU), the 1,500 GPH tactical water purification system (TWPS), the 600 GPH ROWPU, and the 125 GPH lightweight water purification system. ROWPUs are currently placed with Army Reserve units, making their deployment to rapid expeditionary operations difficult.

There are many areas of the world where water can be relatively quickly and easily obtained from surface sources or from groundwater through by drilling wells. When Allied forces drove across North Africa in the Second World War, they did not have bottled water. They exploited local water sources.

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[2] Art Lundquist, Army Institute of Public Health, "Military Field Water," presentation to the committee on February 5, 2014.

The Army Geospatial Center's (AGC's) Water Resources program is the primary Department of Defense (DoD) entity responsible for military hydrologic geospatial analysis and water detection. Its mission is to tell the Services where they can find water in a given region. AGC is the lead for the Water Detection Response Team, which provides well site analysis for DoD outside the United States. Such site analyses boosted well-drilling success rates from 35 percent to 90 percent.[3] AGC also populates, maintains, and disseminates the Water Resource Data Base. This database contains information on existing water facilities, surface water, and ground water for locations outside the United States, focusing on arid and semiarid areas of interest to DoD and on regions of strategic or tactical importance. The data are organized according to military equipment and specifications. The emphasis is on quantity, quality, location, and seasonal availability of each source. Currently, about 35 percent of the world had been mapped. AGC's Hydrologic Analysis Team is actively engaged in providing water resources support in a variety of locations, but its primary focus is currently the Central Command and Africa Command areas of interest. There are places where there is no groundwater or the groundwater is too hard to reach. Examples of such places are areas with hard rock, such as the Sahara and southeastern Egypt, and high-altitude areas such as mountains.[4,5]

Depending on climatology and available local sources, there are numerous simple procedures other than drilling wells, tapping surface water supplies, and using host nation water to augment water supplies and produce water in the field. Many are mature and in use in civilian applications. Others could be put to use by the Army with some development work but would not require a full science and technology effort. Several are discussed below.

Ship-Based Water Production

Deployments near coastlines could be supplied from ships moored along the coast, anchored in harbors, or docked in port. Existing ships have distilling units of between 25 and 50 thousand gallons per day capability (BUPERS, 1966). Some or most of this could be piped ashore. Indeed, in crisis response and humanitarian assistance situations, one reason that aircraft carriers are deployed is their ability to make large quantities of fresh water. Alternatively, tankers could be readily adapted by adding modular reverse osmosis units to produce as much as 10 to 30 million gallons per day.[6] Placing these systems in containers could make this approach more flexible. Tankers are ideal as they can supply the necessary power and possess pumps and tanks for prefiltering, polishing, and storing surge water. Currently, there are no specialized water generation ships in the Navy, Marine Corps, or Army inventory. Such vessels could be used for the inexpensive generation of large quantities of fresh water on short notice. In addition to supporting an expeditionary posture for the Army, such vessels could also be used in humanitarian assistance and disaster relief missions, a major U.S military activity in the Asia-Pacific region.

Finding 3-1. Specialized water generation ships have been designed by industry and could provide a useful expeditionary water capability in areas near oceans or seas.

Recommendation 3-1. The Army, working with the U.S. Transportation Command, should consider converting one or more small tankers for desalination of seawater to produce bulk potable water.

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[3] Personal communication between Thomas R. Spillman, Chief, Hydrologic and Environmental Analysis Branch, AGC, and Gerald Galloway, committee chair, on June 27, 2014.

[4] E-mail communication between Thomas R. Spillman, Chief, Hydrologic and Environmental Analysis Branch, AGC, and Gerald Galloway, committee chair, on June 12, 2014.

[5] Personal communication between Thomas R. Spillman, Chief, Hydrologic and Environmental Analysis Branch, AGC, and Gerald Galloway, committee chair, on June 27, 2014.

[6] Water Standard information available at http://waterstandard.com/h2ocean-solutions/, accessed August 20, 2014.

Rain and Atmospheric Water

One of the simplest water collection methods, conditions permitting, is rain catchment. Gutters and rain barrels can be used on all rigid shelters and tents, and tarps can be specifically arrayed to catch rain water. With sufficient atmospheric humidity, water can be condensed out of the air on tarps and the like. This is already done to some extent, requiring only the adoption of a technique, not research and development. Another technique for generating water is fog collection. Projects in Canada, which use canvas, and in Chile, which use nylon nets, arranged vertically, have produced significant amounts of water via fog collection. In one project in Chile, 100 nets produced an average of 15,000 liters per day. There are such projects in 25 countries worldwide (Cho, 2011).

Atmospheric water generators using cooling condensation are able to extract water from humid air using dehumidifier technology. These generators are more effective at temperatures over 65°F (18.3°C) and relative humidity over 30 percent.[7] Another approach for obtaining water from air uses a chemical desiccant to extract water from the air. One company has a system that can produce up to 2,600 gallons of potable water per day. It is self-contained and transportable in an ISO (International Organization for Standardization) marine container, does not draw external power, and works in low-humidity conditions. The current units are powered by generators and thus would induce a fuel burden. A solar-powered version is in development.[8,9] The U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) continues to explore use of this process.[10,11]

Finding 3-2. In appropriate climates, use of rain and atmospheric water may satisfy a significant portion of the water demand at the point of need. This can be accomplished with available equipment such as tarps, nets, and rain barrels, and simple changes to tents to collect water.

Recommendation 3-2. The Army should implement and, where necessary, develop methods to harvest water from the local environment, including rain and fog, to meet soldier water needs at the point of need.

Distillation and Nanotechnology

Distillation is another approach to water purification whereby water containing any impurities—chemical or biological—is boiled. The water vapor that is generated is free of most contaminants and can be condensed into pure drinking water. Novel work has been done in this area. One technology is a device called the Slingshot. It is a small still, the size of a small refrigerator, that can distill over 180 gallons of water per day using any feedstock, including black water. Fifteen Slingshot systems tested in Ghana for six months in 2013 provided water for five schools. Plans are in place to place 2,000 of these systems around the world by 2015 (Foster, 2014). This type of system could be a suitable replacement for ROWPUs and other large water purification systems. It is energy efficient, simple, and could save energy—fuel—in the process and possibly have lower maintenance costs.

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[7] United Nations, Engineering Standardization and Design Centre Newsletter, http://www.unlb.org/downloads/ESDCNewsletter201208.pdf, accessed October 1, 2014.

[8] Aqua Sciences, "Aqua Sciences: Making Water from Air Virtually Anywhere, Saving Lives," http://www.aquasciences.com/tech_eng.shtml, accessed August 20, 2011.

[9] Aqua Sciences, "Compelling Current Product Line," http://www.aquasciences.com/products_eng.shtml, accessed August 20, 2014.

[10] Jay Dusenbury, Deputy for Science and Technology, U.S. Army TARDEC Force Projection Technology, "Reducing the Forward Operating Base Water Logistics Burden," presentation on May 6, 2009.

[11] Office of Management and Budget, "Liquid Desiccant-Based Atmospheric Water Generation without Reverse Osmosis," http://earmarks.omb.gov/earmarks-public/2008-earmarks/earmark_344860.html, last modified September 4, 2009.

Experimental projects in solar thermal desalination are being carried out in California's Central Valley by a company called WaterFX. Their system, called Aqua4, technique uses reflective parabolic fabrics to focus sunlight on tubes containing thermal oils. These oils are then used to heat water in evaporators, vaporizing the feed water and forming steam that condenses as freshwater.[12] This technology might also be used in addition to desalination to purify water of other chemical or biological contaminants. If the equipment was put into container modules and the parabolic fabric reflectors were made to be easily deployable, then such techniques could be of use to the Army.[13]

A company called Puralytics is marketing a nanotechnology mesh that uses light to purify water. The technology makes uses of photocatalytic oxidation, photocatalytic reduction, photolysis, photoadsorption, and photo disinfection to either break down contaminants or remove them from water. The technology is advertised to be able to treat contaminants including heavy metals, petrochemicals, pesticides, viruses, bacteria, and protozoa. It does not seem to address minerals in water. The technology is available in reusable bags for personal water purification, an LED-activated filter system, and "lily pads" that float on the surface of bodies of water and purify it.[14]

Finding 3-3. Distillation may be a simpler, more efficient method of water purification than systems currently used by the Army. It can produce pure drinking water from any water feedstock with any sort of contaminant, including black water. Similarly, nanotechnology solutions may be able to effectively address Army water purification needs in appropriate settings.

Recommendation 3-3. The Army should develop distillation methods to meet soldier water needs at the point of need. The Army should also explore the use of existing nanotechnology solutions for water purification.

Individual Water Filtration

As noted above, the Army has water purification systems for units of company size and above. However, there is currently no solution for water purification at the platoon and squad levels. Graphene fiber technology shows promise as ultraprecise and ultrafast small filter units. Work in this field is being carried out at the University of Manchester (U.K.) and the Chinese Academy of Science. Filters based on graphene, for instance, are impermeable to all gases and liquids except water, which passes through the filter easily (University of Manchester, 2012). The U.S. Marine Corps and the Army are also working on individual-level water purification systems. The Marine Corps has developed the Individual Water Purification System, which uses a hollow fiber microfilter and a MIOX purifier. The hollow fiber filters out bacteria and protozoa and improves taste and odor. The MIOX filter removes viruses and bacteria. It does not address toxic industrial chemicals or materials.[15] The MIOX purifier works by adding a chlorine tablet to the water and letting it sit for 30 minutes before consumption (Sanborn, 2012b). The Army's individual water treatment device is under development. This unit is meant to be compatible with the modular lightweight load-carrying equipment. The goal of the effort is to develop an individual-level

[12] Aqua4 Information available at http://waterfx..co/aqua4/, accessed August 19, 2014.

[13] Solar stills can also be used to generate drinkable water from dirty water, soil, or the atmosphere. Using the solar still concept, J. Liow, a Monash University graduate student, developed a spherical still in 2011. It is about 24 inches in diameter, with a transparent upper half that can produce about 3 liters of potable water per day. Information available at www.jonliow.com/SOLARBALL-Water-Purifier and http://www.gizmag.com/solarball-creates-drinkable-water/18270/. Last accessed on August 19, 2014.

[14] See Puralytics, http://www.puralytics.com/html/home.php, accessed November 4, 2014.

[15] Art Lundquist, Army Institute of Public Health, "Military Field Water," presentation to the committee on February 5, 2014.

water purification system that will allow soldiers to drink from indigenous water supplies.[16] While initial operating capability was projected for fiscal year (FY) 2014, this is not going to happen. The government intends to consider changes to the requirement and now plans to potentially resolicit the new requirement at a later date.[17] Future development efforts will include providing the capability to purify saltwater and brackish water; to improve filter life and flow rate, to lower the pressure drop across the filter; and to achieve full toxic industrial chemical and material removal.[18,19] However, these filters currently lack the capability to test and assure that they are effective in removing impurities.

Finding 3-4. Current water filtration systems are focused at the Army's company level and above. There is a need to develop and field individual water purification filters. Individual water filters would reduce the amount of water that has to be shipped forward.

Recommendation 3-4. The Army should field individual water filters as soon as possible.

Water Testing

The presence of toxins and pollutants is widespread in the ground and surface water in many Pacific countries. Bacteria, protozoa, animal waste, and fertilizers are ubiquitous in the Far East. Currently, the Army's Public Health Command provides water testing in forward areas. This requires the deployment of special equipment and trained experts. It would be very useful if water testing equipment and training were made available to soldiers to augment those efforts of the Army's Public Health Command. The committee believes there is a need for a universal, consolidated standard for performance and quality control for water. This would include the development of a risk management plan embracing the following:

- Source and exposure characterization,
- Validation through protocol-driven evaluations,
- An operational control designed proof of concept, and
- Verification monitoring of the efficiency.[20]

Finding 3-5. Training soldiers in tactical units to perform water quality testing and providing them with suitably simple field equipment would enhance the timely production of safe water in the field.

Recommendation 3-5. The Army should develop a simple, portable water testing device that a squad can use to ascertain whether water is potable without having to wait for specialists to test it.

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[16] Program Executive Office Soldier, "On the Move Hydration," presentation on May 12, 2011, http://nsrdec.natick.army.mil/APBI/Hydration%20Load%20Carrying%20Equipment/Army_-_Hydration_&_Load_Carriage_Ver_6_MAY_2011.pdf.

[17] Personal communication between Donald W. Matts, Jr., U.S. Army Research, Development and Engineering Command, and James Myska, study director, September 11, 2014.

[18] Art Lundquist, Army Institute of Public Health, "Military Field Water," presentation to the committee on February 5, 2014.

[19] Program Executive Office Soldier, "On the Move Hydration," presentation on May 12, 2011, http://nsrdec.natick.army.mil/APBI/Hydration%20Load%20Carrying%20Equipment/Army_-_Hydration_&_Load_Carriage_Ver_6_MAY_2011.pdf.

[20] James Tuten, Product Manager, Force Sustainment Systems, "Contingency Basing and Operational Energy Initiatives," November 2011, http://www.dtic.mil/docs/citations/ADA558324.

Water from Diesel Engine Exhaust

The exhaust gases from diesel consist mainly of nitrogen, water vapor, and carbon dioxide. Also present are noxious products such as carbon monoxide, hydrocarbon products, nitrous oxides, and particulate matter. It is claimed to be theoretically possible to recover about one pound of water for each pound of fuel burned (Pentland, 2011). This is currently accomplished by a process known as capillary condensation, whereby water vapor in the exhaust is captured by tiny capillaries in porous, tubular inorganic membranes. It is claimed that the water is potable.

Tests of this process were carried out by the Southwest Research Institute and Bend Research under the sponsorship of the U.S. Army Belvoir Research, Development and Engineering Center. Later work (2011) by Oak Ridge National Laboratory further developed the concept. Practically, only about 65-85 percent of the putative pound of water mentioned above is recoverable from diesel exhaust (Boyle, 2011). Committee members have heard anecdotally that this water has a strong bad taste. One member has experienced this directly. A taste problem would be a huge barrier to acceptance of this water by soldiers. Further, current technology for the capillary condensation process adversely impacts weight and power of the engine to which the equipment is attached. The existing technology is also expensive when every diesel engine must be equipped with such a device.

Still, if these shortcomings can be overcome, significant logistical benefits could be realized using this technology. It should also be noted that the water recovered using this technology need not be potable to be usable. Water is also used to wash down equipment, do laundry, and the like. It is possible that water recovered from diesel exhaust might be able to reduce some of the water demand even before it can be widely accepted as drinking water.

Finding 3-6. Water from exhaust is not yet ready to be used as drinking water. There are still many challenges to overcome, not least its taste. Still, it could be used to meet some of the demand for nonpotable water, and if the taste challenge can be overcome, it could have a very great positive impact on the provision of water on the battlefield.

Recommendation 3-6. The Army should continue its research on extracting water from diesel exhaust. It should also explore the use of water recovered with this technology for nonpotable uses. Specific goals, including affordability, minimal weight and power impact, and good taste should be provided to the research community. The Army should also suggest to the Defense Advanced Research Projects Agency (DARPA) that this may be a problem whose difficulty justifies their involvement.

Water Conservation

Another obvious way to reduce water demand in either expeditionary or extended operations is by conserving water. Conservation can be accomplished both by simply using less water and by recycling it where possible. Both approaches require water management. This is a five-step process:

1. Establish a metric,
2. Measure current consumption,
3. Establish a baseline,
4. Set goals, and
5. Monitor usage.

The process necessitates the use of simple water meters, where practicable, and the regular collection of usage data. This would also raise soldiers' awareness of water conservation.

The Army is already actively working on this issue. The Army Base Camp Integration Laboratory at Fort Devens, Massachusetts, is testing technologies expected to reduce the logistics demand for water by up to 75 percent through managing water use and employing technologies such as shower water recycling (Quick, 2011; Reinert, 2013).[21] To accomplish this bold objective many efforts will be required. There are many opportunities to conserve water. Some are technical opportunities, while others are cultural.

There are many small cultural adjustments that can produce considerable water conservation. Typical techniques used by submariners—turning the water off between wetting down, soaping, and rinsing off and not shaving and brushing teeth under running water—are examples of saving water through cultural changes. Inducing cultural and behavioral changes carry no additional cost for developing and procuring technical solutions. They are essentially free and constitute low-hanging fruit.

Finding 3-7. There is a wide variety of simple cultural and behavioral changes that could produce significant water savings.

Recommendation 3-7. Rather than relying solely on technical solutions for water conservation, the Army should aggressively pursue cultural and behavioral changes that would save water at no additional cost.

There is a wide variety of commercially available, simple technical solutions for conserving water at established base camps. These include spring-loaded faucets, reduced-flow shower heads, and the like. On the technology development side, the U.S. Army Engineer Research and Development Center is working to develop an integrated and robust gray water reuse system and intends to have it developed to TRL 6 by mid-FY2016.[22] The system involves reusing shower and laundry water by screening, biofiltration, ultrafiltration, high-efficiency reverse osmosis, and disinfection, resulting in water that meets U.S. Army Public Health Command standard IP-31-027. The result is that only 20 percent of the recycled water goes to waste, and only a 20 percent volume of potable make-up water will be required.[23] This work will have a significant impact on the demand for the delivery of potable water to base camps. Also, an effective water conservation effort requires measuring the amount of water being used. This would also allow water usage to be managed in response to changing circumstances. The most effective way to do this is to put meters on all water tanks and bladders. These are inexpensive and commercially available.

Finding 3-8. There is a wide variety of technical water conservation solutions. These range from commercially available devices to the system that the U.S. Army's Engineer Research and Development Center is developing to recycle water in the field.

Recommendation 3-8. Commercially available water conservation devices should be adopted for use as widely as possible. Additionally, development work such as that of the U.S. Army's Engineer Research and Development Center should be supported and the resulting water recycling systems fielded as quickly as possible.

Finding 3-9. Installing water meters on all water tanks and bladders would allow for the more effective monitoring and management of water usage.

Recommendation 3-9. The Army should install water meters on all water tanks and bladders.

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[21] James Tuten, Product Manager, Force Sustainment Systems, "Contingency Basing and Operational Energy Initiatives," November 2011, http://www.dtic.mil/docs/citations/ADA558324.

[22] Technology readiness levels measure the maturity of a given technology development program (NASA, "Definitions of Technology Readiness Levels," http://esto.nasa.gov/files/trl_definitions.pdf, accessed October 30, 2014.

[23] David Horner, Technical Director, Military Engineering Business Area, "ERDC Reduced Logistics R&D," presentation to the committee on February 5, 2014.

Transportation of Water

It may be possible to introduce efficiencies into the way water is transported. The benefit here would be more logistical efficiency and, to the extent that fewer trucks might be required, fuel savings. The Army's traditional method of moving water to the front is with 2,000 gallon tanks called "hippos" (DA, 2007; Brautigam, 2006). When the hippos are empty, they have to be returned to a water source to be filled, consuming truck and fuel resources. The military is now using simple platforms, such as flatbed semitrailers or container flats, to replace single-purpose vehicles. It is possible to leverage this change to improve the efficiency of the water supply chain. Under some circumstances, such as where road conditions permit, bladders with greater capacity than hippos could be used in their place and transported on the simpler flat platforms now in use. Several empty bladders could be returned for refilling on one flat, reducing the truck and fuel resources required to return empties for refilling.

The committee notes that there have been problems with transporting and fully emptying bladders and with stability when transporting partially full bladders. This instability is known as the free surface effect: When the bladders are partially full the liquid can shift freely. The free surface problem in rigid tank containers has been solved with internal baffles. Industry representatives state that the stability problem with bladders has been solved by using an adequate number of fabric straps. The transport of bladders is now commonplace in the container industry, and they are manufactured specifically for 20 foot and 40 foot containers. To solve the problem of fully emptying bladders, if a platform supporting a bladder is resting on a chassis, one need only crank the chassis landing gear up to get 100 percent drainage. If the platform is set on the ground, then one end can be propped up, or it can be on a on a slope or a hill, to achieve 100 percent discharge of the bladder.

Finding 3-10. Using flexible bladders to transport water could simplify the task of returning empties, increasing efficiency, providing greater utilization of flats, and reducing logistics demand for fuel.

Recommendation 3-10. The Army should consider replacement of water tank containers and hippos by more versatile flexible bladders riding on flats.

Depending on the volume of potable and fresh water required, the distance inland, and the mobility of the units, the most efficient method of water transport is by pipeline. Rigid pipeline can be quickly laid from truck-mounted reels. Hoses are less permanent but more easily deployed. Current pipeline solutions can be laid at a rate of 2 or 3 miles per day. A new expeditionary fuel distribution system is in development that could be laid at 15-20 miles per day.[24,25] Pipelines, of course, reduce the need for motorized transport of water. There are, however, physical security risks to unattended pipeline laid in potentially hostile territory. These risks can include tampering with and interdicting the pipelines, disrupting the flow of water. These concerns are also shared by commercial pipeline operators, and there are a number of companies that offer pipeline monitoring systems. While these systems likely exceed Army requirements for monitoring pipeline security and integrity, they might prove to be useful starting points for the Army to introduce monitoring into its pipelines in order to detect any compromises in their pipelines, either through natural or man-made causes.[26]

[24] James Dusenbury, Senior Technical Expert, U.S. Army Tank Automotive Research, Development and Engineering Center, "Force Protection Technology," presentation to the committee on February 4, 2014.

[25] Comments by LTG Raymond Mason, U.S. Army G-4, to AUSA Hot Topics Sustainment Seminar, Sustaining the Force 2025, on May 20, 2014.

[26] Examples of commercial pipeline monitoring capabilities can be found at PSI Solutions for Oil and Gas Pipelines, http://www.psioilandgas.com/en/ pipeline-monitoring-solutions/pipeline-monitoring-solutions/, and SMARTEC, http://www.smartec.ch/Applications/Pipelines, accessed October 30, 2014.

Finding 3-11. Where appropriate, pipeline is the most efficient method to deliver water to troops and bases. New pipeline systems are under development that will greatly increase the rate at which pipeline can be laid. Also, current pipelines are vulnerable to enemy action. There are commercial solutions available to address pipeline integrity and security, and these might prove useful for the Army to adapt to its needs.

Recommendation 3-11. The Army should develop self-monitoring pipelines that report interdiction, intrusion, tampering, and other detrimental activities. The Army should begin by exploring commercially available applications for pipeline monitoring to see if they can be adapted to its needs.

FUEL AND ENERGY

While watercraft are discussed in Chapter 4, the logistics support of watercraft, including fuel, are not addressed in this report. This report focuses on fuel used by ground and air vehicles.

Fuel is used, broadly, to meet two needs: to power engines (vehicles) and to generate power for camps and tactical units (generators). A significant amount of the fuel consumed during operations in Iraq was for generators. Overall, about 50 percent of the fuel brought onto forward operating bases was used for generating power, for cooking stoves, or for the trucks bringing materiel into and out of the base (Steele, 2014). Anything that significantly reduces the amount of fuel that must be provided to forces in the field will have a significant positive impact on the overall logistics burden.

There is a significant body of Army research into improved energy efficiency in order to reduce fuel demand. This body of work includes research on engine design, electric machines and power electronics, power distribution, alternative power sources, and environmental control systems, and considerable effort has been expended in the area of chemical storage batteries. A summary of current Army work can be found in Box 3-1.

One Army effort to address operational energy is the Joint Operational Energy Initiative (JOEI). This is a partnership between the U.S. Army Program Executive Office Combat Support and Combat Service Support and the U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC). JOEI is a system-of-systems modeling and simulation capability. It provides quantitative data and information to support holistic evaluations of changes in energy technologies and usage patterns to determine their impacts on the overall operational energy picture. This information is used to inform current and future doctrine and to provide input to science and technology and acquisition programs, to trade-space studies, and to cost-benefit analyses.[27]

All of the efforts listed in Box 3-1 are impressive and an important part of the overall research and development strategy to address operational energy and, thus, the fuel issue. This work should be continued. The remainder of this section discusses technologies the committee believes could be particularly effective in reducing the logistics demand for fuel.

Advanced Engine Programs

Aviation Engines

One of the most straightforward ways to reduce fuel demand is to develop more fuel-efficient engines. The U.S. Army has been working on the Improved Turbine Engine Program (ITEP) to produce a smaller, lower-cost, 3,000-shaft horsepower engine for the aviation community. The goal is to provide a 50 percent increase in power, reduce fuel consumption by 25 percent, reduce production and maintenance

[27]JOEI 2014 abstract, document provided to the committee by U.S. Army Research, Development and Engineering Command, June 9, 2014.

BOX 3-1
Current Army Research Efforts in Energy Efficiency and Fuel Demand Reduction

- Combining and integrating energy technologies in order to optimize system characteristics in support of military requirements. For example, combining solar photovoltaic and batteries to achieve optimal performance and reduce cost, weight, and complexity.
- Investigating smart-grid control technologies to effectively manage electrical power generation, distribution, and use, thus reducing the need for periodic liquid fuel resupply to base camps.
- Examining innovative alternative energy sources that minimize or replace current hydrocarbon energy systems, perhaps enabling the elimination of fossil fuel based generators.
- Examining lightweight, low-volume, and highly reliable dense power sources and establishing microgrids for recharging portable and mobile batteries.
- Reducing energy demand through the use of light emitting diode lighting and high-efficiency heating, ventilation, and air conditioning (HVAC) systems coupled with modular relocatable thermally insulated structures.
- Examining high-power and high-energy-density batteries and ultracapacitors to provide load leveling and to support various other applications such as transportation and soldier power.
- Investigating photovoltaic cells integrated into military shelters along with additional structural insulation. This lowers the electrical demand by providing a solar shade to the shelter and at the same time produces some electrical power that can be used for powering some electrical units.
- Improving the process efficiency of biofuels and lowering their cost so they are competitive with traditional fuels.
- Investigating waste-to-energy technology to produce synthetic gas that can power standard generators, displacing up to 85 percent of the JP8 (jet propellant fuel, essentially diesel in this use) used to fuel generators, depending on scale.
- Investigating microhydroelectric plants and wind turbines for use in appropriate geographic regions.
- Examining the use of passive solar hot water and solar air heating units made from light-weight plastics.
- Investigating hybrid propulsion systems and fuel cell based propulsion and power generation.

SOURCE: ARCIC (2010).

costs by 35 percent, and achieve a 20 percent longer engine life. The ITEP concept is to design a drop-in replacement engine for the one that currently powers the AH-64 Apache and the UH-60 Black Hawk. The ITEP is part of U.S. Army's Aviation Applied Technology Directorate Advanced Affordable Turbine Engine program. This program is under the larger research and development umbrella of the Versatile Affordable Advanced Turbine Engines program. The Advanced Turbine Engine Company and GE Aviation are both developing engines for this program: the HPW3000 and GE3000, respectively (Aviation Week, 2013).[28] At the time of the writing of this report, engines were being tested as part of this development effort.

The U.S. Air Force has been funding the development of the Adaptive Versatile Engine Technology (ADVENT) engine, which is being optimized for both high speed and high fuel efficiency.

[28] Mary Miller, Deputy Assistant Secretary of the Army for Research and Technology, "Logistics Science and Technology: A 30 Year Look," presentation to the committee on January 17, 2014.

Until now, engines have been optimized for either speed or fuel efficiency, not both. The program goal is to use 25 percent less fuel than the most advanced engines currently on the market or in development (GE Aviation, 2013; Jordan, 2014). Pratt & Whitney and GE are working on the next version of ADVENT, called Adaptive Engine Technology Development, to develop next-generation engines that could provide better fuel-burn rates and operate at higher speeds while also allowing more operating flexibility for pilots.

Finding 3-12. The committee believes that the Improved Turbine Engine Program will provide significant reductions in aircraft fuel consumption and increases in aircraft engine efficiencies.

Recommendation 3-12. The Army should accelerate development and fielding of the Improved Turbine Engine Program.

Finding 3-13. The Air Force's ADVENT program technologies have the potential to reduce fuel consumption, and their high-efficiency components may also reduce maintenance cost. These engines are likely to have high power density and high fuel efficiency. While the ADVENT program is directed a producing a fighter engine, there may be turbine engine technology synergies that could aid the Army's Improved Turbine Engine Program.

Recommendation 3-13. Without slowing down fielding of the Improved Turbine Engine Program, the Army should explore the possibility of working with the Air Force and industry partners to combine the relevant technologies of the Adaptive Engine Technology Development program and the Improved Turbine Engine-Program to further reduce fuel consumption and improve performance.

Ground Vehicle Engines

The Army is also investing in efficient power trains for ground vehicles. A program called Efficient Power Trains is under way to develop power trains that will provide 15-20 percent increased mission range and increased fuel efficiency. The engines in these power trains will be able to run on a wide variety of fuels, increasing operational flexibility, and will be able to export power off-board. The goal of these efforts is to develop two power trains at TRL 5 by the end of FY2014, one for wheeled vehicles of 25 tons or more and one for tracked vehicles of 30-45 tons. The power trains will use an optimized commercial off-the-shelf engine. An integrated TRL 6 test on an M2 Bradley is planned for FY2017.[29]

Upgrading the M1 Abrams engine to a more fuel-efficient model is also a worthwhile endeavor. For example, the committee learned that a diesel engine with greater fuel efficiency than the current turbine engine was tested at TARDEC in 2013. The vendor claims that this improved engine will use 207 gallons of fuel per combat day versus the 408 gallons used per combat day by the current engine and that the engine could provide a range of 308 miles on 395 gallons of fuel, versus the 205 miles on 436 gallons for the current engine. The test data are not available to the committee, however. Also, a fair amount of integration work would reportedly be needed to install the engine on the M1 Abrams (InsideDefense, 2013). Additionally, the engine is a diesel engine, not the turbine engine currently on the M1, and that change could have significant operational consequences for the Army. The committee takes no position on whether this particular engine would be an appropriate upgrade of the current M1 engine. The committee does, however, believe significant logistics benefits are to be had by developing a more fuel-efficient engine for the M1 and that, in light of the ITEP program, such an effort is feasible.

As shown in Table 2-1, the Computer Aided Map Experiment (CAMEX) 2008 exercise modeled a heavy brigade combat team as using approximately 338 tons of fuel per day. If improved engines were

[29] Ibid.

developed for the M1 and M2 with savings similar to the 25 percent goal for the ITEP engine, this could save approximately 80 tons of fuel per day.

Finding 3-14. Developing more fuel-efficient engines for the M1 Abrams and the M2 Bradley would result in significant fuel savings for the Army. As indicated in the discussion above, a diesel engine that uses approximately 50 percent fuel has been tested. The M2 uses a diesel engine. The Improved Turbine Engine Program is developing an engine with 25 percent greater fuel efficiency. The M1 uses a turbine engine.

Recommendation 3-14. The Army should develop more advanced engines for the M1 Abrams and the M2 Bradley, with a goal of 25 percent greater fuel efficiency as envisioned by the Improved Turbine Engine Program.

Hybrid Drive Systems for Propulsion

Hybrid vehicle propulsion provides another fuel-saving option that could be combined with the possibility of efficiently providing electric power for off-board applications. They come in two types, discussed in Box 3-2. Hybrid electric propulsion provides about 10-20 percent more efficiency than a diesel-powered alternative for ground vehicles, depending on the propulsion system design. It also offers faster acceleration and maneuvering and a higher degree of fault tolerance through system redundancy and a reduction in moving parts. In addition to improved fuel efficiency, hybrid vehicles might also be used to provide power to soldiers and microgrids in the field.

Owing to the higher fuel efficiency of hybrid propulsion systems, the Army has been looking into hybrid propulsion strategies for several of its vehicles, such the High Mobility Multipurpose Wheeled Vehicle, popularly known as the HUMVEE, and various trucks. TARDEC has done much research and development of technology for the combat and tactical vehicle applications. A number of concerns remain that must be addressed before the technology is adopted by the Army. Some remaining considerations are these:

- Reliability,
- Safety,
- Integration issues (thermal management),
- Cost impacts,
- Logistics impacts (engine, batteries, and power electronics), and
- Training and maintenance.

BOX 3-2
Types of Hybrid Power Trains

Hybrid vehicles fall into two general categories, series hybrids or parallel hybrids. In a series hybrid vehicle, the engine drives a generator, which in turn charges the batteries to provide power to an electric motor for propulsion. A series hybrid vehicle is essentially an electric vehicle with a battery being charged on board by the engine-driven generator or by a fuel cell. In a parallel hybrid vehicle, both the engine and the electric motor are used to drive the vehicle.

Presently, TARDEC is pursuing a "crawl, walk, run" approach to developing integrated starter generator technology to provide large amounts of onboard high-voltage power. Mechanically driven devices such as fans and pumps could be electrified and intelligently controlled to gain vehicle efficiency. The final step would be to add a battery (i.e., parallel hybrid drive configuration) for start-stop, silent mobility, and silent watch capabilities.[30] The recently cancelled Ground Combat Vehicle was to have been equipped with a hybrid propulsion system. The Army is currently working on hybrid vehicle technology for light tactical vehicles in the Ultra Light Vehicle program.[31,32] Army research and development efforts, however, have not yet resulted in an operationally deployed hybrid vehicle.

Finding 3-15. Hybrid propulsion offers significant improvement in fuel economy over conventional vehicles. Hybrids could also be used to transfer power to off-board applications or a base camp microgrid.

Recommendation 3-15. The Army should continue to develop hybrid drive technology and should adopt technologies that have been developed for commercial hybrid vehicles for use in military vehicles.

Auxiliary Power Units

Another fuel saving technology is auxiliary power units. Currently, onboard electrical vehicle systems are powered by the engine, either when the vehicle is moving or by idling and running the engine to generate electric power. If the required onboard power is generated using more efficient auxiliary power units instead of using the main engine, fuel consumption can be greatly reduced. For example, an independent JP8-fueled auxiliary power unit (separate from the main engine) could save 4,300 gallons a day for a tank brigade. The Army is working to incorporate a 10 kW fuel cell into the M1 Abrams in a planned upgrade in 2019.[33]

The Army is looking into more than one technology for onboard power generation. In addition to JP8-fueled auxiliary power units, the Army is exploring the use of fuel cells. The use of fuel cells for onboard power generation is two to three times more efficient than using electric power from an engine-driven generator, reducing fuel demand (DOE, 2011). These units provide power to a vehicle without the need for the main engine to be running. One of the fuel cell technologies that the Army is examining is a system based on high-temperature solid oxide fuel cells (SOFCs). These SOFCs can also be combined with lithium batteries as hybrid power system. (Fuel cells are discussed in more depth, and for more applications, below.)

Finding 3-16. Auxiliary power units, particularly those based on fuel cells, are more fuel-efficient than engine-driven generators for onboard power generation, driving down fuel demand.

Recommendation 3-16. The Army should continue its efforts to implement auxiliary power units (APUs) on conventionally propelled vehicles. Moving to non-fossil-fuel APUs such as fuel cells when possible will result in greater efficiencies.

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[30] Personal communication between Michael Blain, TARDEC, and Steven Dellenback, committee member, August 7, 2014.

[31] U.S. Army, "Ultra Light Vehicle (ULV) Research Prototype," http://www.army.mil/article/129285/Ultra_Light_Vehicle__ULV__Research_Prototype/, accessed October 30, 2014.

[32] "U.S. Army Embarks on the Testing of a Hybrid Ultra Light Vehicle (ULV)," http://defense-update.com/20130909_ulv.html#.U86Lr_ldXTo, accessed October 30, 2014.

[33] Mary Miller, Deputy Assistant Secretary of the Army for Research and Technology, "Logistics Science and Technology: A 30 Year Look," presentation to the committee on January 17, 2014.

Electric Vehicles

The military is also beginning to use pure electric vehicles on bases (Robson, 2012). These electric vehicles have predictable usage cycles and can be charged from a central depot, simplifying the installation of the required charging system. Electric vehicles obviously do not directly use fossil fuels, although it is possible that fossil fuels would be used to generate the electricity to charge them. Even with this, electric vehicles are more energy-efficient than those powered by internal combustion engines. Where they can be powered from an existing power grid, as in a friendly host nation, electric vehicles convert 70-75 percent of the grid energy to power at the wheels. For gasoline-powered engines, this figure is only 17-21 percent.[34] The situation is different if electric vehicles have to be powered by generators. A gallon of gasoline contains 115,000 Btu of energy, which works out to 34 kWh.[35] Assuming a gas-powered generator efficiency of 35 percent, a gallon of gasoline would produce 34 × 0.35 = 11.9 kWh of energy for use in an electric vehicle. Computing from a range of actual vehicle data, an electric vehicle requires an average of 0.27 kWh to travel 1 mile. Using these data, the committee figures that an electric vehicle would get approximately 44 miles of travel distance per gallon of gasoline burned in a generator, i.e., 44 mpg. By contrast, a HUMVEE gets an average of 14 mpg.[36] When using the fully burdened cost of fuel, discussed above, it is readily seen that this would not only decrease the logistics burden but also save considerable money that could be applied to other logistics needs.

There are some disadvantages to electric vehicles. Most get 100-150 miles of travel distance per full charge, whereas gasoline-powered vehicles can travel over 300 miles per full tank. Additionally, it can take 4-8 hours to fully charge an electric vehicle, though an 80 percent quick charge may be possible in 30 minutes. Also, their batteries take up considerable volume and weight in the vehicle.[37] Given this, pure electric vehicles are not likely to be suitable for the battlefield for some time. They could, however, be used at forward logistics bases in, for example, utility vehicles and forklifts, where their limitations could be more readily accommodated. This could reduce the amount of fuel that needs to be brought forward to support these bases. The greatest efficiencies for electric vehicles would be achieved where they could get their power from a host nation energy grid. They are less, but still considerably, efficient if they have to be powered from generators. It may also be possible to use other energy sources such as solar and wind to generate and store some of the energy needed to charge electric vehicles, further driving down fuel demand.

Finding 3-17. Pure electric vehicles might have some application in forward logistics bases and may further reduce the amount of fuel that must be brought forward to support operations at these bases.

Microgrids, Power Generation, and Distribution

A significant portion of the fuel consumed during operations in Iraq, and in Afghanistan once large bases began to be established, was by generators providing power to facilities and devices. Generators are assigned in a way to ensure that any given unit or function—a headquarters element or housing, say—has its own power generation capability. When all these organizational units started coming together on a base each brought, and ran, its own generators. The result was significant

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[34] "All-Electric Vehicles (EVs)," http://www.fueleconomy.gov/FEG/evtech.shtml#end-notes, accessed October 31, 2014.

[35] Energy units information available at http://bioenergy.ornl.gov/papers/misc/energy_conv.html, accessed October 31, 2014.

[36] "High Mobility Multipurpose Wheeled Vehicle (HMMWV) (M998 Truck)," http://fas.org/man/dod-101/sys/land/m998.htm, accessed October 31, 2014.

[37] "All-Electric Vehicles (EVs)," http://www.fueleconomy.gov/FEG/evtech.shtml#end-notes, accessed October 31, 2014.

inefficiencies in power generation. In response, the Army began to implement microgrids and smart grids to maximize the efficiency with which electricity is generated, thus minimizing fuel demand.

A microgrid is a locally confined and independently controlled electric power network in which distributed energy resources and loads are integrated. A microgrid has its own power generation sources, and it may or may not be connected to a larger power grid. For established military installations, a microgrid is a contingency source of power to support critical operations in the event of an outage from the main grid. At forward bases, which may not be connected into a larger grid, a microgrid can reduce the number of generators required to provide power, thus increasing efficiency and reducing fuel demand. The Project Manager Expeditionary Energy & Sustainment Systems (Project Manager Mobile Electric Power at the time of the project) implemented a 1 MW microgrid project in Afghanistan that experienced a 17 percent reduction in fuel consumption, an 85 percent reduction in generator operating hours, and 67 percent lower maintenance costs (Lafontaine, 2012a). Microgrid work is also ongoing at the Base Camp Integration Laboratory at Fort Devens, Massachusetts. A 2011 demonstration resulted in a 37 percent decrease in fuel consumption by generators (Lafontaine, 2012b).

A smart grid is a modernized electrical grid that uses information and communications to enhance its efficiency, reliability, and economy and the sustainability of the production and distribution of electricity. A smart grid facilitates integration of renewable energy sources, demand side management, and microgrid components into the overall energy picture, providing opportunities for significant efficiency increases in power generation and usage. It gathers information such as the behavior of energy suppliers and consumers and acts on that information in an automated fashion to balance supply and demand, thus increasing overall system efficiency.

The integration of solar, wind, fuel cells, and other power generation systems, along with advanced storage solutions, is enabling hybrid systems with diesel generator sets to rapidly expand at low cost. Simulation models such as JOEI (discussed above) are an important instrument for incorporating the modular building blocks of generation and storage to match site-specific energy requirements.[38]

Finding 3-18. Microgrids provide energy security for military facilities to assure reliable power without relying on a larger utility grid.

Finding 3-19. Microgrids and smart grids reduce the amount of fuel required to generate electric power by networking generators into a system in order to maximize efficiency, reducing fuel demand. Microgrids can also be used to help integrate renewable energy resources (e.g., wind and solar) into the grid, further reducing fuel demand.

Recommendation 3-17. The Army should expand its microgrid and smart grid deployment activity, focusing on incorporating fuel cells and renewable energy sources such as photovoltaic-based power generation systems for on-site power generation applications.

Alternative Energy Sources and Energy Storage

There are a number of technologies for power generation and storage that could at least partially replace generators and their associated fuel and maintenance demands, and thus be logistically beneficial to the Army. The ones that promise to have the most impact are discussed below.

[38] Alan Nanco, Manager, Military and Energy Systems Analysis, Sandia National Laboratory, “Defense Energy Summit DOE National Lab Programs: Supporting DoD Energy Missions Sandia’s Defense Energy Security Capabilities and Projects,” presentation given on November 13, 2013. Available at http://www.defenseenergy.com/program/slides/Alan_Nanco.pdf.

Fuel Cells

Fuel cells can be used in a variety of military applications, providing power ranging from few watts of power for individual soldiers to large amounts of power for facilities, bases, and tactical vehicles. Compared with diesel- or JP8-powered generators, fuel cells are lighter and are estimated to be in excess of 80 percent more efficient than generators. Fuel cells could be additional source of power for troops for various applications.

A particularly useful type of fuel cell is the SOFC, mentioned above. Fuel can be generated for SOFCs through either external or internal reforming processes.[39] Any hydrocarbon fuel can be used for generating the required hydrogen onboard the vehicle. SOFCs do not need pure hydrogen, unlike proton exchange membrane fuel cells, which do (Angelo, 2014). Additionally, proton exchange membrane units cannot tolerate carbon monoxide in the fuel, while for SOFCs it could be part of the fuel along with hydrogen. Also, SOFCs are more sulfur-tolerant than other types of fuel cells. This flexibility and robustness could make them attractive for military applications. The Army is already doing some work with SOFCs. Some cooperative efforts have been conducted with the Air Force.[40] In 2013 the Army's Communications-Electronics Research, Development and Engineering Center demonstrated a 10 kW tubular SOFC power system. It had a dry weight of 960 lb and a volume of 38 cubic feet, compared with 1,100 lb and 41 cubic feet for the 10 kW Tactical Quiet Generator Set (CERDEC, 2013).The Army Research Laboratory has also developed a technology to reduce the sulfur in fuels so they can be more readily used by SOFCs.[41]

Finding 3-20. The Army is appropriately engaged in fuel cell research for onboard power generation in transportation applications.

Recommendation 3-18. The Army should continue to explore the possibility of using fuel cells wherever appropriate and to deploy them in the field.

Solar

The military is increasingly investing in solar energy as an effective alternative to traditional energy sources in a number of ways, a trend that, if continued, could significantly impact the demand for fuel. It has utilized large, centralized utility-scale solar projects to power bases; smaller distributed-generation systems to power buildings and homes; and portable solar systems to provide energy in the field. Examples of these include a 2 MW solar installation at Fort Carson, Colorado, solar panels on military housing units, and portable solar systems in Afghanistan.

Solar energy based systems using flexible photovoltaic (PV) arrays are significantly more portable and rugged than traditional crystalline or polycrystalline PV units. Flexible solar arrays can be emplaced in tarps to provide some energy in remote settings or integrated into solar shields for field shelters, which would have the double benefit of generating power and providing cooling to the shelter. These lightweight solar electric systems can be rolled up for storage or transportation and unrolled for use

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[39] An external reforming process generates fuel outside the fuel cell. In an internal reforming process the fuel is generated inside the fuel cell (Fuel Cell Today, "Fuel and Infrastructure," http://www.fuelcelltoday.com/applications/fuel-and-infrastructure, accessed October 30, 2014).

[40] Thomas L. Reitz, Chief, Thermal and Electrochemical Branch, Energy/Power/Thermal Division Propulsion Directorate, Air Force Research Laboratory, "Solid Oxide Fuel Cells (SOFC) as Military APU Replacements," presentation given January, 2010. Available at http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/aircraft_7_reitz.pdf.

[41] U.S. Army, Army Research Laboratory, "Creating Desulfurized Fuel for Fuel Cells Technology," Fact Sheet, http://www.arl.army.mil/www/pages/945/docs/powerenergy/ARL_08-25_TFS_Bi-layer_Sorbent-Public_Web.pdf, accessed October 31, 2014.

as needed. For the military, the ability to roll up an array of PV panels and carry them from location to location is an additional benefit in developing these products. These cells can provide power at 2 g/W. In general, there is a continuum of possible applications, from high-efficiency, low-cost wearable configurations to containerized rolls that produce 100 kW of energy. An example of containerized rolls is shown in Figure 3-1.

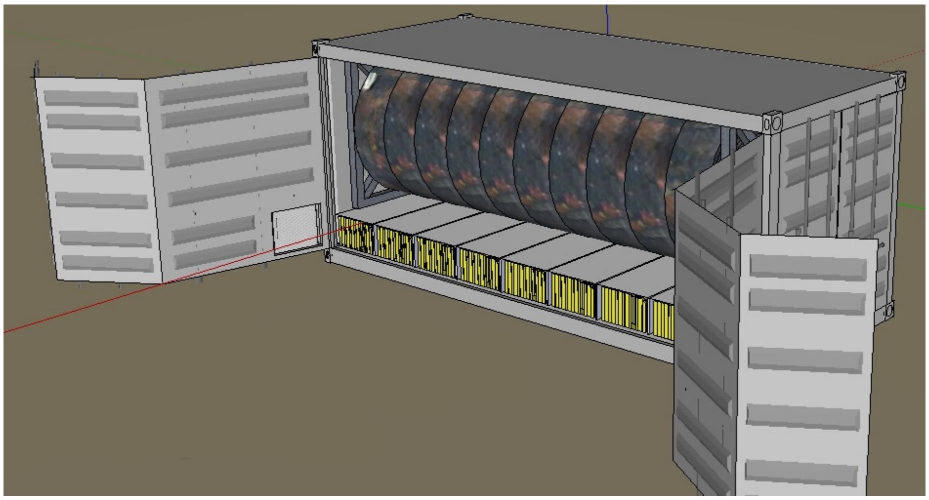

FIGURE 3-1 A containerized system of 100 kW rolls of flexible photovoltaic cell arrays. SOURCE: Courtesy of John Hingley, Founder, Renovagen Ltd. Additional information is available at http://www.renovagen.com.

Finding 3-21. Flexible photovoltaic cells could be an integral part of the electricity supply for a wide variety of applications, including tensioned awnings of photovoltaic cells and spools that are delivered in containers. This could improve expeditionary operational energy capabilities and reduce the requirements for fuel delivery to a given location.

Small Modular Nuclear Reactors

Where operational and security considerations permit, small modular nuclear reactors (SMRs) could replace generators for large bases in rear areas. SMRs, as defined by the Department of Energy, produce 300 MW_e or less of energy. They are built in factories and can be transported by truck or rail.[42] In the context of this report, SMRs for deployment to a staging area or forward operating base, there are emerging reactor design concepts that could be made transportable to the point of need by C-17s or via sea and land in just a few shipping containers. As described in Pfeffer and Macon (2001), an SMR could also be deployed to a remote theater on a barge. In addition to electricity, SMRs can be used to produce hydrogen, and subsequently alternative liquid fuels, as well as potable water. Many ground vehicles can be converted to run on alternative liquid fuels such as methanol. An SMR could also produce hydrogen for use in fuel cells; however, the storage and transportation of hydrogen in its elemental form can be difficult due to its combustible nature. In peacetime, SMRs could be used for humanitarian assistance and disaster relief, generating electricity and producing potable water.

[42] Department of Energy, “Small Modular Nuclear Reactors,” http://www.energy.gov/ne/nuclear-reactor-technologies/small-modular-nuclear-reactors, accessed March 30, 2014.

The DoD has been using small reactors for many years to provide power in remote locations and to power ships and submarines. With the primary focus on supplying power in remote areas, the Army Corps of Engineers maintained a Nuclear Power Program from 1952 until 1977, building stationary nuclear reactors at Fort Belvoir, Virginia, and Fort Greeley, Alaska, and "portable" nuclear reactors at Sundance, Wyoming, Camp Century, in Greenland, and McMurdo Sound in Antarctica (Magnuson, 2013; Pfeffer and Macon, 2001). The MH-1A Sturgis demonstrated the feasibility of putting a nuclear reactor on a barge. The Sturgis, the last nuclear power plant built and operated by the Army, provided electric power to the Panama Canal from 1968 to 1976. The U.S. Navy, operating more than 500 reactor cores in over 200 nuclear-powered vessels,[43] has accumulated more than 6,200 reactor-years of operational experience without a radiological incident.

Following several well-publicized catastrophic nuclear power plant failures, concerns over nuclear power safety have severely constrained development of new SMR concepts. However, there is evidence this is changing. For example, in 2010 the Defense Advanced Research Projects Agency (DARPA) issued a request for information on deployable reactor technologies for generating power and logistic fuels (DARPA-SN-10-37).[44] The goal was to

> Create a fieldable design that could be deployed to maritime and/or ground based forward operations to provide on-site power and fuel production capability in regions not connected to a robust grid and/or not easily accessible for fuel resupply.

According to the request for information, designs of interest would support an electrical load of 5-10 MW and would also produce 15,000 gallons per day of mobility fuel (e.g., JP-8) from a broad range of hydrogen and carbon feedstocks.

DoD has recently funded studies on the use of SMRs on DoD installations, including the 2011 Center for Naval Analyses study *Feasibility of Nuclear Power on U.S. Military Installations* (King et al., 2011) and the National Defense University's (NDU's) Institute for National Strategic Studies paper *Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications* (Andres and Breetz, 2011). The Center for Naval Analyses study showed how SMRs can contribute to DoD missions by increasing energy assurance at DoD installations at the same time as they reduce carbon emissions and reliance on fossil fuels for electricity. The NDU paper looks at the potential utility of SMRs from two perspectives: grid vulnerability (for U.S. military installations) and operational vulnerability (for deployed forces). From an operational perspective, the NDU paper suggests that SMRs could be instrumental in addressing DoD's challenge of fuel supply at forward operating bases but cautions that SMR designs have not yet been licensed by the U.S. Nuclear Regulatory Commission for commercial use let alone military applications.

More recently, the Defense Science Board was asked by the Under Secretary of Defense for Acquisition, Technology and Logistics, to form the Committee on Energy Systems for Forward/Remote Operating Bases. In a February 2014 memo providing the terms of reference for the study, the committee was directed to

> Examine the feasibility of deployable, cost-effective, regulated, and secure small modular reactors with a modest output electrical power (less than 10 megawatts) to improve combat capability and improve deployed conditions for the Department of Defense (DoD) (Kendall, 2014.)

The committee is not aware of any current SMR designs that would meet Army requirements for use as a transportable nuclear power source. The committee does believe, however, that, given Army-

[43] World Nuclear Association, "Nuclear-Powered Ships," http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Transport/Nuclear-Powered-Ships/, accessed March 30, 2014.

[44] FedBizOps.gov, "Request for Information (RFI) on Deployable Reactor Technologies for Generating Power and Logistic Fuels," Solicitation Number: DARPA-SN-10-37, changed May 05, 2010, http://www.fbo.gov/index?s=opportunity&mode=form&id=6a303cc531086d5b4f3cdf374e9b219c&tab=core&_cview=1.

issued specifications, there are technologies that could be modified to produce a safe, secure, and transportable design that would produce electricity and process heat that could be used to produce alternative liquid fuels and potable water.

This committee did not have the expertise to study the current state of nuclear power technology, Army requirements for SMRs, or risks, costs, and benefits associated with deployment of SMR technologies. However, transportable nuclear power plants were considered in some detail in the 1999 National Research Council report *Reducing the Logistics Burden for the Army After Next: Doing More with Less* (NRC, 1999). It is clear now, as it was in 1999, that SMR technologies, if developed to a point where they are deemed sufficiently safe and ready for deployment into an operational theater, would represent a game-changer for Army logistics by eliminating a significant fraction of current fuel requirements.

Finding 3-22. Deployable small modular reactors offer the promise of game-changing impacts to Army logistics if deployed at large bases in rear areas.

Recommendation 3-19. The Army should stay abreast of Department of Energy and Department of Defense research and development initiatives for small modular reactors (SMRs). Army logistics planning should include the possibility that SMRs will provide abundant electrical power, fuel, and water for its deployed forces.

AMMUNITION

Ammunition is the third greatest logistics burden after water and fuel. There are some immediate and near-term approaches the Army can use to address the ammunition logistics demand and some other options that could have a significant impact when the Army replaces its small arms.

Any consideration of Army munitions naturally divides into two categories: small-caliber rounds (e.g., .50 caliber, 7.62 mm, and 5.56 mm) and larger rounds, such as artillery ammunition. To reduce the ammunition logistics burden, it is necessary to either reduce the number of rounds being used, ammunition weight, or both.

Small-Caliber Ammunition

The dominant demands for small-caliber ammunition are for .50 caliber, 7.62 mm, and 5.56 mm rounds. For infantry logistics, it may be useful to view 10 kilograms as comprising 660 rounds of 5.56 mm ammunition, 280 rounds of 7.62 mm ammunition, or 85 rounds of .50 caliber ammunition. This does not include the weight of packaging materials and shipping containers. As shown in Box 3-3, a tremendous amount of ammunition is produced in the United States.

BOX 3-3
The Ammunition Industrial Base

Most Army small-caliber ammunition is manufactured by a government-owned, contractor-operated plant in Lake City, Missouri. This plant can produce 85 million rounds of .50 caliber, 230 million rounds of 7.62 mm, and 1.2 billion rounds of 5.56 mm ammunition annually. During Operation Iraqi Freedom and Operation Enduring Freedom, total ammunition demands have exceeded these capacities by about 15 percent, and the balance has been contracted out to private producers, as are much smaller quantities of eight other types of small-caliber ammunition, such as customized Special Operations Forces ammunition, representing less than 5 percent of total demand (U.S. House of Representatives, 2005).

Caseless, Polymer-Cased, and Case-Telescoped Ammunition

Caseless, polymer-cased, and case-telescoped ammunition have been tested by the Army and Marine Corps as part of the Lightweight Small Arms Technology program. Caseless rounds have no steel or brass case. In polymer-cased ammunition plastic replaces the steel or brass case. Case-telescoped ammunition packages the bullet partially or entirely in the propellant, resulting in a more compact round; individual rounds weigh only 40-50 percent as much as conventional cartridges, and their ballistic performance is no different from that of conventional rounds. Unfortunately, these rounds require the procurement of redesigned carbines and machine guns, but the designs exist and have been successfully tested (Sanborn, 2012a). A 40-50 percent reduction in weight per round is a significant reduction in the ammunition logistics burden and in the soldier's load.[45]

Finding 3-23. A 50 percent reduction in ammunition weight will have an associated reduction in logistics demand.

Recommendation 3-20. As the Army considers replacing small-caliber arms, it should pursue caseless, polymer-cased, or case-telescoped small-caliber ammunition.

Replacing Lead Bullets

It appears to be possible to replace lead bullets with copper bullets that would provide increased consistency in terms of effectiveness. Copper bullets can be machined with much more precision that swaged ones.[46] This reduces ballistic wobble during flight and produces much more consistency. The Army has introduced the M855A1 5.56 mm Enhanced Performance Round into Afghanistan for the M16 and M4 carbines. This round replaces a legacy lead-core bullet with one having a copper core. In tests, the improved rounds are more consistent from shot to shot and more effective. This can serve to reduce the number of rounds that need to be fired and, thus, delivered. The weight per bullet is about the same, but the bullet is slightly longer (Lopez, 2011).

There are some challenges in adopting these new rounds. Some problems have been reported, with the short-barreled M4 permitting muzzle flash from unburned powder in this round (Lopez, 2011). Also, copper is lighter than lead, so the bullet has to be longer, as was mentioned above. This can be exploited by a gun barrel with a faster rifling twist, but this would necessitate changing barrels. Changing gun barrels would be expensive for the Army, but if the Army is considering new caseless ammunition, which would require all-new weapons, perhaps there is an opportunity for a qualitative improvement in shot-to-shot consistency and thus accuracy by adopting copper rounds across the force.[47] The impact of this improvement in consistency and accuracy would be apparent only to the extent that shots are aimed. In previous conflicts—for example, Vietnam—most shots were unaimed. Obviously, no benefit would accrue for unaimed shots.

Finding 3-24. Increasing the shot-to-shot consistency of small-caliber ammunition increases its effectiveness, potentially reducing the amount of ammunition that needs to be used and the logistical demand for ammunition.

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[45] Army Program Executive Office, Ammunition, 2014, "Reducing the Logistical Burden and the Soldier's Load," document forwarded to the committee from this office on May 15, 2014.

[46] Swaging, when applied to bullets, is defined as "forming projectiles (bullets, not loaded cartridges) using high pressure instead of heat, to flow the materials at room temperature within a closed high-strength die" (Corbin, "What is Swagging?," http://www.corbins.com/intro.htm, accessed November 3, 2014).

[47] Cutting Edge Bullets, "Copper vs. Lead," http://site.cuttingedgebullets.com/pages/lead_vs_copper, accessed November 4, 2014.

Recommendation 3-21. The Army should consider new bullet technology in concert with its evaluation of a lighter caseless round. The ideal outcome would be a more consistent, more effective round that weighs less, reducing both the number of rounds that need to be used and the per-round weight, thereby reducing the logistical demand for this ammunition.

Large-Caliber Ammunition

The light (9,000 pound), towed M777 155-mm howitzer is an important logistical improvement for the Army and Marines. It is air mobile (a C-130 can carry two of them, and the MV-22 or CH-47 can each carry one as an external sling load).[48] Each 155-mm round weighs about 100 pounds. The M982 Excalibur 155-mm precision-guided munition has a range of up to 25 miles and features not only jam-resistant global positioning system guidance and inertial guidance but also a seeker to identify moving, time-sensitive targets. It has a circular error probability of approximately 15 feet. The cost per round is approximately $54,000.[49] A simpler, and presumably cheaper, XM 1156 precision guidance kit has been developed for 155-mm shells that reduces circular error probability from 200 to 50 meters (Defense Industry Daily, 2014).[50]

Despite the increased cost (a standard 155-mm round costs between $500 and $2,000) the impact of a precision munition is multifold. While there will still be requirements for standard 155-mm rounds and saturating area fire, for many fire missions fewer rounds need to be fired to achieve the same effect. Accordingly, far fewer rounds need to be convoyed to the howitzers. This reduces fuel consumption and the need to convoy it along with the number and size of convoys and thus the exposure of convoys to attack. There is a logistics benefit spiral here that requires several iterations to completely assess.

Finding 3-25. Precision munitions offer the potential for significant reductions in munition expenditures and qualitative improvements in effectiveness. A reduction in munitions expended also has benefits in other areas, such as a reduction in fuel used to transport munitions and in the number of convoys necessary to do so. As noted in the 1999 NRC report on logistics, the effectiveness of precision munitions is directly related to the ability of the force to locate and precisely identify targets (NRC, 1999). Significant progress has been made in this regard.

Recommendation 3-22. The Army should adopt the use of precision artillery munitions as widely as practical within mission requirements.

Ammunition Packaging

Redesigning ammunition packaging could achieve two ends. First, by reducing weight, it would be possible to reduce the amount of fuel required to deliver it. Second, redesign to minimize waste would address the problem of waste management and disposal. As some wastes need to be retrograded, usually by truck, less waste could also save on fuel. Conventional ammunition packaging can weigh more than the ammunition it contains. A number of initiatives have introduced new, lighter packaging. For instance, 60-mm mortar rounds can be packaged in fiber tubes instead of metal tubes, and eight of these fiber tubes

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[48] GlobalSecurity.org, "M777 Lightweight 155mm howitzer (LW155)," http://www.globalsecurity.org/military/systems/ground/lw155.htm, accessed November 4, 2014.

[49] U.S. House of Representatives, "EXCALIBUR M982," Committee Reports, 112th Congress (2011-2012), House Report 112-493, http://thomas.loc.gov/cgi-bin/cpquery/?&dbname=cp112&sid=cp11284yHn&refer=&r_n=hr493.112&item=&&&sel=TOC_141977&, accessed November 4, 2014.

[50] Peter J. Burke, Deputy Product Manager, Mortar Systems, and Anthony Pergolizzi, Army Fuze Management Office, "XM1156 Precision Guidance Kit (PGK) Overview for 2010 Fuze Conference," presentation on May 12, 2010, http://www.dtic.mil/ndia/2010fuze/IVAPergolizzi.pdf, accessed November 4, 2014.

can then be packaged into a metal container that is stackable and movable by forklift. With some changes for high-explosive versus other sorts of mortar rounds, this packaging method reduces gross weight by about 25 percent. For high-explosive rounds, this lighter packaging still accounts for 48 percent of gross weight.[51]

Finding 3-26. Using conventional materials with innovative, redesigned packaging, the weight of transportable, packaged ammunition has been significantly reduced. Redesign can also be used to minimize the amount of waste left over from packaging.

Recommendation 3-23. The Army should consider replacing conventional ammunition packaging materials with advanced ones, such as carbon fiber tubes, as widely as possible. Also, packaging design should be examined with an eye to reducing leftover waste that needs to be disposed of.

Directed Energy

The committee did not explicitly investigate alternatives to conventional munitions but notes that several recent studies address progress and maturity levels for various emerging technologies, including directed energy (DE) technologies. While DE programs cover a broad range of potential applications across the Services and Joint programs, the Army High Energy Laser–Mobile Demonstrator (HEL-MD) (Figure 3-2) is noteworthy due to its recent technical progress, potential multirole tactical battlefield utility, and significant opportunities to both dramatically reduce (Class V) demand for ammunition and overall logistics support requirements.

FIGURE 3-2 The High-Energy Laser–Mobile Demonstrator (HEL-MD). The beam director is on top. SOURCE: Army vehicle-mounted laser successfully demonstrated against multiple targets, www.army.mil/article/116740/Army_vehicle_mounted_laser_successfully_demonstrated_against_multiple_targets/.

[51] Army Program Executive Office, Ammunition, 2014, "Reducing the Logistical Burden and the Soldier's Load," presentation forwarded from this office May 15.

HEL-MD is a mobile, self-contained, solid-state, high-energy laser undergoing test and evaluation at the High Energy System Test Facility, White Sands Missile Range. The tactical air and missile defense system is designed to defeat multiple threats: rockets, artillery, and mortars; unmanned aerial vehicles; cruise missiles; and also ground-based explosive ordnance disposal. Two platform variants are currently anticipated. A heavy version would be mounted on a heavy expanded mobility tactical truck (HEMTT). A light version would be mounted on an M1126 Stryker fighting vehicle. Recent test results in realistic threat scenarios have been encouraging, suggesting some of the anticipated technological challenges are being rapidly overcome (Parsons, 2014).

Currently at TRL 6, the program underwent an analysis of alternatives (Indirect Fire Protection Capability/Intercept - IFPC2-I), which began in July 2011. The alternatives being compared included various guns (20-, 25-, 30-, 50-mm), missile, and DE (50 and 100 kW solid-state laser) options. The U.S. Army Training and Doctrine Command's Army Capabilities Integration Center reported that the analysis indicated that the HEL-MD can conduct operations immediately (transportable by air, sea, and ground), can be tailored to the mission at the tactical edge, and is self-sustaining with significant logistics demand reduction.

This last study insight—reduced logistics burden for tactical formations—is especially important. For illustrative comparison, a standard 3-4 second burst of 20 mm HEIT-SD ammunition from a Vulcan Ground Based Air Defense System consumes a full canister of ammunition, which weighs about 50 pounds and takes two of the four crew members to manage. In contrast, for a 4-second lethal burst from HEL-MD, the ammunition equivalent is 1.5 cups of diesel fuel. In effect, the 20 mm Class V requirement is completely eliminated and replaced with a much smaller demand for Class III (multipurpose diesel fuel). The reduction in both weight and volume is significant. The single-shot kill probability is much greater for HEL-MD, and the crew manpower requirement is cut in half.

Finding 3-27. Among the many programs with a wide variety of applications across several domains (maritime, space and missile defense, ground-based air defense, etc.), one Army program in particular has achieved significant success: the High Energy Laser–Mobile Demonstrator (HEL-MD). The interacting effects of system effectiveness (lethality) and logistics reduction potential are so significant that the cost exchange ratio can actually be reversed.

Recommendation 3-24. The Army should accelerate the remaining HEL-MD test schedule. Pending success, and consistent with risk mitigation strategies, the Army should expedite production, deployment, and fielding of systems derived from the HEL-MD.

Reducing the Ammunition Burden

Ammunition will continue to be one of the top three logistics burdens in terms of cost, tonnage, and bulk to be transported. Because of its special nature as an explosive, ammunition transportation is also subject to many restrictions. Anything that can be done to reduce this burden along the length of the ammunition supply chain is important.

Ammunition is produced in specialized plants in response to demands that are related to various, but not necessarily coordinated, drivers, including the requirements of the other Services and allies. As indicated in Box 3-3, the Army-controlled ammunition plants are not always able to satisfy requirements, so commercial firms have been called on to fill the gaps.

Ammunition storage once it leaves the production facilities is another challenge. As a result of fiscal constraints, the Army has, in some cases, moved ammunition directly from the plants to users, bypassing the depot system and thereby providing savings on handling.

As discussed earlier in this section, a significant part of the ammunition tonnage that must be moved is the packing material necessary to protect it. The nature of the packing material and containers affects the Army's ability to move ammunition on vehicles and aircraft and generates waste that must eventually be disposed of. Efforts to look at ways to reduce the impact of packing materials have generally been given a lower priority for funding than other aspects of the ammunition programs. Figure 3-3 shows soldiers unpacking ammunition from current packaging.

The committee attempted to determine how, in planning and systems analysis efforts, ammunition demands for future operations are being calculated. It found that there is heavy reliance on historic consumption data going back as far as the middle of the last century and that today's basic loads are similarly tied to historical loads. For specific exercises or modeling efforts, planners and analysts make judgments based on their professional experience. This committee has found little indication that any information on ammunition usage patterns in OIF or OEF has been collected or that it is influencing decisions for the present or future. Few, if any, of these analyses have considered the totality of the fires picture, and the trade-offs between conventional ammunition, precision ammunition, new technologies such as directed energy, and fire support provided by the other Services.

Several studies by the Government Accountability Office and others and research efforts (Hancock and Lee, 1998; GAO, 1999, 2005, 2011, 2014; Mullen, 2002; Freeman, 2005; and Mengel, 2005; Siekman et al., 2010) have pointed out the challenges in management of the supply chain of ammunition. Army responses to these efforts have focused on particular findings and, as a result, major improvements have been made in the management and responsiveness of ammunition logistics.[52] Little has been done, however, to undertake a true supply chain analysis.

FIGURE 3-3 Soldiers unpack ammunition and prepare it for use during predeployment training at Fort Riley, Kansas. SOURCE: Cook (2010).

[52] Joint Munitions & Lethality Life Cycle Command Overview, Program Executive Office Ammunition, provided to the committee on July 15, 2014.

SOLDIER POWER

Soldier power is not a major logistics demand in terms of tonnage. But it is of keen interest to the Army. Improving the soldier power situation could reduce the battery load that soldiers have to carry, and thus battery demand, and could simplify operations for soldiers on patrol. Soldier power encompasses expeditionary power solutions intended to provide power to devices the soldier carries, in the most austere operating environments. These solutions include soldier power generation systems; renewable energy; lightweight power distribution, power management, and power storage solutions; and soldier portable and wearable power systems.

Soldiers carry spare batteries to last for a 72-hour mission, even though few missions last this long. As most systems have battery durations of 8 hours or less, soldiers must be prepared to make battery exchanges several times for each of their systems over the course of a potential 72-hour mission. The total weight of all the batteries a soldier must carry is on the order of 14 pounds. A U.K. study found each soldier carried 27 pounds of batteries for a 36 hour patrol (SoldierMod, 2012).

Soldiers frequently replace batteries, whether or not this is needed. There is no visible state of charge indicator, and it has been reported anecdotally that many batteries are disposed of with nearly 100 percent of their charge remaining. Because soldiers currently have no way of knowing how much charge is left in a battery, they understandably want fresh batteries for every mission. Thus, many more batteries may be being used than necessary, with obvious implications for logistics, both in weight transported and in money wasted that could be spent elsewhere.

Operational energy initiatives related to soldier power examine the number of batteries soldiers must carry and how often they need to replace them and focus on better management of the power to the equipment they carry. In addition, the Army is investigating the potential for net zero energy, which is the ability for soldiers to produce sufficient energy to power their own individual equipment. Some possible technology solutions are discussed below. But in the meantime, an effective short-term step could be charge meters on batteries. Some commercial batteries already have built-in charge indicators. Putting such indicators on military batteries would give soldiers more confidence in the charge state of charge of their batteries, resulting in the use of fewer batteries.

Finding 3-28. Reduction in the number and types of batteries soldiers have to carry and better management of the power to the equipment and tools they carry would ease the demand on logistics systems by reducing the demand for batteries.

Finding 3-29. State-of-charge indicators on batteries would allow soldiers to have confidence in the actual state of charge of their batteries and, with appropriate command guidance, would allow fewer batteries to be used.

Recommendation 3-25. The Army should require that the batteries it uses have state-of-charge indicators so soldiers can have more confidence in their batteries.

Solar Battery Charging

Solar rechargeable batteries may reduce or eliminate the need for soldiers to carry spare disposable batteries. Work is currently ongoing to develop wearable solar-coat chargers for batteries. This is one example of many applications that are now practical for crystalline silicon photovolatic cells.[53] The Army is also researching this approach, as well as weaving photovoltaic fibers into clothing.

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[53] "SWIPES, the Integrated Power Source," http://science.dodlive.mil/2014/02/18/swipes-the-integrated-power-source/, accessed June 27, 2014.

Finding 3-30. Flexible photovoltaic cells emplaced on soldier's clothing could reduce the number of batteries soldiers have to carry.

Lithium–Air Batteries

Lithium–air batteries hold the promise of significantly outperforming lithium-ion batteries. Rechargeable lithium-ion batteries have already been deployed in a variety of applications, including soldier power, computers, and transportation. The energy density of these lithium-ion batteries is of the order of 150-200 Wh/kg. By way of comparison, the energy density of lithium–air batteries could theoretically be equal to the energy density of gasoline. It is estimated that lithium–air batteries could hold 5-10 times the energy of lithium-ion batteries of the same weight and twice the energy in the same volume (Zyga, 2011). They have the potential of achieving the energy density in the range of 2,000-3,500 Wh/kg. Lithium–air batteries are already being examined for use in hybrid-electric and electric vehicles. Toyota Motor Corporation and BMW have announced a joint research program on a lithium–air battery technology that is expected to be more powerful than the lithium-ion batteries currently used in many hybrid-electric and electric vehicles (Kubota, 2013). IBM is working to develop a lithium–air battery that will let electric vehicles run 500 miles on one charge.[54] Researchers have already demonstrated a coin-sized rechargeable lithium–air battery with a current density of 600 mAh/g. This is much greater than the 100-150 mAh/g current densities of lithium-ion batteries (Zyga, 2011). Because of their higher energy and current densities, lithium–air batteries could reduce the number of batteries needed for soldier power and reduce total fuel consumption for vehicles. The Army Research Laboratory is engaged in research on lithium–air batteries and has developed improved electrolytes and longer-lasting lithium–air batteries (Margulies and Read, 2007).[55,56]

One of the biggest challenges with lithium–air battery technology is the limited number of charge and discharge cycles of such batteries. While single-use lithium–air batteries are already in use to power things like hearing aids, batteries that can be recharged thousands of times still need further development (Zyga, 2011). Several companies are making progress in this area.[57] For example, PolyPlus is developing rechargeable and nonrechargeable lithium–air and lithium–sea-water batteries based on protected lithium electrodes.

Finding 3-31. Lithium–air batteries have a very high energy density, longer life span, and higher power density than lithium-ion and conventional batteries. This technology holds the potential to significantly reduce the number of batteries soldiers must carry and, accordingly, the number of batteries that must be recharged or delivered fresh to the unit. In addition, in the longer term, they can also be used for vehicle propulsion systems, thus extending the range and reducing total fuel consumption.

Recommendation 3-26. The Army should continue its research in lithium–air batteries for soldier power and other applications and leverage commercial investments in lithium–air battery technologies that can be applied to Army requirements. An emphasis should be placed on rechargeable lithium–air batteries.

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[54] IBM, "Lithium/Air Battery Project (Battery 500)," http://researcher.watson.ibm.com/researcher/view_group.php?id=3203, accessed November 5, 2014.

[55] U.S. Army, Army Research Laboratory, "Improved Electrolytes for Lithium/Air Batteries," Technology Fact Sheet, http://www.arl.army.mil/www/pages/556/0137TFSImprovedElectrolytesLiAirCells.pdf, accessed November 5, 2014.

[56] U.S. Army, Army Research Laboratory, "Longer Lasting Lithium/Oxygen Battery," Technology Fact Sheet, http://www.arl.army.mil/www/pages/556/0941TFSLongerLastingLiAirBattery.pdf, accessed November 5, 2014.

[57] IBM, "Lithium/Air Battery Project (Battery 500)," http://researcher.watson.ibm.com/researcher/view_group.php?id=3203, accessed November 5, 2014.

Small Radionuclide Power Sources

Another technology that could address the long-term the need for electric power and reduce the logistics demand could be small radionuclide power sources. Indeed, such power sources could dramatically slash battery consumption and even eliminate the need for batteries in certain applications. Conceptual designs exist for D-cell sized radionuclide power sources. Figure 3-4 shows two such concepts. Such sources could potentially deliver 1-5 W of power constantly for several years. In some cases, it might be possible to build very small milliwatt-level radionuclide power sources directly into certain devices, entirely eliminating the battery logistics tail for devices so equipped. Broad experience with this type of power source for medical purposes and exit signs, and with the shipment and handling of radionuclides, give reasons to be optimistic about implementing a small radionuclide power source that poses no significant or insurmountable technical or safety problems. Still, it is expected that a significant amount of additional research and development work will be necessary to bring these power sources to the field. Despite the promise of this power source, research is currently being done on only a small scale with very little funding. With adequate effort and resources, it seems possible that small radionuclide power sources could be ready for fielding in the 2030 time frame. (DSB, 2013)

Finding 3-32. Small radionuclide power sources could significantly reduce the battery logistics demand and the number of batteries soldiers must carry. This is a long-term effort.

Recommendation 3-27. Given their promise, the Army should closely monitor the research and development of small radionuclide power sources by industry and other government agencies, with a goal of eliminating as many replaceable batteries as possible.

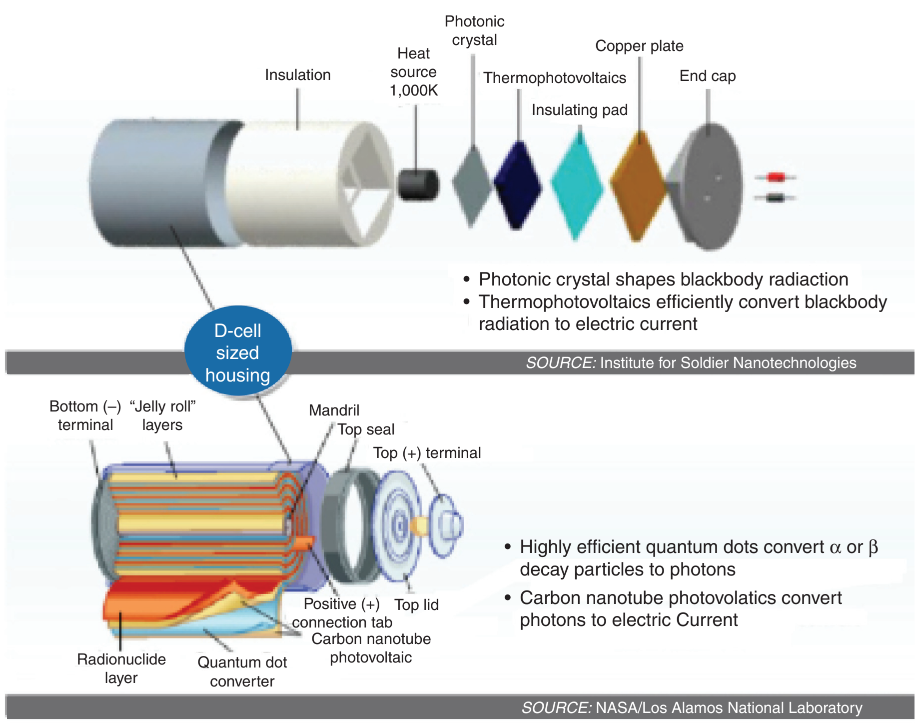

FIGURE 3-4 Two concepts for D-cell sized radionuclide power sources.
SOURCE: DSB (2013).

Battery Charging Methods

Rechargeable batteries require, of course, battery chargers, which in turn add to the systems and weight that must be carried by soldiers. There is little commonality of battery type among the devices soldiers carry: They have to carry different types of batteries with different voltages depending on the type of device being powered. This complicates the charging process by necessitating the use of multiple battery chargers; a different charger for each different battery type. Currently, the Army's Standard Battery Charger is either a vehicle-mounted or a tabletop unit about the size of a suitcase. It is reported not to be very efficient and does not work well with the latest military batteries (Szondy, 2013). Hence there is a need to find compatible charging methods that are lighter, faster, and usable anyplace. The following are a few alternative methods for charging batteries that would be an improvement over the current state of affairs.

Single Charger for Various Batteries

The Army is already working on the development of a lightweight universal battery charger (Rominiecki, 2013). It is a lightweight, portable charger that can charge numerous battery types simultaneously, including the conformal battery discussed below, that will work with any power source—from a generator to a car cigarette lighter—and has a built-in solar panel that could be used when no other energy source is available. For example, using power electronic converters, a photovoltaic-based power generation unit can also be integrated into universal battery charger solutions. Leading providers include SolarEdge, Tigo Energy, ST Microelectronics, Power-One, Ampt, and Maxim Integrated.

Finding 3-33. Universal battery chargers eliminate the need for having different chargers for different types of batteries. They are lightweight, portable, and can be combined with a variety of power sources.

Recommendation 3-28. The Army should continue to advance the universal battery charger technology and work with the companies engaged in this area to deploy them as soon as possible.

Wireless Power Transfer

It might be possible to eliminate the need for hard-wired battery chargers. A number of companies are developing inductive charging and/or highly resonant magnetic coupling technologies that use electromagnetic fields to transfer energy to charge batteries for portable equipment and for electric vehicles. Automakers like BMW and Nissan are developing wireless charging options for electric cars. With further advances in these technologies, wireless charging will be prevalent for future electric vehicles—manned and unmanned—and portable equipment and devices. Wireless power transfer for the various electrical units within a soldier rucksack could eliminate the need for thick cables and other power distribution devices. This would reduce the total weight of the soldier power unit. Wireless power distribution within the rucksack, combined with intelligent power management, discussed below, could significantly reduce the weight of batteries and also the number of primary cells carried by dismounted soldiers.

Finding 3-34. Wireless charging has the benefits of improving and automating the battery recharging process and reducing the number of batteries needed for soldier power.

Recommendation 3-29. The Army should develop a plan to evolve to a wireless charging and wireless power distribution system.

Soldier Power Integration and Management

Recently, the Army has been using the Integrated Soldier Power and Data System (ISPDS), which enables up to four soldier-borne devices to be powered by a central conformal battery, reducing the number and types of batteries that must be carried by the soldier.[58] The number of devices that can be recharged using the ISPDS can be increased through the use of expansion hubs. This battery unit is adaptive, lightweight, and significantly extends the duration of available power. This technology can also eliminate the need for spare batteries of different types for each individual system. Additionally, ISPDS allows for sharing of the data across devices and enables a soldier to be power aware—that is, aware of how much power is being used—and therefore be able to use it more efficiently, lessening the demand for battery recharging. The ISPDS treats soldier-operated electronics as a system rather than as a set of independent components. However, the ISPDS does have some limitations:

- It does not connect to the items on the helmet, rifle, or in the rucksack. It only connects to items worn on the vest.
- Weight savings are not fully achieved, because the total number of batteries carried by the soldiers is still high.
- It is limited in the maximum power that can be provided to any device.
- The recharge time for the device is long and may require that the vest be disassembled.

Draper Laboratory conducted a study to further enhance the ISPDS and reduce its total weight. It has proposed a new design called Fully Connected Power and Data Architecture. This architecture is expected to reduce battery requirements from the ISPDS baseline and to provide power from a combination of two or more sources such as conformal batteries, batteries, or fuel cells carried in the rucksack. It should be able to connect to rifle and helmet-mounted devices, allowing scopes, night vision, and heads-up displays to be powered by the conformal batteries. The connection to the rucksack will enable it to power mission-specific equipment, such as signals intelligence or counter-improvised explosive device (IED) equipment. It would also allow soldiers to be power aware, providing them confidence that their equipment can stay charged throughout a mission.[59]

Finding 3-35. Although the Integrated Soldier Power and Data System is a step in the right direction, it still does not solve many of the problems related to weight, ease of use, recharge time, and the significant number of batteries that would still have to be carried by the soldier. The Fully Connected Power and Data Architecture proposed by Draper Laboratory has the potential to solve many of these problems.

Recommendation 3-30. The Army should continue to work with the Draper Laboratory to advance the research on the Fully Connected Power and Data Architecture and implement these systems as soon as possible.

The committee is aware that the diversity of batteries soldiers must carry is a problem for them. The 2013 NRC report *Making the Soldier Decisive on Future Battlefields* addresses this (NRC, 2013):

> Numerous batteries of varying sizes, shapes, and power outputs must be used by dismounted Soldiers and TSUs as power sources, and spares for all of them must be carried, as part of the Soldier load, to meet the nominal dismounted operation time requirement of 72 hours. (NRC, 2013, p. 160)

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[58] "Individual Equipment and Weapons," Army Magazine, October 2012, http://www.ausa.org/publications/armymagazine/archive/2012/10/documents/weapons7_1012.pdf.

[59] Committee discussion with Draper Laboratory staff on March 14, 2014.

This is a systems engineering problem. In this regard, the 2013 report, in its Recommendation 2, calls for the following:

> The Army should establish a Systems Engineering executive authority to support a system-of-systems engineering environment that will be responsible for developing methodologies and analytical tools to evaluate and acquire total system solutions for the dismounted Soldier and TSU. This executive authority must have sufficient seniority, influence, and budget control to operate effectively across the entire Army acquisition community (including research and development, test, and evaluation) in executing its systems engineering mission (NRC, 2013, p. 3).

This committee agrees with the 2013 report about battery diversity and the need for systems engineering to solve the problem of the diversity of batteries soldiers have to carry. This is something that needs to be addressed.

Finding 3-36. There has been little discipline in reducing the number of different batteries now used.

Recommendation 3-31. The Army should identify a small set of battery types and develop a strategy to incentivize the use of these battery types in future equipment development.

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4

Logistics Mobility

For the purposes of this report, mobility is broken into three groupings: mobility to and within a theater, logistics over the shore, and mobility ashore. Most of the intertheater mobility assets are owned by the Air Force and the Navy. The majority of materiel moved into a theater and operational area will be moved by sea. In the realm of intratheater transportation, the Army has assets that can be used in addition to the available Air Force and Navy assets. Army assets will become more dominant in the ship-to-shore regime. There are a number of Army and commercial watercraft for moving materiel to the shore. Finally, the movement of material once ashore to the operational area will be handled by Army and Defense Logistics Agency assets.

The challenges of not having a port in the area of operations were demonstrated by the U.S. experience in Afghanistan, which is landlocked. It has therefore been necessary to rely on complex overland and air networks from distant ports. These are vulnerable to political disruptions in addition to more conventional military threats. The spread of anti-access/area-denial (A2/AD) technologies, strategies, and tactics makes logistics operations riskier and more difficult. For instance, in hostile areas, the Department of Defense (DoD) plans for ships to lay at least 25 miles offshore and offload their contents to various connectors—smaller watercraft—that will then make the run in to shore (CBO, 2007). Once at the shore, it is possible that there will be no port, or that a port will be inadequate to move the necessary materiel ashore, resulting in a reliance on lighterage and causeway systems or on connectors that can beach themselves or move over the beach.

Thus, improvements in mobility could produce significant benefits for sustainment operations. Improved vessels could move more supplies more quickly to and within the theater. Improved connectors could do the same for the movement of materiel from ship to shore. Current systems would take several hours to transit from ship to shore, offload, and then return to the ship. There are technologies that could be used for the final transportation legs, to a forward logistics base and then to the forward troops, that would take personnel out of harm's way.

MOBILITY INTO THE THEATER AND WITHIN THE THEATER

Each contingency operation brings with it unique challenges. The Army's initial reaction forces in a contingency would probably draw on theater prepositioned stocks, APS-3 (Afloat).[1] Based on the requirements dictated by the supported combatant commander, follow-on forces would flow into the theater according to the time-phased force and deployment data.

U.S. Army Field Manual FM 100-17-3 outlines the processes for forward movement of forces in response to crisis contingencies, including combat operations (DA, 1999). It points out that while most of the troops will deploy by air, 90 percent of their equipment and vehicles will deploy by sea due to weight considerations. While prepositioned stocks may be available to support initial operations, the sustainment of operations will require establishment of a sea bridge. The sea movement of equipment and supplies is

[1] These are equipment and sustainment supplies prepositioned afloat on ships for rapid access and use in event of need.

entirely dependent on having access within the theater of operations to adequate port facilities to offload or transload the inbound materiel. The overall force projection process is shown in Figure 4-1. Forces and materiel move from home stations in the United States to air- and seaports of embarkation. From there they can move to intermediate staging bases, depots, or directly to air- and seaports of debarkation. At this stage personnel can be married up with prepositioned materiel. From there they move to the fight. Figure 4-2 shows the same process using the strategic mobility triad of air transport, sea transport, and prepositioned materiel in a simplified form.

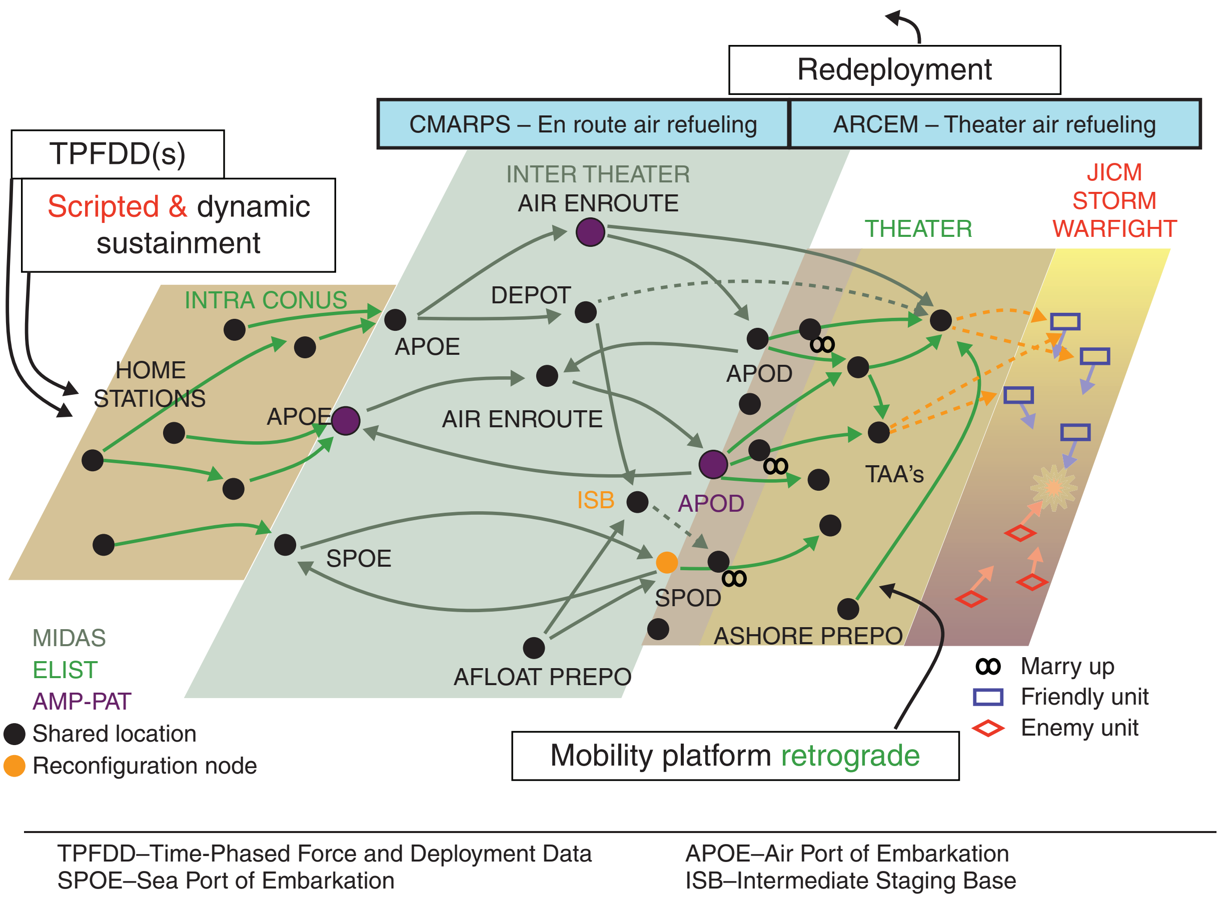

FIGURE 4-1 MCRS-16, modeling and simulation overview of the flow of forces and materiel from the United States to an overseas contingency. NOTE: AMP-PAT, Analysis of Mobility Platform—Port Analysis Tools; APOD, airport of debarkation; APOE, airport of embarkation; ARCEM, Air Refueling Combat Employment Model; CONUS, continental United States; CMARPS, Combined Mating and Ranging Planning System; ELIST, Enhanced Logistics Intratheater Support Tool; ISB, intermediate staging base; JICM, Joint Integrated Contingency Model; MIDAS, Model for Intertheater Deployment by Air and Sea; PREPO, prepositioned; SPOD, seaport of debarkation; SPOE, seaport of embarkation; TAA, tactical assembly area; TPFDD, time-phased force and deployment data. SOURCE: Jackson (2009).

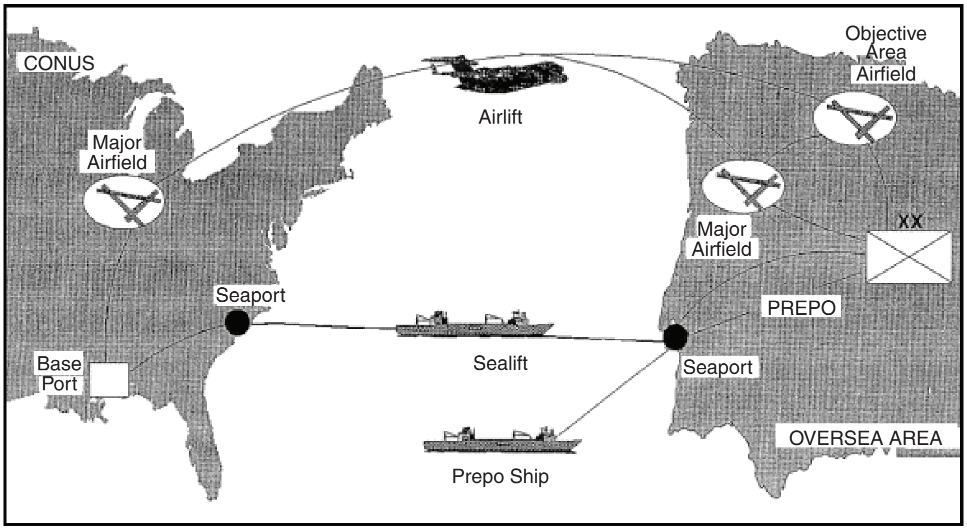

FIGURE 4-2 The strategic mobility triad. NOTE: CONUS, continental United States; PREPO, prepositioned. SOURCE: U.S. Army, *Movement Control*, Field Manual No. 55-10, Headquarters, Washington, D.C., February 1999, available at http://www.globalsecurity.org/military/library/ policy/army/fm/55-10/ch1.htm.

Airlift

For air movement to theater, the Air Force has a fleet of 223 C-17s and a varying number of C-5 aircraft to move large quantities of materiel quickly.[2] When speed is imperative for the initial deployment, the C-17 has the unique ability to go from a major airfield into semi-improved airfields. In November 2001, C-17s landed in the dark on a dirt runway at Camp Rhino in Afghanistan, delivering 481 Marines and 970 short tons of equipment over 8 days. It was the first-ever C-17 combat dirt landing using night-vision goggles (Young, 2011).

The Air Force C-17 and C-5 fleet is part of Air Mobility Command and operates at the direction of the U.S. Transportation Command's (TRANSCOM's) Tanker Airlift Control Center. The Director of Mobility Forces is the key to execution of the support for U.S. Army theater operations. The execution phase is controlled by the Airlift Control Team and the Air Mobility Control Team. According to a U.S. Air Force Fact Sheet on the Air Mobility Division,[3]

> Airlift Control Team (ACT) provides intra-theater airlift functional expertise from the theater organizations to plan, coordinate and integrate the full range of mobility airpower capabilities at the operational level for intra-theater airlift operations in the area of responsibility. Airlift Plans is responsible for completing the airlift portion of the air tasking order by processing validated airlift requests received. . . and merging them with forecast inter-theater airlift movements into the area of responsibility.
>
> . . . Air Mobility Control Team (AMCT) provides Combat Air Operations Center (CAOC) centralized control of all intra-theater airlift operations in the AOR. The AMCT directs or

[2] The total number of C-5s in the fleet changes monthly. This number is based on congressional approval of C-5A retirements. 52 C-5Ms are scheduled to be in service by FY2017 and 16 had been delivered as of December 31, 2013 (U.S. Air Force, "C-5 A/B/C Galaxy and C-5M Super Galaxy," published May 15, 2006, http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104492/c-5-abc-galaxy-c-5m-super-galaxy.aspx).

[3] U.S. Air Forces Central Command, "Air Mobility Division (AMD)," Fact Sheet, published September 8, 2009, www.centaf.af.mil/library/factsheets/factsheet_print.asp?fsID=12153&page=1.

redirects, as required, air mobility forces in concert with air and space forces to respond to requirement changes, higher priorities, or immediate execution limitations. The AMCT integrates and synchronizes all air mobility operations into, out of, and within the AOR. The AMCT maintains execution process and communications connectivity for tasking, coordinating and flight following with the CAOC's Combat Operations Division, subordinate air mobility units, and mission forces.

For intratheater airlift and support, the Air Force has C-130 aircraft. The Army has a fleet of helicopters.

Sealift

Before discussing sealift and operations from ship to shore, it should be noted that the capabilities of various assets to conduct operations are impacted and limited by sea state. While sea state is widely used to express the harshness of conditions, it is not of itself adequate to express the full impact of rough seas. Nor does it take into account surf, which will impact sea systems such as causeways. Surf conditions are greatly affected by the state of the tide, swells, coastal currents, and wind strength. These impacts are not taken into account by "sea state." Sea state and surf are discussed at more length in Appendix D. As mentioned below in a number of places, many systems are designed to be usable only in sea states up to 2. Table 4-1 shows the percentage of time various littoral areas experience seas states of 3 or less. The corollary is that the remainder of the time, sea states are greater than 3.

The committee was briefed on a variety of sealift assets to address the movement, offloading, and transfer of materiel from the sea. The movement of a moderate-sized force into a semiaustere environment can be facilitated by the use of large, medium-speed, roll-on/roll-off ships (LMSRs), operated by the Military Sealift Command. A current-model LMSR has a cargo space of over 380,000 ft^2 and can carry a force of 58 tanks, 48 tracked vehicles, and more than 900 trucks and other wheeled vehicles. Internal ramps, a stern ramp, and removable side ramps facilitate the flow of vehicles within and the offloading of vehicles from the vessel to causeways and other receiving areas. An LMSR also has two cranes, allowing it to load and unload cargo onto a dock or causeway or into smaller vessels alongside in the absence of adequate port infrastructure.[4] Sea state can be a limiting factor in these operations.

TABLE 4-1 Percentage of Time Different Littoral Areas Experience Sea State 3 or Less

Littoral Area	Percent of Time	Littoral Area	Percent of Time
Western Atlantic	60	Mediterranean Sea	75
Eastern Atlantic	40	Persian Gulf	89
North Sea/English Channel	52	North Arabian Sea	73
Eastern Pacific	45	West Indian Ocean	52
Western and Southern Caribbean	53	Cape of Good Hope	21
Northeast South America	54	Gulf of Guinea	71
Western South Atlantic	43	Northwest Africa	48
Eastern South Pacific	40	East coast of Japan	48
Northwest South America	55	East coast of Philippines	62
Western Central America	73	Korean coast	71

SOURCE: DSB (2003).

Another asset is the Joint High Speed Vessel (JHSV), which will be operated by the Navy. In addition to providing intratheater transport, the JHSV will act as a connector between a sea base or a

[4] U.S. Navy, "Large, Medium-speed, Roll-on/Roll-off Ships T-AKR," last update August 31, 2009, http://www.navy.mil/navydata/fact_display.asp?cid=4600&tid=500&ct=4.

mobile landing platform (MLP), discussed below, and the shore (port, causeway, or beach).[5] In an A2/AD environment (no available port), the JHSV is designed to be self-sustaining and operate in austere and degraded environments. These ships are wave-piercing catamarans, run at 35-40 knots, and have a 1,200 mile range, a 600 ton capacity, and a 20,000 ft^2 mission bay. The JHSV can be quickly reconfigured to support a variety of missions. These missions can range from carrying hospitals or supplies for humanitarian relief missions, to transporting combat units and their equipment, including tanks and other vehicles. Ten are being built, with the last to be delivered in 2017.[6]

The MLP is a new addition to the nation's sealift capabilities. Its purpose is to facilitate the transfer of materiel from sea vessels to the vessels that will carry it to shore. The USNS Montford Point (T-MLP-1), the first of three vessels of this class, entered service in May 2013. The MLP is 785 ft long and displaces about 80,000 tons fully loaded. It is able to partially submerge. This allows the operation of various landing craft, including the landing craft air cushion (LCAC), from the deck. The MLP has 25,000 ft^2 of stowage space for vehicles and equipment and can store 380,000 gal of JP-5 naval aviation fuel. It has a top speed of 15 knots and a range of 9,500 nautical miles.[7] The third MLP will be modified as an Afloat forward staging base (AFSB).[8] An AFSB has decks, including a flight deck, and repair facilities and is able to support a variety of operations. Over the next 5 years, the Navy will field 2 MLPs, 2 AFSBs, and 10 JHSVs.[9] The combination of the LMSR, the JHSV, and the MLP/AFSB will provide the Army with the ability to operate in the austere environment of the Pacific. Figure 4-3 depicts an LMSR alongside, and transferring cargo to, an MLP.

Finding 4-1. There is a critical need to enhance the ability to deploy and sustain Army units and their heavy equipment to austere environments using a variety of vessels and platforms. This necessitates that Army leadership support expansion and rapid execution of the current and follow-on programs.

Recommendation 4-1. The Army should continue to work with the Navy to bring the synergy of the large, medium-speed, roll-on/roll-off ship; the Joint High Speed Vessel; and mobile landing platform together into an operational system to enhance its flexibility in responding to contingency operations. This necessitates that Army leadership press forward on achieving closure in this area by continued involvement in the U.S. Navy 30 year ship building program and pursuing congressional funding to execute procurement of these vessels and programs.

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[5] A sea base is one or more ships standing offshore serving as staging points for the delivery of personnel and materiel to the shore.

[6] U.S. Navy, "PEO Ships Joint High Speed Vessel (JHSV). Program Summary," http://www.navsea.navy.mil/teamships/PEOS_JHSV/default.aspx, accessed August 25, 2014.

[7] Naval-technology.com, "Mobile Landing Platform (MLP) Ship, United States of America," http://www.naval-technology.com/projects/mobile-landing-platform-mlp-ship, accessed August 25, 2014.

[8] General Dynamics NASSCO, "Mobile Landing Platform Fact Sheet," August 5, 2014, http://www.nassco.com/products-and-services/usn-dc/usn_dc_pdfs/MLP_Fact_Sheet.pdf.

[9] U.S. Navy, "CNO's Navigation Plan 2014-2018," http://www.navy.mil/cno/130813_CNO_Navigation_Plan.pdf, accessed August 25, 2014.

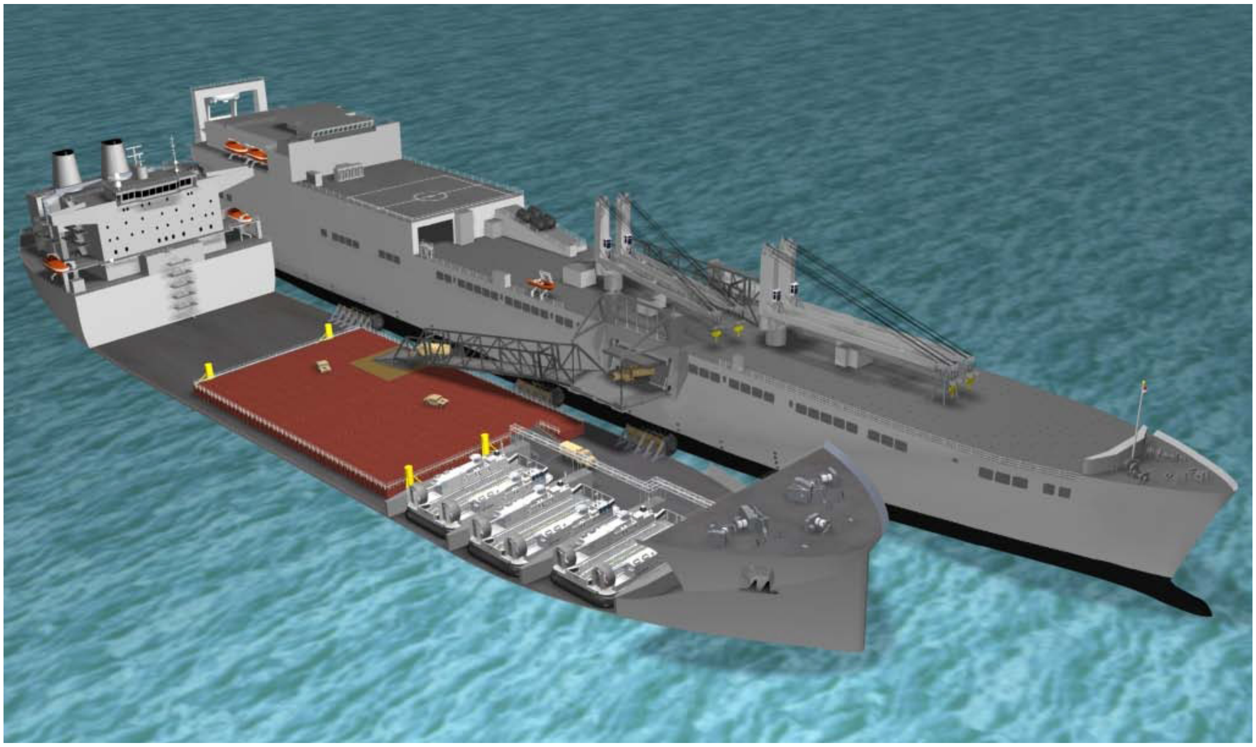

FIGURE 4-3 Artist's concept of an LMSR alongside, and transferring cargo to, an MLP. Note the three landing craft air cushions (LCACs) on the MLP. SOURCE: CAPT Henry Stevens III, Strategic and Theater Sealift Program Manager, PMS 385, "Joint High Speed Vessel (JHSV) and Mobile Landing Platform (MLP) Program," presentation to the Expeditionary Warfare Conference on October 27, 2011.

Hull-Borne Landing Craft

The Army plays an important role in moving waterborne cargo from ship to shore. To carry out these connector missions, the Army employs a variety of craft. In the absence of access to deepwater port facilities, material must move from oceangoing ships to inland points by moving over the shore, into estuaries, up rivers, or through underdeveloped ports. This is done using landing craft and causeway systems. For expeditionary forces, the traditional way of putting troops and material ashore also has been landing craft. The main classes of Army hull-borne landing craft are shown in Table 4-2.

Figure 4-4 shows a landing craft, mechanized (LCM)-8, Figure 4-5 shows a landing craft, utility (LCU)-2000, and Figure 4-6 shows an LSV.

The speeds of all of the hull-borne landing craft are in the 9-12 knot range. If they were to be used as connectors to ships lying a considerable distance offshore (over the horizon), their slowness would be a great detriment to any logistical effort. Also, the LCM craft have very limited capacity. Even the LCU craft lack sufficient capacity as the weight of Army and Marine Corps equipment has grown over time. The LCU-2000 can accommodate five M1 tanks or 29 20 foot containers. Also, the LCU and LCM craft are flat-bottomed and sensitive to sea state and surf conditions. Over the past two decades the Army's focus has been on the Middle East and not on a maritime or littoral environment. With the pivot to the Pacific, the importance of being able to move material and personnel quickly by water and over the shore looms large.

Finding 4-2. The landing craft currently in the inventory are an impediment to efficient logistics in the Asia-Pacific theater. They are aged, slow, have insufficient capacity, are too few in number, and are highly sensitive to sea state.

TABLE 4-2 Main Classes of Army Hull-Borne Landing Craft[a]

Class	Number	In Service	Payload (short tons)	Range (nautical miles)	Speed (knots)
Landing craft mechanized, LCM-8 (Mod. 1)	9 active Army 9 Army reserve 18 prepositioned	1967	53	271	9
Landing craft utility, LCU-2000	7 active Army 7 Army reserve 20 prepositioned	1990	350	6,500	10
Logistics support vessel (LSV)	5 active Army 3 Army reserve	1988	2,000	6,500	11.5-12

[a] Range and speed are when loaded.
SOURCE: CW4 Walter Ortiz, Marine Deck Officer, and CW4 Jennifer Trossbac, Marine Engineer Officer, "U.S. Army Watercraft Quick Reference Cards," TRADOC, undated.

FIGURE 4-4 LCM-8. SOURCE: U.S. Navy photo via Wikimedia Commons, http://commons.wikimedia.org/wiki/, File: Lcm-8_1972.jpg#filelinks.

FIGURE 4-5 LCU-2000. SOURCE: Courtesy of Metal Trades, Inc., http://metaltrades.com/customer-profiles/u-s-army.

FIGURE 4-6 Logistics Support Vessel. SOURCE: CW4 Walter Ortiz, Marine Deck Officer, and CW4 Jennifer Trossbac, Marine Engineer Officer, "U.S. Army Watercraft Quick Reference Cards," TRADOC, undated.

Maneuver Support Vessel to Replace Army Landing Craft

The Army is currently working on developing the maneuver support vessel (MSV) to replace its aging hull-borne landing craft. There will be three versions of the MSV. A light version will replace the LCM-8. It will carry a platoon-size combat-configured force element—for example, one M1 Abrams or two Strykers. A medium version will replace the LCU-200 and will carry a company-size combat-configured force element. A heavy version will replace the LSV and will carry a battalion-size combat-configured force element—for example, 36 M1 Abrams or 60 Strykers. They are all to have a shallower draft than the vessels they will replace, and all will be capable of beaching, either in assault operations or to deliver materiel to unimproved locations lacking port facilities. Table 4-3 summarizes the planned capabilities of the MSV, and Figure 4-7 shows an artist's conception of that craft. As can be seen, all classes are planned to be significantly faster than the vessels they replace. The MSV-Light is currently under development. MSV- Medium and MSV- Heavy development efforts are not yet under way. These improved capabilities would enable the Army to provide support faster and in a wider variety of locations than existing craft. As such they will be important multipliers of logistics capabilities.

Finding 4-3. The three planned classes of the Maneuver Support Vessel are an important step forward in Army landing craft capabilities. It is vital that these improved capabilities be introduced into the Army as soon as possible.

Recommendation 4-2. The Army should proceed with the development of the Maneuver Support Vessel (MSV)-Light with all speed and should proceed with the MSV-Medium and MSV-Heavy concurrently with the MSV-Light.

TABLE 4-3 Planned Capabilities of the MSV, by Class[a]

Class	Range (nautical miles)	Speed (knots)
Light	400	18
Medium	5,000	25
Heavy	5,000	25

[a] All figures are for craft when loaded.
SOURCE: CW4 Walter Ortiz, Marine Deck Officer, and CW4 Jennifer Trossbac, Marine Engineer Officer, "U.S. Army Watercraft Quick Reference Cards," TRADOC, undated.

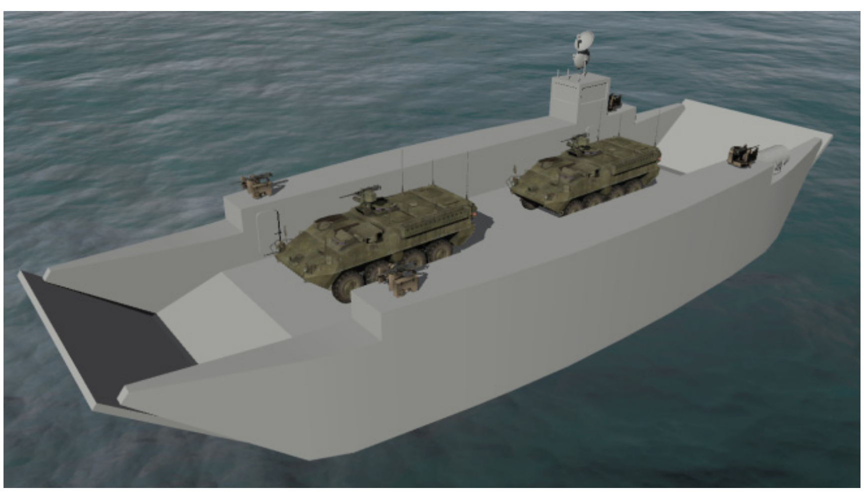

FIGURE 4-7 Artist's conception of an MSV-Light. SOURCE: CW4 Walter Ortiz, Marine Deck Officer, and CW4 Jennifer Trossbac, Marine Engineer Officer, "U.S. Army Watercraft Quick Reference Cards," TRADOC, undated.

Air Cushion Landing Craft

Another important system for sea-to-shore movement is the LCAC. This is a Navy asset. There are some 79 such craft in inventory, built between 1984 and 2000.[10] Each has a payload capacity of 120,000 lb, with an overload capacity of 150,000 in some circumstances. They are 81 feet long by 43 feet wide and have a range of 200 miles. Their speed is dependent on sea state. Their maximum speed, which is only achievable below sea state 2, is 50 knots. Their maximum speed in sea state 2 is 40 knots, and in sea state 3, 30 knots (Polmar, 2013). This is an aging asset with the associated increase in maintenance demands. A service life extension program for 73 LCAC vessels began in 2000 and is scheduled to be completed in 2016. Figure 4-8 shows an LCAC.

Finding 4-4. Existing aging Landing Craft Air Cushion require considerable maintenance, though they are undergoing a service life extension program, and they have limited capacity. Their maximum speed is very sensitive to sea state.

FIGURE 4-8 LCAC. SOURCE: Department of Defense, "LCAC Offload," DoD photo archive, http://www.defense.gov/transformation/images/photos/2007-01/hi-res/070122-N-1175T-018.jpg.

[10] Capt C.P. Mercer, Amphibious Warfare Program Office, PMS377, "Ship to Shore Connector (SSC): A Turning Point in Naval Ship Design," presentation on September 9, 2010.

Ship-to-Shore Connector as a Replacement for LCAC

The Marine Corps is currently looking for a new high-speed connector to transport its next-generation equipment ashore. In March 2014, Marine Corps Commandant GEN James Amos observed that sea bases are expected to be 50 to 100 miles from the coast and what is needed is a high-speed connector capable of 25-35 knots. The ship-to-shore connector (SSC) is a new hovercraft program designed to replace the existing 81 LCACs. The SSC will also be an air cushion landing craft, with speeds in excess of 35 knots and an increased load capacity of 74 tons.[11] The SSCs will have dimensions similar to the LCACs' but have been designed for improved performance (e.g., 11 percent better fuel efficiency than LCACs) with less maintenance. It is envisioned that the SSC will shuttle troops and materiel from ships 25 miles from shore. This distance will provide more opportunities for our forces to intercept incoming antiship missiles in response to A2/AD threats. It will be capable of operating in a sea state as high as 3. The program is scheduled to reach initial operational capability in fiscal year (FY) 2020. There are to be five operational craft and one training craft. Figure 4-9 shows an artist's rendering of an SSC. It should be noted that the French, Chinese, and Russians are building 50 knot air cushion landing craft for expeditionary purposes.

Finding 4-5. The existing ship-to-shore connector acquisition program is targeted to meet the needs of the U.S. Marine Corps, with 72 units planned.

Finding 4-6. The ship-to-shore connector program presents an opportunity for the Army to modernize its landing craft fleet.

Recommendation 4-3. The Army should ensure that its needs are reflected in the ship-to-shore connector acquisition program.

FIGURE 4-9 Artist's concept of an SSC. SOURCE: U.S. Navy, "PEO Ships Ship-to-Shore Connector (SSC)," http://www.navsea.navy.mil/ teamships/PEOS_SSC/SSC_ Images.aspx.

[11] Ibid.

LOGISTICS OVER THE SHORE

Causeways and Lighters

For sustained supply when adequate port facilities are lacking, the Army, Navy, and Marine Corps have developed a series of deployable small barges and floats that can be assembled into effective floating causeways, together known as Joint logistics over-the-shore (JLOTS). Figure 4-10 shows JLOTS causeway sections. The intention in using causeways is to allow deep-draft sea vessels to marry to the seaward end of causeways in relatively deeper water. The causeways extend to the shore, through the surf zone, to the beach. All discussion has been about the capability of the systems in sea states at the seaward end of the causeways, where the difficult operation of transferring cargo takes place. The Army systems have been tested and are reportedly capable of operating in sea state 2. The Navy systems are reportedly capable of operating in sea state 3.[12] This sea state is typical of that encountered most of the time in tropical and sheltered waters. However there are some questions about whether linkages, fendering systems, and ship ramps are usable in these sea state conditions.

The existing causeway systems will likely perform well in sheltered harbors, river estuaries, bays, and even in the lee of islands. Problems occur when the beach and roadstead are open to the sea; at temperate latitudes, where sea states are higher; and on shallow, shoaling beaches where even small swells can build to sizable surf conditions, often in advance of and after tropical storms. These factors may limit the use of causeways at critical times. A sudden increase in sea state could interrupt unloading operations or cause the loss of causeway components. Additionally, sea states 3 and greater present significant challenges to existing floating causeway systems.

FIGURE 4-10 Deployed JLOTS causeway segments. SOURCE: U.S. Navy photo by Mass Communication Specialist 3rd Class Brian Morales [public domain], via Wikimedia Commons, http://commons.wikimedia.org/wiki/, File: US_Navy_080715-N-4973M-028_Midshipmen_walk_along_the_Joint_Logistics_Over-The-Shore_(JLOTS)_Admin_Pier,_an_800-foot_long,_small-craft_pier.jpg.

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[12] Committee discussions with Army presenters during Meeting 3 at the U.S. Army Research, Development and Engineering Command, in Aberdeen Proving Ground, Md.

The Navy has developed the innovative elevated causeway system-modular (ELCAS-M). This is essentially a mobile pier system that can be assembled within days of arriving at the site. ELCAS-M has full-size cranes that can be used to offload materiel from vessels. Notably, it can be used where there is no functional port.[13] This elevated system was successfully demonstrated in 1995 and was a partial solution to the sea state limitation of the JLOTS floating causeway systems. Figure 4-11 shows the ELCAS-M. The Navy has since placed the improved Navy lighterage system (INLS) into service. The INLS is made up of pontoon sections and can be configured in a variety of ways to provide the ability to move materiel from ship to shore (Defense Industry Daily, 2013). Figure 4-12 shows one configuration of the INLS.

FIGURE 4-11 ELCAS-M in place.
SOURCE: U.S. Navy photo by Journalist 1st Class Joseph Krypel. [Public domain], via Wikimedia Commons, http://commons.wikimedia.org/wiki/, File: US_Navy_030426-N-1050K-052_The_U.S._Navy’s_Elevated_Causeway_System-Modular_(ELCAS-M)_stands_completed_at_Camp_Patriot.jpg.

FIGURE 4-12 INLS.
SOURCE: U.S. Navy photo by PO1 Richard Doolin, http://www.defense.gov/homepagephotos/leadphotoimage.aspx?id=3523.

[13] Navy elevated causeway system - modular (ELCAS-M) information available at usfleetforces.blogspot.com/2010/08/navy-elevated-causeway-system-modular.html, accessed August 26, 2014.

The Army Engineer Research and Development Center has developed the innovative lightweight modular causeway system (LCMS). Originally a series of 8 foot wide parallel floats were joined to provide an 80- foot long prototype. Further development has resulted in a very lightweight modular causeway 120 feet long. The LCMS weighs only 90 tons per 80 foot length. A 40 foot section of the LMCS consists of four 6,500 lb modules and has the same footprint as a 20 foot ISO container.[14] The causeway deck is supported by inflatable flotation tubes. The causeway can be deployed by seven persons in 3 hours and can support 70 ton vehicles (Resio and Fowle, 2010). These units can be carried on a JHSV and can even be carried by CH-47 Chinook helicopters. Nevertheless, the system still suffers from sea state limitations. TRANSCOM has a science and technology effort under way to develop a system, the Joint universal causeway interface system, to marry up the LCMS and INLS. TRANSCOM also has a roll-on/roll-off interface motion platform motion compensation study under way to permit ramps on commercial ships to interface with the Army modular causeway system. Figure 4-13 shows an artist's conception of the LCMS in use.

Considerable work may be necessary to allow accurate forecasting of windows of opportunity for existing and future portable causeways. While the ability of the Fleet Numerical Meteorology and Oceanographic Center, the Naval Research Laboratory, the Marine Meteorological Division Monterey, and other organizations to accurately forecast sea states and surf conditions is impressive, assessing the ability of floating causeways, ship ramp interfaces, and at-sea cargo transfer to work in adverse sea states remains a challenge.

Also, more work is necessary to assess the performance of floating causeway units on coral and rocky bottoms and their resistance to damage. More work is needed on causeways capable of operating in sea states higher than 2 and in breaking surf.

Finding 4-7. Many elements in the Army's maritime logistical chain, including causeways, are sensitive to sea state and do not function in sea state 3 or higher. Also, performance in complex surf environments is not well characterized.

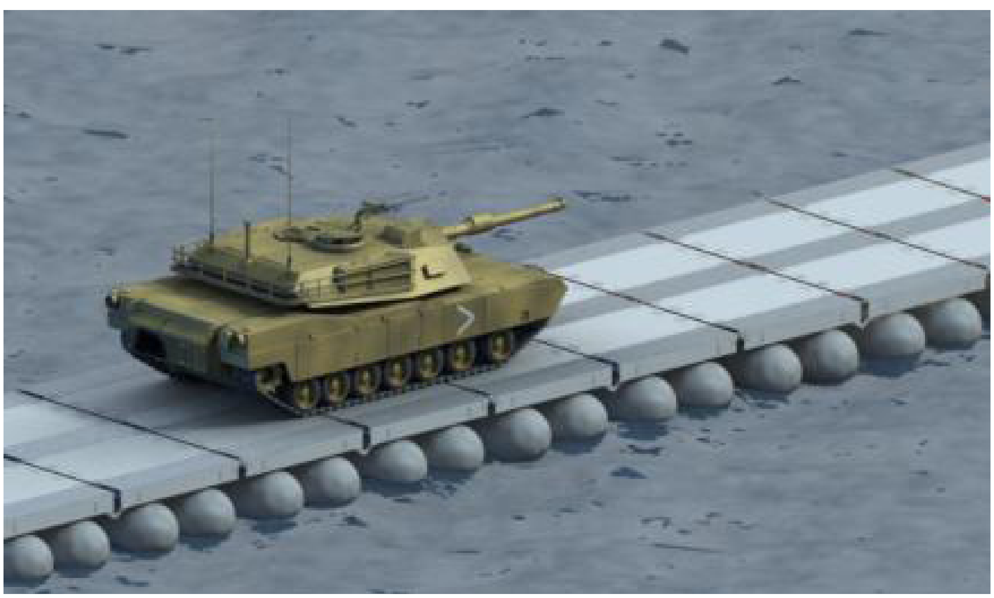

FIGURE 4-13 Artist's conception of the LCMS in use by an M1 Abrams.
SOURCE: David A. Horner, Technical Director, Military Engineering Business Area, "ERDC Reduced Logistics R&D," presentation to the committee on February 5, 2014.

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[14] An ISO container is a container that meets the specifications laid out by the International Organization for Standardization (ISO).

Recommendation 4-4. The Army should support or conduct research and development efforts to improve ramp interfaces, causeway connectors, causeway motions, crane heave compensation, and other components to permit operations in sea states of 3 or more.

Recommendation 4-5. The Army should monitor work to develop methods, systems, and/or procedures to create a lee or otherwise dampen waves and swell to reduce the sea state.

Offshore Petroleum Distribution System

The Military Sealift Command operates the USNS VADM K.R. Wheeler (Figure 4-14). Built in 2007, this vessel is 348 feet long and moves at 15 knots. It is designed to marry deepwater tankers to shore-based bulk fuel reception facilities. The Wheeler carries 8 miles of 8 in., metal-lined, flexible pipe on two 35 foot reels. Together with its 165 foot tender, the MV Fast Tempo, and two lighter, amphibious, resupply cargo vehicles, the Wheeler can deploy and be ready in 48 hours to pump two million gallons of fuel per day.

The Wheeler represents an important capability in support of expeditionary operations, particularly in the Asia-Pacific theater. Having only one of these vessels would seem to pose a significant operational risk to the sustainment of Army operations in certain settings, especially given the A2/AD threat to port facilities. Either having more than one of this type of vessel available or having suitable equipment kits (e.g., pipe on reels, pumps, generators) to enable the conversion of vessels such as tankers to this purpose might give the Army a much-needed sustainment capability.

Finding 4-8. The Military Sealift Command has only one offshore petroleum distribution system vessel. Without having port facilities accessible by tankers, the Army could be highly dependent on this one vessel. There is thus great risk to this capability from breakdown, damage, or enemy action.

Recommendation 4-6. The Army should press for the Navy and/or U.S. Transportation Command to procure additional vessels of this type, and for the acquisition of equipment in modular packages to rapidly convert tankers or other suitable platforms into offshore petroleum distribution system vessels.

FIGURE 4-14 The USNS Wheeler. SOURCE: U.S. Navy, “MSC 2007 in Review,” http://www.msc.navy.mil/annualreport/2007/pm3.htm.

Containers

The use of standardized shipping containers is ubiquitous in international logistics. They provide efficient means to move, secure, and hold cargo. Army logistics efforts have faced challenges with the costs, use, storage, and retrograde of shipping containers. For instance, the Army at one point was paying large demurrage costs for shipping containers sitting empty and not returned to the companies that leased them to the Army. There are many ways to optimize the use of shipping containers and operations involving them. The committee believes that better use of containers offers the Army numerous avenues for cost and effectiveness savings. Appendix E provides a thorough discussion of the potential for such adjustments to current Army container use.

MOBILITY ASHORE

Once ashore, Army logistics will be dependent on Army systems. As noted previously in this report, convoy operations consume a great deal of manpower and place soldiers at risk. Some technologies could take people out of danger and increase the efficiency of logistics operations. The use of autonomous vehicle technologies, both ground and air, and standoff delivery technologies could help address the challenge of A2/AD environments. Autonomous convoys could be used to put fewer personnel into hazardous situations. Aerial technologies such as precision air drop and autonomous aerial vehicles could be used that would reduce the number of personnel in hazardous situations or avoid those situations entirely. Autonomy could be particularly useful in moving supplies the last tactical mile.

Ground Mobility Systems

It has been posited to the committee that the use of autonomous ground vehicles could save weight and, therefore, fuel. However, so long as the vehicles are to be optionally crewed, all the components necessitated by the presence of humans will still have to be carried on board. Also, questions such as whether autonomous convoys would make softer targets, easier to destroy or seize, would have to be addressed.

Over the last 10 years there have been significant efforts by the Defense Advanced Research Projects Agency (DARPA), the U.S. Army Tank Automotive Research, Development and Engineering Center, and private industry to develop technologies that will allow vehicles to operate autonomously. These include a number of well-publicized success stories, such as the Lockheed Convoy Active Safety Technology (CAST) program, Mercedes Benz's autonomous driving S500 class vehicle, and the Google self-driving car (Guizzo, 2011).[15,16]

Prior Autonomy Efforts Relevant to Logistics

In the mid-2000s DARPA established three challenges—two grand challenges and one urban challenge—to engage industry and academia in the development of autonomous vehicle technologies. The two grand challenges were focused on off-road autonomy. In the first challenge, held in 2004, no

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[15] Lockheed Martin, "Autonomous Mobility Appliqué System (AMAS)," http://www.lockheedmartin.com/us/products/amas1.html, accessed August 26, 2014.

[16] Daimler, "Pioneering Achievement: Autonomous Long-Distance Drive in Rural and Urban Traffic: Mercedes-Benz S-Class INTELLIGENT DRIVE drives autonomously in the tracks of Bertha Benz," September 9, 2013, media.daimler.com/dcmedia/0-921-614307-1-1629819-1-0-0-0-0-0-11702-0-0-1-0-0-0-0-0.html.

participant completed more than 7.4 miles of the 150 mile desert course. In 2005, the second grand challenge, 5 of the 23 competitors completed a 132 mile course in the dessert. In the final challenge, the urban challenge, held in 2007 in Victorville, California, 4 of the 11 vehicles in the final competition completed the 60-mile course within the 6 hour time limit. The results of the challenges demonstrated progress in the field. In fact, DARPA stopped funding these types of efforts, believing that private industry would continue to refine and improve the technology.

Recognizing the potential inherent in autonomous vehicle technology, the Army has undertaken a number of research and development (R&D) projects in an effort to understand the capabilities and limitations of autonomous vehicles. The CAST program was undertaken by the Tank Automotive Research, Development and Engineering Center to determine if convoys could be implemented using leader-follower technology. This technology relies on a trailing vehicle focusing on the vehicle immediately in front of it and following that vehicle in close proximity. A follow-on program, Autonomous Mobility Appliqué System (AMAS),[17] is currently under way. This program builds on the success of CAST and is investigating how to implement autonomous technologies in an existing vehicle fleet by retrofitting the technology into existing vehicles to allow truck convoys in a military setting. The AMAS program is focused on three different kits, which could be procured from multiple sources and interface with one another through standard interfaces:

- *A kit:* sensors and software for autonomy;
- *B kit:* components to interface with the steering, braking, acceleration, and shifting controls; and
- *C kit:* a mission-specific platform that can be optionally installed on a vehicle.

Several demonstrations of the AMAS system have shown that the concept is achievable and the technology approach is viable. However, there are several challenges. These include the cost of the A kit and the B kit, which are high because items such as drive-by-wire capability and high-resolution sensors are not yet produced in sufficient quantity to have reached affordable price points. Another challenge is the use of active sensors (e.g., light detection and ranging) in theater, because they announce their location to all onlookers. Passive sensor technology exists to address this issue, but it is not as robust as active sensors across all lighting and weather conditions. The autonomous vehicle developer community widely believes that as private industry embraces autonomous capability, the sensors and hardware required for this capability will see significant cost reductions as well as enhanced capabilities.

In the commercial autonomous vehicle R&D community there are programs ongoing at over 25 companies building the core technologies needed for 360-degree awareness and to enable a vehicle to drive autonomously in a complex urban environment. The efforts by Google are the most widely publicized. The Google self-driving car is based on DARPA Urban Challenge technologies (Guizzo, 2011). It can drive autonomously on previously driven routes utilizing a high-precision digital map. The requirements for a map and the predriving of the route before the system can drive it autonomously obviously limit the applicability of this approach to military applications. The Mercedes self-driving S500 class vehicle has a number of onboard sensors that allow it to sense its surroundings and compare the results to a preinstalled three dimensional map to identify its location as well as potential conflicts. This information is used to provide automated driver assistance as well as automated driving.

As with all technology development efforts, there are still some limitations with each of these efforts. Cost is an issue as the hardware for autonomous operation often costs in excess of $100,000 per vehicle above the platform cost. Software costs are unknown as no developer of autonomous vehicles has provided any software-specific pricing. The most complex limiting factor is determining how to implement automation for the very complex scenarios that may occur only once every several thousand hours of operation. Consider that over an everyday driver's lifetime, 99.9 percent of the situations

[17] Lockheed Martin, "Autonomous Mobility Appliqué System (AMAS)," http://www.lockheedmartin.com/us/products/amas1.html, accessed August 26, 2014.

encountered are predictable and recoverable. However, there are very rare situations that a driver has not encountered before where intuition takes over. Intuition is a very complex thing to program into a computer.

Another developmental and implementation challenge is certifying autonomous vehicles as safe to test and operate. One of the current challenges facing the states that have passed legislation allowing autonomous vehicles on their roadways is how to evaluate and certify that they are safe enough to be on the public roadways. The U.S. Department of Transportation is starting to address this challenge. In order to have a successful testing and certification program, criteria need to exist against which to validate vehicle performance. To date, no set of criteria for the commercial application of autonomous vehicles has been developed by industry or by the federal or state governments. Nor has the Army documented the functional requirements for what it wants autonomous vehicles to achieve. This requirements process has to be in place before the overall effort required to implement autonomous technology can be thoroughly evaluated. The committee estimates that once requirements have been established, autonomous vehicle technology could be ready to use in rough terrain or unpredictable environments in 2-5 years with a properly funded and implemented R&D program.

Finding 4-9. Autonomous vehicle technologies offer a significant opportunity to automate military operations in order to improve logistics operations. They are ready to deploy in constrained settings with limited obstacles and established routes. They are not yet ready to deploy in operational settings with rough terrain or unpredictable routes. This capability could be achieved in 2-5 years, given a properly funded and implemented research and development program.

Recommendation 4-7. Autonomous vehicle technologies should be implemented in phases, starting with what is possible now using semiautonomous technologies such as leader-follower so that incremental improvements to logistics can be realized as the technology matures. Research and development should be continued to develop these technologies for use in challenging, unpredictable environments that are currently beyond their reach.

Autonomous Vehicle Convoys

The European Union sponsored a program called Safe Road Trains for the Environment (SARTRE) that explored the dynamic formation of road trains (which, in this context, means what we call convoys in the United States), including both passenger cars and trucks, using autonomous technologies. The formation and operation of road trains along European highways has been successfully demonstrated.[18] This program was a research program and has concluded, but it has not yet led to the operational use of autonomous technologies.

In both military (e.g., CAST) and commercial applications (e.g., SARTRE) the autonomous vehicle community has demonstrated that automated convoys are feasible, based on existing sensors and current technologies. However, fully automated vehicles that can navigate complex urban environments are not at the point where they could be reliably deployed without further R&D. Currently, commercial autonomous vehicles can successfully navigate in most normal driving conditions in good weather. The challenge is navigating in situations that rarely occur or that were not considered by the system developer during design. These efforts have been successful because convoys do not require elaborate 360-degree situational awareness. They use leader-follower technology, with following vehicles focused on a fiducial on the vehicle in front of them and maintaining pace with that vehicle. They are not concerned with traffic events to their sides or behind them because they are deploying in constrained environments and are not expected to interact with large numbers of manned vehicles with a number of different operational goals.

[18] See "The SARTRE Project," http://www.sartre-project.eu/en/Sidor/default.aspx, accessed August 26, 2014.

Applying Autonomy to Logistics

From the above discussion it can be seen that autonomous vehicle technology would seem to be ready to deploy in constrained, predictable operational environments, mostly where there are roads and established routes to be followed and where a number of technology efforts have met with success. However, developing a system that can address all possible conditions is still not feasible. This is why the states that are allowing the testing of autonomous vehicles still require a safety driver to be in the vehicle to take control from the computer if needed.[19] Nevertheless, the committee believes the technology is robust enough to bring the following benefits to operations:

- Remove warfighters from high-risk tasks such as driving roads in hostile environments,
- Reduce the number of drivers required to move logistics materiel,
- Relieve warfighters from doing repetitive tasks, and
- Eliminate human errors due to factors such as fatigue.

When it comes to deploying autonomous vehicle technologies in a full range of military settings (e.g., rough terrain or unpredictable routes), however, there are technical challenges to overcome. Autonomous vehicles must be capable of operating in an environment where Global Positioning System systems have been degraded or blocked entirely. This means these vehicles need to have good systems capable of determining their location integrated into the vehicle platforms. Another challenge is the overall cost of the hardware; as noted above, many of the sensors widely used on autonomous vehicles are still very expensive because they are not produced in mass quantities. A vital component for any autonomous vehicle is the drive-by-wire system that provides the computer with the ability to control the steering, braking, acceleration, and gear shifting. While some new commercial vehicles have this built into the vehicle, existing Army vehicles would need an expensive retrofit to automate their functions. The use of active sensors (e.g., light detection and ranging) would need to be addressed as these sensors would probably not be acceptable for many in-theater operations.

Finding 4-10. Convoy operations are highly repetitious tasks that could utilize today's existing autonomous vehicle technology to reduce manpower requirements and reduce risk to the vehicle operators.

Recommendation 4-8. The Army should implement secure leader-follower vehicle technology (a vehicle follows a fiducial on the vehicle in front of it), which does not require 360-degree awareness and can be done with low-cost sensors using Autonomous Mobility Appliqué System technology.

While not an autonomy technology, another concept used in states and countries that have open terrain with minimal topography is known as a road train (distinct from the term's meaning in the SARTRE discussion above), which allows freight to be moved more efficiently by connecting multiple trailers to a single tractor. This concept, which emulates some of the properties of autonomous convoys, is

[19] California is leading the country in establishing rules for autonomous vehicle testing (California Department of Motor Vehicles, "DMV Adopts Autonomous Vehicle Testing Rules," News Release, May 19, 2014, https://www.dmv.ca.gov/portal/dmv/detail/pubs/newsrel/newsrel14/2014_34). Florida and Nevada are also writing rules for this. They are widely expected to parallel California's rules.

FIGURE 4-15 An example of a road train. SOURCE: "Road Train Australia" by Thomas Schoch - Own work at www.retas.de/thomas/travel/australia2005/. Licensed under Creative Commons Attribution-Share Alike 3.0 via Wikimedia Commons, http://commons.wikimedia.org/wiki/, File: Road_Train_Australia.jpg#mediaviewer/File:Road_Train_Australia.jpg.

limited to relatively flat environments that have simple roadway geometry without a lot of tight turns. The road train concept could be useful for long-distance logistics operations. An example of a road train is shown in Figure 4-15.

The Last Tactical Mile

Over the last 5 years there have been efforts in the Department of Defense community to explore the use of autonomous vehicle technologies to provide logistical support to the last tactical mile, as well as to explore ways to lighten the load of the warfighter by providing autonomous load-bearing capabilities.[20] The Marine Corps has conducted several R&D programs to develop core technologies to support these capabilities. The Ground Unmanned Support Surrogate (shown in Figure 4-16)[21] was an R&D program to develop a low-speed autonomous vehicle to carry warfighter payloads as well as support medical evacuation. The U.S. Marine Corps Small Unit Mobility Enhancement Technology program[22] focused on utilizing low-cost sensor technology to provide a logistics connector from the forward operating base to the squad in the field.

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[20] The last tactical mile is the last leg of the distribution process, from the forwardmost base to the deployed forces in the field.

[21] Ground Unmanned Support Surrogate information available at www.torcrobotics.com/case-studies/guss, accessed August 26, 2014.

[22] Small Unit Mobility Enhancement Technology (SUMET) Program – Funded by ONR, information available at http://www.swri.org/4org/d10/isd/ivs/sumet.htm, accessed August 26, 2014.

FIGURE 4-16 Ground Unmanned Support Surrogate undergoing testing.
SOURCE: U.S. Marine Corps photo by LCpl Ronald W. Stauffer, http://www.navy.mil/view_image.asp?id=131302.

The Army's Dismounted Soldier Autonomy Tools program developed technologies to assist with efforts to lighten the load that must be carried by soldiers, which ranges from 60 to120 lb depending on the assignment, and to provide off-road mission support (Wright, 2013). To assist with delivery and support along the last tactical mile the Army R&D community is working on the squad mission support system (SMSS).[23] SMSS is an unmanned vehicle based on a turbodiesel-powered, high-mobility, six-wheel, all-terrain vehicle capable of carrying 1,000 lb of payload. The SMSS concept is to carry enough of a load to support a squad, conduct autonomous movement over rough terrain, and provide amphibious capability for crossing rivers and marshes in order to improve combat readiness while assuring resupply channels and the ability to evacuate casualties. Each of these programs has resulted in platforms that have been tested with the warfighters. The initial results suggest that they provide an attractive option for additional R&D investment. Some of these efforts could include the development of more cost-effective sensors, more cost-effective drive-by-wire components, and studies on how to more efficiently integrate autonomous vehicle technology into the warfighters' activities.

Finding 4-11. Autonomous vehicle technology could be utilized to lighten the load dismounted warfighters currently must carry. Also, resupply operations in the last tactical mile could be efficiently performed by autonomous vehicles to reduce the risks to supply vehicle operators.

Recommendation 4-9. The Army should develop and field autonomous platforms to provide logistical support in the last tactical mile by assisting in carrying supplies and equipment to the warfighter in the field.

[23] SMSS information available at www.lockheedmartin.com/us/products/smss.html, accessed August 26, 2014.

Aerial Systems

Aerial autonomy is another area of automation that needs to be considered. Many of the limitations of ground-based logistics support, such as the complexities of terrain and the need to predrive routes, are removed simply by using an aerial vehicle. Many of the A2/AD risks faced by ground vehicles can also be avoided or partially mitigated, although new risks open up for air vehicles. Operational costs and limited payloads may limit broad applicability of aerial autonomy technology, but for logistics operations in highly complex terrains, the technology is worth investigating.

In the last several years, work has been undertaken to use unmanned air systems to support logistics operations. In 2009 DARPA initiated the Transformer program, which was focused on the development and demonstration of a prototype hybrid ground-air vehicle that could provide flexible and terrain-independent support for logistics, personnel transport, and tactical support for ground units.[24] The initial motivation for Transformer was to develop a system that could master transiting complex terrains and countering improvised explosive devices that affected traditional ground-based transportation. Initially the Transformer program was a design competition between multiple organizations. In 2013 the Aerial Reconfigurable Embedded System (ARES) concept being developed by Lockheed Martin, and Piasecki Aircraft was selected to move forward as the Transformer demonstration project.[25] ARES is a vertical takeoff and landing delivery system that will be unmanned and is expected to support multiple payload configurations from a common airframe. ARES is being developed by the Lockheed Martin Skunk Works team and was in its third and final phase of research and development as of February 2014. Artist's concepts of ARES are shown in Figure 4-17.

Another example of a potential aerial logistics support tool is the Lockheed Martin K-MAX helicopter, which is capable of both remote-controlled and unmanned operations.[26] The K-MAX program is under development by the Marine Corps and is designed as a power lift helicopter capable of cargo delivery. It is capable of delivering 6,000 lb of cargo at sea level and more than 4,000 lb at 15,000 feet.[27] The K-MAX began a 6 month testing period in Afghanistan, with the initial unmanned resupply mission having been performed on December 17, 2011.[28] Following nearly 3 years of successful operations in which more than 4.5 million pounds of cargo were delivered over thousands of missions, the K-MAX has been returned to the United States as part of the retrograde from Afghanistan.[29] In March 2014 Sikorsky, under the Manned/Unmanned Resupply Aerial Lifter program with the U.S. Army, demonstrated its capability on its existing fleet of Sikorsky autonomous research aircraft being operated remotely by a pilot on the ground.[30] Sikorsky has developed a platform-independent flight control system that was initially developed for commercial offshore oil industry applications and has been refined for military operations. Sikorsky plans to install autonomous capability onto a Blackhawk helicopter and demonstrate the capability in 2014.

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[24] Aerial Reconfigurable Embedded System (ARES) information available at http://www.darpa.mil/Our_Work/TTO/Programs/Aerial_Reconfigurable_Embedded_System_ (ARES).aspx, accessed August 27, 2014.

[25] ARES information available at www.lockheedmartin.com/us/products/ares.html, accessed August 27, 2014.

[26] K-MAX information available at www.lockheedmartin.com/us/products/kmax.html, accessed August 27, 2014.

[27] Ibid.

[28] Information on Unmanned K-MAX Operational in Afghanistan is available at http://www.aviationtoday.com/rw/military/unmanned/Unmanned-K-MAX-Operational-in-Afghanistan_75637.html, accessed August 27, 2014.

[29] Information on Lockheed Martin's Unmanned K-MAX Cargo Helicopter Team Returns from Deployment with U.S. Marine Corps in Afghanistan is available at http://www.lockheedmartin.com/us/news/press-releases/2014/july/140724-lm-unmanned-kmax-cargo-helicopter-team-returns-from-deployment.html, accessed August 27, 2014.

[30] There are several Sikorsky autonomous research aircraft.

FIGURE 4-17 Artists' renderings of ARES. SOURCE: Defense Advanced Research Projects Agency, Tactical Technology Office.

Finding 4-12. Unmanned and remote-controlled aerial assets have been utilized by the Marine Corps to provide logistics support.

Recommendation 4-10. The Army should work with the Marine Corps to undertake research and development on a common autonomous aerial support capability for logistics.

Precision Air Drop

Precision air drop, a technique that involves air-dropped cargo guiding itself to a landing zone, has been used operationally. It is distinguished from conventional air drop in that the latter drops entirely unguided packages. Precision air drop offloads some portion of Army sustainment to the Air Force and reduces the number of Army vehicles that have to be used to deliver supplies to deployed forces. The main classes of supply air dropped in Afghanistan in 2013 were food, water, and fuel. From an Army-centric logistics viewpoint, the reduction in the number of vehicles used reduces both the fuel and maintenance demands associated with operating those vehicles and thus can have a positive logistics impact.

This technique has been used successfully on a large scale in Afghanistan. The joint precision airdrop system (JPADS), shown in Figure 4-18, uses an airborne guidance unit, electromechanical steering actuators, and a steerable canopy to guide payloads to their landing points. JPADS is a family of systems offered in the following versions:

- Microlight: 10-150 lb;
- Ultralight: 250-700 lb;
- Extra light: 700-2,400 lb;
- Light: 5,001-10,000 lb; and
- Medium: 15,000-42,000 lb.

All of these versions have been developed. The JPADS family of systems allows for drops from up to 25,000 ft and 25 km offset.[31] From 25,000 ft the JPADS can hit a soccer-field sized landing zone within a 23 km radius cone of coverage.[32] One aircraft dropping from one location can deliver payloads to multiple locations on the ground.[33] Work is also ongoing to develop a helicopter sling load system to work with JPADS. This system can carry 32 low-cost, low-altitude airdrop systems, which are expendable air drop systems designed to open at 100-500 ft altitude. It could be modified to carry up to eight container delivery systems. It has been developed to interface with UH-72, UH-60, CH-47, and CH-53 helicopters and has been demonstrated on UH-72, CH-47, and CH-53 helicopters. One benefit of this system is that the Army does not have to depend completely on the Air Force for air drop assets.[34] The helicopter sling is shown in Figure 4-19.

FIGURE 4-18 JPADS. SOURCE: Richard Benney, NSRDEC, "Aerial Delivery Overview to Support NRC Force Multiplying Technology for Logistics Support to Military Operations," presentation to the committee on February 5, 2014.

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[31] Richard Benney, NSRDEC, "Aerial Delivery Overview to Support NRC Force Multiplying Technology for Logistics Support to Military Operations," presentation to the committee on February 5, 2014.

[32] Keith Bowman and Daniel Schreiter, Precision Airdrop Program Office, AFRL, "AFRL Precision AirDrop (PAD) Update," presentation to the committee on February 5, 2014.

[33] Richard Benney, NSRDEC, "Aerial Delivery Overview to Support NRC Force Multiplying Technology for Logistics Support to Military Operations," presentation to the committee on February 5, 2014.

[34] Keith Bowman, and Daniel Schreiter, Precision Airdrop Program Office, AFRL, "AFRL Precision AirDrop (PAD) Update," presentation to the committee on February 5, 2014.

FIGURE 4-19 Helicopter sling for delivering cargo by JPADS, during testing. SOURCE: Keith Bowman and Daniel Schreiter, Precision Airdrop Program Office, AFRL, "AFRL Precision AirDrop (PAD) Update," presentation to the committee on February 5, 2014.

JPADS eliminates some reliance on ground resupply, removing trucks and personnel from convoy duty and thereby mitigating challenges such as improvised explosive devices. In addition to the logistics benefits, this capability allows resupply to more easily keep pace with expeditionary forces on the move. There is a desire to increase precision in the future. The committee was briefed that precision air drop within a forward base's wire could be possible within 10 years. A high-altitude, low-opening JPADS option is also under consideration. The goal would be to provide more standoff and get the dropping aircraft above most ground threats.[35]

The committee was also briefed about two potential but unfunded air drop programs. One is tactical aerial delivery for squads or small units on the move. The purpose of this program would be to develop a technology to deliver 200-500 lb of cargo to squads or small units. This would simplify logistics in the last tactical mile, reduce the burden on the Army logistics system, and reduce soldier burden. It is envisioned that a squad or small unit might be able to secure drop on-demand through a Nett Warrior application.[36] While this would largely leverage Air Force assets, it could also be used with Army air assets. The proposed program schedule envisions a 5-year effort to advance the system from technology readiness level (TRL) 5 to TRL 8.[37]

The other potential program is heavy air drop for payloads of at least 60,000 lb. The purpose would be to deliver bulk supplies and even combat vehicles directly to the point of need. The program would include multiple scalable, modular systems and technologies, including advanced low-velocity, high-altitude, low-opening approaches. The proposed program schedule envisions a 5 year effort to advance the system from TRL 5 to TRL 7. A proof of concept was carried out in 2004. A Stryker armored

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[35] Richard Benney, NSRDEC, "Aerial Delivery Overview to Support NRC Force Multiplying Technology for Logistics Support to Military Operations," presentation to the committee on February 5, 2014.

[36] Nett Warrior is an information technology system to assist unit leaders with situational awareness and mission command. Additional information is available at www.peosoldier.army.mil/docs/pmswar/Nett-Warrior-Poster-061512.pdf, accessed November 7, 2014.

[37] Richard Benney, NSRDEC, "Aerial Delivery Overview to Support NRC Force Multiplying Technology for Logistics Support to Military Operations," presentation to the committee on February 5, 2014.

gun system vehicle was successfully dropped from a C-17. No development work is currently ongoing or envisioned at this time.[38]

Finding 4-13. Precision air drop of sustainment materiel could significantly reduce the demand for ground-based resupply of forward areas. It could take trucks off the road and reduce personnel risk. A helicopter-based Joint precision air drop system capability is being developed that could both reduce Army dependence on other Service assets and expand the number of assets that can be used in a sustainment role, adding flexibility to the sustainment mission.

Recommendation 4-11. The Army should adopt precision air drop for sustainment to forward areas as widely as practical. It should also pursue a helicopter-borne Joint precision air drop system capability to expand its overall sustainment options and capabilities.

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[38] Ibid.

5

Maintenance, Retrograde, and Waste

Maintenance, retrograde, and waste are not major logistics demands from a tonnage perspective. Yet they are necessary parts of the overall logistics picture, and improvements in any of these areas will improve the logistics system overall. Currently, Army ground vehicle fleet maintenance is generally performed on a schedule (aside from emergencies). In the Army aviation fleet, however, maintenance is increasingly being performed based on condition, resulting in overall efficiency improvements in maintenance. Also, additive manufacturing, known colloquially as three-dimensional printing, is being used in limited contexts in the field and is a technology that promises to improve, and perhaps transform, maintenance. Retrograde comprises not only removing materiel from a theater at the conclusion of operations; it also entails the shipping of reparable parts back to depots for repair, in preparation for those parts to be placed back into the supply chain. This is a critical logistics function, and this report has some suggestions for improving its efficiency. Finally, waste is generated in the course of operations. This waste must either be disposed of on-site, typically in open burn pits and incinerators (with considerable potentially adverse environmental and health impacts), or trucked off-site for disposal. Reducing the waste generated in the course of operations, including that which must be trucked off-site, will lessen this demand on the logistics system. This reduction can be accomplished in a variety of ways. One is reducing waste in packaging. Another is converting the waste to usable energy.

MAINTENANCE

One way to improve maintenance is by conducting maintenance based on condition rather than on schedule, called condition-based maintenance (CBM). There are efforts under way to manage maintenance information, known as CBM+. Another way to reduce the maintenance demand could be to improve visibility into the logistics systems that track ordered parts. This is discussed more in Chapter 6. Finally, additive manufacturing (e.g., three-dimensional (3-D) printing, stereolithography, and selective laser melting) is attracting a great deal of interest as a way to meet demand at the point of need. As will be discussed below, additive manufacturing (of which 3D printing is a subset) has some promise, but it also has some drawbacks and may not be the silver bullet some believe it to be. While additive manufacturing might help alleviate one logistics demand, it will create other logistics demands to support it. It requires energy and, thus, fuel, and it must have raw materials to “print” parts.

The maintenance and repair of systems is a multibillion-dollar annual cost to the Department of Defense (DoD). In fiscal year (FY) 2011, maintenance accounted for $79.5 billion, or 12 percent of the total DoD resource allocation of $689 billion (DoD, 2012). As DoD fields new systems that incorporate innovative and increasingly complex weapons system and platform technologies, and as operational imperatives shift, maintenance and repair sustainment challenges can be expected to increase. For instance, as DoD attempts to reduce operational costs by reducing personnel, the maintenance and repair burden on the remaining personnel will increase. In addition, the aging weapons systems in the U.S. inventory will increase the pressure on the supply and maintenance communities to maintain asset readiness. Platforms are being used well beyond their intended design service lives, and this trend is not projected to change in the foreseeable future. Also, U.S. forces operate in extremely stressing environments that bring on a high need for maintenance. This stress has led to numerous supply and maintenance issues, including challenges with parts obsolescence, supply chain management and technical data management, wear and corrosion control, component reliability, and test and repair infrastructure. With these increased pressures on the maintenance community, there is a need for technology solutions that will enable the operational improvements desired while reducing the maintenance cost burden on the Services. These solutions would involve enhancements to maintenance technologies as well as to DoD logistics systems.

Over the last 20 or so years, DoD has supported modest programs (e.g., the ManTech Program[1]) that have demonstrated that platform sustainment costs can be dramatically reduced through the implementation of advanced technologies developed to address platform maintenance challenges. ManTech Program organizations working closely with the maintenance community have developed and transitioned repair technologies that reduce both the cost and time of maintenance activities for specific system components as well as increase the mean time between replacements.

A benefit of deploying improved maintenance technologies would be the reduction in logistics requirements for system maintenance. The ManTech Program has addressed needs in both advanced, depot-level process fabrication technologies and more efficient repair and maintenance procedures.

Additive Manufacturing

The need to repair, remanufacture, or reconfigure components for weapon systems represents a supply chain challenge for the defense industrial base. Aging systems and platforms and the related challenge of parts obsolescence will also impact the Services' ability to maintain fielded systems in the future. Repair parts for older systems may no longer be available. Depots and logistics centers cannot stock sufficient spare components for all of these assets for an indefinite lifetime, so that obtaining them may result in long lead times and high costs. Field-level maintenance is thus constrained by parts availability.

Additive manufacturing is a rapidly developing technology that can support a wide range of commercial and military applications and could support some of the Army's logistics needs. In additive manufacturing, volumes of material are either added to selectively restore the dimensions and features of a part as a repair or are used to directly reproduce a part via a digital representation of it through a computer-assisted design (CAD) file or a point cloud.[2] In contrast to conventional formative and subtractive manufacturing processes, all additive manufacturing technologies fabricate features or components in an additive manner through the layer-wise addition of material. The desired component dimensions, or shape, of the part are achieved through the coordinated motion of a heat source and the material feedstock to repeatedly produce layers of fused material. Objects produced by additive manufacturing usually require some finishing before they are ready for use. Accordingly, many additive manufacturing facilities have three- to five-axis mills for finishing the parts. The combination of additive manufacturing and on-site finishing capability also supports the ability to engage in rapid prototyping.

There is a tremendous level of public and private sector investment being made to advance the technology and to commercialize products made by additive manufacturing. Volumes of polymer-based material ranging from a 1 mm^3 repair to a 1 m^3 component can be produced with this technology. At present, polymer-based additive manufacturing materials and processes have found many application areas in industry, and products from these processes are being used in a variety of applications. Metal-based additive manufacturing is less mature and is still an area of active research for material and process development and for process control and optimization development—for example, under the Defense Advanced Research Projects Agency's (DARPA's) Open Manufacturing Program and the additive manufacturing-focused, public-private partnership, America Makes. Fundamental research is ongoing in

[1] Additional information about the DoD ManTech program is available at https://www.dodmantech.com/.
[2] A point cloud is a collection of points in a coordinate system that defines an object.

other areas that range from multimaterial integrated structures for features such as embedded sensors and electronics to the biological printing of human organs. There are two Network of National Manufacturing Institutes that are funded by DoD. The one at Youngstown, Ohio, funded by the Air Force, was the first such institute and is addressing additive manufacturing in metals for specific parts. The second, which is located in Chicago, is funded by the Army and managed out of Huntsville. It focuses on the digital supply chain, which can have great impact not only on manufacturing but perhaps allow for the robust development of the digital chain for both direct and retrograde logistics. Additive manufacturing has a wide range of possible applications using a wide range of materials.

Additive manufacturing technology is well suited for the repair of high-value components or the production of small lots of components, and it has the potential to address supply chain concerns associated with surge production and long-lead-time items. Thus, additive manufacturing has great potential for addressing the availability of parts and components for critical DoD assets. The ability to provide a repair or a replacement part on demand can bring increased readiness and affordability and could provide surge capacity for sustainment activities of the defense industrial base. In addition, the ability to quickly produce innovative products specifically needed to address emergent operational needs is a unique benefit of the technology.

There have been several demonstrations of repairs using additive manufacturing in DoD. For example, the Anniston Army Depot demonstrated the use of laser-engineered net shaping to repair gas turbine engine components on the M1A1 Abrams tanks (Zhang, 2010; Optomec, 2006). The Applied Research Laboratory at Pennsylvania State University and its partners have demonstrated additive manufacturing repair techniques for titanium compressor blade tips in the F402 engine, valves and shaft components for submarines, gear components for aviation, and aluminum shells used in undersea systems for the Navy. Researchers at Rolls-Royce developed a laser-engineered net shaping repair for high-performance Ti-6Al-4V blisk aerofoils (Tuppen et al., 2006). In addition to depot-level repairs, the Army has pioneered field-level maintenance applications of additive manufacturing. The U.S. Army Tank Automotive Research, Development and Engineering Center has examined the incorporation of additive manufacturing systems into the mobile parts hospitals deployed in Iraq and Afghanistan.

The Army Rapid Equipping Force funded Exponent, Inc., for an expeditionary laboratory support system, which included polymer and metal-based additive manufacturing capabilities.[3] This system made some parts for soldiers in the field much more quickly than waiting for manufacture and shipment from the United States. Under a current Industrial Base Innovation Fund program, the U.S. Army Armament Research, Development and Engineering Center is addressing critical issues so as to accelerate the implementation of additive manufacturing technology for sustainment activities both in the Army and in other Services. This includes identifying families of components that can be repaired and remanufactured by additive manufacturing, the establishment of standards for qualifying parts made by additive manufacturing, development of best practices and procedures for quality control, and education of the defense industrial base. In addition, many aerospace original equipment manufacturers are pursuing additive manufacturing technology for the manufacture of new parts and components.

Despite these often positive (although dispersed) technical successes, there are still engineering challenges to the widespread adoption of additive manufacturing as a tool for improving sustainment in the defense industrial base. For instance, additive manufacturing can be energy-intensive relative to conventional manufacturing, with the ratio having been estimated at approximately 100:1 (Choudhury, 2013). The requirement to melt the materials used in this technique is a fundamental aspect of additive manufacturing, and the energy requirements are not likely to lessen significantly over time, even with research. Energy use would also be a significant issue for the forward deployment of additive manufacturing facilities. In addition, additive manufacturing is not a fast process. Based on run times from the additive manufacturing laboratory at North Carolina State University, making a single 8-inch-high titanium part can take from 40 to 120 hours on an ARCAM machine (a Swedish-produced 3-D

[3] Matthew Cox, "Mobile Labs Build On-the-Spot Combat Solutions," Military.com News, August 17, 2012, http://www.military.com/daily-news/2012/08/17/mobile-labs-build-on-the-spot-combat-solutions.html.

printer capable of printing titanium, stainless steel, and copper articles), depending on the footprint of the part. These build times will improve over time, but the energy cost will probably increase because faster manufacturing will mean melting more material more quickly.

The long run times make a stable electrical source an absolute necessity for field operations, where a disruption in the power supply might cause a partially printed part to become scrap. This would be especially true for hot processes like the ARCAM machine. Cold processes are more forgiving of power interruptions, but objects manufactured by a cold process require the relief of high internal stresses by a heat treatment that involves more equipment, more facilities, and more energy.

Additive manufacturing technology provides tremendous design flexibility in the production of metallic material for structural components. This flexibility can have positive consequences if well understood or potentially negative consequences if not fully understood or controlled. This is because in additive manufacturing, process parameters will directly affect the microstructure and properties of the components produced and, accordingly, their strength and hardness. This aspect of additive manufacturing is the focus of technology programs currently under way to understand the performance limitations of current materials and processes and to come up with improved materials and processes.

A major challenge standing in the way of DoD's acceptance of additive manufacturing is the lack of methods and guidance for process qualification and component certification for a wide range of metals.[4] The issue is ensuring that a part made by additive manufacturing will meet the requirements and standards of the conventionally produced part it replaces. The only existing specification is the aerospace materials specification Titanium Alloy Direct Deposited Products 6Al - 4V Annealed (SAE, 2011).[5] This standard considers the deposition of Ti-6Al-4V in terms of testing requirements, minimum properties, and reporting requirements to achieve certification. The American Society for Testing and Materials F42 Committee on Additive Manufacturing Technologies is in the process of developing a range of standards for additive manufacturing processes. This is clearly an issue for Army aircraft, as parts that fly must be certified. Certification requirements will differ based on platform type—for example, a tank has different requirements from an aircraft.

To obtain qualified and certified components, the aerospace industry has conducted a great deal development work on what are called "design allowables" for Ti-6Al-4V processed by additive manufacturing. Additive manufacturing opens up the design space for components by allowing the design of components that are lighter than but just as strong as components that are limited in design by conventional machining. Design allowables would be approved variations in part construction to account for the capabilities of additive manufacturing. Extensive testing to satisfy conventional design and engineering requirements is often required by organizations wishing to implement any new technology for emerging and existing components and platforms. The development of cost-effective certification protocols will be critical to additive manufacturing technology implementation.

Additive manufacturing is a technology that is moving ahead extremely rapidly in terms of new applications. It may be that the best strategy for the Army is to watch very closely the developments coming from industry and to adapt the new applications to the Army's uses. This applies particularly to the certification of aircraft parts. That said, additive manufacturing is not yet a replacement for conventional manufacturing, particularly high-volume manufacturing. The cost and energy requirements are just too great. It does, however, hold great promise for the repair or remanufacture of parts and components and for very low volume manufacturing.

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[4] Chris English, GE Aviation Senior Engineer, "An Overview of Additive Manufacturing at GE Aviation: The Need for Industry Collaboration in Overcoming Barriers," presentation at the Additive Manufacturing Consortium Kick-off Meeting, Edison Welding Institute, Columbus, Ohio, February 10, 2010.

[5] Craig A. Brice, Materials Engineer, Lockheed Martin, "Direct Manufacturing at Lockheed Martin Aeronautics Co.," presentation at the Additive Manufacturing Consortium Kick-off Meeting, Edison Welding Institute, Columbus, Ohio, February 10, 2010.

Finding 5-1. Additive manufacturing provides a capability for producing components in support of Army logistics system needs at the point of need. Additive manufacturing efforts are ongoing across the Army and are close to the state of the art. However, further technology development is required to fully realize the benefits of additive manufacturing. Owing to its particular energy and materiel demands, additive manufacturing will happen at the depot level for the time being.

Recommendation 5-1. The Army should leverage the industry investments being made in the field and support technology areas that map to the specific needs and implementation barriers of the Army. The Army should support standards development that would form the basis for qualification of components. The Army should work with the other services to address standards for additive manufacturing and certification of parts for procurement.

Finding 5-2. The Rapid Equipping Force's Expeditionary Additive Manufacturing Laboratory is a solid foundation on which to introduce additive manufacturing capabilities into the Army's logistics enterprise, as appropriate.

Recommendation 5-2. The Army should continue to support activities initiated by the Rapid Equipping Force to develop a distributed additive manufacturing network that makes use of both organic and commercial capabilities. This network would be utilized to determine the applicability of additive manufacturing to critical Army components as well as to qualify procedures. It would include depots and both academic and industrial laboratories. It could also be a test-bed for integrating field-based maintenance requirements into a distributed design and manufacturing network.

CBM

CBM is a capability that evolved from work performed in reliability-centered maintenance (RCM) over the last few decades (SAE, 2002). This contrasts with traditional practices of unscheduled replacement upon failure and flying-hour-based replacement during scheduled, phase maintenance for aviation platforms. These traditional maintenance models tend to presume that component condition is exclusively a function of age and to ignore other important exogenous factors such as environmental conditions, manufacturing variances, preventive maintenance history, and, especially, the different types of missions.

RCM embodies the engineering analysis of the probability and consequences of failure for operating equipment. Such analysis informs system design and streamlines maintenance operations. It leads to a preventative maintenance program designed to minimize the impact and cost of component and system failures. CBM refers to an activity within RCM that senses impending failure and enables corrective action prior to catastrophic failure events. CBM uses sensors, either on the platform or brought to the platform, to assess the health and status of important system components. The seminal work on RCM was based on work performed in the commercial aviation community in the 1960s and 1970s (Nowlan and Hemp, 1978). Since that time, RCM and CBM processes have been developed and implemented by a wide variety of commercial organizations. DoD has been developing and utilizing RCM and CBM tools and methods for many years as a means to improve maintenance operations.

CBM+

More recently, DoD has become engaged in the development of condition-based maintenance–plus (CBM+), which builds on RCM and CBM by adding the enterprise-level infrastructure required to manage maintenance information. DoD is focused on the development and implementation of CBM+ to improve mission performance and enhance asset visibility for mission planning, effectiveness, and combat power. CBM+ will provide higher readiness, lower maintenance costs, and improved system safety for DoD assets. Because of the broad impact of CBM+, DoD has established a Joint Service CBM+ Action Group under the Maintenance Executive Steering Committee. Within the Army, the G-4 has the responsibility for CBM+ policy, staff oversight, and monitoring of CBM+ implementation working through the Army Business Process Council. It is well recognized that many stakeholders must be engaged in order for CBM+ to be fully implemented within the Army, and well-structured coordination groups have been working for a number of years on development, demonstration, and implementation of the core components of CBM+ capabilities. Roadmaps and implementation guides that reflect the collective plans and actions of the Army community have been published over the last decade (DA, 2007; DoD, 2008). These documents describe policies, roles and responsibilities, and strategies for CBM+ implementation within the Army.

Coordinated activities are developing the infrastructure needed to implement CBM+ across Army systems. Responsibility for implementation of CBM+ capabilities for specific systems resides with platform program managers. Cost-benefit analyses developed by Army program managers and Program Executive Officers for application of CBM and related topics such as Vehicle System Health Management and CBM+ for specific systems are an important element of DoD's implementation policy. Cost-benefit analyses conducted by Army commands on implementation of these advanced logistics capabilities have consistently indicated substantial benefits.[6]

The current status of CBM+ development and implementation in the Army varies by system type (DA, 2007). Army aviation is furthest along in CBM+ implementation. There is strong evidence for the value of CBM+ from the experiences in the Army aviation community. Ground system programs are actively pursuing initial implementation while developing the core infrastructure required for ground systems. The Army missile systems community has a number of CBM+ programs under way. The C4ISR community has programs under way as well; however, systems health management for electronic systems is not yet mature.[7]

Finding 5-3. Condition-based maintenance–plus (CBM+) supports the goals envisioned in force-multiplying technologies for logistics by enabling the reduction of process costs in the logistics enterprise.

Finding 5-4. CBM+ has the potential to significantly reduce the Army's logistics expenditures.

Recommendation 5-3. The Army should require the implementation of CBM+ on all future Army major system acquisitions without the possibility of waivers.

Connecting CBM to the Supply Chain

Internal platform-focused prognostic capability, which is the current focus for CBM, needs to be complemented with an understanding of the historical consumption patterns and usage trends associated with operational and environmental demand factors external to the platform. These differential effects of operational mission types (e.g., training, combat, stability operations, and humanitarian support) and environmental conditions (e.g., altitude, temperature, humidity and salinity, sand and dust) can be measured by statistically evaluating the empirical consumption patterns associated with recent deployments. This is the essence of a mission-based forecasting (MBF) initiative, further described in Chapter 6. Research has shown that "demand lead times behave in a fashion that is exactly the opposite of supply lead times. An increase in demand lead time improves system performance exactly like a reduction

[6] Ken Beam, U.S. Army Logistics Innovation Agency, "CBM+ IT Bridging Infrastructure," presentation to the CBM+ Advisory Group, Washington, D.C., September 25, 2012.

[7] C4ISR stands for command, control, communications, computers, intelligence, surveillance, and reconnaissance.

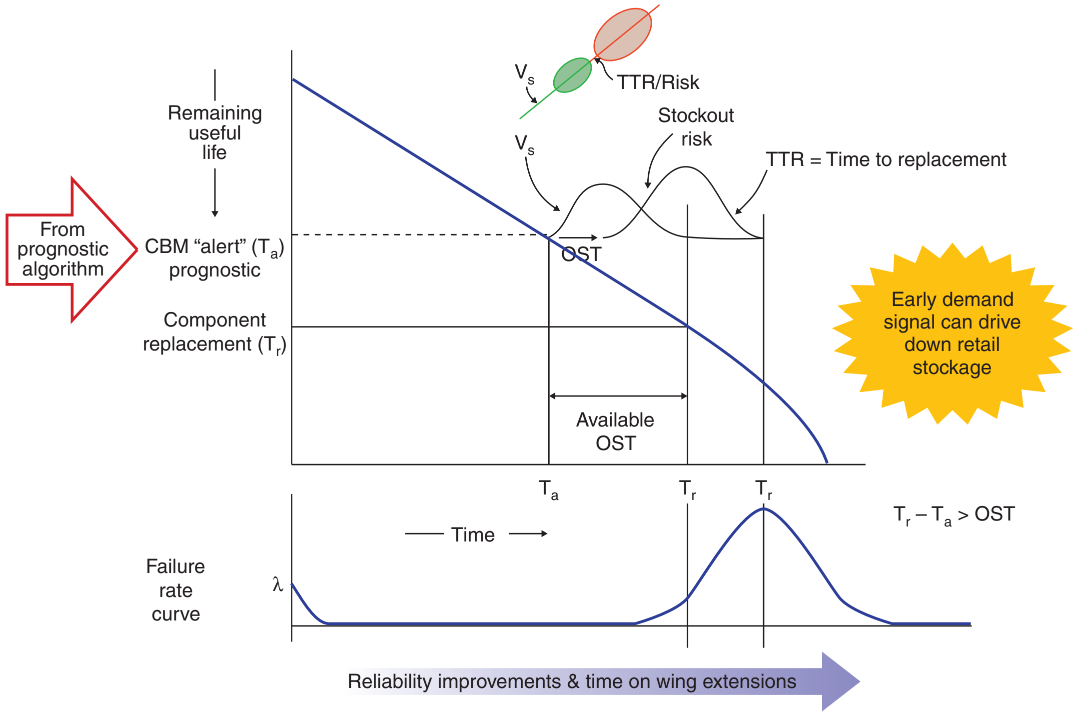


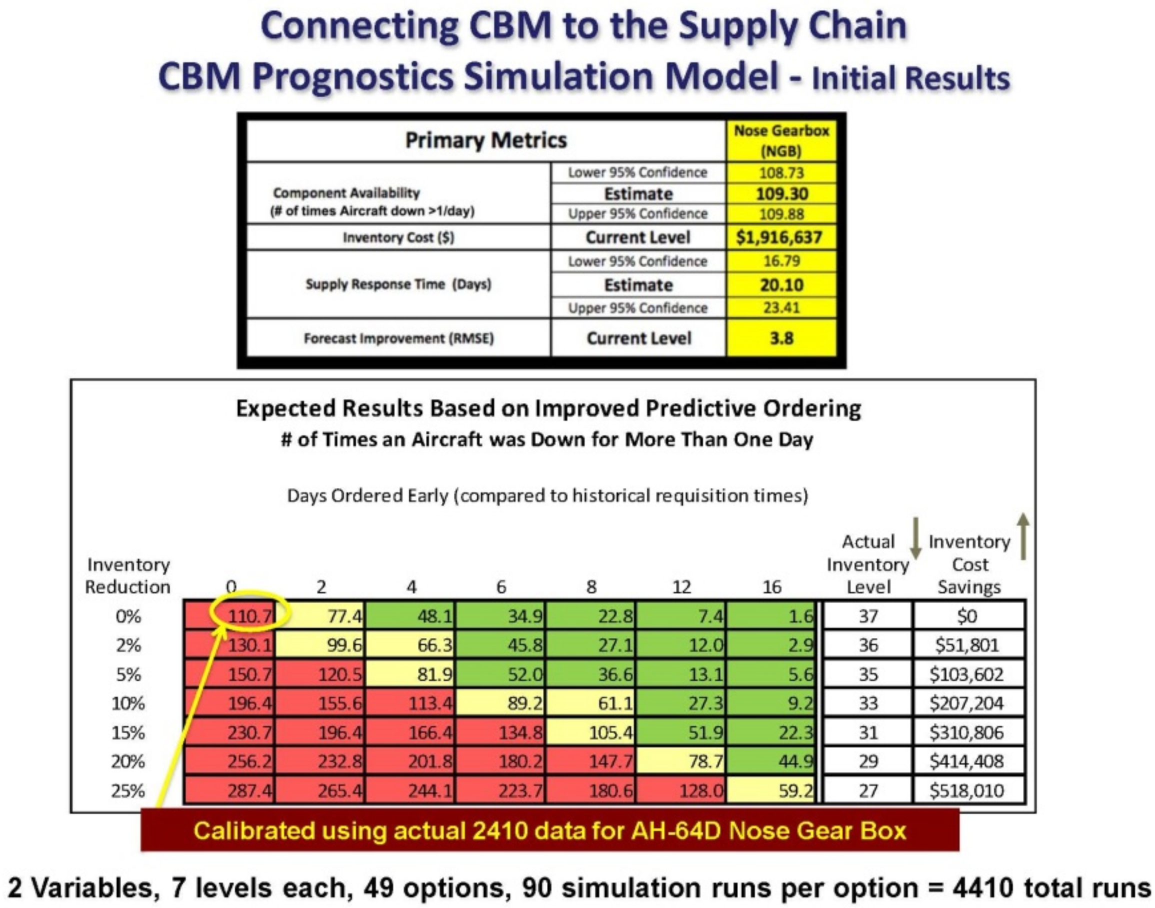
FIGURE 5-1 The prognostic replacement alert signal and order ship time (OST). When OST is less than the alert replacement time, forward (tactical) stocks can be reduced. NOTE: VoS, velocity of supply; TTF, time to failure; R_vS, reliability state vector; T_f, time of failure. SOURCE: Parlier (2013).

in supply lead time" (Gavirneni and Sridhar, 1999, p. 444). This relationship, together with the feed-forward control concept in adaptive control theory, seems to suggest that it is possible to positively affect system output a priori.

Adopting Bayesian updating by creatively combining these two new capabilities, CBM and MBF, holds great promise for improved demand forecasting. The basic logic underlying Bayesian methods is the notion of conditional probability and the systematic incorporation of prior knowledge and expectations about probability distributions into statistical analysis. This method consists of a coherent set of axioms that converts prior information (derived empirically from appropriate historical data using MBF) to posterior evidence (i.e., a revised estimate including new information) by conditioning on observed data (current CBM status).[8] Hence, the logic develops an updated forecast in a dynamic environment. Figure 5-1 shows this in graphic form.

For example, MBF can be used to determine well in advance what will likely be required based on a clear understanding of typical consumption patterns for a platform type (e.g., AH-64) performing specific missions (major combat operations, stability operations, noncombat evacuation operations, and so on) under environmental conditions associated with, or similar to, those that prevail at the geographic location where the deployment will occur. Much of the uncertainty associated with external factors in operational demand forecasting will be significantly reduced by using MBF in this way. Then when the

[8] For a theoretical perspective on Bayesian statistics, see McGee (1971). For applications using revised estimates, see Section 15.3, "Revisions of Estimates," in de Neufville (1990, pp. 279-285), and for practical applications of Bayesian statistics to spare parts forecasting, see Sherbrooke (1992, pp. 71-94).



Primary Metrics		Nose Gearbox (NGB)
Component Availability (# of times Aircraft down >1/day)	Lower 95% Confidence	108.73
	Estimate	109.30
	Upper 95% Confidence	109.88
Inventory Cost ($)	Current Level	$1,916,637
Supply Response Time (Days)	Lower 95% Confidence	16.79
	Estimate	20.10
	Upper 95% Confidence	23.41
Forecast Improvement (RMSE)	Current Level	3.8

Inventory Reduction	0	2	4	6	8	12	16	Actual Inventory Level	Inventory Cost Savings
0%	110.7	77.4	48.1	34.9	22.8	7.4	1.6	37	$0
2%	130.1	99.6	66.3	45.8	27.1	12.0	2.9	36	$51,801
5%	150.7	120.5	81.9	52.0	36.6	13.1	5.6	35	$103,602
10%	196.4	155.6	113.4	89.2	61.1	27.3	9.2	33	$207,204
15%	230.7	196.4	166.4	134.8	105.4	51.9	22.3	31	$310,806
20%	256.2	232.8	201.8	180.2	147.7	78.7	44.9	29	$414,408
25%	287.4	265.4	244.1	223.7	180.6	128.0	59.2	27	$518,010

FIGURE 5-2 Test results for the AH-64 nose gear box. As prognostics improve, significant reductions in forward stocks can be achieved without degrading readiness. NOTE: RMSE, root mean square error. SOURCE: Parlier (2013).

operation is actually conducted with a designated unit and its particular complement of AH-64s, each with its own internal set of depot-level-reparable life-cycle reliability profiles (for remaining useful life), CBM can be used to revise the original (albeit much improved) a priori estimates provided by MBF.

As CBM matures and both data collection and analytical methods improve, this Bayesian approach is likely to dramatically improve demand forecast accuracy for spares and repair parts (which are Class IX supplies). These empirically derived conceptual advances promise to serve as a similar foundational and methodological guide to improve demand forecast accuracy for other planning domains and classes of supply as well.

The test case for connecting CBM to the supply chain is for an AH-64 nose gearbox (a depot-level reparable, or DLR) and compares the current baseline (using empirical data for this specific DLR) with simulated results obtained by anticipatory ordering of the DLR a number of days prior to needing to replace the part based on the prognostic sensor prediction.

The results in Figure 5-2 shows how readiness (actual cell values expressed as fleetwide nonoperating days, with red, amber, green representing lower, the same, or better readiness) and inventory (expressed as the number of DLRs, the percentage of aggregate stock reduction in the supply system across all echelons, and the associated dollar value reduction) are impacted by adopting this anticipatory replacement policy.

The potential, in the case of just this one DLR, is significant. Readiness can be improved, or inventory can be reduced, or (in the real world) both. The matrix quantifies these various trade-offs. Savings can be a few hundred thousand dollars—again for just this one DLR. When this policy is applied for all (or even most) sensor-equipped DLRs (those with imbedded CBM capability) across fleets—and eventually to ground as well as aviation for the Army—the savings in aggregate stock reduction can be many hundreds of millions of dollars, perhaps even billions of dollars. This saving is achieved because it is no longer necessary to buffer uncertainty at the retail—that is, the unit—level by forward stocking these expensive DLRs (Parlier, 2011).

As noted earlier, DoD supply chain management has been on the Government Accountability Office's list of high-risk activities across the entire federal government since 1990. The Army, for instance, cannot determine how readiness would be increased by investing more in spare parts. It asserts there is no direct correlation between the level of investment in spare parts and the impact of such investments on system readiness, saying this is due to factors such as maintenance capacity and training requirements (Parlier, 2005; GAO, 2003). The Army needs a plan to overcome critical spare parts shortages (GAO, 2003). Furthermore, it has not been able to conduct coordinated systemic improvements across the multiple organizations involved in the supply chain. This inability has been attributed to the numerous complexities associated with separate, diverse, and independently operating organizations, which are compounded by a lack of accountability and authority for making improvements across the enterprise. Finally, previous transformation efforts have not provided a clear vision to guide, gauge, and synchronize future supply chain improvement efforts by specifying the performance goals, programs, milestones, and resources needed to achieve the stated objectives.

The Army's inability to relate strategic resource investment inputs to fleetwide readiness has serious consequences for the tactical warfighting Army. The Deputy Under Secretary of Defense responsible for logistics policy stated, "Whether push or pull, our current logistics are reactive. [We have] an industrial age vendor struggling to satisfy an information age customer. Reactive logistics—the old logistics—will never be able to keep up with warfare as we know it" (AUSA, 2004, p. 2).

Finding 5-5. Connecting CBM+ demand information directly to the supply chain could enable advanced scheduling of line reparable unit replacement and preclude replacement before needed. This approach could identify the need to replace a part before it fails. Field testing has demonstrated that such a connection to the inventory system can significantly reduce the requirement for forward stocking of repair parts and dramatically reduce customer (i.e., tactical unit) demand uncertainty.

Recommendation 5-4. As prognostic credibility and accuracy for CBM+ advances, the Army should adopt connecting CBM to the supply chain as inventory management policy, as described above.

RETROGRADE

The material in this section is drawn mainly from *Transforming U.S. Army Logistics: A Strategic "Supply Chain" Approach for Inventory Management*, by Greg Parlier, a committee member (Parlier, 2005).

The reverse logistics pipeline, known as retrograde, constitutes the U.S. Army's value recovery process for reparable spares and includes the vast majority of the value requisitioned at the unit stage. Retrograde constitutes the effort to maintain, repair, overhaul, upgrade, and return large subassemblies and replaceable units that are not consumed but are used as capital assets. Although these items constitute less than 25 percent of the number of demand requisitions, they also represent more than 75 percent of total requisition value. Inefficient retrograde will impose unnecessary costs on the logistics system, will cost time, and will impose logistics burdens associated with the need to transport materiel such as fuel.

From the perspective of systems-control theory, it is important to see retrograde as a feedback loop, one with obvious impacts on output, in this case embodies as unit readiness. Both system dynamics and control theory suggest the responsiveness of retrograde should have considerable impact upon readiness (i.e., operational availability); it is clearly a feedback loop in the supply chain. For reparable items, retrograde forms a closed-loop supply chain to return, rebuild, redistribute, then reuse (repeatedly) capital assets (e.g., DLRs) to continuously enhance readiness. Operating within the larger logistics structure, this closed-loop supply chain creates internal system behaviors that can potentially be changed through feedback to regulate the output of readiness.

From a practical logistics network perspective, the more DLRs that are delayed in retrograde awaiting evacuation for repair, the more inefficient and unresponsive the reverse pipeline becomes, increasing the overall number of those DLRs required. For every DLR in retrograde, another similar serviceable DLR is needed somewhere in the forward supply pipeline, thereby increasing systemwide demand for that DLR. Or, if the DLR is not available, customer wait time for a back order increases, impacting readiness at the unit.[9] This dynamic contributes to the tendency to mass large amounts of supplies forward, the familiar "iron mountains," placing additional demands on the logistics system. Although not yet well recognized, this is characteristic of a very tightly coupled system that can have potentially drastic negative consequences with little or no warning.

Readiness-Responsive Retrograde

A decade ago, for the first time, the U.S. Army Logistics Support Activity mounted an effort to identify, measure, and quantify delay times for DLRs awaiting retrograde in the reverse pipeline. Total retrograde time average values were found to vary considerably across the various overseas commands but are generally measured as several months. Additionally, there was extreme variability in the numbers of these items returned to various sources of repair (e.g., original equipment manufacturers and depots), ranging from a few hundred to several thousand DLRs per month (Pew Project on National Security, Energy and Climate, 2011).

Subsequent U.S. Army Logistics Support Activity efforts focused on ways to capture reverse logistics information, measure total retrograde times for the various theaters, and estimate the value of reparables delayed in retrograde. However, until recently, there has been no focus on defining and quantifying both the potential reduction in aggregate DLR inventory requirements and the effects of reduced customer wait time on readiness that could be achieved by synchronizing retrograde flow and depot operations with the forward supply chain. For example, the U.S. Transportation Command recently announced improved retrograde operations. But the criterion for this was only the reduction in transportation costs by using more less-expensive surface shipping and less more-expensive air transport (G-4 Public Affairs, 2012). Enormous improvements are possible if retrograde is viewed as a dynamic feedback loop with multiple effects—a closed-loop supply chain rather than independent, disconnected operations with linear additive effects. Recent efforts have quantified key relationships between aggregate inventory size (and investment costs), retrograde velocity (the speed of DLR returns from tactical units to depot facilities for repair and overhaul), and associated transportation costs and their impact on tactical readiness for aviation units. Using actual data for specific DLRs, retrograde relationships were established, along with trade-off curves between inventory cost, retrograde speed, transportation cost, and readiness. This could provide a model for a readiness-responsive retrograde system. Such a model could have enormous potential to both improve readiness and reduce total life-cycle costs.

Finding 5-6. The potential for further improvement in retrograde seems considerable. The various depot-level reparable (DLR) network links and flows, including reverse pipeline flow, depot production and scheduling operations, and forward supply chain flow, must be connected and afforded in-transit

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[9] Grace M. Bochenek, Director, U.S. Army TARDEC, "Army Power & Energy: Enhancing Mission Effectiveness, While Preserving Future Choices," presentation at AUSA Annual Meeting and Exposition, October 11, 2011.

visibility. Then the Army's extensive investment in DLR assets can be reduced and, through better management within a synchronized, closed-loop supply chain, both current readiness and future capability can be improved.

Recommendation 5-5. The Army should recognize the potential for efficient retrograde operations to enhance unit readiness. It should adopt a new paradigm of readiness-responsive retrograde as discussed above for the crucial closed-loop retrograde supply chain within the larger logistics enterprise.

Improving Retrograde Efficiency

Over the past two decades the Army Materiel Command has incorporated Lean and Six Sigma manufacturing concepts into depot management practices with measurable success in reducing process variances and rebuild times. The focus of the Lean concept is on better synchronizing process flow, reducing work in progress (stagnant inventory) and waste, leading to a just-in-time approach to meet demand. Six Sigma's complementary focus is on reducing defects to improve product quality by reducing product variation, the proximate cause of product defects within the manufacturing process. Significant additional improvements can now be obtained by adopting synchronized manufacturing (also known as optimized production technology from the theory of constraints, or TOC) for depot repair management. In essence a business-process redesign approach, the TOC enables significant gains in effectiveness (in contrast to efficiency gains) that become possible within a truly synchronized closed-loop supply chain for DLRs. This becomes possible because TOC views the process itself as potentially flawed, an approach that generally aims at identifying weak links in the chain. TOC emphasizes the bottlenecks in the supply chain, improving output by focusing exclusively on these bottlenecks and resolving them. Increasingly, companies that combine their Lean and Six Sigma efforts with a TOC process redesign approach (Caterpillar, Merck, Johnson & Johnson, and IBM, among others) are finding "more success redesigning whole processes," improving weak links, and reducing or eliminating constraints to improve cost-effectiveness and productivity (ARCIC, 2010).[10] It needs to be understood that, like Lean Six Sigma, TOC requires personnel and leaders to be trained as well as ample time to master the skills.

An example of the dramatic improvement that can be obtained using TOC within the military depot system is found at the Marine Corps maintenance facility in Albany, Georgia. Costs, work in progress, and repair cycle times have been reduced, resulting in increased throughput and improved scheduling. The specific results for MK-48 engines have been especially dramatic: Averages and variances for both repair cycle time and labor-hours per engine have been cut in half, with MK-48 engine output per month more than quadrupling.[11]

Synchronizing Retrograde with Depot Repair

Depot maintenance activities have historically experienced delays in being provided with consumable parts for repair and overhaul. This is due partly to the 85 percent target used by the wholesale system for supply availability. but it is also increasingly due to dwindling numbers of manufacturers of materiel and to issues of obsolescence, especially affecting wiring, avionics, corrosion, and dynamic components. degradation caused by aging aircraft systems and subassemblies. As retrograde efficiency and responsiveness improve, however, the combination of in-transit visibility and emerging health

[10] Vic Ramdass, Operational Energy Office, Headquarters, Department of the Army, "Army Operational Energy Overview, Increasing Mission Effectiveness while Preserving Future Choices," available at http://netzero.asu.edu/files/vic_ramdass.pdf, accessed October 23, 2014.

[11] Grace M. Bochenek, Director, U.S. Army TARDEC, "Army Power & Energy: Enhancing Mission Effectiveness, While Preserving Future Choices," presentation at AUSA Annual Meeting & Exposition, October 11, 2011.

monitoring systems for weapons systems, including condition-based maintenance, can provide anticipatory information for depot repair before the component actually arrives through the reverse pipeline. Hence, particular or unusual parts can be ordered before rather than after the components and end items arrive for repair, further reducing depot repair turnaround time.

The intelligent collaborative aging aircraft spare parts support (ICAAPS) project, a Logistics Management Institute initiative for the Navy, explored the value of such an anticipatory ability, illuminating the potential for reducing these forecasting lag effects, especially on consumable parts needed in maintenance and repair. Because current projections for depot-level consumable part requirements are based on historical depot repair maintenance data, there is considerable delay between when the parts are actually needed and when theyare incorporated into future requirement projections. The ICAAPS project successfully estimated correlations and relationships between both depot-level consumable parts usage and the operating environments and field maintenance activities that could be expected to affect future depot-level maintenance requirements. This power to more accurately predict parts requirements and ensure they they are available for use in repair when an aircraft arrives rather than at some later time, cut the growing gaps between predicted usage and actual usage by over 50 percent for many consumable parts. Consequently, by expanding the maintenance planning horizon to include all relevant information gathered during the entire operating cycle before an aircraft arrived at the depot for repair, ICAAPS was able to significantly reduce forecasting lag, improve part requirement forecasting accuracy, and reduce depot repair cycle time.[12]

One of the great challenges to better synchronizing depot repair operations is overcoming the inability to see all of the potentially useful information that could contribute to better forecasting. No integrated knowledge base currently exists to combine aircraft onboard data with potentially relevant unit-level operational information and program depot maintenance data, because each information source is typically maintained by different organizations in multiple, geographically dispersed locations. Recognition of this limitation recently led to a joint initiative between the Air Force's Oklahoma City Air Logistics Center, which overhauls KC-135 tankers, and the Department of Energy's Pacific Northwest National Laboratory. Using visualization techniques originally developed by the laboratory for the U.S. intelligence community, several disparate data types and sources are linked, transformed, and then presented on large computer graphic displays. These multidimensional spatial mappings portray information using complex visual patterns that humans can much more easily interpret than when the information is in the form of standard graphics, data tables, or text.

Known as the Visualization of Logistics Data project, the analysis of trends, patterns, and relationships in a large maintenance data warehouse enables logistics managers to capitalize on and exploit the ability of the human brain's visual processing capabilities to rapidly perceive and absorb visual representations of large amounts of data in a manner not possible through listening or reading. This capability provides for a consistent and integrated picture of the health of the aircraft fleet, better parts forecasting, and reduced depot repair time and enables more informed decisions for work flow, scheduling, and resource forecasting (Lyons et al., 2011).

Finding 5-7. The potential for retrograde improvement using the Intelligent Collaborative Aging Aircraft Spare Parts Support project and the Visualization of Logistics Data project appears enormous. When used in conjunction with improved reverse logistics, these could pave the way toward a truly synchronized retrograde, enabling a responsive closed-loop supply chain with reduced requirement objectives and improved materiel availability and operational readiness.

Recommendation 5-6. The Army should adopt capabilities offered by both the Intelligent Collaborative Aging Aircraft Spare Parts Support project and the Visualization of Logistics Data project as first steps to

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[12] Nickolas Justice, Commanding General, U.S. Army Research, Development and Engineering Command, "Advancements in Soldier Power Presentation," presentation to the Association of the United States Army Institute for Land Warfare Panel on Army Power and Energy Challenges on October 11, 2011.

incorporate predictive analytics toward a synchronized retrograde closed-loop supply chain. These concepts should be further extended, and adapted as appropriate, to sustain other fleets as well, including ground-based systems.

Resilient Retrograde Design

A shortfall in Army aviation depot-level reparable surge repair capacity in the existing Aviation Classification Repair Activity Depot organizational design and mission concept became evident in the early stages of Operation Iraqi Freedom. This recognition led to a new capabilities document for a Mobile Aircraft Sustainment Maintenance Capability (MASMC). This new concept emphasized both sea-based and land-based capacities to better and more responsively support an expeditionary capability, especially during the initial deployment phase, when seaports or airports may not exist or have yet to become available. There is historical precedent for this sea-based concept. The *USNS Corpus Christi Bay* was used as a floating aviation maintenance and repair platform off the coast of Vietnam from 1966 to 1975. The Marine Corps, traditionally an expeditionary force, has use of two aviation logistics support ships, owned and operated by the Navy, for aviation maintenance and repair support to the Marine Corps expeditionary forces.

A regionally aligned force structure could be adopted for the supporting multipurpose aviation sustainment brigades (MASMC, the replacement for Aviation Classification Repair Activity Depots). These brigades would be similarly organized but then tailored, trained, and deployed to conduct support operations in specific regions of the world. This concept of operation would associate each of five MASMC brigades with the five corresponding regional combatant commands: European Command (and the new Africa Command), Pacific Command, Southern Command, Central Command, and Northern Command. This arrangement would enable habitual association and command relationships to develop. It would increase the efficiency with which the MASMCs could meet their commands' needs.

Finding 5-8. Resurrecting a sea-based maintenance and repair concept would be consistent with the Army's evolution toward more robust sea-basing as a practical response to the growing anti-access, area denial environment.

Recommendation 5-7. The Army should re-establish a sea-based mobile repair capability for aviation and consider expanding the sea-basing concept to support maintenance and repair for ground systems as well.

Finding 5-9. Regionally aligned multipurpose aviation sustainment brigades would provide more efficient and responsive reverse logistics support to the major combatant commands.

Recommendation 5-8. The Army should adopt a regionally aligned force structure for multipurpose aviation sustainment brigades.

The concepts discussed above would form a resilient retrograde capability. They suggest the creation of prepositioned, mission-tailored support packages. The packages would be designed using readiness-based sparing and mission-based forecasting. If prepositioned packages are not used, the same effect could be achieved by setting aside small, similarly constructed packages that could be rapidly deployed along with the Army aviation unit; they would be similar to the Marine Corps flyaway element or the Air Force war reserve spares kit. Where existing (e.g., host nation) sustainment is not readily available, tailored mission support packages could be used to meet Class IX supply replacement needs at deployed locations. This would result in surplus inventory that could be used to meet any short-term demand surge that the existing logistics supply network infrastructure could not support (Parlier, 2010).

Further, in order to meet higher sustained demands during extended operations, resilient supply chain design principles would suggest either the creation of additional sustainment capacity or the moving of existing capacity closer to the point of need—or perhaps both. This concept would provide the ability to dynamically change the supply chain configuration in response to needs. Thus, the logistics network could respond quickly to a short-term demand spike with surplus inventory and then adapt to sustain increased longer term requirements by changing its configuration, relocating repair capacity closer to the point of need (Parlier, 2010).

Any effort to achieve resilience must focus on the strategic design and structuring of supply chains so they will be able to respond to the changing requirements of globally positioned forces constantly engaged in the conduct of a variety of operational missions in a wide range of environments. This ultimately requires innovation in supply chain design, implementation, and, especially, supply chain management. The topic of innovation is discussed thoroughly in the following chapter.

WASTE

A significant proportion of materiel shipped to bases winds up as waste, and waste is generated on-site as well through normal living activities (e.g., by cafeterias, latrines, and showers). This waste must be disposed of on-site, typically by incineration, or shipped off-site. The challenges of waste disposal will vary depending on the size of the base; the energy content of the solid waste; and the presence of toxic wastes, especially dioxins, furans, and toxic metals in the waste streams. The disposal of military wastes by any method is also complicated by the potential for the presence of live ammunition in the waste streams. Waste disposal also depends on host nation laws and regulations. The current normal methods of waste disposal, as mentioned above, are incineration and removal from the base by truck. Incineration, however, creates a fuel demand to power the incinerator and increases the number of personnel at the base. Removal by truck, of course, creates a fuel demand for the trucks so used and ties up logistics resources that might be used elsewhere. It would be preferable to destroy waste on-site, recover energy from the process, and significantly reduce the amount of waste that needs to be trucked off-site.

Waste Reduction

Another obvious way to reduce waste is to generate less. The most straightforward to way accomplish this is to minimize the amount of packaging material used. Some items, such as munitions, have their packaging dictated by regulations for safety reasons. For other items, the volume of waste generated might be reduced by redesigning the packaging and packaging items more efficiently.

One concrete example presented to the committee was the various efforts to reduce meal-related waste. The committee learned during data-gathering that field rations—meals-ready-to-eat (MREs)—are commonly stripped for their protein and roughly half of the contents are simply thrown away. In response, the Army developed the First Strike Ration. This ration is nutritionally optimized and is designed to provide soldiers with meals that are compact, can be eaten on the move with no preparation, and used in high-intensity, mobile operations. One of these rations provides a full day's subsistence, as opposed to three MREs, and it is supposed to eliminate the approximately 50 percent waste resulting from stripping MREs. Overall, the First Strike Ration provides a 49 percent reduction in weight and 55 percent reduction in volume over the MRE.[13]

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[13] Keith Bowman, Precision Airdrop Program Office, Air Force Research Laboratory, "AFRL Precision AirDrop (PAD) Update," presentation to the committee on February 5, 2014.

Finding 5-10. It appears to be possible to reduce the waste burden on the logistics system by redesigning packaging, packaging items more efficiently, and minimizing any unwanted materiel so less waste is created in the first place, as demonstrated by the First Strike Ration.

Converting Waste to Energy

There are many different approaches that can be taken to converting waste to energy. Depending on its size, solid waste may provide fuel to boilers that generate steam for electrical generators. Direct conversion of waste by pyrolysis or gasification can create solid, liquid, or gaseous fuels. Gasification or destructive distillation can provide gaseous fuel, such as methane, to power base diesel generators or even, under specific circumstances, vehicles or power equipment. Any resulting ash might also be useful. Bio char is being experimented with for water purification purposes.

The Natick Soldier Research, Development and Engineering Center has a program called Waste-to-Energy for Self Sustaining FOB/COP.[14] This effort is to test a waste-to-energy system that will process 1-2 tons of mixed nonhazardous solid waste per day, producing environmentally benign products. The system is packaged in ISO/TRICON containers and has automated controls and operation, minimizing the manpower needed to operate it.[15] The goal is to reduce or eliminate the need to remove waste from forward and contingency operating bases and to produce energy. The effect would be to reduce the amount of fuel that has to be delivered to bases for generators. There will be spiraling savings as less fuel means fewer trucks to deliver fuel, which means still less fuel.[16]

The Army's Tactical Garbage-to-Energy Refinery, a technology development program, converts 2,000 lb into fuel to power a standard 60 kW diesel generator. Dry, solid wastes are pelletized, and the pellets are converted to syngas to power the generator. Sugar-rich wet wastes are processed using enzymes and fermentation. The result is hydrous ethanol (85 percent ethanol, 15 percent water). Mixing the ethanol and the syngas has resulted in the production of 55 kW using the 60 kW generator. It takes 6 hours to start the system, and during this time the generator uses about 1 gal of fuel per hour, about 5 percent of normal usage. The volume of waste processed by the system is reduced in volume by 30:1. It has been tested in Iraq (LaMonica, 2008).[17]

While the technologies to convert waste to energy in a civilian setting appear to be mature, a key challenge in using military waste to produce energy is the potential for live small arms ammunition to be present in various waste streams. For whatever reasons, such ammunition finds its way into waste, and becomes an obvious safety hazard to the personnel around such a waste conversion system. One committee member's experience has been that this hazard has been an obstacle to testing and has necessitated time-consuming manual sorting of waste. This issue needs to be addressed before waste-to-energy technology can be widely deployed. Systems might be hardened to handle the cooking off of rounds, or the rounds can be sorted from the waste before it is used to generate energy. Also, soldiers could be trained to not throw their unexpended ordnance into waste receptacles or piles.

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[14] A FOB is a forward operating base; a COP is a combat outpost.

[15] An ISO/TRICON container is a shipping container. When three of these are connected together they have the same footprint as a 20-foot ISO shipping container. ISO is the International Organization for Standardization, which sets standards for shipping containers, among many other things.

[16] Richard J. Benney, and R.D. Carney, NSRDEC, and Edward J. Plichta, CERDEC, "Operational Energy—Advanced Woven PV, Equipment & Energy Technologies," presentation to the committee on February 4, 2014.

[17] The battle-tested TGER prototype has been improved since it was used in Iraq (Kristen Dalton, "Battle-tested TGER prototype improved since mission in Iraq," Feature Stories, U.S. Army Edgewood Chemical Biological Center, December 4, 2012, http://www.ecbc.army.mil/news/2012/Battle-tested-TGER-prototype-improved-since-mission-in-Iraq.html).

Finding 5-11. Waste-to-energy technology holds promise for generating energy for forward and contingency operating bases. This technology will probably be less applicable to smaller bases and outposts. A key challenge to implementing such a technology is the presence of small-arms ammunition in the military waste streams.

Recommendation 5-9. The Army should act to eliminate the challenge of small arms ammunition in waste streams for waste-to-energy solutions. This could be done by developing hardened systems that can withstand ammunition cooking off, by developing efficient methods for the removal of ammunition from waste streams, or by training soldiers to not discard unexpended ordnance.

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6

Logistics Enterprise Information Systems and Decision Support

This chapter examines possibilities for improving the quality and effectiveness of the management of Army logistics activities by enhancing the information and decision support systems on which these activities rely.

Logistics decisions are fed by data, and the Army has invested in improving the quality and quantity of data available and in providing the results of the analysis of these data to decision makers. The Army logistics enterprise information systems, as a whole, are an amalgam of systems designed to manage the Army's material, maintenance, supply, acquisition, and financial activities. At the heart of this amalgam is the Army Enterprise Systems Integration Program (AESIP), which guides the Global Combat Support System-Army (GCSS-Army) and the Logistics Modernization Program (LMP). AESIP provides a hub that ties GCSS-Army and LMP to other logistics-related systems, including the General Fund Enterprise Business Systems and other enterprise systems (Figure 6-1).

Decision support for logistics focuses on helping decision makers at all levels of the Army make the best possible logistics decisions given available information. These decisions can be extremely complex and may rely on huge quantities of data. No matter the level at which a decision is made, it is difficult for the decision maker to make an informed decision without support from some sort of analysis. Approximately 75 percent of the Army's budget is impacted by logistics decisions, so that the quality of the logistics decisions has a huge impact on the budget.

GCSS-Army and the LMP provide decision makers with unprecedented access to data. However, the most effective use of these data will require coupling them with decision support systems capable of digesting, analyzing, and then presenting understandable options to decision makers. Both the tools to do this, ranging from rather simple applications to elaborate modeling and simulation, and people who use them are needed to extract the desired content from the data so that the best decisions can be made.

LOGISTICS ENTERPRISE INFORMATION SYSTEM

Army Enterprise Systems Integration Program

The Army has invested heavily in two enterprise resource planning (ERP) systems: GCSS-Army and LMP. These systems are being developed using the SAP-ERP system. SAP is a German multinational software corporation and a leader in the enterprise applications market. ERP based on SAP software (SAP/ERP) had already been implemented in the military domain by the German Bundeswehr when the U.S. Army decided to adopt SAP software. For programmatic and development purposes, GCSS-Army and the LMP, together with an information brokering program (the AESIP Hub), are managed by AESIP under the Army Program Executive Office (PEO) Enterprise Information Systems.

The GCSS-Army and LMP Systems

GCSS-Army, LMP, and GFEBS have the potential to transform Army logistics. Theoretically, an SAP ERP integrates all enterprise functions. Everything that the enterprise does is compiled into a very

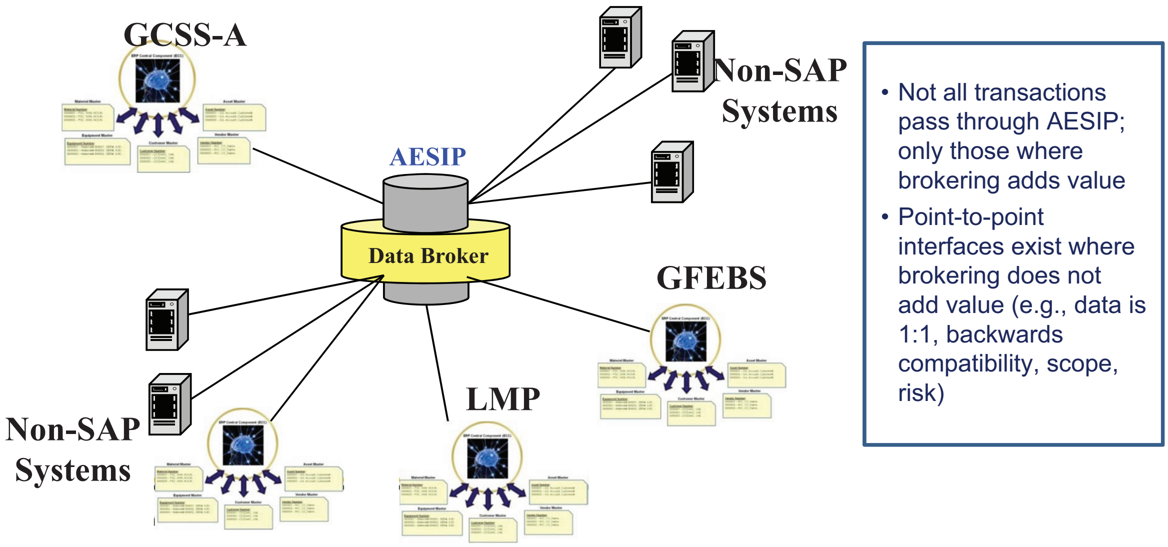

FIGURE 6-1 Army Logistics Enterprise Systems. GFEBS, General Fund Enterprise Business Systems. SOURCE: Dan Parker, PM AESIP, "Logistics ERP Presentation," presentation to the committee, January 16, 2014.

large federated database. In the commercial world, the database would include information on material requirements planning, supply chain management, customer relations management, personnel management, accounts payable, accounts receivable, budgeting, forecasting, and so on. All of these functions are also important to the Army. In the case of the Army logistics system, the database would also need to include every end item in the system: weapon systems, vehicles, rotatable spare parts, to name just a few. The list would be very extensive. The information would also need to include the location and readiness state of each unit and each item of equipment. The centralization of all data functions into GCSS-Army and LMP is helping the Army to eliminate many costly and outdated legacy data systems. The GCSS-Army and LMP systems will be the warehouse for all logistical data. This is good news, and it is bad news. From an operational standpoint, it is highly desirable to have all relevant data federated together so that better decisions can be made more quickly. This is because, when data are federated, all files are kept in sync when an update to a database is made. For logistics, it is vital that the supply, maintenance, distribution, in-transit visibility systems, etc., be synchronized. However, federating data also makes the overall system more vulnerable to cyberattacks.

Implementation

It is a mistake to underestimate the effort involved in implementation of any ERP system. Fully implementing a GCSS-Army and LMP is a daunting task and will require constant attention from the Army leadership responsible for budgetary decisions. There are cases where companies implementing SAP developed systems have had to stop all production and operations because company management significantly underestimated the effort required by the company to successfully implement the SAP system. In the military, the Navy is implementing a SAP ERP and appears to be doing so successfully. The Marine Corps is implementing the Oracle ERP system. The Air Force has had difficulty with its Oracle implementation and has stopped implementation (Kanaracus, 2012). Despite the challenges, using GCSS-Army and LMP offers outstanding opportunities for modernizing Army logistics and achieving operational efficiencies not possible up to now (with commensurate reductions in the logistics tail).

Finding 6-1. The Global Combat Support System-Army and the Logistics Modernization Program form a viable approach to address the issues of in-transit visibility and efficient logistics operations, and to form the basis for the development of robust decision aids.

In examining the ERP approach undertaken by the Army—and most of the Department of Defense (DoD)—it is evident to the committee that Army acquisition leadership thinks of this as similar to a hardware acquisition. The systems are considered to have a traditional investment profile and to reach an end state at some time. In fact, like most complex software systems, the ERP system will never achieve an end state, except one dictated by lack of funding. Like most commercial software, the ERP should be thought of as a continuously evolving product that provides ever-increasing levels of capability. Consider software like Google as an example. There was an initial capability that provided only a text search function from 1998 to 2001. Then Google added the ability to search nontext content, an e-mail service, a calendar, social functions, and the like in a continuously evolving process. The investment level increased from that for the initial capability to that needed today because people desired new functionality. It is unlikely that Google had all this planned at the beginning. More likely it was opportunistic in developing what customers desired as they saw what was possible.

The implementation of GCSS-Army and LMP has been ongoing for over 10 years, and the systems will continue to evolve. SAP/ERP is a highly complex system that requires real understanding for an organization to be successful in implementing it. While the Army has a training program in place for GCSS-Army and LMP, it will be important for the education process to provide sufficient capacity and be comprehensive enough for successful implementation in the near term. It was clear from briefings and conversations with GCSS-Army and LMP executives that they are making progress, and they should be congratulated.

Finding 6-2. The Army has expended considerable resources on implementing what may be the largest enterprise resource planning (ERP) system ever. There is a mixed record of success among the other Services implementing ERPs.

Recommendation 6-1. The Army should make full use of the experience and lessons learned by other Services in implementing its enterprise resource planning systems so as to maximize its chances of success.

Recommendation 6-2. The Army should realize that the enterprise resource planning system will be a continuously evolving product with ever-increasing functionality. The programming and budgeting process should recognize this by providing a continuous funding stream for evolution and upgrades as well as the expected growth in functionality. Army leadership should provide ongoing resource and organizational support for the Global Combat Support System-Army and the Logistics Modernization Program even after full implementation of the system in order to reap the maximum benefits from its investment.

System Security

Having a single federated ERP data and/or execution system magnifies the Army's vulnerability to cyberattack. A successful cyberattack could shut down the entire GCSS-Army and LMP systems, which could easily bring the Army's logistics system to a halt. The military is the target of a tremendous number of cyberattacks on a daily basis. Because SAP has thousands of ERP implementations all over the world, it is possible that a potential enemy may have already determined how to breach the GCSS-Army and LMP systems. A sizeable international hacking enterprise already exists in the commercial SAP-ERP world (Nieto, 2013; Vazquez, 2013).[1]

Part of SAP's vulnerability to hacking rests in its complexity. The granting of authorizations is complex, and maintaining that system is complex. There are many possibilities for inadvertently creating security vulnerabilities. The SAP debugger can allow a hacker to relatively easily change system functionality. There are numerous examples of remote users hacking the civilian SAP/ERP systems. While the GCSS-Army personnel indicated to the committee that they believed the SAP password system was sufficient, it would appear, in light of the discussion above, that the SAP security system could be vulnerable. This is an area of considerable risk to DoD, and anything less than an effort comparable to the one made to protect the U.S. financial system would be inadvisable. The financial systems of the United States are protected with multiple data backups in case of a catastrophic event, and the Army needs nothing less. When it is at war, the Army's security requirements are as important as those of Wall Street. Once the Army fully implements GCSS-Army and LMP and depends on it operationally, the entire Army logistics system will incur the attendant risks of a federated ERP database, including catastrophic failure of the system due to enemy activity.

Finding 6-3. There is the need for a redundant computational capability/infrastructure and data backup for the Global Combat Support System-Army and the Logistics Modernization Program.

Finding 6-4. The Global Combat Support System-Army (GCSS-Army) and the Logistics Modernization Program (LMP) use the SAP enterprise resource planning password system, which may not be sufficient for their security needs.

Recommendation 6-3. Army Enterprise Systems Integration Program leadership should implement further redundancy, data backup, and security measures for the Global Combat Support System-Army and the Logistics Modernization Program.

Data Integrity

Data integrity is now, and will continue to be, a significant challenge for the GCSS-Army and the LMP. Accurate logistical data are an absolute requirement. Without accurate data, the logistics system may not perform at the required level, and decision support systems that rely on that data may deliver erroneous analysis results. The reliability of GCSS-Army and LMP, and the level of data integrity, will directly impact trust in the system. Every supply sergeant in the Army is extremely adept at squirreling away extra items that the logistics system historically may have done a poor job of delivering. This behavior is highly ingrained in the Army's logistics culture, and it is not likely that this culture can be completely changed. Trust in the GCSS-Army and the LMP will improve as the systems prove their worth and reliability to the soldiers who depend on them.

While automated data entry will become the norm over time, much of the data entered into GCSS-Army and LMP will be entered by hand. There will be numerous opportunities for mistakes to be made. To ensure data integrity, automated auditing of the system may be a necessity. This could be achieved with relatively straightforward applications of artificial intelligence, and following SAP standards (Experian QAS, 2008).[2]

[1] Xpandion, "How to Hack SAP®," http://www.xpandion.com/Security-Authorizations/how-to-hack-sap.html, accessed November 13, 2014.

[2] SAP, Help Center, "Data Integrity Manager," http://help.sap.com/saphelp_crm70/helpdata/en/49/2a5a1d6c7f3895e10000000a421937/content.htm, accessed November 13, 2014.

Finding 6-5. Data integrity is absolutely vital to the success of the Global Combat Support System-Army and the Logistics Modernization Program and for the development of future decision aids. It was not clear from information provided to the committee if the system developers have paid sufficient attention to data integrity.

Joint and Coalition Considerations

Because of the complexity of ERP implementation and the specific needs of the Services, DoD did not require procurement of a single ERP system for all U.S. military. While the Navy and the Army are employing SAP software, the Air Force and Marine Corps chose to employ Oracle systems for their ERPs. As a result, linkages between service systems are still under consideration, although, in a demonstration, GCSS-Army and GCSS- Marine Corps were able to link selected elements of their systems.

From a coalition perspective, a large percentage of our allies are also implementing, or have implemented, their own ERP systems. It appears that virtually all are using either SAP ERPs or Oracle ERPs. With the expectation that coalition operations will be the norm in the future, it is possible that it will be necessary to link with allied systems in future military operations. Such linkages would increase the efficiency of future coalition operations by allowing for mutual support across many or all of the coalition participants, but they could also introduce new security concerns.

Finding 6-6. In a Joint environment, the necessity for interoperability among service enterprise resource planning (ERP) systems will become more pressing. It also may be necessary to similarly connect U.S. ERP systems with allied military ERP systems for coalition operations, although this may raise new security issues.

Recommendation 6-4. The Army should continue its efforts to have Global Combat Support System-Army interact with sister Service enterprise resource planning systems. This capability should also include the Logistics Modernization Program. The Army should work on achieving similar, secure interoperability with allied enterprise resource planning systems via federation for coalition operations.

In-Transit Visibility and Supply Chain Management

In the current Standard Army Retail Supply System-based system, individual orders from within units stop at the supporting Supply Support Activity (SSA). If they cannot be filled, an SSA order (with unique SSA document number) is generated to the source of supply, with the unit order held as a "due out." When the SSA order is filled, it then is married up to the unit due out and the unit's order is filled. It was set up this way to reduce excess inventory. If every unit order was unique and perpetuated to wholesale, if the order is canceled or filled through some other means, when the original order is filled from wholesale (cancellations almost never catch up in time), it has nowhere to go but excess inventory. Another advantage of this system is that any given order for an item with a national stock number that is stocked will be filled just as soon as stock is on hand, and any stocked item for which there is no stock on hand will already have "due ins" coming to fill up to the requisitioning objective. In this way, orders for stocked items will almost always get filled faster if the unit's original order is not perpetuated to wholesale. GCSS-Army will work the same way.

In discussions with Army supply personnel, the committee was informed that Authorized Stockage Lists (ASL) have become very responsive, owing to an effort put into place that involves Army Materiel Command (AMC) designing the ASLs, rather than units doing it themselves. Orders for readiness drivers are likely to be on the ASL of the supporting SSA. Over 75 percent of orders for readiness drivers are stocked at the local supporting SSA.

The use of in-transit visibility lets units see when their due outs will be filled. There have even been applications written that mimic the Standard Army Retail Supply System logic. These applications can match up unit orders with the corresponding SSA order that went to wholesale, so tracking orders right to the SSA's doorstep is routine. Just like the commercial marketplace, the Army uses advanced shipping notices and provides units automated estimated shipping dates for their unfilled orders that go right into their unit document register.[3]

With the above in mind, there are reports that suggest the system could be further improved by extending visibility to the end user—that is, the soldier. The committee heard many anecdotal reports of instances of over-stockage, excessive inventory, and low confidence that ordered items would be available when needed. One contributor to this situation may be the (real or perceived) lack of visibility for the end user about whether or when an ordered item will be delivered as requested.

Companies like Amazon, FEDEX, and UPS push shipment and delivery information to the customer. The UPS Supply Chain Solutions organization actually monitors the stocks levels of inventory and advises the customer of the need to reorder based on restocking thresholds provided by the customer. Better resupply in-transit visibility for Army commanders and unit-level operators could go a long way toward relieving the problems that lead to excess orders, stockpiling of supplies, and cannibalization. There are reports that say providing this information is something that would give commanders more confidence in the logistics system.

The Army also uses radio frequency identification (RFID) tags to provide in-transit visibility. DoD is transitioning to an improved RFID tag and infrastructure technology. The new tag addresses operational shortcomings by alleviating tag numbering constraints, improves interoperability with coalition partners, and improves tag capabilities for sensor functions. However, conversations with active-duty soldiers having recent experience in Afghanistan reveals that many containers arrive in country missing their RFID tags. They had been removed during container handling, possibly intentionally. The result is that many containers arrive with no indication of what is actually in the container. Depending on when the RFID is removed, visibility is lost for some part of the container movement.

Finding 6-7. Differences of opinion between the public and private sector continue to exist on how far the in-transit visibility system should extend.

Recommendation 6-5. The U.S. Army, in coordination with commercial supply chain companies, should look at the cost /benefits and advantages/disadvantages of extending the in-transit visibility system to the end user/soldier.

Finding 6-8. The Army continues to encounter challenges, posed by the operational shortcomings described above, with use of radio frequency identification technologies, and these challenges are affecting in-transit visibility.

Recommendation 6-6. The Army should develop robust, reliable radio frequency identification tags that address operational shortcomings experienced with current tags.

Finding 6-9. Technology demonstrated recently will allow for better visibility of in-theater fuel supply.

Recommendation 6-7. The Army should continue to develop and field technologies that improve visibility for in-theater fuel supply levels.

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[3] Various discussions between LTG (ret) Mitchell H. Stevenson, former Deputy Chief of Staff, Army G4 and former commanding general, Combined Arms Support Command, and Leon Salomon, committee member.

MAKING BETTER LOGISTICS DECISIONS

GCSS-Army and the LMP will be the underpinnings for virtually all Army support systems for logistics decisions. The various components of the logistics ERP, when combined with operations research (OR) expertise, provide advanced analytics to support enterprise strategy and integration. The ERP will bring the necessary visibility to the movement of supplies and parts through the logistics system. Current decision support systems, which depend on existing stove-piped data systems, will in the future be supported by the GCSS-Army and LMP data systems. Considerable effort will be required to transform present decision support systems into GCSS-Army and LMP applications—that is, to tap into and make use of the GCSS-Army and LMP systems and data sets.

The truly exciting prospect for GCSS-Army, however, is that all of the Army enterprise data will be in one federated data base. GCSS-Army and LMP will open up incredible opportunities at all levels of the Army for the development of decision support systems that were simply not possible before. The new decision support systems will be the vehicles for vast improvements in logistics operations, bringing with them increased efficiency.

Decisions made during the execution of the Army logistic mission are made at every level, from supply sergeants and maintenance technicians to the commanding general of AMC, and can be very complex. These decisions can include things like which system to work on first, whom to assign to a job, when and where to send supplies, which route to use, how much force protection is needed, and thousands of others. Each of these decisions usually involves considering several alternatives. More often than not, the only decision support currently available is in the form of a “Bunch of Guys (or Generals or Gals) Sitting Around a Table,” known colloquially as BOGSAT. Effective analysis can result in major savings (Box 6-1).

BOX 6-1
The Value of Analysis

During the early Fall of 2002, less than a year after commencing Operation Enduring Freedom and with Operation Iraqi Freedom imminent, the commanding generals for the U.S. Army Aviation and Missile Command (AMCOM) and AMC initiated an ambitious study effort to improve logistics operations in order to better relate resource investment levels to force readiness and future force capabilities.

Even though budgets were increasing in the immediate aftermath of a decade of neglect during the post-Cold War drawdown, rapidly growing back orders for parts and unfunded requirements for spares were causing increasing concern, yet their impact on readiness was not at all clear. Aggregate aviation fleetwide readiness was beginning to decline, and across the Army expensive weapons systems were declared nonoperational owing to a lack of relatively cheap parts. However, all these concerns were accompanied by widespread perceptions of enormous inefficiencies and disconnects across the logistics support system. An initial year-long effort led to several initiatives, including improved demand forecasting, improved inventory management policy, and improved retrograde operations.

Early results based on analytical demonstrations, experiments, and field tests from 2003 to 2005 clearly revealed that readiness could be improved with significantly reduced costs if specific catalysts for innovation were adopted. Among the catalysts identified were mission-based forecasting (MBF), readiness-based sparing (RBS), and readiness responsive retrograde (R3), each of which was key to adopting a systemwide, end-to-end enterprise perspective, referred to in academia and the commercial sector as integrated supply chain management. Each of these catalysts is described in more detail in Appendix G. Each—MBF, RBS, R3, and connecting condition-based maintenance (CBM) to the supply chain—is estimated to be saving on the order of hundreds of millions of dollars annually for the Army aviation fleet. Their combined effect, once they have been fully implemented, is likely to be the saving of many billions of dollars, giving the Army a several-orders-of-magnitude return on its investment.

SOURCE: Parlier (2011, p. xxi).

Now, as overseas operations abate, Army budgets are decreasing. This situation, combined with the effects of a broader national fiscal reality, is renewing the quest for more efficient, cost-effective operations and giving it new urgency. A phrase now used to describe this goal has been costwise readiness. The Army's persistent inability to relate resources to readiness, which is due to both inefficient supply chain management and poor forecast accuracy, has been masked by massive infusions of resources for much of the past decade but is again becoming apparent, resulting in mounting pressures to find efficiencies and generate savings.

To the extent that significant savings can be generated from within the materiel enterprise by adopting, refining, and implementing new analytical approaches, at least some of the force structure that would otherwise be eliminated due to fiscal pressure could instead be retained. Savings obtained by transforming Army supply chain management could help to preclude the re-emergence of a "hollow force," caused by the damaging effects of precipitous budget drawdowns traditionally seen during postwar periods.

Finding 6-10. The application of advanced analytics, systems analysis, and emerging information technologies (e.g., enterprise resource planning systems) provides a powerful opportunity to create effective enterprise decision support systems.

Recommendation 6-8. The Army should strongly support the application of advanced logistics analytics to develop enterprise decision support systems in conjunction with emerging information technologies, sensor-based technologies, and supply chain simulation technologies.

User Access to GCSS-Army Data

GCSS-Army has the potential to quantify spare parts usage and empirically track the readiness production function for major systems. Consequently, vast amounts of data and information will soon be available at the tactical level. However, if the new tactical-level data collection and warehouse systems are not connected to the larger supply chain, then enterprise-wide visibility will not exist to generate the knowledge needed (e.g., using multiechelon readiness-based sparing) to fully capitalize on their promise. Conversely, if this customer (readiness) demand information is made visible using information technology (IT) and provided to the entire logistics enterprise, then the bullwhip effect can be drastically reduced.[4] This can be accomplished for the very first time by providing actual consumption information in near real time to all production, provisioning, distributing, and inventory supply elements in the supply chain. By providing such visibility, collaboration among all organizations can be drastically improved and focused directly on supply performance for readiness capability needs that are now apparent to all. Uncertainty is thereby removed, and inefficiencies induced by information lag across previously independently operating logistics organizations can be dramatically reduced. The supply chain becomes more responsive to real customer demand—that is, to actual readiness requirements. Capability and readiness performance can be improved and aggregate investment levels reduced and tied directly to performance outcomes, thereby linking resources to readiness. The Army has an unprecedented opportunity to improve logistics planning and reduce logistics costs and response times through the use of information being generated under AESIP.

The key requirement for the development of software applications (i.e., software tools or apps) is to be able to access data from GCSS-Army. It should be possible for people at all levels of an organization to develop apps appropriate to their jobs. As an example, a warrant officer in a unit may develop an app that makes transferring equipment easier. The process is currently manual and involves a significant number of steps. It might be possible to develop an app that would do all the steps

[4] The bullwhip effect describes the tendency for the variance of orders in supply chains to increase as one moves upstream from consumer demand (Croson et al., 2013).

automatically based on simple input from the user. This app could then be shared with others in similar jobs. A clearinghouse for GCSS-Army apps would accelerate the process of implementing GCSS-Army and would take advantage of considerable expertise that exists in the operating units of the Army. Most of us use apps on our phones from similar clearinghouses (i.e., app stores). This process could be adapted from the civilian world to meet the needs of the Army.

Finding 6-11. The Army currently has no processes, plans, procedures, funding, people or other resources aimed at encouraging the logistics community to develop and propagate apps and higher level tools using data from the Global Combat Support System-Army, the Logistics Modernization Program, or other data systems to improve the decision process.

Recommendation 6-9. The Army should take advantage of contributors at all levels to develop and distribute apps and other tools to fully realize the potential of the Global Combat Support System-Army. A concept similar to those used in commercial app stores should be implemented to distribute such tools and provide ratings for them.

Operations Research and Logistics Decision Making

The Army is investing heavily in an effort to fully capitalize on the enterprise-wide promise offered by IT. Although enormous sums have been invested by the corporate world in ERP solutions, these investments have had very mixed results (Brown, 2003). Emerging evidence indicates that it is possible to achieve dramatic improvements in performance and competitiveness with IT systems. This success, however, has only been achieved by companies that have applied IT solutions to appropriate, efficient, and mature business processes. Information (especially ERP) systems alone cannot compensate for the lack of such a business-practices. In fact, the evidence suggests the opposite, that attempts to implement IT solutions absent such a business practices actually lead to poorer performance (Heinrich and Simchi-Levi, 2005).

It is important to differentiate between (1) the purpose and functions of OR, which uses knowledge-based decision support systems, and (2) transaction-based ERP technology, which is used to acquire and process raw data and to compile and communicate accounting reports.

ERP solutions have increasingly been touted as a panacea for all kinds of corporate decision-making processes, but they lack the analytical capabilities needed to optimize the efficiency of those transaction-oriented processes.[5] While ERP systems provide considerable visibility into events that have happened, they provide very little insight into why they happened, even less about what is likely to happen, and certainly nothing about "what should happen if current conditions either continue or change." As Massachusetts Institute of Technology Professor Jeremy Shapiro observed, "Enterprise Resource Planning (ERP) is really a misnomer because it fails to provide insights into decisions affecting 'resource planning'" (Shapiro, 2007, p. 35).

In contrast, OR has been described as the "science and technology of decision making" and can be traced to multidisciplinary teams applying several scientific methods to military operations during the early years of the Second World War.[6] Over time OR has become recognized as the discipline of applying advanced analytic and modeling frameworks to the challenges of complexity and uncertainty, especially in large-scale systems and organizations. Utilizing principles from mathematics, engineering, business, computer science, economics, and statistics, OR has developed into a full-fledged academic discipline

[5] See, for example, Hugos (2003), *Essentials of Supply Chain Management,* p. 127.

[6] For additional information, see Fisher (2005), A *Summer Bright and Shining*; Nye (2004), *Blackett, Physics, War, and Politics in the Twentieth Century*; and Air Ministry (1963), *The Origins and Development of Operational Research in the Royal Air Force*.

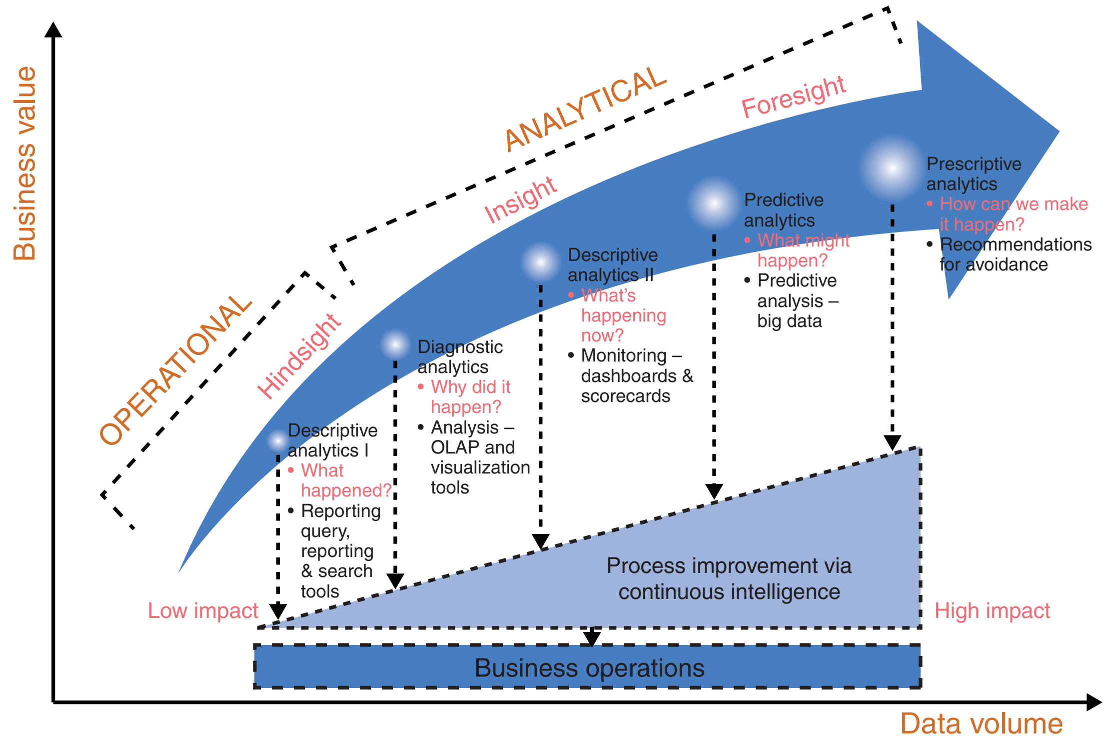

FIGURE 6-2 Difference between the data resident in ERP systems, labeled "Operational," and the data in prognostic, predictive, and prescriptive analytics, labeled "Analytical." OLAP, online analytical processing. SOURCE: Josh Call, HQ AMC G-3/4, Ron Lewis, LMP PMO, Henry Singer, Team CSC, "Logistics Modernization Program (LMP) Enterprise Resource Planning (ERP) 101 Education & LMP Capabilities Overview," presentation to Army Materiel Command (AMC), November 6, 2013.

with practical applications in business, industry, government, and the military. Its purpose is to provide managers and executives with insight and guidance, using advanced analysis to interpret information and create knowledge for them as they apply their decision-making processes to complicated management issues (Parlier, 2005).

In the corporate world the term business intelligence is used to encompass both analytics and the data processes and technologies used for collecting, managing, and reporting decision-oriented information. It is critical that the Army recognize and build on the potential offered by its ERP implementation by developing and connecting to analytic capabilities provided by decision support systems. What is needed is a symbiotic—not merely a complementary—relationship between decision support systems (incorporating analytically based forecasting, planning, and optimization technologies) and ERPs to fully capitalize on the promise of an integrated logistics enterprise. The difference between ERP data systems and advanced analytics, which includes prognostic, predictive, and prescriptive analytics, is shown in Figure 6-2.

Furthermore, the Army materiel enterprise lacks an engine for innovation, a virtual test-bed that can provide a synthetic, nonintrusive environment for experimentation and evaluation of innovative ideas and concepts. Such a synthetic environment is needed to guide and accelerate transformational change along cost-effective paths, providing the analytical glue to integrate and focus what otherwise would be disparate initiatives and fragmented research efforts. In essence, such a capability functions as an engine for innovation to sustain continuous performance improvement. To some extent, the Logistics Innovation Agency has been serving in this capacity by developing and assessing logistics tools and methods for the Army's tactical environment. If these existing, although limited, Logistics Innovation Agency capabilities could be complemented with several others across the broader DoD support community, the Army could generate vastly improved simulation capacity, modeling capabilities, testing, and experimentation. Not only would this allow the rapid assessment of useful logistics tools prior to their infusion into the force, but it would also dramatically improve enterprise supply chain management across multiple classes of supply.[7] These capabilities could streamline development and responsive implementation of tactically relevant, cost-effective logistics tools and concepts and provide the ability to better define new system requirements in support of the acquisition community. This is discussed in more depth in Appendix F.

Finding 6-12. The Army lacks a comprehensive strategy and implementation plan incorporating effective decision support analytical tools (i.e., operations research) along with the appropriate IT required to enable and provide the decision support needed to achieve cost-effective, performance-oriented results. In this era of dramatic resource constraints, the Army logistics community must better harness and apply operations research and strategic analytics across the materiel enterprise.

Recommendation 6-10. To obtain the full decision support potential of the integrated logistics enterprise, the Army should ensure that enterprise resource planning system data transactions and management information systems are complemented by the operations research capabilities needed to conduct modern analytics. The goal should be effective integration of analytics into organizational decision making.

Recommendation 6-11. The Army should develop an engine for innovation for the logistics community and adopt, apply, and refine management innovation as a strategic technology (see Appendix F).

Improving Sustainment Support

Technology readiness levels (TRLs) represent one approach commonly used to support decisions on the front end of the acquisition life cycle (pre-Milestone C).[8] There is currently no analogous measure that can be applied to fielded systems or fleets operating in the sustainment phase of their life cycles or to new systems proposed or under development in the early phases of the acquisition process. No matter the life-cycle phase, sustainment or development, insight into issues of costwise readiness and affordability—the likely future operation and sustainment costs (and cost growth)—can be gained by simply asking whether specific sustainment concepts, policies, or methods are in use, are planned for use, or are not planned. The same is true for the ability to credibly relate budgets (current resources) to near-term readiness and for the ability to relate programs (future resources) to future capabilities. With this in mind, there may be value in considering the concept of sustainment readiness levels (SRLs). Analogous to TRLs, SRLs are post-Milestone C graduated thresholds for a sustainment maturity model, which consist of critical supply chain management policies applicable across all platforms. The supply chain policies identified below support development of readiness-driven supply networks and, collectively, form the analytical foundation for pursuing and achieving cost-wise readiness. Their effects should be assessed and measured in terms of enterprise outcomes: sufficient availability for current operations (current readiness) and systems available for anticipated missions including Defense Strategy Guidance requirements (future capabilities). Adopting such a sustainment maturity model would be a significant

[7] These could include, for example, the Systems Integration Laboratory at Pennsylvania State University's Applied Research Lab; high-resolution supply chain modeling and simulation capabilities developed by the Center for Systems Reliability at Sandia National Laboratories; and the Virtual Factory simulation framework for optimizing complex systems at North Carolina State's Industrial and Systems Engineering Department.

[8] A milestone marks the start or finish of a program phase and has defined entrance and exit criteria. Milestone C is an acquisition program review conducted at the end of the Engineering, Manufacturing and Development phase of an acquisition program. The purpose of this review is to make a recommendation or seek approval for an acquisition program to enter the Production and Deployment phase (AcqNotes, "Acquisition Process: Milestone C," http://acqnotes.com/Acquisitions/Milestone%20C.html, accessed March 18, 2014).

step toward bringing together previously separate, diverse groups to focus on a shared purpose driving toward common goals and readiness-oriented outcomes.

For currently fielded systems in the sustainment portion of their life cycles, empirical impacts for various sustainment policies could be assessed using SRLs. For example, it could be determined whether a policy was being implemented with measurable effect within a cost-performance (resources vs. readiness) trade space. For new systems, these criteria could be used as an assessment and planning checklist in conjunction with TRLs. This approach would be significant because the development of new programs has historically not focused (for various reasons, including lack of empirical operational data) on the costs and logistics implications of the operation and sustainment phase, even though sustainment costs typically constitute more than 70 percent of total life-cycle costs of a program. SRLs could be reviewed by the Joint Requirements Oversight Council for sustainment capability assessment and by the relevant Milestone Decision Authority (MDA). SRLs could provide a means for DoD officials, program managers, and materiel management centers to address, and focus attention on correcting, numerous problems in supply chain management, including persistent deficiencies in demand forecasting, inventory policy, and strategic resource planning.

Specific sustainment management policies—that is, catalysts for innovation (refer to Box 6-1)—should be included as critical enablers for this SRL concept. Management policies for which SRLs can be established include these:

- Mission-based forecasting (MBF),
- Readiness-based sparing (RBS),
- Multiechelon RBS (MERBS),
- Condition-based maintenance (CBM),
- Intermittent demand,
- Readiness-responsive retrograde (R3), and
- Sustainment early warning system (SEWS).

A broader discussion of the above concepts, including possible assessment criteria, is included as Appendix G.

Finding 6-13. Inadequate attention has been focused on the long-standing need to correct numerous problems in supply chain management, including persistent deficiencies in demand forecasting, inventory policy, and strategic resource planning.

Finding 6-14. Unlike pre-Milestone C technology readiness levels for major acquisition programs, there are no Joint and/or Army requirements for post-Milestone C sustainability assessments.

Recommendation 6-12. The Army should adopt critical supply chain management policies—catalysts for innovation—and apply a sustainment readiness level (SRL) maturity model concept to both currently fielded systems and new systems in development. The Army should further extend the SRL concept, particularly mission-based forecasting, beyond Class IX to other classes of supply as well, especially III and V.

(Lack of) Analysis of Logistics Issues Related to Acquisition

Anecdotally, there are many instances when, as a program faces budget constraints (which all programs inevitably do), the first requirements that are sacrificed are those related to logistics and sustainment. They are sacrificed in favor of those that more directly affect warfighting performance. There exist many examples, such as relaxation in reliability, fuel consumption, system life, maintenance access, and the like as the first requirements relaxed to save dollars. Whether or not these ultimately proved to be good decisions, they were generally the best available to a responsible decision maker forced to operate with incomplete data. These decision makers, when choosing a logistics-related requirement rather than a nonlogistics requirement, are typically presented with the benefits of each choice in an apples-to-oranges comparison. For example, reliability improvements to an artillery system, expressed in terms of mean time between failure, would not usually compete well against rate of fire, range, or other capabilities more easily quantified in terms of combat measures. Yet improved mean time between failure would have beneficial mission impacts such as more mission-ready systems available to the commander and less likelihood of a system or subsystem failing during a mission. Despite its significant effort looking for apples-to-apples assessments of logistics versus nonlogistics system analyses, the committee was unable to find any. One emerging capability that shows promise is the Whole System Trades Analysis Toolset developed for the Army's Ground Combat Vehicle program and now being applied more broadly by PEO Ground Combat Systems.

Finding 6-15. When systems are being developed, the results of logistics analyses are not quantified in terms of warfighting effects. As a result, logistics systems and logistics requirements do not fare well when competing with other types of systems or subsystems.

Recommendation 6-13. The Army should develop and implement methodologies to quantify the warfighting effects of logistics in analyses.

During data gathering for this report, a subset of the committee visited the Training and Doctrine Command (TRADOC) Analysis Center (TRAC) at Fort Lee, Virginia (TRAC-Lee). During this visit the committee learned that TRAC-Lee is responsible for performing most of the Army's analyses supporting logistics decisions for TRADOC. Yet TRAC-Lee has only about 25 trained analysts to perform these studies and analyses. Overall, the entire TRAC enterprise, consisting of centers at Fort Lee, Fort Leavenworth, Monterey, and the White Sands Missile Range, has about 250 analysts. Thus only 10 percent of the analysis force is dedicated to logistics analysis, even though sustainment costs typically account for more than 70 percent of a system's overall life-cycle costs.

While it can be difficult to perform comparative analyses of logistics and nonlogistics systems using common relevant measures of effectiveness, it is generally possible. The main requirements to successfully do this are quality analysts and well-designed tools.[9] If such analyses were broadly available, the committee believes that in many cases better acquisition decisions might be made. Rather, the decision maker is usually forced to make a choice between two or more alternatives with only experience and advice from others with the same information deficits. No data exist to indicate how often a decision is made where the alternative would actually be a better choice for the Army. However, given that the decision is generally made to sacrifice the logistics requirement, and given the large portion of the Army budget devoted to support systems, it is likely that there is a substantial long-term cost impact of poor decisions.

Finding 6-16. Because logistics decisions are complex, are often mostly subjective, and often have great impacts on life-cycle cost, an investment in logistic decision support systems could result in significant savings over a system's life cycle.

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[9] Two examples of Army efforts along these lines are the Contingency Basing Initiatives and Joint Operational Energy Initiative. The Joint Operational Energy Initiative is discussed in Chapter 3. The Contingency Basing Initiative is focused on making contingency bases more efficient, reducing waste, reducing energy demand by reducing usage and using alternative energy sources, and reducing water demand by more efficient usage and recycling efforts.

Many logistics-related issues are not being addressed at TRAC-Lee, despite its role in performing logistics assessments. For example, TRAC-Lee currently does not perform assessments of the potential impacts of adopting CBM+ across major weapon systems and vehicle fleets and their supporting supply chains. As a consequence, the potential impacts on tactical workload and unit-level workforce reduction have not been quantified. Nor has the possibility of significantly reduced forward stock levels or aggregate requirement objectives for CBM-enabled components been assessed. With the exception of the Joint Operational Energy Initiative, a lack of analysis appears to generally be the case for most ongoing and contemplated logistics technology initiatives. Another example of failure to assess logistics impacts is the recent decision to reduce the size of brigade combat teams from 4,000 to 3,000 personnel authorizations within the current program (which encompasses fiscal year [FY] 2016 to FY2020), assuming that robotics will somehow enable this reduction in manpower. TRAC-Lee has neither the necessary analytical experience nor the modeling capabilities to actually assess, much less validate, such a crucial decision.

Army leadership, particularly in making acquisition decisions, has become accepting of the difficulty in analyzing logistics systems vis-à-vis nonlogistics systems. As a result, they do not demand comparison of such alternatives using common metrics. The committee believes that such comparisons are usually possible, and Army decision makers should insist on such results from their analysts.

Finding 6-17. Modeling and simulation resources (personnel and tools) are insufficient at Training and Doctrine Command Analysis Center-Fort Lee to evaluate, compare, and contrast various science and technology initiatives and their respective impacts on both the force structure alternatives currently under consideration and operational outcomes across the spectrum of operations.

Finding 6-18. Institutional enterprise-wide modeling, simulation, and analytical capacity for conducting strategic logistics is fragmented and is inadequate to provide the cause-and-effect understanding essential for designing the force of the future.

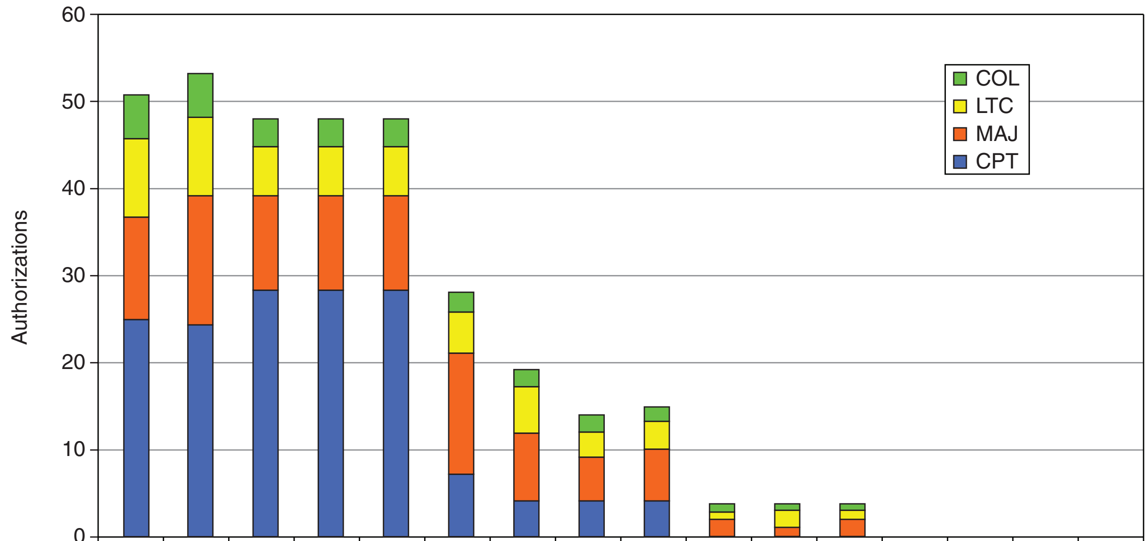
Recommendation 6-14. The Army should revitalize its logistics analysis capability by acquiring the necessary tools and qualified people in quantities commensurate with the number and impact of logistics decisions that need to be made.

Recommendation 6-15. The Army should educate its leadership about what is possible in logistics analysis, and about the importance of demanding analyses of alternatives using common metrics.

Operations Research Support for Logistics

The military drawdown during the decade of the 1990s decimated the existing analytical brain trust of logistics-focused military operations research/systems analysts (ORSA) within AMC. Officer ORSA authorizations declined from 55 in fiscal year 1989, including five colonels, to none by fiscal year 2000, as shown in Figure 6-3 (Parlier, 2004). They have remained at zero until just a few years ago, when one position was restored to the U.S. Army Materiel Systems Analysis Activity.

Army civilian ORSAs also saw disproportionate cuts relative to the rest of the Army, declining from half of Army-wide authorizations in FY1990 to less than a third by FY2002, where they remain today (Figure 6-4). Nearly all those that remain, however, are providing matrix customer support to program management offices as cost analysts rather than analyzing supply chain challenges. Furthermore, in the case of the U.S. Army Aviation and Missile Command, for example, there have been no dedicated resources to support outsourcing logistics systems analysis, research, or studies for nearly two decades now (Parlier, 2011).



	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03
COL	5	5	3	3	3	2	2	2	2	1	1	1	0	0	0	0
LTC	9	9	6	6	6	5	5	3	3	1	2	1	0	0	0	0
MAJ	12	15	11	11	11	14	8	5	6	2	1	2	0	0	0	0
CPT	25	24	28	28	28	7	4	4	4	0	0	0	0	0	0	0

FIGURE 6-3 Officer ORSA (Army Functional Area 49) authorizations in AMC from FY1988 through FY2003. SOURCE: COL Greg Parlier, Deputy Commander for Transformation, AMCOM, "Enabling a Strategically Responsive, Transforming Army: A Systems Approach to Improve Logistics Chain Efficiency and Effectiveness," presentation to Commanding General, Army Materiel Command, and Commanding General, U.S. Army Aviation and Missile Command, August 22, 2003.

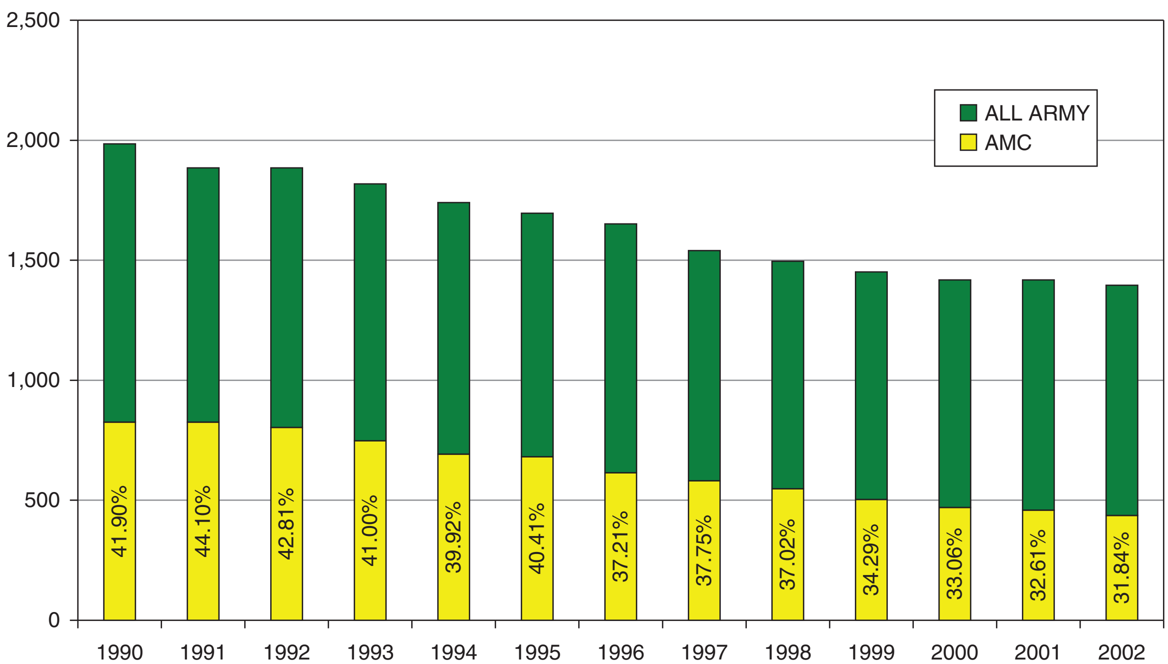


FIGURE 6-4 Civilian ORSA strength in AMC from FY1990 through FY2002. SOURCE: Republished with permission of Business Expert Press LLC, from Parlier (2011), permission conveyed through Copyright Clearance Center, Inc.

This situation is not confined to AMC. Similarly acute conditions prevail across all levels of the materiel enterprise:

- *Headquarters Department of the Army G-4 staff:* No authorizations for FA49;[10]
- *Logistics Innovation Agency:* No authorizations for FA49 and no authorizations for civil servant 1515;[11]
- *TRADOC:* 2 of 30 FA49 TRADOC authorizations are in the Sustainment Center of Excellence at Fort Lee;
- *TRAC-Lee:* 5 authorizations at TRAC-Lee out of 84 across all four TRADOC Analysis Centers; and
- *Army Logistics University:* 7 ORSA instructor authorizations compared to 31 at the U.S. Military Academy.

It is also noteworthy that during Operation Iraqi Freedom, Multi-National Forces Iraq (and later U.S. Forces-Iraq) had a robust contingent of deployed OR analysts from all Services, as well as contractor support. For example, in early 2010 there were 31 Army FA49 field-grade officers deployed in a variety of organizations and staff positions across the major commands in-theater. However, no FA49 officers were assigned to the organization responsible for theater logistics operational planning, U.S. Forces-Iraq J-4, which had a staff of 200.

The Army has not conducted a thorough, comprehensive assessment of the state of OR for nearly two decades. The need for such an introspective, forthright evaluation is clear, especially for the logistics community given the paucity of existing analytical capacity (personnel authorizations) allocated to its various commands and organizations.

Finding 6-19. The Army's ability to perform logistics studies and analyses has eroded over the last 25 years to the point where there is inadequate organic capacity left to conduct the rigorous analyses required to responsively support fact-based decision-making. An analytical renaissance is desperately needed, long overdue, and a precondition for achieving the significant improvement that is not only possible but also can be realized within a relatively short time frame (a few years rather than decades).

Recommendation 6-16. The Army should make an appropriate investment in organizing the Army analytical community to better support the materiel enterprise. Such an investment is a precondition for sustainment excellence.

Recommendation 6-17: In addition to rebuilding analytical capacity within the materiel enterprise, the committee strongly suggests a more comprehensive assessment of the state of operations research across the entire Army using an evaluation construct that includes analytical capacity, capability, utilization, organization, and contribution.

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[10] FA49 is a military designation for an operations researcher/systems analyst.
[11] 1515 is a civilian government designation for an operations researcher/systems analyst.

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7

Use of Contractors and the Army Reserve

Contractor support for military operations has been part of the history of the armed forces since the Revolutionary War. The Army Reserve is a 20th century addition to the military forces of our nation. Under the law, the reserve forces are a federal entity to "provide trained units and qualified persons available for active duty in the armed forces, in time of war or national emergency, and at such other times as the national security may require, to fill the needs of the armed forces whenever more units and persons are needed than are in the regular components" (10 U.S.C. 10102). This report does not consider the relative merits of using contractors versus Reserve capabilities. This would be a complex matter to address and whether to use contractors or Reserve capabilities in a given situation would have to be decided on a case-by-case basis.

HISTORICAL CONTRACT SUPPORT

Contractor roles have been varied. They have supplied materiel needed to support U.S. and allied forces and their activities. They have maintained and repaired equipment, built and operated camps and bases, and provided basic logistics support (e.g., power, food, and sustainment services) to those in those camps and bases. As technology has become more complex, contractor personnel are performing maintenance and repair of high-tech equipment (e.g., helicopters) in the theater of operations beyond the unit level.

This contractor support is provided by U.S. citizens, third-country nationals, and local nationals. This support is administered through three types of contracts: theater support, external support, and system support. Theater support contracts are handled by contracting personnel deployed to the theater operating under the military services, special operations commands, or joint contracting authorities. External support contracts are administered by contracting organizations that do not derive their authority directly from theater support or system support authorities; they include the Logistics Civil Augmentation Program (LOGCAP) contracts, which since the early 1990s have provided nearly $15 billion in support to deployed U.S. forces, primarily base support. System support contracts are put in place to "provide support to newly fielded weapons systems, including aircraft, land combat vehicles, and automated command and control systems" and are normally administered by Service system materiel acquisition program offices (DoD, 2011). Figure 7-1 indicates the size of the contractor workforce in Iraq from 2008 to 2012 and the breakdown among functions performed by the contractors.

Figure 7-2 shows the size of the contractor workforce, by functional area, in Afghanistan in 2010 and 2012. In 2014 a different breakout was used, and that is shown in Table 7-1.

Table 7-2 provides the breakdown in Afghanistan of the contractor workforce among U.S. citizens, third-country nationals, and local personnel.

In March 2014 the ratio of contractors to military personnel for the U.S. and the International Security Assistance Force in Afghanistan was 1.34:1. In July 2012, it was approximately 0.97:1 (Livingston and O'Hanlon, 2014). In Iraq there was an average of 1.1 contractors per deployed Service member (DSB, 2014).

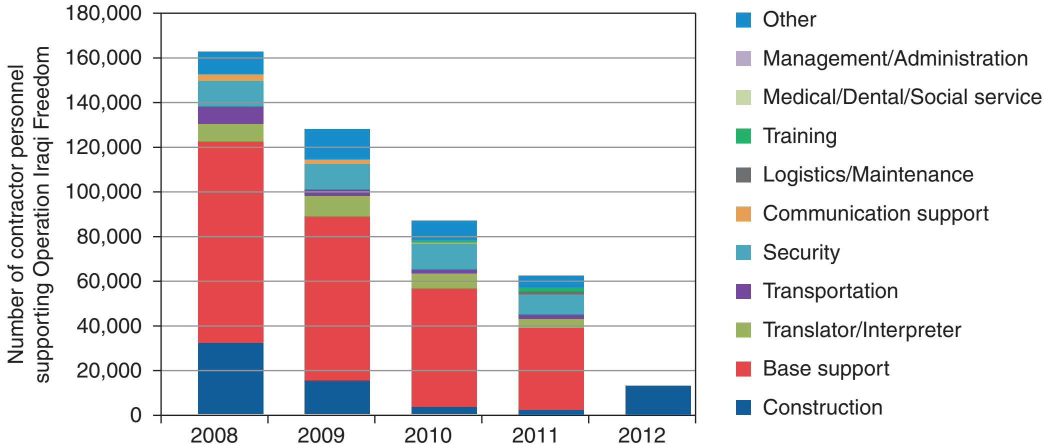

FIGURE 7-1 Contractor personnel and their functions in Iraq, 2008-2012. SOURCE: DSB (2014).

FIGURE 7-2 Size of the contractor workforce, by functional area, in Afghanistan in 2010 and 2012. "Other" includes Defense Logistics Agency, Army Materiel Command, Air Force External and Systems Support contracts, Special Operations Command, and the U.S. Army Intelligence and Security Command. SOURCE: Deputy Assistant Secretary of Defense, Program Support, CENTCOM, Quarterly Contractor Census Reports, http://www.acq.osd.mil/log/PS/CENTCOM_reports.html.

TABLE 7-1 Contractor Support Breakout in Afghanistan, 2014

Support Function	Number of Contractors	Support Function	Number of Contractors
Base support	6,834	Translator/interpreter	4,889
Communications support	2,451	Transportation	5,064
Construction	7,877	Medical/dental/social services	283
Logistics/maintenance	20,568	Management/administrative	5,316
Security	5,591	Other	791
Training	1,788		

NOTE: "Other" includes Defense Logistics Agency, Army Materiel Command, Air Force External and Systems Support contracts, Special Operations Command, and the U.S. Army Intelligence and Security Command.
SOURCE: Deputy Assistant Secretary of Defense, Program Support, CENTCOM, Quarterly Contractor Census Reports, http://www.acq.osd.mil/log/PS/CENTCOM_reports.html.

TABLE 7-2 Breakdown of Contractor Personnel in Afghanistan in 2010, 2012, and 2014

Date	Total Contractors	U.S. Citizens	Third Country Nationals	Local and/or Host Country Nationals
April 2014	61,452	20,865	19,235	21,352
April 2012	117,227	34,765	37,898	44,564
May 2010	112,092	16,081	17,512	74,499

SOURCE: Livingston and O'Hanlon (2014).

STUDIES OF OPERATIONAL CONTRACT SUPPORT

The contracting process and the effectiveness of contracting have been the subject of several major studies and commission reports over the last decade, including the following:

- Congressional Budget Office, *Logistics Support for Deployed Military Forces*, October 2005;
- Commission on Army Acquisition and Program Management in Expeditionary Operations, *Urgent Reform Required: Army Expeditionary Contracting*, October 2007;
- Defense Science Board, *Improvements to Services Contracting*, March 2011;
- Commission on Wartime Contracting in Iraq and Afghanistan, *Transforming Wartime Contracting: Controlling Costs, Reducing Risks*, August 2011;
- Government Accountability Office, *Defense Contracting: DOD Initiative to Address Audit Backlog Shows Promise, but Additional Management Attention Needed to Close Aging Contracts*, December 2012; and
- Government Accountability Office, *Contractor Performance: DOD Actions to Improve the Reporting of Past Performance Information*, June 2013.

In July 2014, the Defense Science Board Task Force on Contractor Logistics in Support of Contingency Operations released a report that was a follow-up to the above-referenced reports and studies and was an independent review of the subject by the task force. The report reviewed increasing contractor participation in activities in the theater of operations, noting that

> The growth of contracted support per member of the military committed to a mission in the major conflicts is driven by many factors. Clearly, more sophisticated weapons systems drive the need for specialized support and highly skilled personnel. Improvements in the scale and scope of military living standards have also driven up the number of support personnel. Political constraints can also affect the allocated uniformed force strength and this uncertainty can drive the use of contracted support.
>
> The extent that contracted support was used in recent conflicts is remarkable. For the majority of the duration of each contingency conflict, the number of contractor personnel was equal to or larger than organic military personnel. At one point there were over 160,000 contingency contractor personnel in Iraq (DSB, 2014).

The report also found that "over 2,600 fatalities and 22,400 serious injuries were reported for contractor personnel in Iraq and Afghanistan from 2001 to 2011" (DSB, 2014, p. 12).

After completing its review of the previous findings and conducting its own interviews and analysis, the task force found that

> - Strategic leadership across the Department does not yet recognize OCS (operational contract support) as a critical component of combat readiness.

> - Contractor support is critical to military performance during all types of military and humanitarian contingency operations, and has been since the Revolutionary War.
> - Planning for deployed contractor support is essential.
> - Risk management assessment needs to be part of planning and readiness.
> - Execution and management of contingency contracts is crucial, often complex, and costly in both wartime and peacetime missions.
> - The capability to audit contingency contracts in a timely manner is essential, and is far more important than the existing emphasis in the Department. (DSB, 2014, p. 3)

Based on its findings, the task force identified the need for DoD to do the following:

> - Establish the role of contracted support of deployed military operations within the total force mix;
> - Ensure leadership accountability across the Department and in the combatant commands for operational contract support in their area of responsibility;
> - Institute a readiness measurement capability and institute accountable measures of success for operational contract support as a component of combat readiness;
> - Develop and implement a risk management plan for operational contract support; and
> - Ensure timely audits of contingency contracts that are useful for contract management. (DSB, 2014, p. 14)

INTEGRATING CONTRACTORS INTO PLANNING AND OPERATIONS

While this committee did not examine contracting procedures in detail, it did find that contracting has become an essential part of logistics operations, and that conducting Army operations under current force structure conditions without contractor support would be extremely challenging. The Army has accepted the fact that contractors will be present in operational areas to provide maintenance and repair services for complex equipment, carry out many logistics functions, and provide other services as necessary to U.S. and allied forces. In many potential contingency areas, contractor personnel are already working with the local population to carry out other (commercial) missions. They have experience operating in these areas and have established contacts with key organizations and personnel who will be needed in the event of military activity in that area. They are also able to rapidly mobilize for support of military contingency needs. In areas where distance plays a large factor, contractors can become available days, if not weeks, before military units can carry out critical sustainment operations.

This committee found that contractors are frequently seen by combatant commands as outsiders who are brought into military planning only after, not before, critical decisions have been made and are not part of the planning process. Thus there is a lack of understanding on the part of both service personnel and combat command staff about the role of contracting in a theater of operations (this is also cited in the Defense Science Board report). This results in inefficiencies in the provision of support, unnecessary costs, and poorer performance. The Joint Chiefs of Staff J-4 has prepared templates that could be used to plan contractor support and which might provide a useful starting point for defining standards of sustainment in different situations.

Finding 7-1. Contractors are frequently seen by the combatant commands as outsiders who are brought into military planning only after critical decisions are made rather than beforehand, so they can be part of the planning process. Indeed, contractors are an important element of the logistics team and, given the reductions in active military force structure, must be considered as an essential component in the planning and execution of operations.

Recommendation 7-1. Both Army and combatant command leaders should formulate plans and operations to integrate contractors into these operations from the beginning.

Finding 7-2. Contractors have indicated to the committee that they are prepared to be active participants in planning military operations and that they possess not only knowledge of the functions they may be called on to carry out but also ground experience in the potential areas of operations. At present they are excluded from participation in contingency planning until contracted to do so.

Recommendation 7-2. Planners in both the Services and the combatant commands should be schooled in the capabilities of contractor organizations to assist in contingency planning. The contracting organizations should provide for the continuous participation of contractors in the military planning process. This may require establishing on-going contracts for support of specific combatant commands or regions within the combatant commands.

Contractors respond to client requests and generally do their best to meet these requests within the limits of the contracts. Since contractors are also evaluated based on performance (and penalized for client complaints), they logically go out of their way to ensure client satisfaction. Their goal, however, is to make the customer happy, not to ensure the most efficient provision of logistical support. It is up to the combatant commander to set the guidelines for what is and is not to be provided to deployed soldiers.

During the early stages of an operation, when the focus is on support of ongoing combat operations, the support requirements are battle oriented. As an operation transitions from the initial crisis to longer-term operations (e.g., counterinsurgency, stabilization, and nation building) and the client seeks to improve the conditions under which military personnel operate, support requirements change. In the absence of theater standards for logistics support—for example, what foods are served, the number of meals per day, the amount of air conditioning and power generation required, and standards of maintenance—client requests can become open-ended.

Under open-ended conditions, competition among contractors and their logical desire to please the clients not only increases the cost of contractor support but can dramatically increase the logistics burden of meeting these demands. A failure to establish reasonable theater standards for sustainment not directly related to combat (i.e., nonexpeditionary) sustainment can have significant negative effects on logistics operations in a theater. The reverse situation, clearly established standards, can reduce not only the logistics burden but also the casualties that result from the necessity of assigning more personnel to satisfy increased logistics burdens (e.g., more convoy operations). Establishing support standards in a Joint way, together with the other Services and in conjunction with the Joint staff, would provide the greatest benefit and ensure commonality across the operational area. The necessity for preoperational establishment of these standards was a lesson learned in Vietnam (Dunn, 1991).

Finding 7-3. Standards for support of military operations by contractors are frequently formulated on the fly, as operations evolve. This results in inconsistencies in the provision of services and a lack of attention to both potential support costs and the logistical burdens that are created.

Recommendation 7-3. Combatant commanders, in coordination with the Services and the Joint staff as part of contingency planning, should establish a uniform level of support to be provided over time for each contingency operation.

THE ARMY RESERVE

The Force

As of September 2013, there were 198,209 soldiers in the selected Army Reserve. The selected Reserve includes units and individuals within the Reserve structure designated as essential to initial wartime missions. Reserve soldiers typically are assigned to units near their home location and participate in monthly weekend drills and summer exercises. They may be involuntarily called to active duty under a number of circumstances, the most normal of which are related to wars or armed conflicts. Prior to 1990, Reserve call-ups were infrequent, but, according to a recent Congressional Research Service report (2014), the picture has changed. During the Persian Gulf War (1990-1991), 238,729 reservists of all the Services in the National Guard were involuntarily activated. During Operations Noble Eagle, Enduring Freedom and Iraqi Freedom/New Dawn (2001 to May 27, 2014), 896,815 Reserves and Guard personnel were involuntarily and voluntarily activated (Kapp and Salazar Torreon, 2014).

Sustainment Challenges

Approximately 50,000 individuals in the Reserve force are assigned to sustainment units or specialties. As the Army adjusts its force structure to increase the number of soldiers in direct combat, more sustainment troops are moved into the Reserve force. Certain military specialties and types of units, such as those dealing with water production, petroleum pipelines, strategic transportation management, and terminal operations, are found primarily or almost totally within the Reserve force, and it is this type of organization that is critical to the ability to rapidly sustain combat operations. When all is working well, an Army Reserve unit that is being called up is given 30 days' notice of their deployment. This is followed by field training at U.S. installations to ensure that the mobilized forces are adequately prepared for their assignments. The total time between notification and the appearance of a unit at an embarkation location may range from two to several months.

While the Reserve forces have proven their capabilities time and time again, once they arrive in a theater of operations, the tyranny of time and distance can have significant impacts on their ability to provide the sustainment operations. In some cases the absence of their unique skills can delay or severely impede operations requiring these skills. For this reason, the Army Reserve has initiated programs to make available to combatant commands and Army theater components planning teams whose members not only will be able to assist in developing computer contingency plans but also will provide to the planners information about the capabilities of the specialized reserve units. It is not unusual to find that within a higher-level headquarters there is limited knowledge about the types of units and their capabilities involved in complex logistical operations such as those that occur at ports and critical transit locations. Unfortunately, the offer by the Army Reserve to provide planning assistance is often overlooked by the combatant commands and Army theater components.

Finding 7-4. The Army Reserve is an indispensable element in the conduct of Army sustainment operations, but their employment must be carefully orchestrated to ensure that their capabilities are put to use in a timely and efficient manner. Army Reserve planners can provide accurate information on the response times for units being considered for employment in expeditionary operations. The opportunity to involve Army Reserve expertise in the planning process for contingency operations is often not exercised.

Recommendation 7-4. Combatant commands and theater Army components should include Army Reserve elements in their planning for contingency operations, especially when elements of the operation may require the use of specialties present only in the Reserve element.

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8

Optimizing the Logistics Effort

There are no silver bullets to reduce the logistics demand or to make sustainment easier. Enhancing the sustainment capability of the Army of the future will require attention to technological, operational, analytical, managerial, educational, and cultural elements of the Army across a wide spectrum of activities, both inside and outside the logistics community.

As noted in Chapter 2, the effective sustainment of military forces in the future, under conditions of resource constraints and geographic and environmental realities will require reductions in the logistics burdens currently being experienced and improvements in the efficiency of the process through which sustainment is delivered. While technology and management improvements will assist in achieving these efficiency goals, real success may rest with modifications to the culture of the Army and the other Services as it affects logistics and sustainment. These cultural modifications pertain to the willingness of the Army and the other services to become more Joint, both logistically and operationally; to understand and accept a leaner logistics profile that continues to provide in-the-battle support at the levels required, while concurrently reducing nonessential logistics demands; and to educate the Army as a whole, not just its logisticians, concerning the logistics system—how it operates, its costs, and the role of the nonlogistician in ensuring that what is requested is what is needed and that it is available when needed. Ensuring implementation of such efforts will require carefully orchestrated change management.

JOINT OPERATIONS

Chapter 2 highlighted Department of Defense (DoD) and Joint staff guidance on Joint operations, noting that the *Capstone Concept for Joint Operations: Joint Forces 2020* calls for Joint force elements, globally postured, to be able to combine quickly with each other and mission partners to integrate capabilities fluidly across domains, echelons, geographic boundaries, and organizational affiliations (JCS, 2012). The document identifies a series of implications for Joint Force 2020 tied to key warfighting functions of command and control, intelligence, fires, movement and maneuver, protection, sustainment, and partnership strategies, with partnership strategies being introduced as equivalent to the traditional warfighting functions. Future operating environments will be characterized by increasing uncertainty, rapid change, extreme complexity, and persistent conflict. In addition, as the United States rebalances to the Asia-Pacific region, the military must enhance its presence there to preserve peace and stability, invest in long-term strategic partnerships, and expand coordination with emerging partners throughout the region. In the midst of these new missions, the U.S. military, as a Joint force, must continue to project and sustain our military presence despite an increasingly capable adversary who will employ weapons and other technologies capable of denying access to or freedom of action within an operational area (JCS, 2012).

The 2010 *Joint Concept for Logistics* emphasized the need for increased integration and synchronization of Joint logistics processes within the Joint logistics enterprise in order to provide support for Joint force commanders across a range of military operations. The *Defense Logistics Strategic Plan* (July 2009) identified goals, performance measures, and key initiatives to drive the DoD logistics enterprise in order to achieve its mission, which is to provide globally responsive, operationally precise, and cost-effective logistics support (DoD, 2010a).

A *Joint Logistics White Paper* (June 2010) offered a first step at defining a common framework for providing logistics support to Joint forces. It emphasized the importance of a whole of government approach and the need for integration and synchronization of DoD processes and capabilities and the implementation of a Joint logistics enterprise consisting of common metrics, business rules, and standardization that enable integration, synchronization, and optimization; the unifying of effort to achieve a common set of objectives; the simultaneous need to deliver, position, and sustain Joint forces across a range of operations; and the development of a digital network for sharing information across the enterprise. The expected outcome would be sustained Joint logistic readiness to support the Joint force commander and improved trust and confidence that the Joint logistics enterprise will provide the required resources at the right place and time. The paper called for an integration and synchronization of joint logistics enterprise processes and capabilities and suggested the need for further study to map logistics processes from end to end, identify integration and synchronization points, and apply metrics that lead to optimizing outcomes (DoD, 2010b).

Army 2020 and Beyond Sustainment White Paper: Globally Responsive Sustainment (August 2013) outlined the future strategic environment and strategic guidance; outlined the implications for sustainment in terms of people, organization, mission command and information systems, science and technology, and unified action partners; and defined the response in terms of the solution—globally responsive sustainment, the importance of measuring performance, and the big ideas that will transform Army processes (CASCOM, 2013).

Appendix B of the *Joint Concept*, *Key Indicators of the Military Problem,* provided a detailed list of recognized concerns that need to be addressed in order to provide adequate logistics support for the Joint force in the anticipated future operating environment. These concerns include

- Insufficiently integrated logistics processes, organizations, and planning capabilities;
- Insufficient rules, tools, and authorities to exercise joint logistics;
- Shortage of logisticians trained in joint processes and operation;
- Insufficient joint material management;
- Deficiencies in policies and processes;
- Limitations in distribution capabilities and capacities;
- Insufficient expeditionary materiel management capability;
- Limitations in capabilities to manage and execute processes;
- Insufficiently interoperable or integrated command and control, logistics management, and financial systems;
- Insufficient visibility over requirements, assets, and processes; and
- Limited communications between logisticians. (DoD, 2010a, pp. B-1-B-4)

Army logisticians saw that addressing these issues would create process changes and new business rules that would allow for "visibility of knowledge, capacity, and expertise across the Joint, interagency, intergovernmental, multinational, nongovernmental, and commercial community," and that would enable logisticians to tap into all resources as they were required (CASCOM, 2012). But, for the most part, changes in rules and processes have not been realized. Today the J-4 struggles with the language of Jointness:[1] "The lack of a shared language has created or exacerbated many of the challenges to achieving the logistics community's vision of integrated logistics capabilities and, ultimately, freedom of action for the Joint warfighter." To deal with this, the J-4 has developed a lexicon, a "single,

[1] The J-4 is the Logistics Directorate of the Joint Chiefs of Staff.

consolidated list of approved and emerging logistics terms to help facilitate logistics interoperability through a common operating language."[2]

In 2011, LTG Mitchell Stevenson, then the Army Deputy Chief of Staff, G-4, pointed out that the Army needed to move on several Joint operations issues:

> - *Networked communications.* While there are a number of communications systems in the theater, no single network provides guaranteed communications for all organizations. As a result, some organizations are unable to establish or maintain contact while they are on the move.
> - *Joint distribution information systems.* A variety of information technology systems are used by joint and service organizations, but many are organization-centric and do not communicate or transfer data readily across the Joint Deployment and Distribution Enterprise (JDDE). This hinders their ability to coordinate and control distribution operations in a holistic manner.
> - *Distribution-based logistics.* Distribution operations are managed by a variety of disparate joint and service organizations, and their efforts are not adequately synchronized. As a result, distribution operations are not managed for effectiveness, stock holdings are larger than they could be, and delays occur that adversely impact distribution.
> - *Joint operational-level logistics command and control.* No standing joint logistics organization can command and control logistics and theater distribution operations at the operational level in the theater in support of the regional combatant and joint force commanders.
> - *Integration of coalition and host-nation capabilities.* Current and future operations increasingly involve coalition and host-nation partners. These partners will have requirements that need to be provided for and capabilities that can contribute to the distribution operation. (Stevenson, 2011, p. 8)

The 1999 National Research Council report *Reducing the Logistics Burden for the Army After Next: Doing More with Less* pointed out the need for the Army to be a strong participant in Joint efforts across the spectrum of activities being undertaken by DoD and the Services (NRC, 1999). It also pointed out the need for Joint programs in several areas of research and technology. It noted that "the Army will depend on the Air Force and the Navy to ferry the battle force and sustaining supplies to the staging area, to provide coordinated fire support, and to assist with C4ISR. Therefore the Army should participate in planning for this support to ensure that AAN operational and logistical needs are met" (NRC, 1999, p. 5). It also urged that the Army identify overlapping requirements of the Services and encouraged DoD to establish responsibilities among the Services for satisfying these requirements. The 2012 Combined Arms Support Command document *Path to 2028* identifies the same need for Joint development activities (CASCOM, 2012).

LOGISTICS SUPPORT OF SPECIAL OPERATIONS FORCES

Although Congress specifically gave the Special Operations Command (SOCOM) the authorities it deemed necessary to create and maintain a robust and effective special operations capability, it is equally clear from 30 years of legislative history and supporting documentation that Congress also intended SOCOM to be dependent on the military departments and their respective Services for the provision of platforms, systems, equipment, and a variety of support functions that are common between a given Service and SOCOM—for example, logistics and sustainment and personnel administration. The types and extent of this dependence continue to evolve in response to national strategy and changes in the geopolitical and operational environments. For example, during Operation Iraqi Freedom and Operation Enduring Freedom, the Central Command commander was able to provide significant breadth and depth

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[2] Additional information is available at Joint Chiefs of Staff, "J4 Logistics," http://www.jcs.mil/Directorates/J4%7CLogistics.aspx, accessed November 18, 2014.

of conventional force support to special operations forces (SOF) over this sustained period of engagement.

Within the SOCOM structure, the Army has the largest footprint when it comes to personnel and diversity of specified missions. Similarly, Army field manuals FM 4-94 (*Theater Support Command*) and the final draft of FM 3-93 (*Theater Army Operations*) articulate an impressive array of support and sustainment capabilities that would be beneficial for all SOF, not just Army SOF (DA, 2010, 2011). The Army is moving to become more expeditionary in nature. Taking these factors together, it would appear that the Army has the capability to become the common support provider for SOF across all geographic combatant commands (with the possible exception of the Pacific Command at the present time), albeit with appropriate assistance from the other Services. Box 8-1 discusses some of the factors that complicate integrating Army and SOF logistics.

BOX 8-1
Integrating Army and SOF Support Activities

Within the Army, the principal organization responsible for the support of Army SOF-unique equipment is the special forces group support battalion. This support battalion has a group support company that provides military intelligence, chemical reconnaissance, and tactical communications, along with an operations detachment and an associated service support company. The service support company provides medical, maintenance, distribution, and sustainment support for SOF-unique equipment and systems to the companies and detachments of the operational units of the special forces group.

SOF have organic contracting capabilities at all levels. For example, if an operational detachment-A (ODA) team has a requirement for a service or an item that is not available from the service support company within the required time frame, the theater special operations command (TSOC) may have the contracting capability to obtain this support via local contracts or, if the cost is below the contracting threshold, it could use operational funds to procure the commodity or service. If the ODA team is unable to get the support from the forward support company of a conventional Army battalion (e.g., a tank battalion) that occupies the same area of operations as the ODA, the ODA could pay for a commodity or service by paying cash if the cost is below the micropurchase threshold. Alternatively, the ODA could coordinate through command channels with the supporting TSOC to contract for the support. Normally, a request for support comes from the engineer noncommissioned officer of the ODA through the operational detachment-B, which is the headquarters element of a special forces company, to the support operations office of the group support battalion; or, in some instances, directly to the servicing forward support company. ODAs have soldiers trained as field ordering officers and paying agents. If a request is for a SOF-unique item, the request goes back through special forces supply channels.

The issue that most frequently arises in this arrangement is the duplicative resourcing of sustainment requirements for items that are not SOF-unique. For example, an ODA could be contracting locally for support requirements for daily living (e.g., food, water, and shelter) when the capability to provide those requirements already exists within a regionally aligned forward support company located within the combat battalion. Part of the problem is that the brigade or battalion commander may not know that the ODA is in his area of operations or that the forward support company is responsible for providing support of common requirements to SOF in the area. This ignorance is typically caused by either the timing of the request or the lack of communications between the deployed SOF task force and the theater logistics network. The typically small, but widely dispersed, SOF footprint, together with a rapid resourcing environment, often leads the deployed SOF to utilize internal resourcing actions such as contracting actions rather than fully articulating requirements to the theater sustainment enterprise early in planning cycles. The support of Marine Corps Special Operations Forces and Naval Special Warfare Forces within a Joint environment has similar issues. Establishing a training program to educate SOF commanders about the Army supply system and processes, and how to effectively integrate into the Army logistics network while deployed in a joint area of operations, may also be necessary.

Finding 8-1. There are opportunities to more tightly integrate Army and special forces logistics. For instance, it may be practical and desirable to designate each theater Army as the primary logistics and sustainment support organization for special operations forces in each geographic combatant command's area of responsibility.

Recommendation 8-1. The Army G-4, working in conjunction with the individual geographic combatant commands and special operations command (SOCOM), should determine the feasibility and acceptability of designating each theater Army as the primary logistics and sustainment support organization for special operations forces in each geographic combatant command's area of responsibility. A good test case for such an arrangement would be to examine the recent redeployment of special operations forces to Iraq to assess the feasibility of the concept and obtain valuable lessons learned in the process. Doing so would enable all parties (e.g., the Army, SOCOM, and Central Command) to build on previous efforts and experiences gained in Operation Iraqi Freedom.

GIVING LOGISTICS ITS DUE

Many of the logistics challenges in the Army can be related to a culture within the Army that does not properly recognize the complexity of logistics operations and the necessity for operational planning to fully involve its logistics elements. It is frequently assumed that because logistics support has always been there, it will be there the next time it is needed. The availability of the exceptional funding stream in support of operations in Iraq and Afghanistan permitted the logistics community to work around issues as they arose, but often at considerably greater expense, with less efficiency, and at greater risk than had more attention been paid to the logistics challenges in planning. As indicated in Chapter 2, the more supplies that have to be moved, the greater the risk to those involved in the movement and the greater the logistics burden for the force as a whole. These cultural issues fall into the following categories.

Control of Requirements

Much of today's Army has served the nation at a time when its focus was on nation building and counterinsurgency operations carried out from nearly permanent bases. As the focus shifts from conduct of such operations over extended periods in limited geographical areas to the employment of forces in an expeditionary mode with continuous movement and lean sustainment, leaders at all levels need to be prepared to adjust to a significant change in the manner in which operations are carried out and supported.

While the Army has data, information, and doctrine concerning resupply rates once combat operations begin, operational commanders drive the requirements. No one questions the necessity for these commanders to identify their equipment and supply requirements to conduct their operations. However, as reports from both Operation Iraqi Freedom and Operation Enduring Freedom indicate, attention to the levels of supply and the justification of requirements in areas beyond direct combat, especially base support operations, is frequently put this way: "If we can get it, then let's get it." The use of bottled water is a reflection of this approach. While U.S. forces were clearly more comfortable being supplied with bottled water, the logistics burden created by this method of water supply not only resulted in losses of life in convoy operations but created other disposal and operational challenges. There are few service or theater standards established that limit what can be asked for, and the Services, eager to support their forces and to solidify their Title X responsibilities, do their best to respond to the theater requests. This results in part from a poor understanding of the implications of logistics requests that go beyond what is absolutely needed, and in part from a failure of either the Services or the combatant commands to establish standards. As resources become scarcer and supply lines become longer, it will be imperative for the Army to give greater attention to the control of requirements.

Recognition of the Logistics Mission

In discussions with active and retired civilian and military logisticians, it became clear that in planning exercises and war games, logistics support is frequently assumed to be available and passed over in dealing with the specifics of what support will be required, how supplies will be moved to the theater, and what forces will carry out the sustainment operations. An emphasis on ensuring the fighting capability of combat elements, including the brigade combat team, has led to the reduction in the structure of the forces that must sustain the combat elements and an assumption that supplies will get there somehow. As indicated in Chapter 7, contractors are not part of the planning process and may or may not be available to provide sustainment if they are not prepared to carry out these support operations. Nor are contractors included on the Time-Phased Force and Deployment List even though they are likely to be a substantial component of the overall force that needs to be moved. As plans are considered that move more and more of the sustainment forces to the reserves, the separation between the combat elements and their sustainment grows. Repetitive use of the reserve forces is highly dependent on national will to continue the exceptional load that is been placed in recent years on both the National Guard and the Reserves. As former Secretary of Defense Robert Gates noted in his recent book, *Duty: Memoirs of a Secretary at War*, this use of the National Guard and Reserves could be called into question (Gates, 2014).

Consideration of logistics must be fully integrated into all Army activities, including requirements writing, budgeting, testing, research and development, operational, and force support activities. Logistics must also be integrated into professional military education on topics that would either impact, or be impacted by, logistics. Decisions made during the research and development process often consider trade-offs between the capabilities of a weapon system, an aircraft, or a vehicle and its logistics demands and its life-cycle costing. Pressure is great on developers to meet the capability requirements, while logistics demands and life-cycle challenges are often seen as concerns that can be pushed to the future. History has shown that this is shortsighted. Similarly, the logistics positions on sustainment issues are often represented by the system developer or user rather than by the logistics community, and logistics needs are frequently given less priority. At every level in the decision process for material development and operational planning, logistics needs to have a seat at the table and to be given the opportunity to be heard.

As indicated in Chapter 6, for the logistics community to be capable of effectively articulating its position, it must be given the analytical resources to carry out the appropriate logistics studies and to bring this information to the attention of decision makers who shape future force structures and plan future operations.

In a paper for the Army War College, career logistician COL Kevin Powers, found that

> While it can be argued that Army transformation has been constant and ongoing for the past two decades, it is apparent that the change we have seen has truly only been evolutionary in nature for the sustainment community. Most of what has come about over this period has been adapting new technologies, improved process, and a basic reorganization of sustainment organizations to match the Army's modular Brigade Combat Team redesign. In many cases, we have simply rearranged organizations and called it transformation. Dr. David A. Anderson and Major Dale L. Farrand postulated in 2007 that what we have seen has been 'logistics evolution, logistics reaction, or logistics adaptation.' Five years later, their analysis still serves as the best conclusion for the Army's transformation efforts in an attempt to achieve a revolution in military logistics. Now is the time to harness the initiative and break new ground with Army logistics transformation. We certainly are in a time when the choices we make with the resources available will be very difficult. However, placing the necessary changes in the Army sustainment warfighting function at the bottom of the priority list cannot continue, we must invest in the technologies and equipment that will finally allow us to realize revolutionary change and enable us to meet the challenges of the twenty-first century.

> Senior Army leadership must create the environment and set the conditions for us to succeed… The logistics community must articulately state the case for ensuring the placement of the distribution function of sustainment at the top of the list of priorities when it comes to equipping our force in order to ensure we remain the best-equipped fighting force and finally realize a revolution in military affairs by achieving a revolution in military logistics. (Powers, 2013, pp. 22 and 23)

Overall, there is no tool that allows the Army G-4 to see and track resources allocated to budgets and programs and their impact upon current readiness and future capabilities. Furthermore, the Army leadership responsible for logistics does not and cannot know all the work going on across the Army, and across DoD, that impacts Army logistics. This deprives the Army G-4 of the ability to impact and influence programs that have a logistics component, or even those programs that are explicitly devoted to logistics. It also prevents collaboration among programs and Services that could allow the fielding of logistics improvements more quickly and at less cost.

Finding 8-2. Logistic activities within the Army do not receive the attention necessary to ensure the effective sustainment of operational forces on the battlefield over the long term. Currently there is no management tool that allows the G-4 to track the resources allocated to logistics across the program evaluation groups. A logistics-centric look at those programs that reduce the logistics burden and make the logistics system more efficient—across the science and technology, research and development, procurement, operations and maintenance, and procurement phases—would provide the G-4 the information to track all the resources being applied to making logistics more effective and efficient.

Recommendation 8-2. Army leadership should develop a logistics-centric resource management system or program that will allow senior Army leadership to ensure that adequate resources and priorities are given to logistics activities across the spectrum of Army activities, to include research and development, analytical and decision support, force structure, and operational planning.

Logistics Education

In the Army education system, 21st century logistics operations and the challenges of Joint and combined logistics across a global area of operations are largely omitted from the curriculum of Army personnel not attending logistics-specific courses. When they are considered, they are focused on notional organizational structure as opposed to the higher-level issues that must be addressed and the trade-offs that must be made to accomplish the long-term materiel development goals and effective sustainment operations. If the importance of logistics is to be appreciated and the complexity of logistics activities is to be understood across the military community, logistics education should not be confined to those in the logistics community. Service members attending military education programs, from the senior service college-level to the basic entry program, need to better understand the role of Joint logistics in the conduct of military operations, and their responsibilities for facilitating the execution of logistics activities. It would be helpful to include logistics activities in training exercises and war games, such as at the National Training Center.

Army commanders lack adequate training in how Army SOF are to obtain support for common items. The unique nature of Army support for SOF requires greater attention in the Army and SOF schoolhouses to ensure that all individuals involved with the support function understand their responsibilities and the opportunities that exist to facilitate the operations of both conventional and SOF forces. Nor are the SOF commanders themselves adequately trained in coordinating with the Army to obtain support. Attention must continue to be paid in the education system to the responsibilities of nonlogistics personnel who serve as contracting officer representatives for a wide variety of in-theater contracting activities in both SOF and non-SOF organizations. While improvements are taking place and as a result many serious problems have been avoided, the education program must be fully supported because of the frequency of personnel turnover in these positions. The duplicative provision by both the Army and SOF of sustainment requirements for support of non-SOF-unique items results in additional logistics costs. The committee notes that the Naval Postgraduate School offers a graduate curriculum in operational logistics that addresses many of the issues raised in this section.

Finding 8-3. Army personnel not directly engaged in logistics need better training and education about their roles in facilitating logistics support and driving logistics demand. There also needs to be better education of both Army and special operations forces (SOF) personnel about the Army's role in supporting SOF and improving coordination in this regard. Including logistics activities in training and exercises and war games would be useful in this regard.

Recommendation 8-3. The commander of Training and Doctrine Command should undertake a review of the logistics content of Professional Military Education across all levels to determine where insertion of logistics education would be appropriate. Specific attention should be paid to courses that include individuals likely to be responsible for in-theater contracting activities and support for special operations forces (SOF). Precommand courses should cover how Army Special Forces are employed and how their Service-common and SOF-unique needs are appropriately supported. Consideration should also be given to the inclusion of logistics activities in war games and at the National Training Center.

Recommendation 8-4. If an agreement is reached for the Army to provide primary logistics support to special operations forces (SOF), the Training and Doctrine Command (TRADOC) should join with the Special Operations Command-Joint Capabilities organization within the Special Operations Command (SOCOM) and the Joint Special Operations University to create two sets of courses, a TRADOC set and a SOCOM set. The TRADOC courses should enable Army personnel to understand the proper employment of SOF in general and their associated support. Conversely, the SOCOM courses should familiarize SOF personnel with the logistics and sustainment support organizations and associated capabilities that the Army can provide to them when they have been assigned to a Theater Special Operations Command. Establishing a program to teach SOF commanders about the Army supply system and processes and how to effectively integrate themselves into the Army logistics network while they are deployed in a Joint area of operations, may also be necessary.

TAKING ADVANTAGE OF TECHNOLOGY INNOVATION

The report *Reducing the Logistics Burden for the Army After Next: Doing More with Less* (NRC, 1999) found that

> The rapid growth and global competition in commercial markets for complex technological products, coupled with decreases in defense spending, are challenging the role DoD has played since World War II in determining the direction of product development, although DoD is still the principal sponsor of high-risk, innovative research at universities and federal laboratories. In their roles as consumers of technology, DoD and the Army must take full advantage of cooperative endeavors involving industry, academia, and the other services. . . . Army dollars should be invested primarily in projects that address Army-specific requirements or projects that would not be undertaken without Army support. (NRC, 1999, p. 5)

This finding continues to be relevant and is clearly reflected in the research and technologies associated with logistics. The commercial logistics sector has grown immensely since 1999 and carries out many functions identical to those required of the military. Commercial efforts to improve vehicle and aircraft maintenance activities, increase reliability, and lower energy demands are objectives of both the manufacturers of end items and those who use them. In addition to commercial research and development, such work is ongoing in the multinational and nongovernmental sectors. One example of this is the Safe Road Trains for the Environment work discussed in Chapter 4. Another example is the Coca Cola Foundation's deployment of Slingshot water distillation technology as part of its efforts to deploy Ekocenters around the world. The Slingshot system appears to be an efficient, compact system for purifying large quantities of water. (Coca Cola Company, 2013) There is a tremendous amount of work that the Army might be able to take advantage of.

Finding 8-4. Joint, interagency, intergovernmental, multinational, nongovernmental, and commercial activities remained heavily involved in material development and technology innovation in areas directly relevant to logistics operations and sustainment goals. Continuous monitoring of the efforts of entities outside the Army and collaborations with them offer opportunities for reducing military expenditures for needed technologies and for the early acquisition of systems that have been proven in the private sector. The Army should avoid duplication of efforts under way in other sectors wherever possible.

Recommendation 8-5. In carrying out its material development programs, the Army S&T community should continue and increase, where appropriate, close collaboration with Joint, interagency, intergovernmental, multinational, nongovernmental, and commercial organizations in S&T areas where these organizations are pursuing program similar to those required by the Army.

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9

Logistics-Centric Science and Technology and Research and Development Investment Strategy

The committee did not develop a logistics investment strategy as called for in the statement of task. The assumption was that the G-4 had a current strategy that could be used as a basis for the committee to develop one that would include potential new investments. Part way through data gathering the committee learned that such a strategy does not exist. The programs that impact logistics are spread across the Army in many programs, many of which are outside the purview of the G-4. For example, the Assistant Secretary of the Army (Acquisition, Logistics, and Technology) has a 30-year strategic research and development (R&D) plan that includes programs that will impact logistics, and would be an important part of developing a logistics R&D strategy. Developing a credible strategy will require careful coordination with other staff elements and Program Executive Offices that have responsibility for programs that have impact logistics, and for significant analysis of these programs. The committee was not structured to carry out such an analysis and was not given access to information concerning potential force structuring and contingency scenarios or other data with the level of resolution required for such an analysis. To best assist the G-4 in developing a strategy, the committee focused on identifying areas of greatest payoff for the Army and in offering advice as to how such a strategy should be developed (a roadmap, in Tables S-2 and 9-1).

SETTING AN AZIMUTH

Science and technology (S&T) and R&D efforts in support of reducing the logistics burden and improving the efficiency of the logistics system on the battlefield are found in programs across the entire Army. For the most part, the principal efforts that would drive reductions in the logistics burden are found in S&T and R&D programs for major Army systems and are essentially carried on without full consideration of the impacts and consequences of programmatic decisions on logistics. There are some S&T and R&D programs in support of logistics, but these are essentially unique efforts that have come about from a specific driving action and that are not part of an overall logistics strategy.

Finding 9-1. There is no explicit Army investment strategy to guide efforts that would reduce the logistics burden of the Army in the field and that would guide nonlogistics efforts that greatly affect the logistics burden of the Army in the field. Without such a strategy, the Army G-4 and the Army sustainment community are unable to effectively influence critical decisions in science and technology and research and development.

The committee reviewed many S&T and R&D technologies that influence the logistics burden. It appears that reduction of the logistics burden is for the most part a secondary consideration. The committee did not see evidence of any formally established logistics-related research objectives that, taken together, would form an Army strategy for reducing the logistics burden. The only possible exception to this is the Joint Operational Energy Initiative, discussed in Chapter 3. Without clearly defined logistics-related objectives, the reduction of the logistics burden becomes something to be accomplished only if it does not interfere with the other more formally established objectives of an R&D program. Clear objectives must therefore be established along with a commitment for the funding needed to meet them. If funding becomes unstable or the objectives are frequently changed, then the continuity and success of any logistics R&D investment strategy will be compromised. In this event, it is unlikely that the objectives will be met and the R&D funds could turn out to have been wasted.

An important consideration when developing an S&T and R&D investment roadmap is the amount of time it will take to reap the benefits of investments. Since funds are not unlimited, their expenditure needs to be evaluated to determine the optimal return on investment for the government. For example, if a program has significant S&T or R&D costs but could produce significant results quickly, it should be given higher priority than longer-term S&T or R&D efforts with unknown return. Making these decisions will require the availability of adequate analytical talent and resources. This is discussed at length in Chapter 6, with accompanying findings and recommendations. If the government establishes a clear, well-defined, and stable roadmap, then a company is more likely to invest in S&T and R&D that will address government objectives because its investment will clearly have the potential to provide a return as the government moves forward with procurement once the S&T or R&D efforts have been completed.

Without clear objectives and monitoring of the success in achieving them, the Army G-4 and the broader logistics community are unable to either influence or track the success of efforts to reduce the logistics burden or to improve logistics efficiencies. The committee does not suggest a realignment of program responsibilities. Rather, it suggests the establishment of an Army logistics strategy, framework, and objectives that would enable senior Army leadership to understand the operational implications of decisions impacting the Army logistics burden and the life-cycle trade-offs.

The committee also believes that the Army logistics S&T and R&D effort is influenced by the activities of the other Services and Department of Defense (DoD) components as they develop programs and systems that parallel or support those within the Army, and that this is appropriate. Efforts across the DoD to improve operational energy, increase joint logistics efforts, and the other Services' efforts to improve the effectiveness of their logistics and operational activities have definite impacts on what happens within and to the Army. The committee was impressed by the close relationship between several Army efforts and those of the Marine Corps to address movement of supplies on the battlefield. As was found in the report *Reducing the Logistics Burden for the Army After Next: Doing More with Less* (NRC, 1999), increased lethality and accuracy of other Service weapons can substantially reduce the needs of the Army on the battlefield. Deeper penetration into the forward area by the Defense Logistics Agency also influences the needs of the Army. All Army plans for movement are tied closely to the capabilities of the Air Force, the Navy, the support contractors, and U.S. Transportation Command. As resources shrink and the need for Jointness increases, it becomes incumbent on the Army to ensure that its efforts to reduce logistics burdens and increase logistics efficiency are tied closely to the efforts of other members of the DoD team. Little attention has been paid to identifying and integrating the long-range S&T and R&D of other members of the DoD into the Army.

Finding 9-2. There is no explicit effort by the Army logistics community to closely monitor the science and technology (S&T) and research and development (R&D) activities across other Department of Defense components, or to capitalize on the S&T and R&D successes in those organizations and to integrate any new capabilities into considerations of possible future joint logistics environment.

Recommendation 9-1. The Army, through the G-4 and with the support of the Combined Arms Support Command, should develop, staff, publish, and annually update an Army strategy for science and technology and research and development that clearly defines the long-range objectives for Army logistics, the programs that will influence the attainment of these objectives, and the actions that will be taken to ensure the close integration of Army logistics enhancement activities with those of the Joint and DoD-wide community.

As indicated in Chapter 6, this committee, like the committee that wrote *Reducing the Logistics Burden for the Army After Next: Doing More with Less* (NRC, 1999), is very concerned about the lack of analytical support for the Army logistics community and the resultant inability of this community to effectively quantify the value of reductions in logistics burdens within the logistics community. This committee is also very concerned about the lack of the Army's ability to coordinate with those outside the Army logistics community regarding the impact of changes in their systems on the logistics burden, especially given previous recommendations that it should deal with this problem. Development of an Army logistics S&T and R&D strategy will require a high level of analytical support and the enhancement of tools such as the 2008 Air-Ground Distribution Computer-Assisted Map Exercise. A strategy cannot be developed without such support.

The committee also believes that for the strategy to be effective it should include specific quantitative objectives whose attainment can be measured, and that attainment of these objectives should be the mission of the Army as a whole and not just the logistics community. Progress requires quantitative objectives. The development of standards and quantitative objectives tied to those standards has proven successful in the design of energy systems for equipment ranging from vehicles to aircraft to generators. An example of a quantitative objective would be this: By 2025 reduce the daily resupply tonnages to the Brigade Combat Team, the Fires Brigade, and the Aviation Brigade by 20 percent while also eliminating from the force structure the distribution assets that currently resupply these brigades.

Once an R&D strategy with clearly defined objectives is established it must be followed by plans to carry out the activities required to achieve these objectives. Such plans create a roadmap of actions and required resources, responsibilities, and time lines. Simply establishing objectives does little to ensure progress.

Finding 9-3. Establishing specific, quantitative objectives is an effective tool in any successful science and technology and research and development strategy. This needs to be followed by a roadmap of actions and required resources, responsibilities, and time lines.

Recommendation 9-2. A strategy for Army logistics science and technology and research and development should include specific objectives for the reduction of the logistics burden. It should also include a roadmap laying out the responsibilities and actions the overall research and development community needs to take to ensure that the strategy objectives are accomplished.

TAKING ADVANTAGE OF INDUSTRY WORK

In many of the areas of interest to the Army, such as autonomous vehicles, fuel efficiency, in-transit visibility, water source development, and modeling and simulation, private industry is actively engaged and, in many cases, ahead of military R&D. Because it is difficult for private industry to surmise the direction the Army will go with an R&D program and the likelihood of a program being funded, the needs and interests of the Army are frequently not given the consideration they otherwise might. In some cases private industry views Army R&D as competing with industry R&D activities. If proper relationships are established, partnership efforts could produce results for both groups more quickly.

Finding 9-4. The Army would benefit from monitoring and leveraging industry work on technologies and systems that would reduce logistics burdens.

Recommendation 9-3. When developing the science and technology and research and development strategy and the related roadmap, the Army should identify and include areas for potential industry-military partnership, whereby progress by one party will accelerate progress by the other.

IMPLEMENTING LOGISTICS S&T AND R&D

In conducting its data gathering, the committee was surprised by the great number of R&D efforts under way and, among them, the number of programs that have been under way for many years without moving from S&T or early R&D phases to fielding. As resources diminish, spreading the residual resources across this large family of activities will further constrain the ability to move ahead with the efforts deemed to be the most valuable. While continuing to move ahead on competing solutions within a program area does ensure that eventually the best solution will probably be found, doing so may also prevent the fielding of systems that might be of immediate utility. Even if the fielded system failed to meet all of its requirements, its use might well identify requirements that had never previously been considered and result in modifications or developments that could quickly be accomplished. For example, the Army is entering a period where it no longer makes sense to rely on bottled water for its troops. Several programs are under way to take advantage of field sources to provide water to the forward elements of tactical units, but none are moving into full or even limited production pending the results of even more research. If forces must deploy in the immediate future, they should have one of the systems that are now under evaluation available to them. Decisions have to be made, even if it appears to some that a later decision might have better results.

Finding 9-5. Many logistics-related science and technology and research and development programs seem to be stuck in continual development without proceeding to the field. Faced with diminishing resources and the need to field equipment to meet current and future demands, waiting until the perfect solution is discovered is no longer a feasible approach.

Recommendation 9-4. The Army should work to rapidly identify the logistics-related science and technology and research and development programs that best support current and projected needs and adequately fund them to ensure fielding sooner rather than later. Where major breakthroughs could occur in the future, low-level science and technology work should also continue.

WHAT IS IMPORTANT

The committee's priorities for R&D investments are given in Table 9-1 and represent the professional judgment of the committee in assessing the technologies behind the technology-based recommendations in the report. High priority investment areas represent a coalescence of a promise of a substantial reduction in logistics burden and/or a reduction in resource demands and a committee judgment that the programs are achievable within the next decade or sooner and meet an immediate operational need identified by the Army. However, these priorities are closely tied to the force structure the Army chooses or is directed to implement.

REFERENCE

NRC (National Research Council). 1999. Reducing the Logistics Burden for the Army After Next: Doing More with Less. Washington, D.C.: National Academy Press.

TABLE 9-1 Road Map and Areas to Focus Logistics S&T and R&D Efforts

Technology Development Area	Research Area	Logistics Area	Goal
High Priority—High return and recognized feasibility			
Adaptive Engine Technology Development	Accelerate the Improved Turbine Engine Program	Fuel and Power	Reduce fuel requirements
Alternative engine for the M1 Abrams tank	Investigate alternative engines or techniques to improve efficiency	Fuel and Power	Reduce fuel requirements
Autonomous re-supply convoys	Refine technologies to provide reasonable cost autonomous leader-follower convoy vehicles for non-tactical movement	Mobility	Reduce troop and equipment risk and burden in convoy operations
Small unit water supply	Accelerate R&D and fielding of platoon and squad water sets	Water	Provide point of need water supply
Micro-grids and smart-grids	Accelerate R&D and fielding	Fuel and Power	Maximize energy efficiency
Low Ammo Demand Weapon System	Accelerate R&D and fielding of High Energy Laser–Mobile Demonstrator (HEL-MD).	Ammunition	Reduce Ammunition Demand
Unmanned aircraft and precision parachute resupply	Refine technologies to support cost efficient aerial supply operations	Mobility	Remove dependency on ground vehicles in critical areas
Improved sea mobility	Complete and deploy Maneuver Support Vessel (MSV)-Light; develop MSV-Medium and Heavy concurrently	Mobility	Improve sea-borne Army logistics support
High Priority—High return, but require R&D or feasibility of immediate use in question			
Water from Diesel Exhaust	Explore technologies to obtain potable or non-potable water from diesel exhaust with small impact to weight, power, and cost of systems incorporating the technology; taste is a major barrier to acceptance	Water	Develop alternative water sources
Additive manufacturing	Monitor industry; continue Army field evaluation	Maintenance	Improve supply of critical items
Radionuclide power sources	Sponsor R&D in the development of small radionuclide power sources	Fuel and Power	Reduce battery weight

Medium Priority—Large return; longer time to fielding			
Hybrid technology to power vehicles	Investigate existing commercial hybrid and electric technology	Fuel and Power	Reduce fuel requirements
Base area power generation small modular reactors	Monitor Department of Energy and research for power production	Fuel and Power	Reduce fuel requirements (generators);provide significant base camp power source
Alternative battery types that produce more power and are rechargeable	Investigate lithium-air batteries for application in the Army	Fuel and Power	Reduce battery weight
State of charge indicators to batteries so soldiers do not discard usable batteries because they do not know how much charge remains	Integration of small, rugged, reliable state of charge indicators on batteries soldiers carry	Fuel and Power	Reduce battery weight
Ammunition consumption	Improve ammunition lethality and effectiveness	Ammunition	Increase small caliber ammunition effectiveness
Reduce ammunition weight	Investigate caseless, polymer cased, or case telescoped small-caliber ammunition	Ammunition	Decrease weight of small caliber ammunition
Innovative packing to reduce volume and weight	Investigate replacing conventional packing materials	Ammunition	Ammunition packaging
Shipboard desalination	Investigate converting existing tanker for providing desalination of seawater to produce bulk potable water	Water	Develop alternative water sources
On-board auxiliary power units (APUs) to produce electricity	Determine if fuel cell based systems are technically feasible to operate as APUs	Fuel and Power	Reduce fuel requirements

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Future Operations: How It Might Be

The U.S. Army is in a position to move forward and transform its logistics organization as part of a Department of Defense-wide effort to create a military force capable of efficiently and effectively operating in a Joint force environment. Combining a greater use of Joint forces logistics capabilities with advances in technology that could, with proper support, take place over the next decade could enable the logistics forces of the 2020s to operate in a manner that would produce less of a logistics burden than the current force while improving the level of support provided to operational forces. The committee was asked to postulate three scenarios that might reflect the changes that could occur should the actions it recommends and the actions recommended by other study groups be implemented. The three scenarios are as follows.

THE THREAT TO INLANDIA

It is September 15, 2020. COL Robert Scholes, commander of the 3rd sustainment brigade, stands on the shore of the Sea of Artask watching Military Sealift Command vessels unloading cargo in the port city of Highrise. U.S. forces have been working with elements of the Inlandia military for nearly two months as three U.S. brigade combat teams (BCTs) moved from the continental United States to the Pacific nation of Inlandia and convoyed nearly 300 miles to deploy along the border Inlandia shares with the hostile nation of Outlandia. Outlandia has threatened to invade Inlandia and, under a bilateral treaty arrangement, the United States has agreed to stand along the border with Inlandia's forces to prevent any hostile movement into its territory.

Scholes thought back to the planning that took place at Southern Command over a year earlier as part of preparations for routine contingency actions. He, along with representatives from Strong, Inc., a logistic support contractor brought on board by Army Contract Command, had carefully assessed the logistic profile of Inlandia to determine the ability of that country to assist in the support of U.S. forces should they be deployed to that country. They were heartened by the presence of significant port facilities and a large airfield, both of which had previously been used by Strong, Inc., in its support of commercial mining operations in the region. The highways from the port to the border with Outlandia and into the capital of Outlandish were in very good shape and could support use as a main supply route. When tensions between Outlandia and Inlandia heated up, the United States began to move the equipment of the BCTs by sea to Highrise. They then used local facilities and personnel to prepare the equipment for the arrival of troops, who would come later by air. When the equipment and troops were linked, the BCTs deployed to the border area, one astride the main supply route and the other two on their flanks at some distance.

On his flights to Inlandia, COL Scholes recalled the many questions he still had even after the Southern Command briefings. He smiled as he recalled being met on arrival in Inlandia by the U.S. embassy defense attaché, a Navy captain, who provided a thorough brief of the situation on the ground in Inlandia, describing essentially the social network, including the political and military leadership and the real power centers. The attaché then took questions, some of which required more research and a secondary brief. Scholes was also happy to meet the embassy military attaché, an Air Force major, whose job was to keep in touch with the U.S. embassy in Outlandia, which had not yet been asked to leave that country, and with a network of allied and neutral country contacts in Outlandia. He learned that not all Outlandians were hostile to Inlandia or to the United States. This knowledge was most enlightening and reassuring.

COL Scholes was also surprised when the embassy defense attaché introduced some nongovernmental organization representatives, who maintained extensive regional logistics contacts for their continued humanitarian assistance and disaster relief activities. He recalled that the Army had recently joined the other U.S. services in supporting humanitarian assistance and disaster relief activities in the Pacific and understood that our military role in these situations was principally emergency logistics, to buy time until the nongovernmental organization s could take over. These relationships were proving useful and having Army personnel on hand with established logistics experience in the area was invaluable.

During the 60 days since the decision to move was made, a steady stream of supplies had moved through the port and airfield. The use of the Global Combat Support System-Army (GCSS-Army) and associated applications made it easy to get unit-specific supplies and equipment to the right location. Three years of working with GCSS-Army had convinced the combatant commanders that they would have asset visibility at all times and that they would have what they needed, when they needed it.

Movement of the supplies and equipment to the forward area was accomplished by convoys of autonomous leader-follower vehicles creating their unique brand of the Red Ball Express of World War Two. Convoy security was provided by unmanned aerial vehicles, controlled from an Air Force facility near the port. Once the supplies reached a forward operating base some 50 miles behind the border, they were transferred to autonomous aerial supply vehicles for movement to company and battalion positions.

COL Scholes, thinking back to his days with a battalion during Operation Enduring Freedom, was amazed at the significant reduction in supplies required by the forward elements. Water, which had been a major load in Afghanistan and Iraq, was being produced by quartermaster units deployed with and positioned near the forward elements. While the artillery still brought in a heavy load of ammunition, initial efforts to reduce the weight of dunnage were paying off, and the total load was being substantially reduced. The total load of artillery ammunition was further reduced by the increased use of precision munitions compared to Col. Scholes' days in Afghanistan. The ability to accomplish the same fire objectives with far less ammunition had turned out to be a real logistics force multiplier. Fuel demands for aviation and the armored force continued to be substantial, but the initial modification to turbine engines was noticeably reducing the demand. The colonel was also surprised by the reduction in the number of aviation components being shipped to the theater. His aviator colleagues had told him that condition-based maintenance was allowing them to determine what they would need and when as opposed to stocking everything just in case. He was also pleased to see an expeditionary three-dimensional (3-D) printing facility in place in Highrise to support emergency replacement of critical parts. The facility had deployed with the necessary software that would permit it to rapidly build any of the parts in any of the equipment that had been brought to the theater.

Since it was not the intention of the U.S. government for its forces to remain in place for more than 6 months, there had been no development of semipermanent base camp facilities, substantially reducing the need for construction materials and energy to power facilities. Where there was a need for substantial electric power, its distribution was carefully controlled by a smart grid to ensure that critical facilities were serviced and fuel loads reduced. COL Scholes observed that the net result of the reductions in demand had also caused a reduction in the number of people required to provide sustainment for the deployed forces.

Still hoping that the tensions would be resolved and that ground combat would not be necessary, COL Scholes understood that the logistics organization that was on the ground in Inlandia was ready and able to support the deployed forces should they be required to engage the Outlandia army and to maneuver into that country.

THE THREAT TO PACISLANDIA

It is October 2020. MG William Williams, Commanding General of the 1st Expeditionary Support Command (ESC), is in his Operations Center at Fort Bragg and is going through the details of the command's planned deployment to PACISLANDIA, a Pacific Island nation. His staff is briefing him on the logistics situation on PACISLANDIA. They have pointed out to him the following:

- Ports are not available. PACISLANDIA is a developing country and has focused on support of low-level fishing operations.
- Logistics over the shore (LOTS) will be required to support the command's operations. Data indicate that sea state at this time of the year is between 2 and 3.
- Landing will be minimally opposed by the PACISLANDIA militia (hostile forces).
- There are ongoing conflicts in the interior between the militia and native freedom-fighter forces (friendly forces).
- At first, resupply will have to by aviation assets. Initial forces may have to capture air fields.
- Marines or airborne forces will be deployed first. There will be limited or no use of heavy forces.
- Unit basic loads and combat loads will be increased to 5 days of supply because of the uncertainties.
- According to the Army Geospatial Center, ample sources of fresh water are available on PACISLANDIA.
- An intermediate operating base will be established on the island of Independence, which is 100 km from PACISLANDIA. This will be primarily a contractor operation. Power, Inc., is the contractor.
- Initially, an air line of communication (LOC) will operate from Independence. A sea-based LOC from Independence will be established as soon as feasible.
- Special operating forces (SOF) have already been clandestinely deployed to PACISLANDIA. Locations and size of the force have not been provided to the 1st ESC. Army and Marine forces are responsible for support of SOF in their areas of operations. It will be important to ensure that the local Army and Marine commanders know of the existence and number of special forces operating in their areas.
- Representatives from the 1st ESC are working at U.S. Army Pacific, Pacific Command, and the U.S. Pacific Fleet.

Based on these considerations MG Williams gave his guidance to his staff with respect to capabilities required:

- Because of the sea state situation, we need ensure that we have sufficient aviation assets to establish an air LOC from Independence to PACISLANDIA. We must plan on being able to resupply one day of the combat and basic loads each day. Our autonomous aviation assets, both air vehicles and precision airdrop capabilities, have given us a much greater capability than we had in the past. Let me know how much, how often, and what the autonomous aviation resupply will be.
- See what the Navy can do for us with respect to sea-based support. I want the intermediate operating base and Navy capabilities to complement each other. We should always strive for synchronized joint logistics solutions. Don't overlook the regional capabilities of our logistics contractor, Power, Inc., and our allies in the region.
- Make sure the early entry forces can produce and distribute water at the small-unit level from local resources and that we follow with water generation units using the advanced technologies we now have available. If, under emergency conditions, we go with bottled water, we must inform Pacific Command and U.S. Army Pacific of the amount of aviation assets that will have to be dedicated to this.

- With the new caseless ammunition and copper 5.56 mm rounds, our lift requirements for ammunition should be reduced because the copper ammunition is more effective and less needs to be transported, and the caseless ammunition weighs significantly less than cased ammunition. Check with Program Executive Office Ammunition to determine whether the forces will be issued the precision guided munitions rounds prior to deployment. Also check with Training and Doctrine Command to determine if the increased accuracy of the precision guided munitions and the lethality of copper 5.56 mm have been factored into the number of rounds in the basic load. There should be fewer rounds, which again will help us with our lift requirements.
- Since Power, Inc., has been in on the planning of this operation since the beginning, we should get information from both it and the Defense Logistics Agency on whether fresh food and other commodities can be purchased in PACISLANDIA.
- Make sure our contracting officers arrive early in the deployment and hook up with the operational forces they are there to support.
- I want a separate briefing on the capabilities of our decision support systems and of the recent upgrades to GCSS-Army. These are real logistics multipliers and will give both our logistics units and the operational forces continuous visibility of our supply chain.
- Find out if our aviation support assets have the new engine developed by the Improved Turbine Engine Program. As you know, the fuel savings are considerable. The recently fielded combat vehicle fuel and power efficiency programs and the auxiliary power units will also result in fuel savings. We should see significant reductions in fuel demands because of all this. On the side, check to determine if there are any research and development programs that will improve the fuel efficiency of our resupply and basic-load- and combat-load-carrying vehicles. We need that work to be moving ahead.
- Get in touch with our Combined Arms Support Command and Army G-4 representatives to see if we can run a quick computer-aided map exercise based on this scenario, with the capabilities we now have, to determine what the two additional days of basic and combat loads do to our resupply tonnages, along with our current capability to satisfy these requirements.
- Fuel resupply will be an issue. Check with the Navy and see what they can do for us. The farther forward they can go, the better for us. Again, since we have fielded the improved power trains, our combat vehicles should be more fuel efficient. I expect to see the use of the Appliqué Autonomous Follower Systems on our resupply trucks, reducing the risk to our drivers' safety and cutting the number of transportation soldiers we will need to put on the island.
- Also check with Special Operations Command, Pacific, to see if all the Operational Detachment-A team leaders have been trained on how to get support for common items. Same goes for the Marine forces. Training instituted by both Training and Doctrine Command and U.S. Special Operations Command has been very useful in this regard.
- We need to have our sea-based repair vessel deployed to the operational area. Since it now has a considerable 3-D printing capability, we will be able to reduce our repair cycle times for critical parts. Also, work with the Navy to use its 3D printing capability.
- Be sure to involve Power, Inc., in all stages of planning and execution. They have worked in this area for years and can be of great assistance.
- Find out if we can accelerate the current research and development program that is working to improve the sea state capability of our LOTS equipment. Working on the PACISLANDIA shoreline is going to be tough, especially with the higher sea state levels we are going to encounter. This has been a long-standing issue, and we need an improved sea state capability now. I am disappointed that we still haven't fielded a more sea state capable LOTS.

At the completion of the briefing MG Williams mentioned to his Deputy Commander that our logistics capabilities are so much better then when he was company commander in the 1st Corps Support Command around 2005 because of the systems and technologies now available.

THE BATTLE FOR ARIDIA IN 2021

As she looked over plans for the withdrawal of U.S. forces from Aridia at the end of the 180 day Operation Secure Lands, LTC Barbara Smith, G-4 of the First Cavalry Division, thought back over how well the operation had been carried out. The operation had been instigated by the continuing threat that Aridia might use chemical, biological, radiological, nuclear or explosive (CBRNE) weapons against its neighbors, bringing to a head long-standing tensions between Aridia and the United States and its allies in the region. Aridia had long been considered one of the most bellicose nations in the region. While possessing a 300-mile coastline, most of its assets and population were separated from the sea by a large desert.

When Aridia employed chemical weapons against a dissident group in its own country and fired biological weapons across the border at one of its neighbors, a multi-national effort was mounted against Aridia to seize the CBRNE materials that were stored in four supply depots and to defeat Aridian forces protecting those facilities. Initial entry into Aridia was spearheaded by the Marine Corps, which seized critical port facilities and the communities surrounding these facilities. The Aridian forces fell back deep into the interior of their country to four separate locations, where brigade sized armored forces set up defenses of the CBRNE facilities.

After picking up prepositioned equipment located in one of the nearby friendly countries, Army BCTs landed in Aridia, passed through the Marines, and moved to the interior to engage the Aridia forces deployed in arcs in front of the storage facilities, located approximately 500 miles from the port complex.

When she arrived in theater, LTC Smith had been concerned about the length of the routes that would carry supplies to the advancing BCTs. Although the highways were relatively secure because of the overhead surveillance provided by Air Force drones operating in theater, she worried that the heat, desert sand, and distance would combine to create problems for the movement of supplies. Thinking back on the supply figures she had used as a student at Command and General Staff College, she remembered that she had been concerned about the ability of the sustainment package in the current operation to keep up with the rapidly advancing armored forces. Over the course of the operation she learned that the reduction in fuel consumption of aircraft and armored vehicles brought about by advances in turbine engine design had cut the fuel demand by a quarter. She also learned that the move to condition-based maintenance would allow her to get the right part to the right location at the right time throughout the campaign.

LTC Smith had also been impressed by the ability of the mobile 3-D printing unit attached to the division to take care of issues that arose with one-of-a-kind critical parts resupply. She also thought back on the reduction in the size of the support force brought about by the use of autonomous resupply vehicles that moved rapidly in leader-follower convoys across the desert from the port to forward resupply bases, and the flexibility in resupply that was brought about by the use of autonomous aerial resupply to move the most critical equipment forward from forward operating bases to the battalions engaged in combat. Having been stationed at forward operating bases during Operation Enduring Freedom and Operation Iraqi Freedom, she was amazed at how the size of these bases had been reduced in the intervening years. They had become mobile and lean.

Because of the vastness of the battle space and the presence of nomadic natives, she had initially been concerned about the threat these local groups might pose in interdicting the main supply routes. She had been relieved when special operations forces moved into the area to work with these local groups when possible or to confront them when necessary. She had met some of the SOF personnel a few years earlier when she was at the Army Logistics University and had developed the procedures that integrated SOF resupply into the system that was also providing for the conventional forces in theater.

Providing water to the troops, which she remembered as a heavy resupply burden in Afghanistan and Iraq, had been easily handled through the use of water delivery teams that were able to take portable purification units to areas near engaged units and to provide them with all of the water they needed. Liaison with Army Geospatial Center prior to deployment had identified probable locations of water supplies within the theater and turned out to be on the mark when forces actually arrived. She was also thankful for the opportunity she had had to work closely prior to deployment with RGC, Inc., the contractor that was providing base-level logistics support for the division. The company had previously worked with many of the local firms and was able to use this knowledge and experience to find places where local facilities could be used for billeting, storage, and other activities, thereby reducing the effort required of military forces.

Perhaps most satisfying to her was her ability to know where critical material was at all times. The in-transit visibility information on supplies, shared with logistics personnel and commanders in the forward units, greatly reduced her anxiety and theirs about what she would have, where she would have it, and when. The linkage of the logistic information system across services and contractor forces allowed her to quickly address any unique problems that arose. Frequent preoperational tabletop exercises conducted with personnel from the U.S. Transportation Command and the Defense Logistics Agency ensured that these linkages were locked in long before units left their home stations, and that those linkages remained solid throughout the operation. They would also greatly assist in the retrograde of the material from Aridia.

LTC Smith could truly see the transformation that had begun in military logistics and the effectiveness of an all-hands approach to modern logistics operations.

11

Findings and Recommendations

KEY FINDINGS AND RECOMMENDATIONS

The committee's overall priorities are set out in the Key Recommendations, which represent the committee's identification of the actions that it believes need to be taken to reduce the logistics burden and improve the efficiency of Army logistics. The first Key Recommendation carries the highest priority. The subsequent Key Recommendations follow the structure of the report and are essentially equally important. They address technologies, operating procedures to include resourcing, decision-making, education, joint and special operations support. If there is going to be substantive improvement in the logistics system the Army relies on for its sustainment, all of the Key Findings accompanying these recommendations must be recognized and all of the Key Recommendations addressed. They are substantively intertwined.

Key Findings and Recommendations either rest on one or more underlying findings and recommendations in the report body or represent a finding and recommendation drawn from the substance of the report or a section as a whole. Where the former is the case, the pertinent findings and recommendations are noted in brackets.

The committee's priorities for R&D investments are given in Tables S-2 and 9-1 and represent the professional judgment of the committee in assessing the technologies behind the technology-based recommendations in the report. High priority investment areas represent a coalescence of a promise of a substantial reduction in logistics burden and/or a reduction in resource demands and a committee judgment that the programs are achievable within the next decade or sooner and meet an immediate operational need identified by the Army. However, these priorities are closely tied to the force structure the Army chooses or is directed to implement.

General

Key Finding 1. Logistics activities within the Army do not receive the attention necessary to ensure the effective sustainment of operational forces on the battlefield over the long term. This is because, unlike things that directly affect combat effectiveness, it is difficult to understand the ultimate impact of logistics activities on Army capability. In R&D, analyses, exercises, and planning, logistics challenges are often minimized or postponed to be addressed another day. As a result, when systems are developed or plans are executed, the logistics enterprise is placed in a catch-up position, significantly reducing its ability to support the ongoing operations. Capability requirements, along with off-the-shelf solutions that create logistics burdens, are outpacing the development and fielding of burden-reducing logistics and logistics-related technologies.

Key Recommendation 1. Senior Army leadership should ensure that adequate resources and priorities are given to logistics activities across the spectrum of Army activities, including research and development, analytical support, force structure, military education, and operational planning.

Water

Key Finding 2. As a matter of doctrine, bottled water is used in the initial stages of operations until the bulk purification, storage, and distribution of water can be established. The use of bottled water weighs heavily on the logistics systems, puts soldiers and civilians at risk to deliver it, and generates a significant waste burden. Because of the availability of contractor-provided bottled water in Iraq and Afghanistan, earlier peacekeeping missions, and humanitarian assistance and disaster relief missions, the Army reduced its organic active force capability to provide water at the point of need and is now heavily reliant on the use of bottled water.

Key Recommendation 2. The Army should rely on its existing water technologies, and adopt or develop appropriate additional technologies, to satisfy water demand at the point of need and limit the use of bottled water except where the situation dictates its use e.g. for humanitarian assistance and disaster relief operations.

Fuel and Energy

Key Finding 3. Emerging technologies such as the improved turbine engine program and high-efficiency drive systems would provide significant reductions in fuel demand for aircraft, the M1 Abrams, and the M2 Bradley and increases in system efficiencies. Selective use of hybrid and electric vehicles in rear areas would reduce fuel demands. Use of high-efficiency auxiliary power units could not only reduce fuel demands but could also enable use of electric systems in vehicle design. Advancements in fuel cell design, micro- and smart-grid employment, and battery efficiency would similarly reduce the demand for fuel. Use of small modular nuclear reactors in rear areas could provide large-scale power sources. [This is based on Findings 3-12, 3-14, 3-15, 3-16, 3-17, 3-19, and 3-22.]

Key Recommendation 3. The Army should strongly support continued development and fielding of a portfolio of promising technologies to reduce fuel and energy demand, including acceleration of the improved turbine engine program and more fuel-efficient engines for the M1 Abrams and the M2 Bradley or their replacements, recognizing that it will take success in several areas to reduce the overall demand. [This is based on Recommendations 3-12 and 3-14.]

Ammunition

Key Finding 4. Precision munitions potentially offer significant reductions in required munition expenditures and qualitative improvements in effectiveness, thereby reducing ammunition demand and its logistics burden. The additional costs of precision munitions must be weighed against the total costs of employing nonprecision munitions in the aggregate, from the ammunition plant to the target. Similarly, initial tests of directed energy weapons have indicated both their effectiveness and the reduction in logistics support required for their employment. [This is based on Findings 3-25 and 3-27.]

Key Recommendation 4. The Army should adopt the use of precision munitions as widely as practical within mission requirements, and should use directed-energy weapons systems if ongoing tests are successful. [This is based on Recommendations 3-21 and 3-23.]

Key Finding 5. The planning of Army production, transportation, maintenance, storage, and expenditure of ammunition are carried out as relatively independent activities that have successfully supported military operations and has improved the efficiency of several elements of the ammunition supply chain. However, there is no indication that the Army is taking advantage of usage data from the past 25 years, experience from changes in weapons technology over past decades, or future opportunities that may exist to lessen the ammunition burden. There has been no significant effort to examine ammunition as a system or which ammunition mixes will provide the optimum combination of fires effectiveness and logistics burden minimization. The recent "Improve/Lean & Control Phases (Combined) Gate Review" by the Program Executive Office Ammunition could provide the baseline for the development of the optimum mix of weapons system effectiveness and logistics burden reduction.[1]

Key Recommendation 5. As one of the largest logistics burdens faced by the Army, it is imperative that the Army maintain cognizance over all aspects of the ammunition supply chain and identify steps that could be taken to ensure the effectiveness of the support provided to combat units and the potential for reductions in the ammunition tonnages that needs to be moved in battle situations. The Army should conduct a comprehensive analysis of the ammunition system with a view toward linking analysis of battlefield experience with the operations of the system as a whole.

Soldier Systems

Key Finding 6. Over the past decade, the effectiveness of the individual soldier has been increased by on-person combat support systems. However, at the same time, the weight the soldier must carry has increased. Technologies for effectively meeting power demands for individual soldiers are emerging and offer the potential to reduce soldier load and increase soldier trust in the power reliability of carried systems. [This is based on Findings 3-28, 3-29, 3-30, 3-31, 3-32, 3-34, and 3-35.]

Key Recommendation 6. The portfolio of projects under way to reduce the weight of power supplies for an individual soldier should be given emphasis, and the resulting equipment should be fielded as soon as possible. [This is based on Recommendations 3-25, 3-26, 3-27, 3-29, and 3-30.]

Mobility

Key Finding 7. The Army will be dependent on its organic watercraft capabilities for much of its intratheater transportation in many areas of the world. The age and capabilities of the watercraft currently in the inventory will limit such support. They are slow, have insufficient capacity, are too few in number, are highly sensitive to sea state, and could be impediments to efficient and effective logistics in the Asia-Pacific theater. [This is based on Findings 4-2 and 4-4.]

Key Recommendation 7. The Army should maintain priority support for the acquisition of the Maneuver Support Vessel (MSV) (Light) and concurrent development of the MSV (Medium) and the MSV (Heavy). It should also consider the acquisition of the Ship-to-Shore Connector vessel under the Navy program. [This is based on Recommendations 4-2 and 4-3.]

Key Finding 8. Autonomous vehicle technologies offer a significant opportunity to automate military operations in an effort to improve logistics operations. Unmanned and remote-controlled helicopters and precision air drop systems can significantly reduce the demand for ground-based resupply of forward areas in high-risk or limited-access situations. Resupply operations over the last tactical mile could be efficiently performed by autonomous vehicles to reduce the risks to supply vehicle operators and lighten the load that small units currently must carry. Autonomous vehicles are ready to be deployed in

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[1] Improve/Lean & Control Phases (Combined) Gate Review, September 12, 2012. Provided by Chris J. Grassano, Deputy Program Executive Officer Ammunition to Leon Salomon, committee member, by e-mail on May 16, 2014.

constrained settings with limited obstacles and established routes. They are not yet ready to deploy in operational settings with rough terrain or unpredictable routes. Unmanned and remote-controlled helicopters have been effectively employed by the Marine Corps for resupply in Afghanistan on a test basis, and development continues. [This is based on Findings 4-9, 4-11, 4-12, and 4-13.]

Key Recommendation 8. Autonomous vehicle technologies should be implemented in phases, starting with what is possible now using semiautonomous technologies, such as leader-follower, so that incremental improvements to logistics can be realized as the technology matures. Research and development should be continued to develop these technologies for use in challenging, unpredictable environments that are currently beyond the capabilities of these technologies. The Army should work with the Marine Corps to combine research and development efforts to develop a common autonomous aerial support capability for logistics. The Army should continue to support rapid development and fielding of precision airdrop for sustainment to forward areas and pursue a helicopter-borne Joint Precision Airdrop System capability to expand its overall sustainment options and capabilities. [This is based on Recommendations 4-7, 4-10, and 4-11.]

Additive Manufacturing

Key Finding 9. Additive manufacturing provides an emerging capability to produce components in support of Army logistics system needs at the point of need and to improve the responsiveness of the Army maintenance system. Present additive manufacturing efforts are ongoing across the Army and are close to the state of the art. However, additional development is required to (1) fully realize the benefits of additive manufacturing and (2) make it widely useful forward of fixed facilities, such as depots, given the current heavy power demands and challenges in base material management and standard setting. [This is based on Findings 5-1 and 5-2.]

Key Recommendation 9. The Army should leverage the industry investments in additive manufacturing and support technology areas that map to the Army's specific needs and implementation constraints. The Army should support standards development that would form the basis for qualifying components produced by additive manufacturing. [This is based on Recommendations 5-1 and 5-2.]

Logistics Enterprise Information System

Key Finding 10. The Army Logistics Enterprise System, which includes the Army Enterprise Systems Integration Program Hub, the Global Combat Support System-Army (GCSS-A), and the Logistics Modernization Program (LMP), is a viable approach to support efficient and effective logistics for the Army. The Army has expended considerable resources on implementing what may be the largest enterprise resource planning system ever. The other Services have a mixed record of success in implementing such systems. Successful implementation of the program will require strong and continuous support and an understanding by Army leadership of the challenges and opportunities that the continuously evolving systems will face. In addition to the ever-present technical issues that will develop, there will be a need to develop new decision support tools and applications that can utilize GCSS-A and LMP data and to pay attention to cybersecurity issues as the threats evolve. [This is based on Findings 6-1, 6-2, 6-3, and 6-4.]

Key Recommendation 10. To ensure that the Army Logistics Enterprise Systems is fully implemented and operated efficiently over its life, the Army should provide constant resource and organizational support for the Army Enterprise Systems Integration Program, the Global Combat Support System-Army, and the Logistics Modernization Program, even after full implementation of the initial systems and related tools and applications. Without such support, the overall system will rapidly atrophy. [This is based on Recommendation 6-2.]

Key Finding 11. The U.S. Army logistics network has made considerable progress in improving in-transit visibility to the supply support activity and the unit motor pool. Estimated shipping dates and advanced shipping notices are routinely provided, which has improved availability and readiness. More confidence in the system might be realized by also letting the end user/soldier know about the availability of the item he or she requested from the supply system. The benefit of this would be a reduction in the current practice of placing redundant orders due to a lack of confidence in the supply system.

Key Recommendation 11. Using the capabilities of Global Combat Support System-Army and the Logistics Modernization Program, the Army, in conjunction with industry, should compare the costs and benefits of extending the in-transit visibility to the end user/individual soldier to those of the current systems. [This is based on Recommendation 6-5.]

Logistics Decision Support

Key Finding 12. Modeling and simulation and systems analysis capabilities in support of Army logistics are insufficient to evaluate, compare, and contrast various S&T initiatives and their respective impacts on both the force structure alternatives currently under consideration and the outcomes across the spectrum of operations. (This same condition was identified in the 1999 NRC report *Reducing the Logistics Burden for the Army After Next.* (NRC, 1999)) When systems are being developed, the results of logistics analyses are not quantified in terms of warfighting effects or the impact they might have on the logistics system as a whole (e.g., adding fuel capacity to a vehicle family may result in a need for additional fuel transport vehicles, with the accompanying additions to force structure). As a result, logistics systems and logistics requirements do not fare well when competing with other types of systems or subsystems. Because logistics decisions are complex and often mostly subjective and because they have great impacts on life-cycle cost, investment in decision support systems for logistics could result in significant savings over a system's life cycle. The Army's ability to perform informed logistic studies and analyses has eroded over the past two decades to the point where there is little intrinsic capability left to conduct these analyses. [This is based on Findings 6-15, 6-16, 6-17, 6-18, and 6-19.]

Key Recommendation 12. The Army should revitalize its logistics analysis capability by acquiring the necessary tools and qualified military and civilian analysts in quantities commensurate with the number and impact of logistics decisions that need to be made. Modeling, simulation, and analysis tools need to be improved to explicitly include logistics factors. [This is based on Recommendations 6-14 and 6-16.]

Use of Contractors and the Army Reserve

Key Finding 13. Contractors and the Army Reserve represent important elements of the Army and joint logistics team and, given the reductions in active military force structure, must be considered an essential component in the planning and execution of operations. They possess unique knowledge of the functions they may be called on to carry out and, in the case of contractors, on-the-ground experience in potential areas of operations. At present, they are excluded from participation in contingency planning until contracted or invited to do so. [This is based on Findings 7-1, 7-2, and 7-4.]

Key Recommendation 13. Both Army and combatant command leaders should integrate contractors and the Army Reserve into their contingency planning process from the beginning and on a continuous basis. Planners in both the Army and combatant commands should be schooled in the capabilities of contractor organizations and the Army Reserve to assist in contingency planning. For contractors, this may require establishing ongoing contracts for the support of specific combatant commands or regions so they can engage in planning processes within the combatant commands. [This is based on Recommendations 7-1, 7-2, and 7-4.]

Key Finding 14. Guidelines for support of military operations over time by contractors are frequently formulated on the fly as operations evolve. This results in inconsistencies in the provision of services, competition among units and services, and a lack of attention to both potential support costs and the logistical burdens that are created. The necessity for these guidelines prior to the start of operations was a lesson learned in Vietnam. [This is based on Finding 7-3.]

Key Recommendation 14. Army leadership, in coordination with its sister Services, the Joint Staff, and combatant commanders, should establish guidelines for the support to be provided for contingency operations over time as the mission and needs develop. [This is based on Recommendation 7-3.]

Joint Logistics

Key Finding 15. Given the resource constraints that face today's armed forces and the necessity to develop an effective joint fighting force, jointness in logistics is an imperative. The committee recognizes that transformation takes time and that moving to joint logistics represents a significant change in culture. However, it has been over a decade since the military community began serious discussions of joint logistics and nearly 5 years since the Joint Staff articulated a vision for integrated logistics, and signs of progress are limited. The committee, during its review and its interviews with senior logistics personnel, both retired and active, could not find strong evidence that the Army and the joint community were actively involved in implementing a joint logistics effort. There remains a strong belief among the leadership of the Services that their Title X responsibilities trump the authorities of the Secretary of Defense and the combatant commanders to require the conduct of joint logistics operations. There was clear articulation that, absent directives from the Secretary of Defense, the services will not move rapidly to embrace joint logistics activities or aspects of joint operational activities. It is this committee's opinion that the trump card for jointness should be held by the combatant commander since the execution of the strategy is the combatant commander's responsibility.

Key Recommendation 15. Wherever possible and appropriate, the Army should strongly support and become a part of joint logistics and related research and development activities. As a starting point, the Army should review the status of implementation of Appendix B of the *Joint Concept*, *Key Indicators of the Military Problem*, along with the operational issues described in 2011 by the G-4 of the Army.

Logistics Support of Special Operations

Key Finding 16. Based on lessons learned from Operation Iraqi Freedom and Operation Enduring Freedom, the Army's new thrust to become more expeditionary, and the additional focus on geopolitical areas beyond the Middle East, an extraordinary opportunity has arisen for the Army and Special Operations Command to jointly revisit and redefine their working relationships in the areas of logistics and sustainment for their mutual benefit. [This is based on Findings 8-1 and 8-3.]

Key Recommendation 16. The Army G-4 should initiate discussions with Special Operations Command (SOCOM) to revisit existing logistics and sustainment support policies, agreements, and capabilities (including linked databases) with the stated objective of revising them for their mutual benefit. In parallel, the Army G-4, working in conjunction with the individual geographic combatant commands and

SOCOM, should determine the feasibility and acceptability of designating each Theater Army as the primary logistics and sustainment support organization for special operations forces in each geographic combatant command's area of responsibility. [This is based on Recommendations 8-1, 8-3, and 8-4.]

Taking Advantage of Technology Innovation

Key Finding 17. Joint, interagency, intergovernmental, multinational, nongovernmental, and commercial organizations remain heavily involved in material development and technology innovation in areas directly relevant to Army logistics operations and sustainment goals. (1) Continuous monitoring of these efforts outside the Army and (2) collaborative efforts with other organizations offer opportunities for reductions in military expenditures for needed technologies and the early acquisition of systems that have been proven in the private sector. [This is based on Finding 8-4.]

Key Recommendation 17. In carrying out its material development programs, the Army should continue and, where appropriate, increase close collaboration with joint, interagency, intergovernmental, multinational, nongovernmental, and commercial organizations in science and technology areas where these organizations are pursuing programs similar to those required by the Army. The Army should avoid duplication of efforts underway in other sectors wherever possible. [This is based on Recommendation 8-5.]

Logistics Science and Technology and R&D Strategy

Key Finding 18. There is no explicit strategy for Army investment in logistics and related goals, such as a 25 percent reduction in fuel consumption for a given system. Such a strategy is needed to guide efforts to reduce logistics requirements and to guide the non-logistics material development efforts that increase the logistics burden of the Army in the field. Without such a strategy and goals, the Army G-4 and the Army sustainment community are unable to effectively influence critical decisions in S&T and R&D. In addition, there is no explicit effort by the Army logistics community to closely monitor the S&T and R&D activities of the other elements of the Department of Defense or the defense industry to capitalize on S&T and R&D successes in those organizations and to integrate their new capabilities into consideration of a future joint logistics environment. [This is based on Findings 9-1 and 9-2.]

Key Recommendation 18. The Army, through the G-4 and with the support of the Combined Arms Support Command, should develop, staff, publish, and annually update an Army Logistics Science and Technology (S&T) and Research and Development (R&D) Strategy that clearly defines the long-range objectives for Army logistics, the programs that influence the attainment of these objectives, and the actions that will be taken to ensure the close integration of Army logistics enhancement activities with those of the joint and Department of Defense community and related industry. The Army Logistics S&T and R&D Strategy should include specific burden reduction goals, such as a 25 percent reduction in fuel consumption for a given system. Development of the Army Logistics S&T and R&D Strategy should be followed by development within the entire R&D community of a roadmap specifying the responsibilities and actions that need to be taken to ensure accomplishment of the objectives of the strategy. [This is based on Recommendations 9-1 and 9-2.]

FINDINGS AND RECOMMENDATIONS FROM THE CHAPTERS

Chapter 3—Reducing the Major Logistics Demands

Water

Finding 3-1. Specialized water generation ships have been designed by industry and could provide a useful expeditionary water capability in areas near oceans or seas.

Recommendation 3-1. The Army, working with the U.S. Transportation Command, should consider converting one or more small tankers for desalination of seawater to produce bulk potable water.

Finding 3-2. In appropriate climates, use of rain and atmospheric water may satisfy a significant portion of the water demand at the point of need. This can be accomplished with available equipment such as tarps, nets, and rain barrels, and simple changes to tents to collect water.

Recommendation 3-2. The Army should implement and, where necessary, develop methods to harvest water from the local environment, including rain and fog, to meet soldier water needs at the point of need.

Finding 3-3. Distillation may be a simpler, more efficient method of water purification than systems currently used by the Army. It can produce pure drinking water from any water feedstock with any sort of contaminant, including black water. Similarly, nanotechnology solutions may be able to effectively address Army water purification needs in appropriate settings.

Recommendation 3-3. The Army should develop distillation methods to meet soldier water needs at the point of need. The Army should also explore the use of existing nanotechnology solutions for water purification.

Finding 3-4. Current water filtration systems are focused at the Army's company level and above. There is a need to develop and field individual water purification filters. Individual water filters would reduce the amount of water that has to be shipped forward.

Recommendation 3-4. The Army should field individual water filters as soon as possible.

Finding 3-5. Training soldiers in tactical units to perform water quality testing and providing them with suitably simple field equipment would enhance the timely production of safe water in the field.

Recommendation 3-5. The Army should develop a simple, portable water testing device that a squad can use to ascertain whether water is potable without having to wait for specialists to test it.

Finding 3-6. Water from exhaust is not yet ready to be used as drinking water. There are still many challenges to overcome, not least its taste. Still, it could be used to meet some of the demand for nonpotable water, and if the taste challenge can be overcome, it could have a very great positive impact on the provision of water on the battlefield.

Recommendation 3-6. The Army should continue its research on extracting water from diesel exhaust. It should also explore the use of water recovered with this technology for nonpotable uses. Specific goals, including affordability, minimal weight and power impact, and good taste should be provided to the research community. The Army should also suggest to the Defense Advanced Research Projects Agency (DARPA) that this may be a problem whose difficulty justifies their involvement.

Finding 3-7. There is a wide variety of simple cultural and behavioral changes that could produce significant water savings.

Recommendation 3-7. Rather than relying solely on technical solutions for water conservation, the Army should aggressively pursue cultural and behavioral changes that would save water at no additional cost.

Finding 3-8. There is a wide variety of technical water conservation solutions. These range from commercially available devices to the system that the U.S. Army's Engineer Research and Development Center is developing to recycle water in the field.

Recommendation 3-8. Commercially available water conservation devices should be adopted for use as widely as possible. Additionally, development work such as that of the U.S. Army's Engineer Research and Development Center should be supported and the resulting water recycling systems fielded as quickly as possible.

Finding 3-9. Installing water meters on all water tanks and bladders would allow for the more effective monitoring and management of water usage.

Recommendation 3-9. The Army should install water meters on all water tanks and bladders.

Finding 3-10. Using flexible bladders to transport water could simplify the task of returning empties, increasing efficiency, providing greater utilization of flats, and reducing logistics demand for fuel.

Recommendation 3-10. The Army should consider replacement of water tank containers and hippos by more versatile flexible bladders riding on flats.

Finding 3-11. Where appropriate, pipeline is the most efficient method to deliver water to troops and bases. New pipeline systems are under development that will greatly increase the rate at which pipeline can be laid. Also, current pipelines are vulnerable to enemy action. There are commercial solutions available to address pipeline integrity and security, and these might prove useful for the Army to adapt to its needs.

Recommendation 3-11. The Army should develop self-monitoring pipelines that report interdiction, intrusion, tampering, and other detrimental activities. The Army should begin by exploring commercially available applications for pipeline monitoring to see if they can be adapted to its needs.

Fuel and Energy

Finding 3-12. The committee believes that the Improved Turbine Engine Program will provide significant reductions in aircraft fuel consumption and increases in aircraft engine efficiencies.

Recommendation 3-12. The Army should accelerate development and fielding of the Improved Turbine Engine Program.

Finding 3-13. The Air Force's ADVENT program technologies have the potential to reduce fuel consumption, and their high-efficiency components may also reduce maintenance cost. These engines are likely to have high power density and high fuel efficiency. While the ADVENT program is directed a producing a fighter engine, there may be turbine engine technology synergies that could aid the Army's Improved Turbine Engine Program.

Recommendation 3-13. Without slowing down fielding of the Improved Turbine Engine Program, the Army should explore the possibility of working with the Air Force and industry partners to combine the relevant technologies of the Adaptive Engine Technology Development program and the Improved Turbine Engine-Program to further reduce fuel consumption and improve performance.

Finding 3-14. Developing more fuel-efficient engines for the M1 Abrams and the M2 Bradley would result in significant fuel savings for the Army. As indicated in the discussion above, a diesel engine that uses approximately 50 percent fuel has been tested. The M2 uses a diesel engine. The Improved Turbine Engine Program is developing an engine with 25 percent greater fuel efficiency. The M1 uses a turbine engine.

Recommendation 3-14. The Army should develop more advanced engines for the M1 Abrams and the M2 Bradley, with a goal of 25 percent greater fuel efficiency as envisioned by the Improved Turbine Engine Program.

Finding 3-15. Hybrid propulsion offers significant improvement in fuel economy over conventional vehicles. Hybrids could also be used to transfer power to off-board applications or a base camp microgrid.

Recommendation 3-15. The Army should continue to develop hybrid drive technology and should adopt technologies that have been developed for commercial hybrid vehicles for use in military vehicles.

Finding 3-16. Auxiliary power units, particularly those based on fuel cells, are more fuel-efficient than engine-driven generators for onboard power generation, driving down fuel demand.

Recommendation 3-16. The Army should continue its efforts to implement auxiliary power units (APUs) on conventionally propelled vehicles. Moving to non-fossil-fuel APUs such as fuel cells when possible will result in greater efficiencies.

Finding 3-17. Pure electric vehicles might have some application in forward logistics bases and may further reduce the amount of fuel that must be brought forward to support operations at these bases.

Finding 3-18. Microgrids provide energy security for military facilities to assure reliable power without relying on a larger utility grid.

Finding 3-19. Microgrids and smart grids reduce the amount of fuel required to generate electric power by networking generators into a system in order to maximize efficiency, reducing fuel demand. Microgrids can also be used to help integrate renewable energy resources (e.g., wind and solar) into the grid, further reducing fuel demand.

Recommendation 3-17. The Army should expand its microgrid and smart grid deployment activity, focusing on incorporating fuel cells and renewable energy sources such as photovoltaic-based power generation systems for on-site power generation applications.

Finding 3-20. The Army is appropriately engaged in fuel cell research for onboard power generation in transportation applications.

Recommendation 3-18. The Army should continue to explore the possibility of using fuel cells wherever appropriate and to deploy them in the field.

Finding 3-21. Flexible photovoltaic cells could be an integral part of the electricity supply for a wide variety of applications, including tensioned awnings of photovoltaic cells and spools that are delivered in containers. This could improve expeditionary operational energy capabilities and reduce the requirements for fuel delivery to a given location.

Finding 3-22. Deployable small modular reactors offer the promise of game-changing impacts to Army logistics if deployed at large bases in rear areas.

Recommendation 3-19. The Army should stay abreast of Department of Energy and Department of Defense research and development initiatives for small modular reactors (SMRs). Army logistics planning should include the possibility that SMRs will provide abundant electrical power, fuel, and water for its deployed forces.

Ammunition

Finding 3-23. A 50 percent reduction in ammunition weight will have an associated reduction in logistics demand.

Recommendation 3-20. As the Army considers replacing small-caliber arms, it should pursue caseless, polymer-cased, or case-telescoped small-caliber ammunition.

Finding 3-24. Increasing the shot-to-shot consistency of small-caliber ammunition increases its effectiveness, potentially reducing the amount of ammunition that needs to be used and the logistical demand for ammunition.

Recommendation 3-21. The Army should consider new bullet technology in concert with its evaluation of a lighter caseless round. The ideal outcome would be a more consistent, more effective round that weighs less, reducing both the number of rounds that need to be used and the per-round weight, thereby reducing the logistical demand for this ammunition.

Finding 3-25. Precision munitions offer the potential for significant reductions in munition expenditures and qualitative improvements in effectiveness. A reduction in munitions expended also has benefits in other areas, such as a reduction in fuel used to transport munitions and in the number of convoys necessary to do so. As noted in the 1999 NRC report on logistics, the effectiveness of precision munitions is directly related to the ability of the force to locate and precisely identify targets (NRC, 1999). Significant progress has been made in this regard.

Recommendation 3-22. The Army should adopt the use of precision artillery munitions as widely as practical within mission requirements.

Finding 3-26. Using conventional materials with innovative, redesigned packaging, the weight of transportable, packaged ammunition has been significantly reduced. Redesign can also be used to minimize the amount of waste left over from packaging.

Recommendation 3-23. The Army should consider replacing conventional ammunition packaging materials with advanced ones, such as carbon fiber tubes, as widely as possible. Also, packaging design should be examined with an eye to reducing leftover waste that needs to be disposed of.

Finding 3-27. Among the many programs with a wide variety of applications across several domains (maritime, space and missile defense, ground-based air defense, etc.), one Army program in particular has achieved significant success: the High Energy Laser–Mobile Demonstrator (HEL-MD). The interacting effects of system effectiveness (lethality) and logistics reduction potential are so significant that the cost exchange ratio can actually be reversed.

Recommendation 3-24. The Army should accelerate the remaining HEL-MD test schedule. Pending success, and consistent with risk mitigation strategies, the Army should expedite production, deployment, and fielding of systems derived from the HEL-MD.

Soldier Power

Finding 3-28. Reduction in the number and types of batteries soldiers have to carry and better management of the power to the equipment and tools they carry would ease the demand on logistics systems by reducing the demand for batteries.

Finding 3-29. State-of-charge indicators on batteries would allow soldiers to have confidence in the actual state of charge of their batteries and, with appropriate command guidance, would allow fewer batteries to be used.

Recommendation 3-25. The Army should require that the batteries it uses have state-of-charge indicators so soldiers can have more confidence in their batteries.

Finding 3-30. Flexible photovoltaic cells emplaced on soldier's clothing could reduce the number of batteries soldiers have to carry.

Finding 3-31. Lithium–air batteries have a very high energy density, longer life span, and higher power density than lithium-ion and conventional batteries. This technology holds the potential to significantly reduce the number of batteries soldiers must carry and, accordingly, the number of batteries that must be recharged or delivered fresh to the unit. In addition, in the longer term, they can also be used for vehicle propulsion systems, thus extending the range and reducing total fuel consumption.

Recommendation 3-26. The Army should continue its research in lithium–air batteries for soldier power and other applications and leverage commercial investments in lithium–air battery technologies that can be applied to Army requirements. An emphasis should be placed on rechargeable lithium–air batteries.

Finding 3-32. Small radionuclide power sources could significantly reduce the battery logistics demand and the number of batteries soldiers must carry. This is a long-term effort.

Recommendation 3-27. Given their promise, the Army should closely monitor the research and development of small radionuclide power sources by industry and other government agencies, with a goal of eliminating as many replaceable batteries as possible.

Finding 3-33. Universal battery chargers eliminate the need for having different chargers for different types of batteries. They are lightweight, portable, and can be combined with a variety of power sources.

Recommendation 3-28. The Army should continue to advance the universal battery charger technology and work with the companies engaged in this area to deploy them as soon as possible.

Finding 3-34. Wireless charging has the benefits of improving and automating the battery recharging process and reducing the number of batteries needed for soldier power.

Recommendation 3-29. The Army should develop a plan to evolve to a wireless charging and wireless power distribution system.

Finding 3-35. Although the Integrated Soldier Power and Data System is a step in the right direction, it still does not solve many of the problems related to weight, ease of use, recharge time, and the significant number of batteries that would still have to be carried by the soldier. The Fully Connected Power and Data Architecture proposed by Draper Laboratory has the potential to solve many of these problems.

Recommendation 3-30. The Army should continue to work with the Draper Laboratory to advance the research on the Fully Connected Power and Data Architecture and implement these systems as soon as possible.

Finding 3-36. There has been little discipline in reducing the number of different batteries now used.

Recommendation 3-31. The Army should identify a small set of battery types and develop a strategy to incentivize the use of these battery types in future equipment development.

Chapter 4—Logistics Mobility

Mobility Into and Within the Theater

Finding 4-1. There is a critical need to enhance the ability to deploy and sustain Army units and their heavy equipment to austere environments using a variety of vessels and platforms. This necessitates that Army leadership support expansion and rapid execution of the current and follow-on programs.

Recommendation 4-1. The Army should continue to work with the Navy to bring the synergy of the large, medium-speed, roll-on/roll-off ship; the Joint High Speed Vessel; and mobile landing platform together into an operational system to enhance its flexibility in responding to contingency operations. This necessitates that Army leadership press forward on achieving closure in this area by continued involvement in the U.S. Navy 30 year ship building program and pursuing congressional funding to execute procurement of these vessels and programs.

Finding 4-2. The landing craft currently in the inventory are an impediment to efficient logistics in the Asia-Pacific theater. They are aged, slow, have insufficient capacity, are too few in number, and are highly sensitive to sea state.

Finding 4-3. The three planned classes of the Maneuver Support Vessel are an important step forward in Army landing craft capabilities. It is vital that these improved capabilities be introduced into the Army as soon as possible.

Recommendation 4-2. The Army should proceed with the development of the Maneuver Support Vessel (MSV)-Light with all speed and should proceed with the MSV-Medium and MSV-Heavy concurrently with the MSV-Light.

Finding 4-4. Existing aging Landing Craft Air Cushion require considerable maintenance, though they are undergoing a service life extension program, and they have limited capacity. Their maximum speed is very sensitive to sea state.

Finding 4-5. The existing ship-to-shore connector acquisition program is targeted to meet the needs of the U.S. Marine Corps, with 72 units planned.

Finding 4-6. The ship-to-shore connector program presents an opportunity for the Army to modernize its landing craft fleet.

Recommendation 4-3. The Army should ensure that its needs are reflected in the ship-to-shore connector acquisition program.

Logistics Over the Shore

Finding 4-7. Many elements in the Army's maritime logistical chain, including causeways, are sensitive to sea state and do not function in sea state 3 or higher. Also, performance in complex surf environments is not well characterized.

Recommendation 4-4. The Army should support or conduct research and development efforts to improve ramp interfaces, causeway connectors, causeway motions, crane heave compensation, and other components to permit operations in sea states of 3 or more.

Recommendation 4-5. The Army should monitor work to develop methods, systems, and/or procedures to create a lee or otherwise dampen waves and swell to reduce the sea state.

Finding 4-8. The Military Sealift Command has only one offshore petroleum distribution system vessel. Without having port facilities accessible by tankers, the Army could be highly dependent on this one vessel. There is thus great risk to this capability from breakdown, damage, or enemy action.

Recommendation 4-6. The Army should press for the Navy and/or U.S. Transportation Command to procure additional vessels of this type, and for the acquisition of equipment in modular packages to rapidly convert tankers or other suitable platforms into offshore petroleum distribution system vessels.

Mobility Ashore

Finding 4-9. Autonomous vehicle technologies offer a significant opportunity to automate military operations in order to improve logistics operations. They are ready to deploy in constrained settings with limited obstacles and established routes. They are not yet ready to deploy in operational settings with rough terrain or unpredictable routes. This capability could be achieved in 2-5 years, given a properly funded and implemented research and development program.

Recommendation 4-7. Autonomous vehicle technologies should be implemented in phases, starting with what is possible now using semiautonomous technologies such as leader-follower so that incremental improvements to logistics can be realized as the technology matures. Research and development should be continued to develop these technologies for use in challenging, unpredictable environments that are currently beyond their reach.

Finding 4-10. Convoy operations are highly repetitious tasks that could utilize today's existing autonomous vehicle technology to reduce manpower requirements and reduce risk to the vehicle operators.

Recommendation 4-8. The Army should implement secure leader-follower vehicle technology (a vehicle follows a fiducial on the vehicle in front of it), which does not require 360-degree awareness and can be done with low-cost sensors using Autonomous Mobility Appliqué System technology.

Finding 4-11. Autonomous vehicle technology could be utilized to lighten the load dismounted warfighters currently must carry. Also, resupply operations in the last tactical mile could be efficiently performed by autonomous vehicles to reduce the risks to supply vehicle operators.

Recommendation 4-9. The Army should develop and field autonomous platforms to provide logistical support in the last tactical mile by assisting in carrying supplies and equipment to the warfighter in the field.

Finding 4-12. Unmanned and remote-controlled aerial assets have been utilized by the Marines to provide logistics support.

Recommendation 4-10. The Army should work with the Marines to undertake research and development on a common autonomous aerial support capability for logistics.

Finding 4-13. Precision air drop of sustainment materiel could significantly reduce the demand for ground-based resupply of forward areas. It could take trucks off the road and reduce personnel risk. A helicopter-based Joint precision air drop system capability is being developed that could both reduce Army dependence on other Service assets and expand the number of assets that can be used in a sustainment role, adding flexibility to the sustainment mission.

Recommendation 4-11. The Army should adopt precision air drop for sustainment to forward areas as widely as practical. It should also pursue a helicopter-borne Joint precision air drop system capability to expand its overall sustainment options and capabilities.

Chapter 5—Maintenance, Retrograde, and Waste

Maintenance

Finding 5-1. Additive manufacturing provides a capability for producing components in support of Army logistics system needs at the point of need. Additive manufacturing efforts are ongoing across the Army and are close to the state of the art. However, further technology development is required to fully realize the benefits of additive manufacturing. Owing to its particular energy and materiel demands, additive manufacturing will happen at the depot level for the time being.

Recommendation 5-1. The Army should leverage the industry investments being made in the field and support technology areas that map to the specific needs and implementation barriers of the Army. The Army should support standards development that would form the basis for qualification of components. The Army should work with the other services to address standards for additive manufacturing and certification of parts for procurement.

Finding 5-2. The Rapid Equipping Force's Expeditionary Additive Manufacturing Laboratory is a solid foundation on which to introduce additive manufacturing capabilities into the Army's logistics enterprise, as appropriate.

Recommendation 5-2. The Army should continue to support activities initiated by the Rapid Equipping Force to develop a distributed additive manufacturing network that makes use of both organic and commercial capabilities. This network would be utilized to determine the applicability of additive manufacturing to critical Army components as well as to qualify procedures. It would include depots and both academic and industrial laboratories. It could also be a test-bed for integrating field-based maintenance requirements into a distributed design and manufacturing network.

Finding 5-3. Condition-based maintenance–plus (CBM+) supports the goals envisioned in force-multiplying technologies for logistics by enabling the reduction of process costs in the logistics enterprise.

Finding 5-4. CBM+ has the potential to significantly reduce the Army's logistics expenditures.

Recommendation 5-3. The Army should require the implementation of CBM+ on all future Army major system acquisitions without the possibility of waivers.

Connecting CBM to the Supply Chain

Finding 5-5. Connecting CBM+ demand information directly to the supply chain could enable advanced scheduling of line reparable unit replacement and preclude replacement before needed. This approach could identify the need to replace a part before it fails. Field testing has demonstrated that such a connection to the inventory system can significantly reduce the requirement for forward stocking of repair parts and dramatically reduce customer (i.e., tactical unit) demand uncertainty.

Recommendation 5-4. As prognostic credibility and accuracy for CBM+ advances, the Army should adopt connecting CBM to the supply chain as inventory management policy, as described above.

Retrograde

Finding 5-6. The potential for further improvement in retrograde seems considerable. The various depot-level reparable (DLR) network links and flows, including reverse pipeline flow, depot production and scheduling operations, and forward supply chain flow, must be connected and afforded in-transit visibility. Then the Army’s extensive investment in DLR assets can be reduced and, through better management within a synchronized, closed-loop supply chain, both current readiness and future capability can be improved.

Recommendation 5-5. The Army should recognize the potential for efficient retrograde operations to enhance unit readiness. It should adopt a new paradigm of readiness-responsive retrograde as discussed above for the crucial closed-loop retrograde supply chain within the larger logistics enterprise.

Finding 5-7. The potential for retrograde improvement using the Intelligent Collaborative Aging Aircraft Spare Parts Support project and the Visualization of Logistics Data project appears enormous. When used in conjunction with improved reverse logistics, these could pave the way toward a truly synchronized retrograde, enabling a responsive closed-loop supply chain with reduced requirement objectives and improved materiel availability and operational readiness.

Recommendation 5-6. The Army should adopt capabilities offered by both the Intelligent Collaborative Aging Aircraft Spare Parts Support project and the Visualization of Logistics Data project as first steps to incorporate predictive analytics toward a synchronized retrograde closed-loop supply chain. These concepts should be further extended, and adapted as appropriate, to sustain other fleets as well, including ground-based systems.

Finding 5-8. Resurrecting a sea-based maintenance and repair concept would be consistent with the Army's evolution toward more robust sea-basing as a practical response to the growing anti-access, area denial environment.

Recommendation 5-7. The Army should re-establish a sea-based mobile repair capability for aviation and consider expanding the sea-basing concept to support maintenance and repair for ground systems as well.

Finding 5-9. Regionally aligned multipurpose aviation sustainment brigades would provide more efficient and responsive reverse logistics support to the major combatant commands.

Recommendation 5-8. The Army should adopt a regionally aligned force structure for multipurpose aviation sustainment brigades.

Waste

Finding 5-10. It appears to be possible to reduce the waste burden on the logistics system by redesigning packaging, packaging items more efficiently, and minimizing any unwanted materiel so less waste is created in the first place, as demonstrated by the First Strike Ration.

Finding 5-11. Waste-to-energy technology holds promise for generating energy for forward and contingency operating bases. This technology will probably be less applicable to smaller bases and outposts. A key challenge to implementing such a technology is the presence of small-arms ammunition in the military waste streams.

Recommendation 5-9. The Army should act to eliminate the challenge of small arms ammunition in waste streams for waste-to-energy solutions. This could be done by developing hardened systems that can withstand ammunition cooking off, by developing efficient methods for the removal of ammunition from waste streams, or by training soldiers to not discard unexpended ordnance.

Chapter 6—Logistics Enterprise Information Systems and Decision Support

Logistics Enterprise Information System

Finding 6-1. The Global Combat Support System-Army and the Logistics Modernization Program form a viable approach to address the issues of in-transit visibility and efficient logistics operations, and to form the basis for the development of robust decision aids.

Finding 6-2. The Army has expended considerable resources on implementing what may be the largest enterprise resource planning (ERP) system ever. There is a mixed record of success among the other Services implementing ERPs.

Recommendation 6-1. The Army should make full use of the experience and lessons learned by other Services in implementing its enterprise resource planning systems so as to maximize its chances of success.

Recommendation 6-2. The Army should realize that the enterprise resource planning system will be a continuously evolving product with ever-increasing functionality. The programming and budgeting process should recognize this by providing a continuous funding stream for evolution and upgrades as well as the expected growth in functionality. Army leadership should provide ongoing resource and organizational support for the Global Combat Support System-Army and the Logistics Modernization Program even after full implementation of the system in order to reap the maximum benefits from its investment.

Finding 6-3. There is the need for a redundant computational capability/infrastructure and data backup for the Global Combat Support System-Army and the Logistics Modernization Program.

Finding 6-4. The Global Combat Support System-Army (GCSS-Army) and the Logistics Modernization Program (LMP) use the SAP enterprise resource planning password system, which may not be sufficient for their security needs.

Recommendation 6-3. Army Enterprise Systems Integration Program leadership should implement further redundancy, data backup, and security measures for the Global Combat Support System-Army and the Logistics Modernization Program.

Finding 6-5. Data integrity is absolutely vital to the success of the Global Combat Support System-Army and the Logistics Modernization Program and for the development of future decision aids. It was not clear from information provided to the committee if the system developers have paid sufficient attention to data integrity.

Finding 6-6. In a Joint environment, the necessity for interoperability among service enterprise resource planning (ERP) systems will become more pressing. It also may be necessary to similarly connect U.S. ERP systems with allied military ERP systems for coalition operations, although this may raise new security issues.

Recommendation 6-4. The Army should continue its efforts to have Global Combat Support System - Army interact with sister Service enterprise resource planning systems. This capability should also include the Logistics Modernization Program. The Army should work on achieving similar, secure interoperability with allied enterprise resource planning systems via federation for coalition operations.

Finding 6-7. Differences of opinion between the public and private sector continue to exist on how far the in-transit visibility system should extend.

Recommendation 6-5. The U.S. Army, in coordination with commercial supply chain companies, should look at the cost /benefits and advantages/disadvantages of extending the in-transit visibility system to the end user/soldier.

Finding 6-8. The Army continues to encounter challenges, posed by the operational shortcomings described above, with use of radio frequency identification technologies, and these challenges are affecting in-transit visibility.

Recommendation 6-6. The Army should develop robust, reliable radio frequency identification tags that address operational shortcomings experienced with current tags.

Finding 6-9. Technology demonstrated recently will allow for better visibility of in-theater fuel supply.

Recommendation 6-7. The Army should continue to develop and field technologies that improve visibility for in-theater fuel supply levels.

Making Better Logistics Decisions

Finding 6-10. The application of advanced analytics, systems analysis, and emerging information technologies (e.g., enterprise resource planning systems) provides a powerful opportunity to create effective enterprise decision support systems.

Recommendation 6-8. The Army should strongly support the application of advanced logistics analytics to develop enterprise decision support systems in conjunction with emerging information technologies, sensor-based technologies, and supply chain simulation technologies.

Finding 6-11. The Army currently has no processes, plans, procedures, funding, people or other resources aimed at encouraging the logistics community to develop and propagate apps and higher level tools using data from the Global Combat Support System -Army, the Logistics Modernization Program, or other data systems to improve the decision process.

Recommendation 6-9. The Army should take advantage of contributors at all levels to develop and distribute apps and other tools to fully realize the potential of the Global Combat Support System-Army. A concept similar to those used in commercial app stores should be implemented to distribute such tools and provide ratings for them.

Finding 6-12. The Army lacks a comprehensive strategy and implementation plan incorporating effective decision support analytical tools (i.e., operations research) along with the appropriate IT required to enable and provide the decision support needed to achieve cost-effective, performance-oriented results. In this era of dramatic resource constraints, the Army logistics community must better harness and apply operations research and strategic analytics across the materiel enterprise.

Recommendation 6-10. To obtain the full decision support potential of the integrated logistics enterprise, the Army should ensure that enterprise resource planning system data transactions and management information systems are complemented by the operations research capabilities needed to conduct modern analytics. The goal should be effective integration of analytics into organizational decision making.

Recommendation 6-11. The Army should develop an engine for innovation for the logistics community and adopt, apply, and refine management innovation as a strategic technology (see Appendix F).

Finding 6-13. Inadequate attention has been focused on the long-standing need to correct numerous problems in supply chain management, including persistent deficiencies in demand forecasting, inventory policy, and strategic resource planning.

Finding 6-14. Unlike pre-Milestone C technology readiness levels for major acquisition programs, there are no Joint and/or Army requirements for post-Milestone C sustainability assessments.

Recommendation 6-12. The Army should adopt critical supply chain management policies—catalysts for innovation—and apply a sustainment readiness level (SRL) maturity model concept to both currently fielded systems and new systems in development. The Army should further extend the SRL concept, particularly mission-based forecasting, beyond Class IX to other classes of supply as well, especially III and V.

Finding 6-15. When systems are being developed, the results of logistics analyses are not quantified in terms of warfighting effects. As a result, logistics systems and logistics requirements do not fare well when competing with other types of systems or subsystems.

Recommendation 6-13. The Army should develop and implement methodologies to quantify the warfighting effects of logistics in analyses.

Finding 6-16. Because logistics decisions are complex, are often mostly subjective, and often have great impacts on life-cycle cost, an investment in logistic decision support systems could result in significant savings over a system's life cycle.

Finding 6-17. Modeling and simulation resources (personnel and tools) are insufficient at Training and Doctrine Command Analysis Center-Fort Lee to evaluate, compare, and contrast various science and technology initiatives and their respective impacts on both the force structure alternatives currently under consideration and operational outcomes across the spectrum of operations.

Finding 6-18. Institutional enterprise-wide modeling, simulation, and analytical capacity for conducting strategic logistics is fragmented and is inadequate to provide the cause-and-effect understanding essential for designing the force of the future.

Recommendation 6-14. The Army should revitalize its logistics analysis capability by acquiring the necessary tools and qualified people in quantities commensurate with the number and impact of logistics decisions that need to be made.

Recommendation 6-15. The Army should educate its leadership about what is possible in logistics analysis, and about the importance of demanding analyses of alternatives using common metrics.

Finding 6-19. The Army's ability to perform logistics studies and analyses has eroded over the last 25 years to the point where there is inadequate organic capacity left to conduct the rigorous analyses required to responsively support fact-based decision-making. An analytical renaissance is desperately needed, long overdue, and a precondition for achieving the significant improvement that is not only possible but also can be realized within a relatively short time frame (a few years rather than decades).

Recommendation 6-16. The Army should make an appropriate investment in organizing the Army analytical community to better support the materiel enterprise. Such an investment is a precondition for sustainment excellence.

Recommendation 6-17. In addition to rebuilding analytical capacity within the materiel enterprise, the committee strongly suggests a more comprehensive assessment of the state of operations research across the entire Army using an evaluation construct that includes analytical capacity, capability, utilization, organization, and contribution.

Chapter 7—Use of Contractors and the Army Reserve

Integrating Contractors into Planning and Operations

Finding 7-1. Contractors are frequently seen by the combatant commands as outsiders who are brought into military planning only after critical decisions are made rather than beforehand, so they can be part of the planning process. Indeed, contractors are an important element of the logistics team and, given the reductions in active military force structure, must be considered as an essential component in the planning and execution of operations.

Recommendation 7-1. Both Army and combatant command leaders should formulate plans and operations to integrate contractors into these operations from the beginning.

Finding 7-2. Contractors have indicated to the committee that they are prepared to be active participants in planning military operations and that they possess not only knowledge of the functions they may be called on to carry out but also ground experience in the potential areas of operations. At present they are excluded from participation in contingency planning until contracted to do so.

Recommendation 7-2. Planners in both the Services and the combatant commands should be schooled in the capabilities of contractor organizations to assist in contingency planning. The contracting organizations should provide for the continuous participation of contractors in the military planning process. This may require establishing on-going contracts for support of specific combatant commands or regions within the combatant commands.

Finding 7-3. Standards for support of military operations by contractors are frequently formulated on the fly, as operations evolve. This results in inconsistencies in the provision of services and a lack of attention to both potential support costs and the logistical burdens that are created.

Recommendation 7-3. Combatant commanders, in coordination with the Services and the Joint staff as part of contingency planning, should establish a uniform level of support to be provided over time for each contingency operation.

The Army Reserve

Finding 7-4. The Army Reserve is an indispensable element in the conduct of Army sustainment operations, but their employment must be carefully orchestrated to ensure that their capabilities are put to use in a timely and efficient manner. Army Reserve planners can provide accurate information on the response times for units being considered for employment in expeditionary operations. The opportunity to involve Army Reserve expertise in the planning process for contingency operations is often not exercised.

Recommendation 7-4. Combatant commands and theater Army components should include Army Reserve elements in their planning for contingency operations, especially when elements of the operation may require the use of specialties present only in the Reserve element.

Chapter 8—Optimizing the Logistics Effort

Logistics Support of Special Operations Forces

Finding 8-1. There are opportunities to more tightly integrate Army and special forces logistics. For instance, it may be practical and desirable to designate each theater Army as the primary logistics and sustainment support organization for special operations forces in each geographic combatant command's area of responsibility.

Recommendation 8-1. The Army G-4, working in conjunction with the individual geographic combatant commands and special operations command (SOCOM), should determine the feasibility and acceptability of designating each theater Army as the primary logistics and sustainment support organization for special operations forces in each geographic combatant command's area of responsibility. A good test case for such an arrangement would be to examine the recent redeployment of special operations forces to Iraq to assess the feasibility of the concept and obtain valuable lessons learned in the process. Doing so would enable all parties (e.g., the Army, SOCOM, and Central Command) to build on previous efforts and experiences gained in Operation Iraqi Freedom.

Giving Logistics Its Due

Finding 8-2. Logistic activities within the Army do not receive the attention necessary to ensure the effective sustainment of operational forces on the battlefield over the long term. Currently there is no management tool that allows the G-4 to track the resources allocated to logistics across the program evaluation groups. A logistics-centric look at those programs that reduce the logistics burden and make the logistics system more efficient—across the science and technology, research and development, procurement, operations and maintenance, and procurement phases—would provide the G-4 the information to track all the resources being applied to making logistics more effective and efficient.

Recommendation 8-2. Army leadership should develop a logistics-centric resource management system or program that will allow senior Army leadership to ensure that adequate resources and priorities are given to logistics activities across the spectrum of Army activities, to include research and development, analytical and decision support, force structure, and operational planning.

Finding 8-3. Army personnel not directly engaged in logistics need better training and education about their roles in facilitating logistics support and driving logistics demand. There also needs to be better education of both Army and special operations forces (SOF) personnel about the Army's role in supporting SOF and improving coordination in this regard. Including logistics activities in training and exercises and war games would be useful in this regard.

Recommendation 8-3. The commander of Training and Doctrine Command should undertake a review of the logistics content of Professional Military Education across all levels to determine where insertion of logistics education would be appropriate. Specific attention should be paid to courses that include individuals likely to be responsible for in-theater contracting activities and support for special operations forces (SOF). Precommand courses should cover how Army Special Forces are employed and how their Service-common and SOF-unique needs are appropriately supported. Consideration should also be given to the inclusion of logistics activities in war games and at the National Training Center.

Recommendation 8-4. If an agreement is reached for the Army to provide primary logistics support to special operations forces (SOF), the Training and Doctrine Command (TRADOC) should join with the Special Operations Command-Joint Capabilities organization within the Special Operations Command (SOCOM) and the Joint Special Operations University to create two sets of courses, a TRADOC set and a SOCOM set. The TRADOC courses should enable Army personnel to understand the proper employment of SOF in general and their associated support. Conversely, the SOCOM courses should familiarize SOF personnel with the logistics and sustainment support organizations and associated capabilities that the Army can provide to them when they have been assigned to a Theater Special Operations Command. Establishing a program to teach SOF commanders about the Army supply system and processes and how to effectively integrate themselves into the Army logistics network while they are deployed in a Joint area of operations, may also be necessary.

Taking Advantage of Technology Innovation

Finding 8-4. Joint, interagency, intergovernmental, multinational, nongovernmental, and commercial activities remained heavily involved in material development and technology innovation in areas directly relevant to logistics operations and sustainment goals. Continuous monitoring of the efforts of entities outside the Army and collaborations with them offer opportunities for reducing military expenditures for needed technologies and for the early acquisition of systems that have been proven in the private sector. The Army should avoid duplication of efforts under way in other sectors wherever possible.

Recommendation 8-5. In carrying out its material development programs, the Army S&T community should continue and increase, where appropriate, close collaboration with Joint, interagency, intergovernmental, multinational, nongovernmental, and commercial organizations in S&T areas where these organizations are pursuing program similar to those required by the Army.

Chapter 9—Logistics-Centric Science and Technology and Research and Development Investment Strategy

Setting an Azimuth

Finding 9-1. There is no explicit Army investment strategy to guide efforts that would reduce the logistics burden of the Army in the field and that would guide nonlogistics efforts that greatly affect the logistics burden of the Army in the field. Without such a strategy, the Army G-4 and the Army sustainment community are unable to effectively influence critical decisions in science and technology and research and development.

Finding 9-2. There is no explicit effort by the Army logistics community to closely monitor the science and technology (S&T) and research and development (R&D) activities across other Department of Defense components, or to capitalize on the S&T and R&D successes in those organizations and to integrate any new capabilities into considerations of possible future joint logistics environment.

Recommendation 9-1. The Army, through the G-4 and with the support of the Combined Arms Support Command, should develop, staff, publish, and annually update an Army strategy for science and technology and research and development that clearly defines the long-range objectives for Army logistics, the programs that will influence the attainment of these objectives, and the actions that will be taken to ensure the close integration of Army logistics enhancement activities with those of the Joint and DoD-wide community.

Finding 9-3. Establishing specific, quantitative objectives is an effective tool in any successful science and technology and research and development strategy. This needs to be followed by a roadmap of actions and required resources, responsibilities, and time lines.

Recommendation 9-2. A strategy for Army logistics science and technology and research and development should include specific objectives for the reduction of the logistics burden. It should also include a roadmap laying out the responsibilities and actions the overall research and development community needs to take to ensure that the strategy objectives are accomplished.

Taking Advantage of Industry Work

Finding 9-4. The Army would benefit from monitoring and leveraging industry work on technologies and systems that would reduce logistics burdens.

Recommendation 9-3. When developing the science and technology and research and development strategy and the related roadmap, the Army should identify and include areas for potential industry-military partnership, whereby progress by one party will accelerate progress by the other.

Implementing Logistics Science and Technology and Research And Development

Finding 9-5. Many logistics-related science and technology and research and development programs seem to be stuck in continual development without proceeding to the field. Faced with diminishing resources and the need to field equipment to meet current and future demands, waiting until the perfect solution is discovered is no longer a feasible approach.

Recommendation 9-4. The Army should work to rapidly identify the logistics-related science and technology and research and development programs that best support current and projected needs and adequately fund them to ensure fielding sooner rather than later. Where major breakthroughs could occur in the future, low-level science and technology work should also continue.

REFERENCE

NRC (National Research Council). 1999. Reducing the Logistics Burden for the Army After Next: Doing More with Less. Washington, D.C.: National Academy Press.

Appendixes

A

Committee Activities

FIRST COMMITTEE MEETING
NOVEMBER 12-14, 2013
ARLINGTON, VIRGINIA

Objective: Engage in dialogue with sponsor; obtain sponsor perspective on study and statement of task; initiate data gathering; conduct initial study administrative actions, conduct composition and balance discussion; review report writing process and project plan; discuss future data gathering needs and plans; and set future meeting dates.

Briefings

- *Supply.* Ms. Cathy Reese, Chief, Supply Division, U.S. Army G-44S, Supply Directorate
- *Force Protection and Distribution.* Mr. Jason Trubenbach, Transportation Planning Specialist, U.S. Army G-44D, Force Protection and Distribution
- *Maintenance.* COL Steven Pace, Deputy Director, Maintenance, U.S. Army, G-44M, Maintenance Directorate
- *Logistics Automation.* Mr. George Brewer, Logistics Automation Analyst, U.S. Army G-46, Logistics CIO
- *Operations and Readiness.* Mr. Randy Lewis, Chief, Contingency Operations, U.S. Army G-43, Operations and Readiness
- *Strategy and Integration.* Mr. Desmond Keyes, Deputy Director, Operational Energy/ Contingency Basing; COL Charles Cobbs III, Chief, Force Integration Division, U.S. Army G-45/7, Strategy and Integration; and Mr. Clay Hurt, PACOM Planner, U.S. Army G-45/7, Strategy and Integration
- *Logistics Innovation Agency.* Mr. Sam Cooper, Research Analyst, Logistics Innovation Agency
- *Defense Logistics Agency.* Mr. Edward J. Case, Vice Director, Defense Logistics Agency
- *Combined Arms Support Command.* COL Bruce McPeak, Director, Materiel Systems Directorate (MSD); Mr. Steve Bourgeois, Deputy Director, Sustainment Battle Lab (SBL); Mr. Mike Kriz, Operational Energy, MSD; and Mr. Larry Perecko, Branch Chief, Science and Technology, SBL

SECOND COMMITTEE MEETING
JANUARY 16-17, 2014
WASHINGTON, D.C.

Objective: Conduct composition and bias discussion for remaining members not covered by November discussion; continue data gathering; engage in report discussion and planning; discuss future data gathering needs and plans.

Briefings

- *RFID Tagging.* Mr. Reginald Madden, Operations Team Chief, Product Director Automated Movement and Identification Solutions; Mr. Fred Naigle, Automated Information for Movements SME and Product Director Automated Movement and Identification Solutions; Mr. Charles McCracken, Operations–Infrastructure, Product Director Automated Movement and Identification Solutions; and Mr. Robert Carpenter, Senior Logistics Analyst, Product Director Automated Movement and Identification Solutions, all from Army Enterprise Systems Integration Program
- *GCSS-Army, the Logistics Modernization Program, and the Army Enterprise Systems Integration Program Hub.* Dr. Daniel C. Parker, Product Director AESIP Hub, Army Enterprise Systems Integration Program
- *DoD Operational Energy Plans and Programs.* Ms. Sharon Burke, Assistant Secretary of Defense for Operational Energy Plans and Programs Department of Defense
- *TRANSCOM Future Transportation Strategy.* Mr. Kenneth D. Watson, Deputy Director, Strategy, Policy, and Logistics, U.S. Transportation Command
- *Joint Logistics.* Mr. Chris Christianson, LTG (ret.), Director, Center for Joint and Strategic Logistics, National Defense University
- *Marine Corps Logistics.* COL Chris A. Arantz, Branch Head, Logistics Vision and Strategy Branch, Headquarters, United States Marine Corps; and Mr. Nick Linkowitz, Logistics Vision and Strategy Branch, Headquarters, United States Marine Corps
- *Supply Chain Transformation.* Dr. Greg H. Parlier, Committee Member
- *Logistics R&D and Long Term R&D Strategy.* Ms. Mary Miller, Deputy Assistant Secretary for Research and Technology, Assistant Secretary of the Army for Acquisition, Logistics, and Technology
- *Rapid Equipping Force Expeditionary Laboratory.* Mr. Lee D. Gazzano, Futures Division, Rapid Equipping Force; and Ms. Paige Rasmussen, Futures Division, Rapid Equipping Force

THIRD COMMITTEE MEETING
FEBRUARY 4-6, 2014
ABERDEEN PROVING GROUND, MARYLAND; FORT LEE, VIRGINIA; FORT BELVOIR, VIRGINIA; AND WASHINGTON, D.C.

Objective: Continue data gathering, conduct committee deliberations, discuss report, discuss path ahead, and make any necessary work assignments.

On February 4-5, one team of the committee met at the Army Research, Development and Engineering Command (RDECOM) headquarters at Aberdeen Proving Ground, Maryland. They received the following briefings:

- *U.S. Army Research, Development and Engineering Command (RDECOM) Overview and Opening Discussion.* Mr. Jyuji D. Hewitt, Deputy Director, RDECOM; and Mr. John M. Miller, Special Assistant to the Director, RDECOM
- *Ammunition Logistics—Precision Guided Munitions; Shared Services Umbrella; Lifecycle Maintenance of the Logistics Modernization Program.* Mr. Alan J. Galonski, Chief, Future Concepts Division, U.S. Army Armament Research, Development and Engineering Center (ARDEC)
- *Condition-Based Maintenance.* Mr. Steven E. Parker, U.S. Army Aviation and Missile Research Development and Engineering Center (AMRDEC); Mr. Johnny L. Prater, AMRDEC; Mr. Herman W. Robertson, AMRDEC; Mr. James J. Kelly, U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC); Mr. Edward J. Plichta, U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC); Mr. Joshua J. Fischer, Space and Terrestrial Communications Directorate, CERDEC; and Mr. Robert G. Cole, CERDEC
- *Fuel Efficiency.* Mr. James J. Kelly, TARDEC; Mr. Steven E. Parker, AMRDEC; Mr. Johnny L. Prater, AMRDEC; and Mr. Herman W. Robertson, AMRDEC
- *Logistics Automation—Automated Material Handling; Advanced Weapon Resupply and Management.* Mr. Alan J. Galonski, Chief, Future Concepts Division, ARDEC; and Mr. Joshua J. Fischer, Space and Terrestrial Communications Directorate, CERDEC
- *Water Acquisition—Sustainability/Logistics Basing; Waste/Blackwater Reuse.* Mr. Richard J. Benney, U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC); and Mr. R.D. Carney, NSRDEC
- *TARDEC Water Purification Technologies.* Mr. James J. Kelly, TARDEC
- *Water from Air.* Mr. Richard J. Benney, NSRDEC; and Mr. R.D. Carney, NSRDEC
- *Networking.* Mr. Gary M. Lichvar, U.S. Army Communications-Electronics Command (CECOM)
- *Operational Energy—Advanced Woven PV, Equipment and Energy Technologies.* Mr. Richard J. Benney, NSRDEC; Mr. R.D. Carney, NSRDEC; and Mr. Edward J. Plichta, CERDEC
- *Autonomous Vehicle Arena.* Mr. Thomson David, TARDEC
- *AMRDEC Hunter/Killer.* Mr. Steven E. Parker, AMRDEC; Mr. Johnny L. Prater, AMRDEC; and Mr. Herman W. Robertson, AMRDEC
- *Networks for Autonomous Vehicle.* Mr. Edward J. Plichta, CERDEC; Mr. Joshua J. Fischer, Space and Terrestrial Communications Directorate, CERDEC; and Mr. Robert G. Cole, CERDEC
- *3D Printing.* Mr. Rick Moore, U.S. Army Edgewood Chemical Biological Center
- *Other R&D Efforts to Reduce the Logistical Burden—Precision Air Drop.* Mr. Richard J. Benney, NSRDEC; and Mr. R.D. Carney, NSRDEC
- *Joint Combat Feeding.* Mr. Richard J. Benney, NSRDEC; and Mr. R.D. Carney, NSRDEC

- *RF Convergence.* Mr. Edward J. Plichta, CERDEC; Mr. Joshua J. Fischer, Space and Terrestrial Communications Directorate, CERDEC; and Mr. Robert G. Cole, CERDEC
- *U.S. Army Materiel Systems Analysis Activity.* Mr. Clarke J. Fox, Chief, Logistics Analysis Division, U.S. Army Materiel Systems Analysis Activity
- *U.S. Army Public Health Command.* LTC Gayle E. McCowin, Portfolio Director, Environmental Health Engineering, U.S. Army Public Health Command—Institute of Public Health
- *U.S. Army Corps of Engineers Engineer Research and Development Center.* Dr. David A. Horner, Technical Director for Military Engineering, U.S. Army Engineer Research and Development Center

Also on February 4-5, a second team met at Fort Lee, Virginia, and received briefings and engaged in discussions with the following individuals and organizations:

- *TRAC-LEE Command Brief*. Dr. Gordon J. Goodwin, Director, TRADOC Analysis Center-Fort Lee (TRAC-Lee)
- *Logistics Battle Command (LBC) Model Brief.* Mr. Morris Hayes, Chief, Modeling and Analysis Division, TRAC-Lee
- *Dynamic Maintenance (DM) Model Brief.* Mr. Morris Akers, Modeling and Analysis Division, TRAC-Lee
- *Operational Energy (OE) Analysis Task Force Brief and OE Models—Current and Future.* Mr. Morris Hayes, Chief, Modeling and Analysis Division, TRAC-Lee
- *Decision Point (DP) 15 Modeling and Analysis*. Mr. Phil Raiford, Modeling and Analysis Division, TRAC-Lee
- *Discussion with US Army Logistics University Students.* Various participants
- *Meetings with U.S. Army Combined Arms Support Command on Logistics Game, Futures Center, and Sustainment Battle Laboratory.* Various participants

On February 5, the Fort Lee team also visited Fort Belvoir, Virginia, and spoke with the following individuals:

- *Meeting at Center for Army Analysis.* Dr. William F. Crain, Director, Center for Army Analysis; COL Brian K. Sperling, Chief of Staff, Center for Army Analysis; Dr. Steven A. Stoddard Center for Army Analysis; COL Mark W. Lukens, Deputy Director, U.S. Army Materiel Systems Analysis Activity

On February 6, the whole committee met in Washington, D.C., to conduct deliberations.

FOURTH COMMITTEE MEETING
MARCH 4-6, 2013
IRVINE, CALIFORNIA

Objective: Continue data gathering, conduct committee deliberations, conduct report drafting work, plot path forward, plan for final meeting.

The committee engaged in discussions with the following individuals and organizations:

- *U.S. Army Pacific Command*. COL Skip Adams, U.S. Army Pacific Command (USARPAC) G4, PEPM Division Chief; Mr. Charles Willoughby, USARPAC G4 Material Readiness Branch; Mr. Doug Tostrud, USARPAC G4 Plans; CW4 James Moore, USARPAC G4 Mobility; CW4 Tamara Degrafenread, USARPAC G4 AVN Maintenance; and Mr. Jim Muldoon, USARPAC Science and Technology Advisor
- *Defense Logistics Agency Views on Future Logistics.* RADM MacLaren, Director, Joint Reserve Force and Joint Contingency Acquisition Support Office, Defense Logistics Agency
- *Report Back on Meetings with the United States Army Tank Automotive Research, Development and Engineering Center.* Steve Dellenback, Committee Member

FIFTH COMMITTEE MEETING
MAY 5-7, 2014
WASHINGTON, D.C.

Objective: Receive briefing from Army Material Command (AMC); conduct committee deliberations; Conduct report writing; plan path forward to concurrence.

- *AMC Virtual Contracting*. Mr. Mark Morrison, AMC
- *AMC Virtual Integrated Materiel Management Center.* Ms. Lisha Adams, AMC
- *AMC Virtual Labs.* Mr. Mark Morrison, AMC

INDIVIDUALS CONTACTED BY COMMMITTEE MEMBERS

Ilker Adiguzel, Director, Construction Engineering Research Laboratory, U.S. Army Engineer Research and Development Center
Jon Alt, LTC, USA, Naval Postgraduate School
Jeff Appleget, Naval Postgraduate School
Aruna Apte, Naval Postgraduate School
Darrell J. Bennis, COL, USA, PEO EIS Military Deputy
Jay Carr, U.S. Army Sustainment Command
Dan Coban, MAJ, USA, Student, North Carolina State University, about actual logistics experience in Afghanistan
Gregory Couch, MG (Ret.), USA, former USTRANSCOM Chief of Staff
Robert Dell, Naval Postgraduate School
James Eagle, Naval Postgraduate School
Glenn Edelschein, SAS Federal
Lee Ewing, Naval Postgraduate School
William M. Faulkner, LTG, USMC, Deputy Commandant Installations and Logistics
Kristin K. French, BG, USA, Commanding General, Joint Munitions and Lethality Life Cycle Management Command and Joint Munitions Command
Nancy J. Grandy, COL, USA, Assistant Commandant, U.S. Army Transportation School
Chris J. Grassano, Deputy PEO Ammunition (Acting)
James Grazioplene, MG (Ret.), USA, Vice President Contingency Operations. DynCorp International LLC

Ola Harrysson, North Carolina State University
Lynn Hinman, Headquarters, Quantum Research International
Casey Hodgson, Coca Cola
Jeff Holland, Director, U.S. Army Engineer Research and Development Center
Jeffrey House, LTC, USA, Naval Postgraduate School
Wayne Hughes, Naval Postgraduate School
Harry H. Hungerford, COL, USA, J-4, U.S. Special Operations Command, Central
Jeff Hyink, CAPT, USN, Naval Postgraduate School
Paul Kern, GEN (Ret.), USA, former Commanding General, United States Army Material Command
Russell King, North Carolina State University
Jeffrey Kline, Naval Postgraduate School
Moshe Kress, Naval Postgraduate School
Stephen Krivitsky, U.S. Army Maneuver Center of Excellence
William D. Lewis, CW5, USA, Headquarters, Department of the Army, Deputy Chief of Staff G-4 (Ammunition)
Brandon McConnell, CAPT, USN, Student, North Carolina State University, about actual logistics experience in Afghanistan
John J. McGuiness BG (Ret.), USA, former PEO Ammunition
Connor McLemore, LCDR, USN, Naval Postgraduate School
Patricia E. McQuistion, LTG, USA, Deputy Commanding General , U.S. Army Materiel Command
Vikram Mittal, of Draper Labs
James Moore, COL, USA, Commander, 404th Army Field Support Brigade
Daniel Nussbaum, Naval Postgraduate School
Noel J. Paschal, U.S. Army Space and Missile Defense Command/Army Forces Strategic Command
Steven Pilnick, Naval Postgraduate School
Robert Prieto, Senior Vice President, Fluor Corporation
Matt Rogers, LTC, USA Student, North Carolina State University, about actual logistics experience in Afghanistan
David Schrady, Naval Postgraduate School
Chad Seagren, MAJ, USMC, Naval Postgraduate School
Stephen G. Sherbondy, COL, USA, Army Reserve G-4, U.S. Army Reserve Command
James Shields, PEO Ammunition
James Phil Shubert, Headquarters, Department of the Army, Deputy Chief of Staff G-3-5-7
David Simchi-Levi, Massachusetts Institute of Technology
Ryan Slocum, MAJ, USA, Student, North Carolina State University, about actual logistics experience in Afghanistan
Mitchell Stevenson, LTG (Ret.), USA, Liedos Inc.
Jeffrey Talley, LTG, USA, Chief, Army Reserve
Bradford Tousley, Director, Defense Advanced Research Projects Agency Tactical Technology Office
Tracy D Underkoffler, CW5, USA, U.S. Army Sustainment Center of Excellence (Watercraft)
Alan Washburn, Naval Postgraduate School
John F. Wharton, MG, USA, Commanding General of the United States Army Sustainment Command (ASC) and Commanding General, Rock Island Arsenal
Jerry W. Wheeler, Advanced Turbine Engine Company, LLC
Donald Whelan, BG (Ret.), USA, Former Director, Cypress International, Inc
Thomas R. Willemain, Rensselaer Polytechnic Institute
Richard Zilmer, LTG (Ret.), USMC, former Commanding General, Multinational Forces -West (Anbar Province, Iraq) and Commanding General, III Marine Expeditionary Force, Okinawa, Japan

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Biographical Sketches of Committee Members

GERALD E. GALLOWAY, JR., *Chair*, is a Glenn L. Martin Institute Professor of Engineering, Department of Civil and Environmental Engineering, and an affiliate professor, School of Public Policy, University of Maryland, College Park, where his focus is on water resources policy and management. He joined the faculty of the University of Maryland following a 38-year career in the U.S. Army, retiring as a brigadier general, having served 8 additional years in the civil government service and 3 years in industry. Professor Galloway is the former dean of the faculty and academic programs at the Industrial College of the Armed Forces, and former dean of the academic board, United States Military Academy at West Point where he was also a professor of geography and the first head of the Department of Geography and Environmental Engineering. He served for 3 years as district engineer for the U.S. Army Corps of Engineers in Vicksburg, Mississippi, and later, for 7 years as a presidential appointee to the Mississippi River Commission. In 1993 and 1994 he was assigned to the White House to lead an interagency study of the causes of the Great Mississippi River Flood of 1993 and to make recommendations concerning the nation's floodplain management program. Dr. Galloway was elected to the National Academy of Engineering (NAE) in 2004 for distinguished leadership in the management of sustainable water. He has been a member of 11 National Research Council (NRC) committees studying complex engineering and policy issues, including disaster resilience, U.S. ocean research science and technology priorities, river science activities of the U.S. Geological Survey, and Federal Emergency Managemnt Agency Flood Maps. He was chair of an NRC committee studying logistics support for the future U.S. Army and the national Flood Insurance Program. He has also been a member of the NRC's Water Science and Technology Board and is currently a member of its Disasters Roundtable. He holds a master's degree in engineering from Princeton University, a master's in public administration from Penn State (Capitol Campus), a master's in military art and science from the U.S. Army Command and General Staff College, and a Ph.D. in geography (water resources) from the University of North Carolina, Chapel Hill.

GERALD G. BROWN is a Distinguished Professor of Operations Research and executive director of the Center for Infrastructure Defense at the Naval Postgraduate School, where he has taught and conducted research in optimization and optimization-based decision support since 1973, earning awards for both outstanding teaching and research. His military research has been applied by every uniformed service, in areas ranging from strategic nuclear targeting to capital planning. He has been awarded the Barchi, Rist, and Thomas prizes for military operations research, and been credited with guiding investments of more than a trillion dollars. He has designed and implemented decision support software used by the majority of the Fortune 50, in areas ranging from vehicle routing to supply chain optimization. His research appears in scores of open-literature publications and classified reports, some of which are seminal references. Dr. Brown is a member of the NAE, a recipient of the U.S. Navy Distinguished Civilian Service Medal, an INFORMS Fellow, and a founding director of Insight, Incorporated, the leading provider of strategic supply chain optimization tools to the private sector. He recently served on NRC Board on Mathematical Sciences and Their Applications. Dr. Brown earned his Ph.D. in mathematical methods at the University of California, Los Angeles.

CHARLES R. CUSHING is president and founder of C.R. Cushing & Company, a firm of naval architects, marine engineers, and transportation consultants. His expertise includes ship design and ship building, port and terminal projects, material handling studies, marine operation and maintenance studies, automation studies, and planned maintenance and repair systems. Dr. Cushing has been responsible for the design of numerous types of intermodal shipping containers and the purchase, inspection, and testing of containers, container refrigeration equipment, container chassis, and container handling equipment. He authored the *United States Coast Guard Tankerman's Manual*. Dr. Cushing served as chief naval architect at Sea-Land Service, Inc. for 7 years. His accomplishments in this role include the design and conversion of 45 container ships and the development of cranes and cargo handling systems. He holds a number of patents in maritime and intermodal technology. In his current role, he has designed and/or supervised the construction of more than 250 ships. Prior to his graduation from the Massachusetts Institute of Technology (MIT), Dr. Cushing sailed as a cadet and a licensed deck officer on a number of U.S.-flagged general cargo and passenger vessels. He has been involved in cargo handling operations in the United States, South American, Southeast Asia, Australia, New Zealand, the Far East, the Middle East, Africa, and Europe. He also served in the U.S. Naval Reserve for 30 years. Dr. Cushing earned a B.S. in marine transportation from the U.S. Merchant Marine Academy and a B.S. in naval architecture and marine engineering from MIT. He earned an M.S. in ocean transportation from the State University of New York and a Ph.D. in maritime studies from the University of Wales, Cardiff University. Dr. Cushing was elected to the NAE in 2004.

STEVEN W. DELLENBACK is the executive director of research and development of the Intelligent System Department at Southwest Research Institute (SwRI), which performs research and revelopment (R&D) projects in the following domains: automated vehicles, cooperative vehicle systems, active safety systems, transportation systems, cybersecurity data analytics, flight software and decision support systems. The department performed in excess of $15 million of R&D projects each year; the staff exceeds 70 staff members with a majority of the staff holding advanced degrees in computer science, mechanical engineering, or electrical engineering. The department he manages has three times been independently assessed (and currently maintains) as a maturity level 5 organization consistent with the Software Engineering Institute (SEI) Capability Maturity Model Integration® (CMMI®) Version 1.2a DEV. In 2005 Dr. Dellenback led the SwRI efforts to initiate an automated vehicle program, SwRI demonstrated a fully autonomous vehicle that included cooperative vehicle technology at the ITS World Congress on the streets of New York City in November 2008. SwRI has since performed over $40M of R&D for a number of commercial companies (U.S., Japan and Europe) and defense organizations including the U.S. Army, Marines, and Navy. Under his leadership SwRI has developed eight different fully automated vehicle platforms ranging from small off-road all-terrain vehicles to multiple military vehicles to a Class 8 truck. These platforms are capable of operating in on-road environments but SwRI has distinguished itself in the industry by developing low-cost, off-road automated vehicle platforms for the U.S. Army and Marine Corps. Dr. Dellenback also served for four years providing insight into unmanned vehicle technology for the Wassenaar Arrangement for the Departments of State, Commerce and DoD in Vienna. Dr. Dellenback was elected to ITS America's board of directors in May 2012 and also serves as chairperson of the Coordinating Council. He is chairman of the National Transportation Communications for ITS Protocol (NTCIP) Test and Conformity Assessment Working Group and is a voting member on the NTCIP Joint Committee and the Traffic Management Data Dictionary (TMDD) Steering Committee. He has authored over 45 publications and has presented at numerous national and international conferences. Dr. Dellenback received his B.S. in computer science from the University of Texas at Austin; his M.S. and Ph.D. in computer science from the University of Kansas.

THOMAS M. DONNELLAN is the associate director for materials and manufacturing at the Applied Research Laboratory (ARL) at Penn State University. ARL is a Department of Defense (DoD) University Affiliated Research Center (UARC) for the DoD and as such is tasked with providing technology solutions for emergent DoD problems. One role of a UARC is to serve as a trusted agent for the government in the organization's core competency areas. Within the Materials and Manufacturing Office at ARL, Dr. Donnellan is responsible for technology development and demonstration programs, including a number of improved fuel efficiency technology development and demonstration projects for the Department of the Army (DoA) and the U.S. Marine Corps (USMC); advanced logistics architecture development and demonstration projects for DoA and USMC; condition-based maintenance development and demonstration projects for DoA and USMC; advanced manufacturing technology projects (e.g., the leading DoD laboratory for additive manufacturing with support from DoA, Department of the Navy [DoN], and the Defense Advanced Research Projects Agency [DARPA]; responsible for the Institute for Manufacturing and Sustainment Technologies, a DoN ManTech Center of Excellence; technology development projects for improved Systems Acquisition (e.g., DARPA Adaptive Vehicle Make, Office of the Secretary of Defense Engineered Resilient Systems); and maintenance technology development and implementation projects for reducing operations and maintenance costs for DoN and DoA. Dr. Donnellan has a 30-year career in advanced technology development and has worked at government laboratories, in industry, and in academia. Prior to joining ARL, he was the FBI's senior scientist for physical science, with responsibility for advising bureau management on the technology R&D portfolio for forensic and intelligence applications. From 1991 to 1999, Dr. Donnellan worked at the Northrop Grumman Corporation where he held a number of positions and eventually became the director of structural sciences. He started his career at the Naval Air Development Center where he performed and directed R&D in support of Navy needs and also provided technical support to DoN for a number of Navy acquisition programs. Dr. Donnellan currently serves on the Executive Steering Committee of the Composites Manufacturing Technology Center and on the governance board of the National Additive Manufacturing Innovation Institute. He is a graduate of Drexel University (B.S. in materials engineering) and has advanced degrees from MIT in polymerics (S.M.) and materials science (Sc.D.).

JULIA D. ERDLEY is an assistant to the director for educational programs at the Applied Research Laboratory (ARL) at the Pennsylvania State University. Ms. Erdley was a principal investigator (PI) for the Counter-Improvised Explosive Device (IED) Basic Research Program where she managed Penn State's Counter-IED research program, a 6.1 Office of Naval Research-funded portfolio of science and technology (S&T) projects to address the IED threat. She participated in counter-IED basic research in anomalous behavior detection and participated in counter-IED basic research in reconfigurable antennas for explosive detection. Ms. Erdley was also the PI for the Anti-Torpedo Torpedo Guidance and Control System where she provided oversight for systems engineering, hardware and software design, and signal and tactical algorithm development for Canisterized, Countermeasure Anti-Torpedo Torpedo Guidance and Control System. This effort required an understanding of entire torpedo functionality with specific knowledge of acoustic array design, receiver and transmitter analog hardware design, digital processing hardware design, signal and tactical algorithm design, and interface specification. She led a team of 30 scientists, engineers, and technicians in support of this effort. Ms. Erdley has been a member of the technical staff at the ARL at Penn State since 1990. From September 2010 through September 2011, Ms. Erdley served as the science advisor of the Joint IED Defeat Organization (JIEDDO), advising the director, LTG Michael Barbero, on matters relating to S&T. She also served from 2007 to 2010 as the deputy to the science advisor. JIEDDO is a $2.8 billion per year organization within DoD with a focus on the rapid acquisition of counter-IED capabilities in support of the wars in Iraq and Afghanistan. She was assigned to the organization from the Pennsylvania State University through the Intergovernmental Personnel Act Agreement program. During her 4 years with JIEDDO, Ms. Erdley supported S&T strategy development across a broad range of topics in the hard and soft sciences. She led three S&T programs examining sensor and information fusion for the counter-IED mission, served as a voice for JIEDDO to the external community, and led efforts to coordinate S&T for counter-IED across the DoD and inter-agency. Ms. Erdley received her B.S. and M.S. degrees in electrical engineering from Penn State.

RONALD P. FUCHS is an independent consultant on systems of systems and modeling & simulation (M&S). He is retired from The Boeing Company and from the U.S. Air Force. His most recent position was as vice president for modeling and simulation at The Boeing Company. There he led a group that is responsible for developing, maintaining, and coordinating Boeing's government and defense modeling and simulation efforts for approximately 2,500 people. His additional responsibilities for Boeing included identifying, prioritizing, and allocating funding to M&S technology needs; developing and operating the collaboration environment for Boeing's M&S community; developing Boeing's simulation based acquisition program; and managing Boeing's M&S technology development group. Prior to that, Dr. Fuchs was the director for system of systems architecture development at Boeing where he led a Phantom Works group that was responsible for defining and analyzing system of systems architectures with emphasis on command and control systems for communications, fire control, and logistics. His work resulted in Boeing's initial Future Combat System contract. Dr. Fuchs also served Boeing as director of virtual simulation technology, corporate director of strategic planning, and as chief program engineer while at Boeing. During his Air Force career, he served as chief analyst for Air Force studies and analyses, program manager for several major avionics upgrades on the F-16 fighter, assistant professor of astronautical engineering, director of the USAFA Guidance and Control Laboratory, and program manager for a number of space and space technology programs. Dr. Fuchs has been a member of the Board on Army Science and Technology, a member and Vice Chairman of the Air Force Scientific Advisory Board, and a member and officer of numerous professional and honorary organizations. Dr. Fuchs received a B.S. in aerospace engineering and an M.S. in control systems engineering from Virginia Polytechnic Institute and State University; and a Ph.D. in nonparametric statistics from the Air Force Institute of Technology.

CHARLES F. GAY is the founder and managing director of the Greenstar Foundation. He has more than 38 years of professional management, manufacturing and advanced technology experience in renewable energy and solar photovoltaic production and deployment. Specific areas of expertise include industrial manufacturing and technical marketing, photovoltaic research and production process development, product planning, supply chain logistics, and solar technology roadmapping. As creator of the Greenstar Foundation, Dr. Gay has worked continuously to apply solar technology to improve people's lives by delivering internet access and solar power to villages in developing countries. The Greenstar development model has received recognition from international awards programs as diverse as the World Bank, the Stockholm Challenge, the Davos Conference and The Tech Awards. Dr. Gay is a member of the NAE. He earned his B.S. and Ph.D. degrees in chemistry from the University of California, Riverside.

THOM J. HODGSON is a Distinguished University Professor in the Edward P. Fitts Industrial and Systems Engineering Department at North Carolina State University (NCSU). He is also the co-director of the Operations Research Program and has served as the director of the Integrated Manufacturing Systems Engineering Institute at NCSU. He possesses logistics and systems analysis expertise across the commercial and military regimes. Dr. Hodgson's research has focused on scheduling and logistics. The problem areas run the gamut from classic job shop scheduling, to specific industrial scheduling problems, to supply chain issues, to military logistics and operational problems. Many real problems are simply not amenable to classic approaches. His major concern is finding modeling and/or optimization approaches that are effective in real-world scenarios. Dr. Hodgson is a member of the of the NAE, the Institute of Industrial Engineers, and the Institute for Operations Research and the Management Sciences. He earned his B.S.E. in science engineering, his M.B.A. in quantitative methods, and his Ph.D. in industrial engineering, all from the University of Michigan.

LEON A. JOHNSON is currently working as an independent consultant. He retired from the U.S. Air Force with the rank of brigadier general after 33 years of service. During his Air Force career, General Johnson commanded a fighter squadron, fighter group, was the vice commander of 10th Air Force at the Joint Reserve Base in Ft. Worth, Texas, and served as mobilization assistant to the assistant secretary of the Air Force and director operations at Air Education and Training Command. As a command pilot, he had more than 3,500 hours of military flying time in the T-37 trainer, A-37, and A-10 fighter aircraft, including missions over Bosnia in support of Operation Deny Flight. Following the events of 9/11, the general served as a Director of the Air Force Crisis Action Team in the Pentagon. General Johnson retired from United Parcel Service (UPS) after nearly 20 years of service. During his time with UPS, he served as the flight operations employment manager, administrative chief pilot, Asia chief pilot, flight operations employee relations manager, and A300 training manager, and he concluded his career working on a special project as the manager of airline manuals. At UPS, he flew the B727 and the A300-600 aircraft. Prior to UPS, he worked for Trans World Airlines as a line pilot and pilot hiring manager, flying the B727 aircraft. At both airlines, he amassed more than 3,500 hours of flight time. In 2013, General Johnson concluded a 6-year appointed as a member of the NRC's Naval Studies Board. During that time, he participated on five research studies. In 2011, General Johnson was awarded a doctorate in humane letters by Tuskegee University, and he received an appointment by the Secretary of the Air Force to the Civil Air Patrol board of governors. In 2009, General Johnson was selected as a trustee of the U.S. Air Force Academy Falcon Foundation, where he was appointed to serve as a governing trustee in 2013. He is a member of several organizations, including the Air Force Association, Military Officers Association of America, Military Order of World Wars, Veterans of Foreign Wars, Reserve Officers Association, League of United Latin American Citizens, Women in Aviation, the International Black Aerospace Council, Inc., and Tuskegee Airmen, Incorporated. General Johnson was elected to his second 2-year term as the Tuskegee Airmen, Inc., national president in 2012.

GREG H. PARLIER is a defense analyst and management consultant at G.H. Parlier Consulting and a retired Army colonel. He began his 30-year career as a section leader in an airborne infantry battalion and retired as the senior, most experienced operations research/systems analyst on active duty in the Army. A graduate of West Point and career Air Defense Artillery officer, he was stationed overseas in the Far East, Europe, and Southwest Asia where units he led and served with performed missions and conducted training in more than 20 foreign countries. He has extensive experience in operations research, management science, and strategic planning. Earlier in his career he served on the faculty at West Point as an engineering management instructor, then assistant professor of operations research, and was later selected among the first associate professors in the newly created Department of Systems Engineering. A graduate of the Army War College and Marine Corps Command and Staff College, his civilian education includes graduate degrees in operations research (M.S., Naval Postgraduate School), systems engineering (Ph.D., Wesleyan), and national security studies (M.A., Walsh School of Foreign Service). He was a national defense fellow at MIT. Since retiring from the Army, he has been a university research scientist, systems analyst for a major aerospace defense firm, vice president for a new company specializing in engineering and analysis, and an independent consultant to the public and private sectors. He has continuously served on the research staff at the Institute for Defense Analyses where he has been an advisor to several foreign governments, and senior operations research analyst supporting U.S. Forces in Iraq. A member of several professional societies for which he has held appointed and elected leadership positions at the local, state, regional, national, and international levels, he is past president and awards committee chair for the Military Applications Society of the Institute for Operations Research and the Management Sciences. Dr. Parlier authored *Transforming U.S. Army Supply Chains: Strategies for Management Innovation* in 2011, which received the Koopman Prize as the best military operations research publication in 2012.

KAUSHIK RAJASHEKARA is a Distinguished Professor of Engineering at the University of Texas, Dallas. He has received numerous awards and honors, including for his work in electric power conversion systems in transportation, the advancement of power conversion technologies through innovations and their applications to industry, and for contributions to the advancement of power conversion and propulsion systems for electric, hybrid, and fuel cell vehicles, and for a solid oxide fuel cell based hybrid power generation system. Dr. Rajashekara has published more than 100 papers in international journals and conferences in areas such as renewable energy, energy conversion, electric, hybrid, and fuel cell vehicles, and distributed power generation systems. He has 30 patents, and several more are pending. He has written six monographs and co-authored one IEEE Press book and contributed individual chapters to five published books. Dr. Rajashekara is a member of the of the NAE. His research interests include the following: power electronics systems and electric drives for propulsion, energy management, and efficiency improvements in transportation, particularly for electric, hybrid (including plug-in hybrid) and fuel cell vehicle systems; power conversion and intelligent energy management for renewable electric energy delivery for an efficient electric power grid (micro grid/local) integrating highly distributed and scalable alternative power sources such as solar, wind, fuel cell, etc.; hybrid power generation systems for transportation and stationary power generation: fuel cell, solar and wind; solar and fuel cell; solid oxide fuel cell and turbine generator; vector control of electric motors and variable frequency drives, power conversion topologies, and power device applications; and advancing the technology of electrification of transportation with high-power-density and high-temperature power conversion systems, control, and electric machines for more electric aircraft, ships, and automobiles. His interest is to put many of these innovative technologies to greater use in practical systems and commercialize these technologies for practically reducing the emissions, improving the energy efficiency, and for the development of sustainable energy resources. Dr. Rajashekara earned a B.S. in science and maths from the Bangalore University, India; a B.S., M.S., and Ph.D. in electrical engineering from the Indian Institute of Science in Bangalore, India; and an M.B.A. from the Indiana Wesleyan University.

LEON E. SALOMON is currently a supply chain/logistics and contracting consultant. He retired from active duty in 1996. Prior to his retirement, he commanded the U.S. Army Materiel Command where he oversaw daily operations for an organization of more than 70,000 people at 255 facilities worldwide, reengineered and streamlined the Army's acquisitions programs through process improvement and process change; reduced acquisition lead-times 41 percent and inventories by more than $4 billion; oversaw the operational supply, maintenance, and distribution programs for the Army; and developed and implemented plans to reduce more than 20,000 spaces in response to changing missions and financial realities. From 1996 to 1999, General Salomon was vice president for purchasing and logistics and, in turn, the Senior Vice President for Procurement, Rubbermaid, Inc., where he oversaw the corporate-wide procurement and logistics policies and programs for a $2.5 billion consumer products company. He retired from Rubbermaid in March of 1999. General Salomon held numerous command and staff positions in the Army, including Deputy Chief of Staff for Logistics, Department of the Army; Deputy Commanding General for Combined Arms Support, U.S. Army Training and Doctrine Command; and Commanding General, U.S. Army Logistics Center U.S. Army Combined Arms Support Command. He is also is on the boards of several companies; is the honorary colonel of the Ordnance Corps, emeritus; and is a senior fellow of the Association of the United States Army. GEN Salomon is a member of the Board on Army Science and Technology. In addition to a bachelor of science degree in chemistry and biology from the University of Florida, he has a master of science degree in management logistics from the U.S. Air Force Institute of Technology.

PRABHJOT SINGH is the manager and leads the Additive Manufacturing Lab at GE Global Research in Niskayuna, New York. His background is in additive manufacturing (AM) process development and the computational aspects of AM process planning. During his graduate studies at the University of Michigan, he developed a process-planning framework for the five-axis layered deposition complex three-dimensional, computer-aided design models. Upon joining GE, Mr. Singh developed a novel digital microprinting system for producing ceramics. This system is being employed to manufacture components in GE's ultrasound probes. Currently, he leads the metal additive manufacturing activities at GE Global Research with a focus on the industrialization of laser powder-bed processes.

BRUCE M. THOMPSON is manager of the System Readiness and Sustainment Technologies Department and leads Sandia National Laboratories' Center for System Reliability. He is the program manager for a portfolio of military systems analysis projects supporting the military services and the DoD. He leads projects focused on the design, development, and application of unique and broadly applicable modeling, simulation, analysis, and optimization capabilities and tools to help customers make high-impact decisions. In addition, Mr. Thompson serves on an investment area team that manages Sandia's internal investments in research and development projects to create and develop new and advanced decision support capabilities for national defense applications. Mr. Thompson has more than 30 years of experience in modeling, simulation, and optimization. He also has expertise in the design, development, and application of advanced scientific and engineering software systems. His military systems and project experience includes analyses and tool development to support lifecycle operations and sustainment decisions for DoD legacy and current acquisition programs in areas as diverse as the F-35 Joint Strike Fighter, the Army's Program Executive Office (PEO) Ground Combat Systems and Program Manager Apache Helicopter, the Missile Defense Agency's Airborne Laser, and the Navy's PEO Littoral Combat Ship. In addition to his DoD experience, Mr. Thompson has addressed operations and sustainment challenges in the commercial sector, the energy sector (wind, coal, nuclear, and high-power electronics), and the Department of Energy nuclear weapons enterprise. As a distinguished member of the technical staff at Sandia, he led development of the System of Systems Analysis Toolset for the U.S. Army's Future Combat Systems Program and the Support Enterprise Model, a global-scale integrated military logistics simulation toolset as a joint program with Lockheed Martin Aeronautics. In 2011, he served on the NRC's Committee on Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs for the NRC. Mr. Thompson has a B.S. in civil engineering from Loughborough University of Technology in England and an M.S. in structural mechanics from the University of Wales, Swansea.

DALE G. UHLER is currently a senior program manager at Battelle Memorial Institute. He supports the Office of the Under Secretary of Defense (Acquisitions, Technology, and Logistics; Personnel and Readiness) on acquisition matters (including countering weapons of mass destruction), operational readiness, safety, and survivability. Prior to this, he held executive level positions at U. S. Special Operations Command (USSOCOM). These included deputy commander for acquisition, acquisition executive, senior procurement executive, and J4 director. His responsibilities included developing, acquiring, fielding, and maintaining all the platforms, systems, munitions, and equipment used by Special Operations Forces to execute their diverse responsibilities and missions. Before being assigned to USSOCOM, Dr. Uhler was deputy assistant secretary of the Navy with responsibilities for Navy and Marine Corps space, electronic warfare, command, control, communications, computers, and intelligence (C4I) programs; deputy commander/vice commander for the Space and Naval Warfare Systems Command (naval warfare systems architecture and engineering, development and acquisition of Navy and Marine Corps C4I and space systems); and deputy PEO (Mine Warfare). Prior to these Navy Department assignments, he served as deputy associate administrator for systems assurance at NASA Headquarters immediately following the *Challenger* accident. Prior to that, he was an assistant commissioner of the Federal Supply Service within the General Services Administration and was responsible for wholesale and retail operations (depots and supply centers, inventory management, distribution, pricing, and ordering); federal interagency motor vehicle fleet (management, acquisition, maintenance); federal property management (warehousing, inventory management and tracking, reutilization, and disposal). Dr. Uhler also held senior level positions in the Navy Department with responsibilities for worldwide underwater operations (salvage, diving, search and recovery, ocean engineering, oil and hazardous materials pollution abatement, ship husbandry) and associated logistics support. Dr. Uhler received his B.S. in civil engineering from the Carnegie Institute of Technology, his M.S. in civil engineering from the University of Miami, and his Ph.D. in mechanical engineering from the Catholic University of America.

C

Statement of Task

This study explores capabilities and technologies which can be used to perform distributed operations and meet sustainment requirements in the Army through 2020 and Beyond in support of the Joint Force Commander primarily focused on the Asia-Pacific regions. Using the Multi Level Scenario, Module 2 (MLS 2.0) Corps Scenario describe systems and operational concepts that will reduce the need for logistics support by exploring technologies which reduce or eliminate the challenges of storing, transporting, maintaining, distributing or returning sustainment and transforming or dramatically reducing waste in forward areas or in mature base camps. In requesting this study, the Army asked the National Research Council (NRC) to undertake the following tasks:

- Explore options that could enable support to units operating in a global, complex environment in response to emerging anti-access and area-denial security challenges with a focus on the Asia and Pacific regions, as identified in the Joint Operational Access Concept (v1.0 17 Jan 12), as well as support to dispersed special operations units.
- In the context of the first bullet, describe technology and advanced systems solutions that: reduce drivers for logistics requirements, particularly power and energy, maintenance, fuel and water by fundamentally changing the demand characteristics of the force and increasing capabilities that will allow demand to be satisfied at the point of need; improve intra-theater mobility and distribution; improve near real time visibility of logistics information. Identify S&T initiatives to predict and resolve equipment faults and failures to reduce life cycle sustainment costs.
- Explore options and describe solutions that contribute to the integration and execution of Army logistics capabilities that improve responsiveness, agility, flexibility, and precision within a Joint concept of employment, to include optimization of SOF and Conventional Force interdependence within the areas of strategy, policy and concepts.
- Recommend a logistics-centric R&D investment strategy that includes a framework, specific research objectives and a roadmap to achieve the previously-described objectives.
- Using the sponsor-provided unclassified scenario, develop 2-3 illustrative examples to support and validate the concepts described in the committee's report; the examples shall provide an operationally-focused assessment of the military value provided through solutions addressed in the concepts.

D

Sea State

Sea state is a factor that affects moving logistics over the shore because it places limits on when and how different systems can operate. Describing the sea is not an easy task, as any oceanographer will admit. Rather than over-simplify the sea state by describing it as a simple train of sinusoidal waves, which it is not, it is more effective to describe the sea condition as an energy spectrum. Sea state also encompasses factors such as confused seas, swells, combined sea and swell dynamics, and other complications. None of these factors are addressed in any description of the capabilities of causeways, mobile landing platforms, landing craft air cushions, or other at-sea transfer methods mentioned in this report.

There are different classification systems for sea states. Researchers such as Pierson, Moskowitz, and Bretschneider, have developed different energy spectra to characterize an open ocean and shallow water conditions. For example, Pierson-Moskowitz describes North Atlantic open ocean sea states generated from steady wind blowing over long distances (known as the wind's fetch). Joint North Sea Wave Project (JONSWAP) spectra are based on are based on North Sea data, and are more descriptive of fetch-limited coastal waters.[1] Three sea-state classification systems are summarized in Table D-1. While oceanographers are able to quantify the energy, commonly used terms such as sea state do not capture the impact of the energy on ships and floating causeways. Consequently, the Beaufort scale is still used, although it is centuries old. The World Meteorological Organization scale is in more common usage.

SEA STATE AND SURF

Surf zone conditions are equally important as sea state when considering littoral logistics. Surf conditions cannot simply be defined by sea state, but rather are affected by the slope of the bottoms and abruptness or gradualness of shoaling. Non-monochromatic waves are a further complication. These surf conditions are greatly affected by the state of the tide, swells, coastal currents, wind strength, and other factors. Surf conditions before, during, and after storms can build up or decay rapidly, and the ability to forecast these changes is limited. Thus, the use of sea state alone as a metric is insufficient.

Where possible, it would be desirable to directly analyze the surf conditions in areas where over-the-shore logistics operations are anticipated. One possibility is the use of unmanned watercraft to investigate and update surf conditions. Such watercraft could directly sample and map underwater and surf conditions in a potential area of operation. As an added benefit, they could also identify mines, obstacles and other navigational hazards, bottom conditions (rocks, coral, sand, etc.), and the effects of tide on surf.

There are ways to determine the impact of sea conditions on causeways and watercraft. One is full-scale testing. This, however, has limitations, the chief one being the cost and time that would be required to explore all possible variations in sea conditions. Another is to perform scale model testing in test basins, allowing for more comprehensive data collection in controlled settings. Experimental model basins include those at the Navy's David Taylor Model Basin and at various universities.

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[1] See "Section 2.8.3-JONSWAP Spectrum," in S. Gran, 1992, "A Course in Ocean Engineering," Developments in Marine Technology, Vol. 8., Amsterdam: Elsevier Science Publishers, http://research.dnv.com/hci/ocean/bk/c/a28/s3.htm.

TABLE D-1 Various Sea State Classification Systems

System	Sea State	Wave Height (feet)	Description
World Meteorological Organization	0	0	Calm (glassy)
	1	0.3	Calm(rippled)
	2	0.3-1.6	Smooth (wavelets)
	3	1.6-4.1	Slight
Beaufort	0	0	Flat
	1	0-1.0	Ripples without crests
	2	1.0-2.0	Small wavelets
	3	2.0-3.5	Large wavelets
	4	3.5-6.0	Small waves
Pierson-Moskowitz[a]	0	<0.5	
	1	0.5-1.0	
	2	1.5-3.0	
	3	3.5-5.0	
	4	6.0-7.5	

[a] Heights are "significant wave heights" or the average of the highest 1/3 of waves. The discontinuity in wave height ranges is not an error.
SOURCE: Bowditch (1984).

OBSERVATIONS

While sea state, which is based on wave height, is a commonly used and understood term, it is too simplistic to encompass all the variables acting on causeways and watercraft. Vessel motions are subject to not only sea state, but also wavelength, celerity, steepness, combinations of different wave trains, and also swell height, length, and direction. Surf conditions, too, limit the capability of causeways and watercraft to operate. Surf conditions are governed by many variables. For the general characterization of the effects of sea and surf conditions on causeways and watercraft, full-scale testing, while effective, cannot capture all the variables acting on causeways and watercraft within a reasonable time and cost. The testing of scale models in basins allows for more comprehensive, timely, and efficient data collection. While the Army has only limited influence in these matters, identifying a new metric to either replace or complement sea state might be useful in understanding under what sea conditions logistics systems can operate. This effort might be assisted by model basin testing to obtain a broad data set to support establishing a new metric.

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E

Containers

Containerization provides increased efficiency and reduced cost. It is not a technology that will reduce logistics demand, but is still a tool that, properly applied, could continue to have an increasingly significant positive impact on the Army logistics enterprise. Containers come in a variety of types, including the following:

- *Dry*—a fully enclosed weather-tight container;
- *Reefer*—an insulated container equipped with refrigeration machinery, for carrying frozen and/or perishable cargoes;
- *Flat rack*—an open platform with rigid or foldable ends;
- *Tank*—a rigid tank fitted into a container frame for carrying liquid cargoes;
- *Open top*—a container with solid sides and a tarp roof, used for cargoes lifted with an overhead crane;
- *High cube*—a container higher than the standard 8 feet, 6 inches; usually 9 feet, 6 inches; and
- A variety of specialized containers.

Containerization has had a profound impact on all forms of transportation. Industry has enjoyed many benefits of containerization, such as lower terminal and warehousing costs, less packaging, less pilferage, faster throughput, lower insurance costs, simpler documentation, faster ship turnaround, less cargo damage, greater efficiency, and dramatically lower shipping costs.

The U.S. military has taken notice and has adopted many aspects of containerization. The U.S. Transportation Command (TRANSCOM) employs many commercial shipping companies to fulfill its logistical needs. However, the intense competition in the commercial container field and its steady expansion have led to rapid innovation and increased efficiency in the manufacture and use of containers. There are more than 35 million 20-foot-equivalents of containers currently in service.[1] The Army has only a small share of these. The Army could find it useful to more closely monitor and track much of what is done by commercial shipping companies. Where appropriate to the Army's mission, new intermodal shipping techniques could bring improvement to the Army's container programs. Commercial companies are quick to adapt new methods. The Army may want to consider how they can be more agile in adopting innovation. Improvements in Army logistics could be realized if many of the techniques common in commercial service were adapted to fit the Army's objectives and needs.

For example, in established port facilities, an extremely efficient way to lift containers into and out of ships with a crane is to attach the containers vertically, so they hang one above the other when the crane lifts them. Lifting two or more containers this way is called vertical tandem lift. Although this technique had been banned by the Occupational Safety and Health Administration, the ban was revoked in court in April 2014, and this technique again became permitted after July 21, 2014.[2] It may be worthwhile for the Army and TRANSCOM to investigate the use of this technique where appropriate.

[1] Twenty-foot equivalent is standard measure of container volume. The volumes of different sized containers are related to the volume of a standard 20-foot container.

[2] 29 CFR 1917.71 (i), revised.

Visibility into the container standard-setting process would also be beneficial. Army or TRANSCOM representation on the U.S. American National Standards Institute Technical Advisory Group committee to the International Organization for Standards (ISO) TC-104 container standards committee would prove useful. The Army and TRANSCOM are major stakeholders, and changes to standards have major impacts on their container assets. More importantly, representation on both the main committees and particularly on the four subcommittee working groups would give the Army insight to potential changes and the underlying problems driving changes in standards. It would be worthwhile for the Army to monitor industry practice, both in the United States and abroad, and, where practical and appropriate, adopt any innovations to meet their logistical needs.

Today, TRANSCOM and the Army and Navy appreciate the potential for containers to augment and support logistics, with a four-decade commitment to using containers. Currently, however, TRANSCOM relies heavily on a number of U.S. subsidiaries of foreign-flagged shipping companies for the transport of sustainment cargoes in containers. In the case of an all-out conflict, or a conflict on multiple fronts, the demand for container transport may overwhelm the capacity of the limited number of U.S. flagged commercial vessels that TRANSCOM currently relies on. In this case, the Army and TRANSCOM might have to turn to foreign flagged shipping, with all the attendant risks. There are currently a number of foreign flagged, U.S.-owned tankers and cargo ships. They are crewed by foreign nationals. While the United States would have access to these ships in time of conflict, crewing the vessels might be problematic, as occurred during the Vietnam War.

ROLL-ON/ROLL-OFF VERSUS CONTAINERS

A basic philosophy of the Army and Marine Corps has been, and to a great extent today still is, to put wheels under everything. The purpose is obvious in theater-opening expeditionary operations, to have everything mobile and able to advance rapidly. For invasion and advance inland, both the warfighting and initial supply chain needs to be highly mobile and agile. This dictates that sealift capability and initial supply must provide mostly roll-on/roll-off (RO/RO) transport and discharge capability. Unfortunately, it is the nature of RO/RO transport that there is an abundance of broken stowage or wasted space on RO/RO ships. Nevertheless, with limited U.S. sealift capability, it is the committee's opinion that RO/RO has priority over other cargo transport and cargo handling needs. In the commercial arena, the efficiencies inherent in containerization quickly displaced commercial RO/RO ships, palletization, barge carriers, and other competing shipping modes.

In Vietnam, tedious break-bulk ship unloading at overcrowded waterfront facilities resulted in arriving ships waiting an average of 30 days at anchor for a space at a dock. In 1966, an experiment was performed. A container ship, the *SS Fairland*, equipped with its own shipboard gantry cranes, was brought to Cam Ranh Bay. In 1 day, the ship completely discharged and was even able to return some empties to the ship. This eye-opening demonstration was a watershed event and broke the logistical log jam in Vietnam. The Army in Vietnam was quick to see the potential.

So, containers are more efficient for the shipping of materiel. But RO/RO ships are necessary to meeting military needs in theater opening expeditionary operations. It might be possible, however, to develop techniques to create temporary decks on container ships to store RO/RO cargo in their large holds using readily available container flats. This could allow these ships to take full advantage of the efficiencies of containers and could be especially helpful in surge situations.

Containerized cargo is stowed in vertical cells in container ships. Different mission scenarios will likely call for different mixes of cargo. This would likely apply especially in the case of removing equipment from prepositioned equipment stores. Retrieving a container from further down in the cell necessitates removing the containers above it. This is an arduous and time consuming task. Improving the ability to selectively retrieve specific containers without having to first remove the containers above them holds the promise of significantly improving the efficiency of operations.

CONTAINER COSTS

There is the potential to save money by reexamining how the Army procures and uses containers in initial theater-opening phases. Opportunities exist in considering where standard industrial containers may be used, the use of second-hand containers instead of new ones, and in managing the decision whether to buy or lease containers. During the sustainment or resupply stages, the use of commercial carrier containers simplifies decision making on these points.

Military Specifications Versus Standard Industrial Containers

It is worth asking whether special-use containers for the Army need to be built to military specifications, or whether standard industrial containers could be modified for these special applications. The 35 million containers in commercial service are durable (with physical lives in excess of 15 years) and function well in both developed and developing countries. Such containers are very inexpensive. It would be advantageous to the Army to use these containers where possible instead of specialized containers built to military standards per MIL-STD-648D (DoD, 2008).

Possibly complicating the use of standard industrial containers are buy-American requirements for containers built for the military. Currently, however, "U.S. made" containers for the military are only assembled in the United States—not constructed in the United States from basic raw materials (e.g., sheet metal, rolled sections). The components and assemblies are fabricated in China and shipped knocked-down. So, the final cost of "U.S. made" containers in current use is higher than industry pays for its containers. Containers made entirely in China are cheaper than "U.S. made" containers. The committee recognizes that this is an issue of national policy, but feels compelled nonetheless to point out that "U.S. made" containers are more expensive, even though they are still mostly manufactured overseas.

New Versus Second-Hand Containers

Even less expensive than new industrial containers are rugged second-hand containers with considerable physical life remaining. These can be purchased at very low cost, especially in the United States. Due to the imbalance in trade, the cost for commercial shippers to return empties from the United States to Asia is prohibitive, and they tend to stockpile in the United States. It is sometimes cheaper for commercial operators to build a new container in China than to send an empty back to its point of origin. Further, shipping containers are put to many alternate uses by innovative soldiers as shelters, workshops, and so on (see below). Sending second-hand containers into settings where this is likely to happen could free up capital that would otherwise be used for costly new containers or avoid demurrage (detention) charges for leased containers that are not returned to the vendor.

Another point of difference between newer and older containers is quality. The quality of newer containers is less than that of older containers. Manufacturers of new containers are using cheaper construction materials. For example, some newer containers have 4.5 mm corner posts rather than the 6.0 mm posts on the older containers. Newer bamboo plywood floors delaminate and are less durable than older hardwood floors. Also, some newer corner castings are of questionable quality.

Commercial operators constantly face the question of lease versus own. The same market considerations should drive government decision-making on this subject. Once leased containers move into theater, there is a chance they may not return for a variety of reasons. The purchase price and lease rates for commercial containers fluctuate based on a number of factors, including supply and demand, availability of second-hand containers, interest rates, and steel prices.

Many of TRANSCOM's and the Army's needs, especially during conflict, have containers moving one way, to the front. Also, as mentioned above, soldiers find innovative uses for containers. Obviously, if leased and carrier containers are used this way, significant costs will be incurred. To try to prevent this, Army policy is that "all commanders in theater must return containers as soon as they are emptied" to assure that they do not incur demurrage charges (DA, 2013). Nonetheless, it appears that containers are being retained in forward areas. *USA Today* reported in 2011 that the Pentagon has "spent more than $720 million in late fees for storage containers." (Vanden Brook, 2011) The Surface Deployment and Distribution Command claims that the annual demurrage costs have dropped significantly since 2004 through better management. For example, only $30 million in 2010 (Vanden Brook, 2011).

The Inefficiency of Small Containers

Army policy, currently, is to restrict containerization to 20-foot containers. The 40-foot variation is being used for sustainment by TRANSCOM (DA, 2013). Commercial container ships, RO/RO ships, developed port handling equipment, and developed infrastructure are capable of handling 40-foot and larger containers. It costs nearly the same to move one 20-foot container through a terminal and onto or off a ship as it does for a 40-foot container. This is true even if the gantry cranes are equipped with twin-lift capability. A high-cube 53-footer, which is now the most common trailer size on U.S. highways, has 50 percent more volume than a 40-foot container and three times the capacity of a 20-foot container.

While recognizing that the larger 40- and 53–foot containers do not serve every situation (i.e., high-density cargoes) the enormous economies attendant with large containers, where appropriate, should not be ignored. In the opening and advancing phases of a conflict, a military force must be agile, flexible, lightweight, and fast moving. It is in the resupply and sustainment phases where large unit loads may be practical. Using larger containers also depends on adequate availability of infrastructure, such as container cranes, roads, and so on. TRANSCOM and Army logisticians may find a way to reap some of these benefits of using larger containers. It is axiomatic in materials handling to use the largest unit load appropriate to the circumstances.

USING CONTAINERS TO MEET OTHER LOGISTICS NEEDS

Among the various logistics needs is providing shelter for soldiers and facilities for base camp operations. A number of innovative containerized shelters are, or are about to come, on the market. These can be transported by truck, flatbed chassis, or helicopter and set up in minutes. Often, military resources are used for humanitarian purposes. Containerized shelters would be of great value in humanitarian relief missions, which is expected to be a predominant mission in the Asia-Pacific Theater.

The permanent prepackaging of various types of camp equipment, such as reverse osmosis water purifiers, diesel generators, waste treatment plants, incinerators, and so on, in containers to reduce transport costs is laudable. However, it is not always necessary to mount this equipment permanently in containers. It might be preferable to skid-mount the equipment for easy removal, allowing the container to be repurposed. While there is abundant anecdotal evidence of shelters being built into units that conform to ISO handling requirements, knock-down kits consisting of insulation, bunks, climate control, and lighting units, and so on could be made up so as to permit troops in the field to adapt empty containers into shelter or work spaces if required. Containers can be stacked, put into blocks, arrayed end-to-end, spaced apart with joining roofs, and generally assembled into a great variety of configurations. Many of these modifications can be readily made using common hand tools.

OBSERVATIONS

Container industry practices are constantly and steadily improving. Many of these improvements could be of use to the Army. For instance, in ports, it is more efficient to employ vertical tandem-lift procedures, especially when moving empty foldable platform containers. Also, the commercial container industry has overwhelmingly adopted 40-foot and larger sizes for reasons of economy and speed of handling. The Army might find it useful to monitor industry practice, both in the United States and abroad, and, where practical and appropriate, adopt any innovations to meet its logistical needs. This would include container design, repair, refurbishment, container operations, container refrigeration, container terminal operations, container handling, inventory control, and container tracking and monitoring. Army logistics might also benefit from the development of flooring techniques to create temporary decks in container ships so they could carry more RO/RO cargo.

It may be more cost-effective for the Army to use second-hand containers in some applications rather than purchasing new containers. Further, the quality of newer containers is generally lower than that of older containers. Ordinary, standard dry containers can fulfill many very useful alternative functions in forward areas. Second-hand, older, non-leased containers can readily be used to serve these needs. Soldiers should not be discouraged from the innovative use of containers.

Finally, progress is being made in reducing container demurrage costs. This is something that has been a drain on Army budgets for a number of years. Clearing the backlog of containers on which the Army is paying demurrage will improve the logistics picture.

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F

Management Innovation as a Strategic Technology

During most of its existence, the operations research community has been "cursed" with both data challenges and computational power (e.g., Bellman's "curse of dimensionality" in dynamic programming). But that is clearly changing in this new digital technology era of big data. Indeed, data has become ubiquitous; the challenge now is to somehow make sense of it all. And just as diminishing returns finally seemed to be dampening Moore's Law on computing power, Los Alamos National Laboratory demonstrated the first supercomputer to achieve a petaflop of sustained performance—a million, billion calculations per second and 1,000 times faster than the existing teraflop standard.[1] And in September 2013, Stanford University researchers announced the creation of a computer using carbon nanotubes that may further improve performance by an order of magnitude over silicon chips.

So, these twin banes of operations research's past, data and processing power, are now far more likely to offer opportunities than to hinder future work in this area. The link between big data and analytics has already been established; namely, the extensive use of data, statistics, and quantitative algorithms for descriptive (explanatory), predictive (forecasting), and prescriptive (optimization) modeling and analyses for fact-based, analytic management. And through sensor technology, radio frequency identification, Total Asset Visibility, enterprise resource planning systems, and the Internet, information technology has now expanded to capture, track, monitor, and visualize data in near-real time across disparate, dislocated entities comprising an entire enterprise.

However, the Army has yet to fully integrate analytical architectures into its persisting enterprise system challenges. Complementary decision-support systems have not yet been developed that could capitalize on available enterprise data and, using analytically based methods, make sense of it all, enable improved decisions, and dramatically improve enterprise performance.

For a fixed demand, the three quantities shown in Figure F-1 (inventory, capacity, and knowledge) represent a trade space: If more of one of these quantities is available, then less of one (or both) of the others is necessary to reach the same level of system performance. This trade-off suggests a fundamental truth: If the amount and timeliness of useful data and good information for actionable decisions improves (i.e., increased knowledge), then with the same capacity for action, it now becomes possible to improve system performance with fewer resources.

For large, complex organizations, the greatest return on investment is derived from integrating relevant analytical tools and analysis with the appropriate information technology to provide actionable decisions support. This path achieves cost-effective, performance-oriented results aligned with strategic plans, organizational vision, and ultimately, the purpose for which the enterprise exists. The goal should be the effective integration of analytics into organizational decision-making.

Improvements in data storage and processing continue at a rapid pace, but most organizations struggle to manage, analyze, apply, and transform data into useful information for knowledge creation and actionable decision options. The corporate world has come to realize that investment in new information technology systems, without first examining and implementing the necessary business process changes, simply automates existing inefficiencies and results in negligible benefits. The term

[1]Additional information on Reaching for New Computational Heights with Sequoia is available at str.llnl.gov/july-2013/mccoy. Last accessed on September 22, 2014.

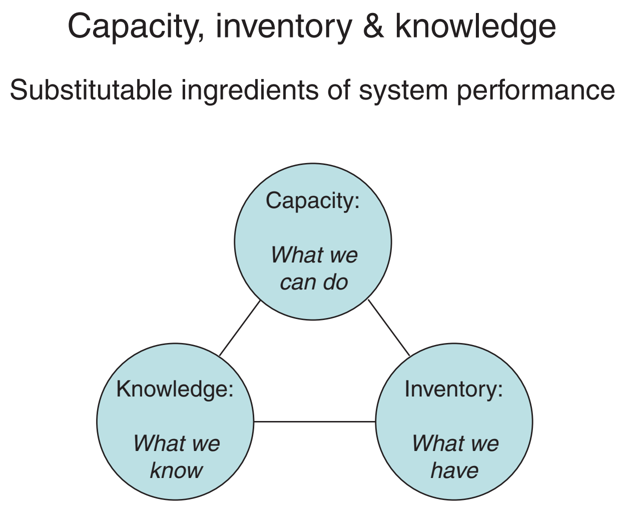

FIGURE F-1 Transformational analytics: Capacity, inventory, and knowledge. SOURCE: Adapted with permission of Business Expert Press LLC, from Parlier (2011), permission conveyed through Copyright Clearance Center, Inc.

business intelligence is now used to encompass both analytics and the data processes and technologies used for collecting, managing, and reporting decision-oriented information. Nonetheless, analytic management is often impeded by organizational pathologies: conventional wisdom crowds out critical thinking; high-level managers fail to demand rigor and dispassionate analysis; and organizations lack the capacity for empirical work. What must be created is the analytical capacity for insight, refinement, and better decision-making.

Although studies linking analytical approaches and business performance are still relatively immature, one must be wary of so-called information technology solutions. It is imperative to realize that information systems, especially enterprise resource planning systems, must be connected to analytics in order to create decision support capabilities. There is mounting evidence (e.g., Davenport and Harris, 2007; Ferguson et al., 2005) that the true gains are not obtained just by procuring information technology solutions, but rather by the organizational capacity to create insight and decision options from the information and improved situational awareness provided by information systems technologies. Figure F-2 shows some of the components of an effective management innovation technology system.

Although information technology solutions have ubiquitous appeal (and enormous investment levels), focusing only on information technology results in growing complexity and information overload that exceeds the interpretive capacities of the organizations responsible for developing and using information technologies. Organizations need the analytical, integrative power of operations research to focus business process reengineering on desired outcomes. This has been termed the ingenuity gap (Homer-Dixon, 2000). A complementary relationship, both symbiotic and synergistic, is needed between decision support systems and management information systems.

Two distinctly different planning approaches can be distilled from the management literature: (1) the traditional, or incremental approach and (2) a transformational perspective. The traditional approach focuses on a short-term horizon, usually annual, where internal budget constraints and financial targets constitute the primary management objectives to defend and extend existing business. For stable environments with growing market potential, this familiar incremental approach can yield steady business growth. In contrast, the transformational perspective focuses on penetrating other, perhaps emerging,

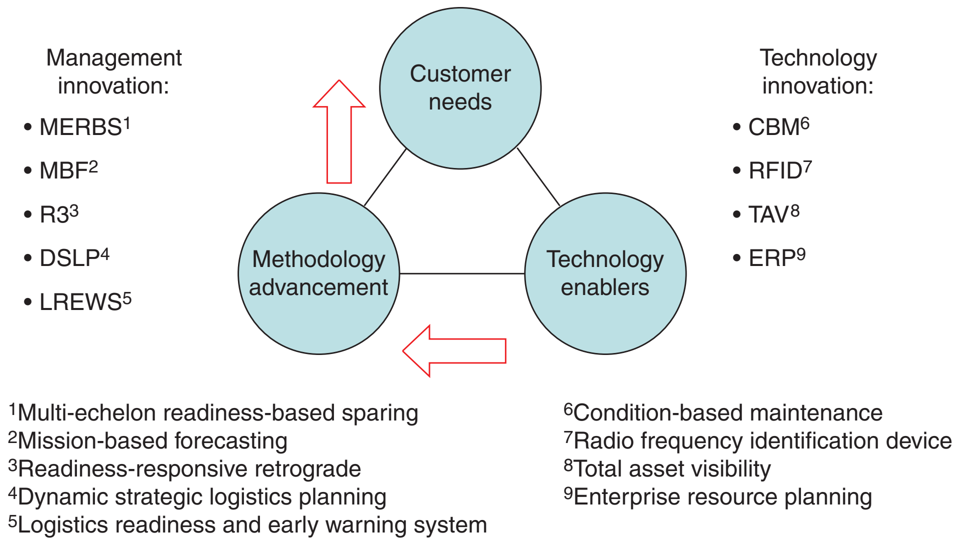

FIGURE F-2 Management innovation for improved logistics decision-making.
SOURCE: Republished with permission of Business Expert Press LLC, from Parlier (2011), permission conveyed through Copyright Clearance Center, Inc.

markets and creating new ones. This externally focused approach views environmental conditions and future challenges as potential opportunities rather than constraints to existing business. Because past performance is now irrelevant as a benchmark for planning objectives, an organizational vision must be imagined for a future horizon, and creative plans developed to engineer progress toward this future vision. In this sense, transformational strategic planning requires "imagineering"—that is, leading from the future—by pulling the organization forward, rather than pushing it by managing to the past.

Key ingredients for successfully pursuing a transformational strategy include an engine for innovation and strategic architectures for analysis, management, and planning. An engine for innovation is a virtual test bed that can provide a synthetic, nonintrusive environment for experimentation and evaluation of innovative ideas and concepts. This synthetic environment guides and accelerates transformational change along cost-effective paths, providing the analytical "glue" to integrate and focus what otherwise would be disparate initiatives and fragmented research efforts. In essence, such a capability functions as an engine for innovation to sustain continuous performance improvement.

The organizational construct for an engine for innovation is shown in Figure F-3. The construct includes the following three main components:

1. A research model and supporting framework, including a strategic outreach mechanism, to function as a generator, magnet, conduit, filter, clearinghouse, and database for good ideas;
2. A modeling, simulation, and analysis component that contains a rigorous analytical capacity to evaluate and assess potential impacts and associated costs of good ideas; and
3. An organizational implementation component to enable the transition of promising concepts into existing organizations, agencies, and companies by providing training, education, technical support, and risk reduction and mitigation methods to reduce operational and organizational risk during periods of inevitably disruptive transformational change.

Within the U.S. Army, tactical units are renowned for pioneering and refining the after-action review concept as a continuous learning method to uncover, diagnose, and correct deficiencies that improve and

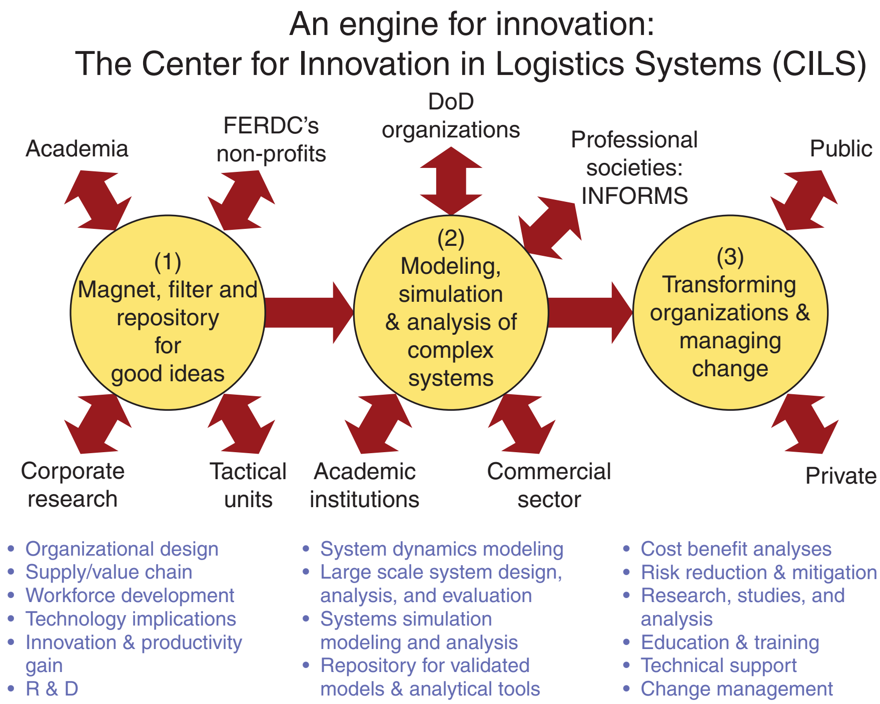

FIGURE F-3 An organizational construct for an engine for innovation.
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sustain operational excellence. Yet, comparable diagnostic effort has not been prevalent at strategic levels within the institutional Army logistics bureaucracy. Because analytically rigorous root cause analysis and understanding of problems and effective response for management issues are not routinely performed at the strategic level to uncover ground truth and learn from mistakes, reactive crisis management seems to be the institutional response to visible symptoms. In other words, the institution is always reacting to logistics problems rather than getting ahead of them.

Institutional adaptation and agility requires a culture of innovation. However, sources for innovation must exist for the culture to embrace. An engine for innovation would provide a source of innovation by building a capacity for low-risk, low-cost experimentation using a synthetic environment where analytically rigorous cost-benefit analyses can be performed to differentiate between desirable objectives and attainable ones that can actually be implemented.

The purpose of this deliberate, cyclical discovery process is to sustain continuous improvement through experimentation, prototyping, field testing, feedback, and especially through rigorous analysis. Organizational vision and analytical tools must not be viewed as mutually exclusive paradigms. Rather, analytical tools should link organizational vision to operational results by defining and monitoring metrics tied to strategic enterprise objectives and aligning incentives to those objectives. In organizations with strong cultures, especially the military services, it is critical that incentives for behavior and performance be carefully and thoughtfully targeted to attain desired institutional outcomes.

Also, strategic planning and management frameworks are essential to enable learning within organizations and to ensure that strategies pursued achieve intended operational results. Strategic architectures for analyses, management, and planning visually portray relationships between system-wide goals, supporting objectives, and strategies to pursue these objectives. They also illuminate the need for adaptation and change by providing mechanisms to sense the need for reacting to, as well as creating, change when necessary.

Strategy, then, is fundamentally about dealing with change. It represents the heart of management. Despite the inexorable advance of technology (both physics-based and information-based), it will be improved decision support systems for enterprise management, pursuing future-oriented visions linked by transformational strategic plans, that ultimately enables the potential of innovation to be realized.

Applying the power of operations research, advanced analytics, and management innovation for dramatic performance improvement, including cost savings on the order of many billions of dollars, could provide enormous efficiency impacts at a crucial time. Current work by TASC suggests that costs savings are indeed possible (Parlier, 2011). Advanced analytics can provide engines for innovation that generate and sustain continuous improvement in demanding, increasingly resource-challenged environments. Recognizing these needs and then developing the capacity to achieve them are the first steps toward demonstrating management innovation as a strategic technology for our defense enterprise bureaucracies and, perhaps, the broader national security community.

It will be improved decision support systems for enterprise management, pursuing future-oriented visions linked by transformational strategic plans, which ultimately enable the potential of innovation to be realized. The concept of management innovation as a strategic technology can be a leading source of innovation and a crucial enabler for sustaining continuous improvement in increasingly resource-challenged environments.

OBSERVATIONS

In this era of dramatic resource constraints, the Army logistics community needs to better harness and apply operations research and strategic analytics across the materiel enterprise. To this end, the Army would find it useful and helpful to develop an engine for innovation for the logistics community and adopt, apply, and refine management innovation as a strategic technology.

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G

Sustainment Readiness Levels

This appendix presents a set of proposed policies and supporting criteria for establishing Army and joint requirements to better contain and improve predictability for operational and sustainment (O&S) costs consistent with better buying power mandates from the Office of the Secretary of Defense. Sustainment readiness levels (SRLs), loosely analogous to technology readiness levels for the front end of the acquisition life cycle, are characterized here. Each SRL policy and its associated criteria can be applied to either currently fielded systems or fleets operating in the sustainment phase of their life cycles, or to new systems under development in the acquisition phase. In both cases, insight into cost-wise readiness and affordability issues can be obtained. Future O&S costs (and cost growth), and the ability to credibly relate current budgets to near-term readiness and programs to future capabilities, can likely be illuminated by addressing the degree to which these policies are in use or planned. For fielded systems currently operating in the sustainment portion of their lifecycles, empirical results for the sustainment policies described herein can be assessed; that is, either the policy is being implemented with measurable effect within a cost-performance (resources versus readiness) trade space, or it is not. For new systems, which have historically ignored the cost implications of the O&S sustainment phase, even though they typically constitute more than 70 percent of total life cycle costs, these criteria could be used as a planning checklist in conjunction with technology readiness levels. SRLs provide a means for Department of Defense (DoD) and Army officials, program managers, and materiel management centers to formally address and focus attention on the long-standing need, first identified by the Government Accountability Office on its high-risk list of federal agency shortcomings in 1990, to correct persistent problems in supply chain management, including deficiencies in demand forecasting, inventory policy, and strategic resource planning.

In the case of Army aviation, cost savings derived from implementing each of these supply chain policies have been estimated to be on the order of many multiples of $100 million (Parlier, 2010). This proposed sustainment concept supports development of readiness-driven supply networks and forms the analytical foundation for pursuing and achieving cost-wise readiness. Once fully implemented, the combined and interacting effects of these SRL policies are likely to be in the range of many billions of dollars, resulting in savings several orders of magnitude greater than the cost of implementation (Parlier, 2010). Using Class IX (spares and repair parts for major end items) as an example, proposed SRL policies follow. Assessment tools, or levels of maturity, for each SRL are also suggested.

1. *Condition-based maintenance (CBM).* CBM capitalizes on prognostic, sensor-based technologies (e.g., digital signal collectors) to determine the remaining useful life for expensive depot-level reparables (DLRs) and line-replaceable units (LRUs). CBM is intended to preclude collateral damage and lengthy repairs caused by catastrophic DLR failure, while also ensuring that these expensive items are not prematurely replaced based on arbitrary time-based maintenance policies. Connecting CBM to the supply chain enables DLR replacement to be anticipated—scheduled in advance (rather than needing unscheduled maintenance due to failure)—reducing the requirement for forward stocking. This anticipatory maintenance policy significantly reduces the overall fleet-wide requirement objective for those DLRs that are CBM-enabled by reducing tactical unit customer demand uncertainty and by capitalizing on risk-pooling. Possible assessment tools include the following:

- Does the supported end item (e.g., aircraft fleet) consist of DLR and/or LRU components or assemblies that have condition monitoring sensors (e.g., digital signal collectors) to support a CBM program?
- If so, how is remaining useful life prognostic information used to connect CBM to the supply chain for anticipatory supply support; what algorithms or processes are used, and what impact does this ability have on operational readiness, DLR and LRU positioning and distribution, materiel availability, and aggregate requirement objective reduction across the supply support enterprise?

2. *Mission-based forecasting.* This is a forecasting concept and method that identifies, differentiates, and uses empirical spare and repair part consumption patterns associated with different tactical missions and the operational environments within which they are conducted. Possible assessment tools include the following:

- Is customer demand accurately captured at the point of readiness generation (tactical units), and, if so, how?
- What are the explanatory factors (e.g., different operational missions, operating environmental conditions, etc.) that cause different customer demand patterns for spare and repair parts?
- How is this knowledge incorporated into demand forecasts for retail stock planning methods; specifically, how is supply aligned to real customer demand at the point of sale where readiness is generated (i.e., the tactical unit)?

3. *Intermittent demand.* It is often difficult to determine any pattern or trend that would otherwise enable accurate demand forecasts for spare and repair parts to be developed. This is especially true for infrequently used parts in complex systems—referred to as sporadic or intermittent demand. Standard traditional forecasting methods—typically time-based (e.g., exponential smoothing and its derivatives)—do not yield good results when applied to intermittent demands, although their use has been pervasive. New methods have shown great promise, although they have not yet been incorporated into current DoD enterprise resource-planning systems. Possible assessment tools include the following:

- Are there empirical spare or repair part usage profiles that are not amenable to standard forecasting methods, and can these non-standard patterns be characterized as intermittent?
- For those categorized as intermittent, what forecasting method is used for demand planning? Describe the metric used to assess forecast error and what forecast accuracy is achieved with this metric.

4. *Sparing to availability.* Inventory optimization policies, including readiness-based sparing (RBS) methods, trade off the cost of parts, contribution to readiness (criticality), and frequency of use to achieve a desired operational availability objective at minimum cost. Possible assessment tools include the following:

- Where are the costs for current and planned operational performance (e.g., readiness) and associated retail (tactical)-level spare parts and repair parts incurred? Portray graphically within a cost-performance trade space.
- How does this performance compare to a cost-effective, efficient operating curve? Describe. How has this efficient operating curve been developed or computed, and what inventory policy has been incorporated? Explain.

These sustainment maturity model polices, with their associated SRLs, could be combined as integration opportunities to pursue cost-wise readiness outcomes. For example, combining RBS and MBF can provide a means for aligning and synchronizing Class IX logistics support consistent with the force management process, mission requirements, and also regionally aligned forces.

5. *Readiness responsive retrograde*. Unlike consumable repair parts, DLRs are not consumed in the readiness generation process. Rather, a DLR is removed; replaced by a serviceable one; returned through the reverse pipeline for inspection, rebuilding, and modification, as needed by organic depots and commercial repair facilities; then returned back to the forward supply chain for distribution and re-use. This process forms a closed-loop supply chain—a feedback loop in terms of system dynamics. The responsiveness of this retrograde process impacts the output of the system (readiness) as well as the aggregate requirement objective for these DLRs. Possible assessment tools include the following:

- What is the retrograde (reverse pipeline) structure, existing and anticipated materiel availability, and what is the impact of retrograde performance on the aggregate end item requirement objective? Describe.
- What reverse logistics metrics are used to assess responsiveness, efficiency, and effectiveness, and how is the retrograde process synchronized with depot repair?

6. *Multi-echelon RBS.* This is a centralized, risk-pooling inventory optimization method used in large-scale, multistage supply distribution systems. It incorporates single-stage RBS elements along with transportation costs and times to optimize the placement and distribution of spare and repair parts within a supply support network. Possible assessment tools include the following:

- What is the organizational structure of the supply chain? Describe.
- If multiple stages (organizational echelons beyond the retail level) exist for supply distribution and/or maintenance support, what multi-echelon inventory optimization method, if any, is used for inventory distribution allocation across the supply support network? Explain.

7. *Sustainment early warning system*. The Defense Readiness Reporting System requires the services to report not only the current and expected near-term readiness of tactical units in the field, but also the readiness of their respective Title X institutional support capacities as well (e.g., man, organize, train, equip, sustain). Leading indicators are needed to anticipate, diagnose, and then preempt potential supply chain failures. Analytically based decision support systems can significantly contribute toward this DoD mandate by linking planning, programming, budgeting, and execution (i.e., a resource planning system) to operational planning systems (i.e., capabilities). Informed by this supply chain health monitoring and management concept, planning guidance, funding decisions, and execution performance can then be related in meaningful ways (Parlier, 2010). Possible assessment tools include the following:

- Has a materiel enterprise supply support early warning system been established; and, if so, how is it characterized?
- Are the predictive analytics used for early warning credible and useful to management?

The potential magnitude for improvement by adopting a sustainment early warning concept is truly dramatic—tens of billions of dollars in further savings are likely, and more importantly, it becomes possible to actually achieve predictive readiness by credibly and accurately relating investment levels to current readiness and future capabilities. Collectively, these SRLs can yield a more effective, resilient, and increasingly more efficient materiel support enterprise that achieves equipment readiness goals, is adaptive to change, and has greater materiel availability at less cost.

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