Equipment Sustainment Requirements
for the Transforming Army

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SUMMARY

A central goal of the Army Transformation is a large reduction in the amount of combat service support (CSS) personnel and equipment—the CSS footprint—in the combat zone. Reduced footprint will enhance not only strategic mobility through increased deployment speed but also operational and tactical mobility, key parts of emerging Objective Force operational concepts that envision a fast-paced, nonlinear battlefield with forces rapidly shifting across large distances. The wide dispersion of units and unsecure lines of communication that will result from these envisioned nonlinear operations lead to a second goal: self-sufficient maneuver units during operational "pulses."[1]

To achieve these goals, the Army must improve the supportability of future systems and the effectiveness of the logistics system, which together determine the sustainability of the Army's weapon systems.[2] To drive such improvements, the Army needs to identify an effective set of equipment sustainment requirements for weapon system

[1]For a discussion of future Army warfighting concepts and force requirements, see "Concepts for the Objective Force," United States Army White Paper, 2001. Support footprint goals are found in "The Army's CS/CSS Transformation: Executive Summary," Briefing, January 21, 2000.

[2]Supportability, a characteristic of weapon systems that can be influenced to the greatest degree in early design stages, is a measure of the amount and nature of resources needed to support a weapon system. It consists of reliability, maintainability, and durability. "Equipment sustainment capability" in this report is defined as the Army's ability to keep equipment operational from a maintenance standpoint. It is driven by two factors: equipment supportability and logistics system capabilities. Other sustainment capabilities, such as providing fuel, ammunition, and water, are not treated in this report.

programs that are aligned with Objective Force operational concepts. To assist with this task, the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA[ALT]) asked RAND Arroyo Center to develop a set of metrics to define equipment sustainment requirements and to assess their potential merit as key performance parameters (KPPs).

WHY DOES THE ARMY'S EQUIPMENT SUPPORTABILITY NEED IMPROVEMENT?

Poor supportability exacts substantial costs: low mission availability, a large maintenance footprint, and high maintenance costs. Although Army readiness rates averaged across time and units often meet or exceed Army goals (90 percent for ground systems and 75 percent for aviation), the reality of equipment availability is more complex. During battalion-level training exercises, daily not-mission-capable (NMC) rates frequently climb above 20 percent, and daily battalion-level NMC rates as high as 45 percent have been observed for M1A1 Abrams tanks—despite the presence of a large maintenance footprint. Maintainers currently make up close to 20 percent of the personnel in both Army of Excellence and Force XXI heavy divisions, and about 15 percent of the personnel in task-organized heavy brigade combat teams. And the costs of maintenance are high: in 1999, for example, the Army spent about $8.5 billion, or more than 12 percent of its budget, to maintain equipment.

THE GOALS OF EQUIPMENT SUSTAINMENT

The Army's desire to reduce the costs of poor supportability reflects in three overarching equipment sustainment goals: high availability during combat pulses, small maintenance footprint, and low maintenance costs. In the course of the Objective Force concept development, the Army has added another goal: maneuver force self-sufficiency, that is, operating without external support or resupply during surges of continuous operations or "combat pulses." Pulses have been defined as three days of continuous combat in mid- to high-intensity conflict, and seven days of continuous operation in low-end conflict.[3]

The aggressiveness of the Army's Transformation goals is leading to new force designs with substantially reduced maintenance footprint. For example, in the Interim Division (draft) and the Stryker Brigade Combat Team (SBCT) designs, the ratios of maintainers to total personnel are about a half and a third, respectively, of heavy division and brigade combat team ratios. Moreover, the Future Combat Systems (FCS) concept, envisioned as a system of highly interdependent systems, implies a need for higher-than-ever availability for some system elements; draft FCS-based unit designs target much lower maintenance footprint than even the SBCT. Achieving the aggressive CSS Transformation goals will require changes not only in logistics structures and processes but also in the nature and amount of demands placed upon the logistics system by the Army's equipment—the supportability of systems that results from the requirements development, concept development, engineering design, engineering development, and testing processes. Thus, the requirements and acquisition processes must play key roles in the CSS Transformation.

EQUIPMENT SUSTAINMENT REQUIREMENTS

When an acquisition program begins, the Army should first assess how mission needs influence the relative importance of each overarching equipment sustainment goal, along with desired levels of performance. This assessment will help identify any potential KPPs that should be emphasized during concept and technology development and will facilitate the comparison of various concepts. Table S.1 provides a potential template for the overall goals and associated metrics. These are high-level equipment sustainment requirements that directly reflect operational and overall Army needs. The middle column provides generic requirements or program goals associated with each high-level requirements category, and the far right column provides metrics for defining the requirements and setting objective and threshold values.

[3]DARPA Solicitation No. PS 02-07, DARPA/Army FCS Program, Competitive Solicitation, Defense Advanced Research Projects Agency.

Table S.1

Overall Equipment Sustainment Program Goals and Metrics

Requirement Category	Equipment Sustainment Program Goals	Potential Standard Metrics for Defining Sustainment Requirements
Availability	• Meet mission needs • Maximize pulse availability • Maximize sortie availability (as applicable)	• Pulse A_o (operational availability) — Use derived pulse A_i in some cases • Prob(successful sortie completion) (as applicable) • Specify pulse, refit, and sortie parameters[a]
Self-sufficiency	• Unit self-sufficiency during pulses	• Self-sufficiency pulse length
Equipment sustainment footprint	• Minimize deployment footprint and maneuver force footprint	• Maintainers by echelon (cost and footprint driver); or maintenance ratio by echelon • Maintenance equipment lift requirements
Life cycle equipment sustainment cost	• Minimize life cycle cost	• Total life cycle cost to “maintain” • Annual operation (cost per operating hour/mile) • Planned recapitalization • Spare parts provisioning • Investment in reliability (e.g., materiel)

[a]Critical assumptions that are necessary to determine the associated requirements.

To measure the ability to keep equipment available for use during combat or other operations—the ultimate purpose of equipment sustainment—the Army should employ the metric pulse operational availability (A_o). Pulse A_o is defined in this document as the percentage of time a system is available over the course of a combat pulse, which is equivalent to the probability that the system is operational at any point in time during a pulse. An alternative form of a pulse A_o requirement would be to specify the minimum A_o that must be maintained over the course of a combat pulse by a unit—call this minimum pulse A_o. It would be defined as the probability that availability remains above a threshold for an entire pulse. This would be important when a minimum level is deemed necessary to maintain a unit's combat effectiveness. Pulse A_o, in one or both of these forms, is what commanders care about.

In cases where the pulse A_o is to be achieved without external support, self-sufficiency should be an overall goal. Self-sufficiency from a maintenance standpoint is defined as a period during which an organization will operate without resupply of spare parts or maintenance support from units that are not part of the maneuver force. To achieve a desired level of A_o, self-sufficiency has implications for the required levels of reliability and maintainability and the amount of spare parts and the maintenance capacity within a maneuver force.

From the pulse A_o requirement, between-pulse recovery assumptions, the self-sufficiency requirement, reliability requirements, combat damage rate assumptions, and maintainability requirements, the Army can determine the maintenance capacity in terms of personnel and equipment necessary at each echelon. Alternatively, these capacity requirements could be fixed if the desire is to constrain footprint to a certain level, and then one or more of the other requirements could be derived. Two simple footprint metrics—the number of maintenance personnel by echelon (or the maintenance ratio) and the lift requirements for equipment by echelon—should be sufficient. The number of personnel and the amount of equipment they have create demand for strategic lift, intratheater lift for nonlinear operations, and sustainment resources (water, food, fuel, food service personnel, medical personnel, force protection, etc.).

Total life cycle cost related to equipment sustainment should include annual maintenance support costs, initial spare parts provisioning, and any planned recapitalization or overhaul costs. It could also include design-driven costs when design decisions made solely to improve reliability or maintainability increase cost. Such design characteristics could include component or subsystem redundancy, more robust components, failure-prevention sensors, new materials, and built-in prognostic or diagnostic sensors and automation.

Once a concept is selected for full development, successful program development will require supplementing the broad, overarching goals (equipment pulse availability, maintenance footprint, self-sufficiency, and cost) with a set of detailed, “one-dimensional,” directly measurable requirements, based on the design assumptions of the concept, that can provide performance feedback and accountability throughout the development of the weapon system. For equipment sustainment, we have laid out a set of metrics (see Table S.2) along the functional dimensions of reliability, maintainability, fleet life cycle management, and supply support that, when employed in conjunction with the overarching goals, will indicate whether the program is making the desired progress.

Reliability is critical to all four overarching goals for two reasons: its effect on a force’s ability to accomplish missions and its effect on the resources, in terms of cost and footprint, required to restore and sustain weapon systems. The effect of reliability on mission accomplishment can be measured in terms of mean time between critical failures (MTBCF).[4] Although critical failures are of the most interest to operators because they can affect mission accomplishment, logisticians are concerned also with noncritical failures, because every failure produces resource demands. Thus it is imperative to measure mean time between maintenance actions (MTBM), which should be divided into MTBUM (unscheduled maintenance—what we think of when things break) and MTBSM (scheduled maintenance—what we think of when we bring our cars in for service or when we schedule a tank for overhaul), because they place different types of demands on the logistics system in terms of total resources and the ability to control when they occur.

Maintainability encompasses factors that affect the resources and time needed to complete repairs—including diagnosis and actual work—and capabilities that enable the logistics system to keep failures from affecting operations. Important questions are: How long does it take to do the repair work (“wrench-turning time”)? How much training is needed to complete repairs? What special tools and equipment are needed? The answers to these questions are affected,

[4]In this document, a critical failure is defined as a failure that makes a piece of equipment NMC.

Table S.2

Equipment Sustainment Functional Design Objectives and Metrics

Requirement Category	Equipment Sustainment Functional Design Objectives	Potential Standard Metrics for Defining Equipment Sustainment Requirements
Reliability	• Minimize mission-critical failures • Minimize maintenance requirements	• Standard form of MTBCF • MTBUM and MTBSM (by echelon)
Maintainability	• Prevent faults from becoming mission critical • Minimize downtime and cost • Minimize maintenance footprint and cost • Minimize maintenance footprint forward	• FFSP = Fn(FFP, FIR, FAR/NEOF Rate) • FFSD = Fn(FFD, FIR, FAR/NEOF Rate) • MTTR (by echelon) • MMH/UM (by echelon) • MMH/SM (by echelon) • Percent UM-crew, org, DS, GS
Fleet life cycle management	• Recognize life cycle costs up front • Account for life cycle operations	• Specify replacement/recap/ retirement schedule • Use estimate of reliability degradation in requirements analysis[a]
Supply support	• Minimize CWT • Minimize cost and footprint	• Local fill rate • Battle damage parts kit • Wholesale backorder rate • Percent of parts that are unique • Number and positioning of end item "spares" • Specify ALDT assumption[a]

[a]Critical assumptions that are necessary to determine the associated requirements.

in part, by how components and subsystems, whichever represent the desired level of replacement, are packaged within the total system. For example, how easy are they to get to (accessibility)? Another key maintainability area is the quality of troubleshooting procedures, whether fully automated through sensors and built-in tests, completely manual using paper technical manuals, or something in between. Quickly diagnosing a problem and getting the diagnosis right the first time can have a big effect on repair time, and the knowledge required for diagnosis determines who potentially can do maintenance.

Besides reducing total workload (total footprint and costs) and affecting workload distribution (footprint distribution), maintainability can play a role in reducing mission-critical failures, thereby improving pulse A_o, through prognostic technology that makes anticipatory maintenance feasible. The Army is making strong efforts to encourage the development and use of prognostics. The benefit of prognostics, though, is limited by the percentage of faults that can be successfully predicted, which should be measured if prognostics are viewed as a key part of a system concept.

Beyond affecting total force structure requirements, better maintainability can reduce footprint in the maneuver force. For example, if crews can repair a large percentage of faults, it would reduce both the overall need for maintainers as well as those in the maneuver force. To encourage this, a metric such as the percentage of unscheduled maintenance actions that can be accomplished by the crew could be used. Expressly designing new weapon systems to take advantage of new support concepts will further enhance their effectiveness and value.

Fleet life cycle management considerations include supportability degradation over time (how quickly does a system wear?) and the planned actions to maintain equipment performance at its design capability. Such requirements should be explicitly recognized up front in program planning and resource allocation. Computing a meaningful life cycle cost requires a reasonable, supportable estimate of life cycle length. Any needs for recapitalization or major overhaul programs based on this life cycle length should be explicitly forecast and recognized as a program requirement. Additionally, to the degree that reasonable means can be found to develop such estimates, degradation in system failure rates from wear over time should be accounted for—both in evaluating life cycle cost and determining reliability requirements.

In general, the spare parts supply chain that provides supply support is thought of as a broad system designed by the Army and Department of Defense (DoD) to support all weapon systems, so it is not generally thought of as an area that should have program-specific requirements. However, some systems are so significant or important to the Army's future that they may drive the entire support structure to begin a transition toward a new support concept. Similarly, a system may represent the first in a new generation of weapon systems that will necessitate a new support concept. From this vantage point, the support structure becomes integral to the total weapon system concept, and thus the Army may want to include in the program's requirements any changes to the structure that are critical to the concept's success.

Aside from this, program requirements always rest on some assumptions, often with regard to parts support. A key element of parts support that drives much of the differences in total repair time among weapon systems and units is local inventory performance. Programs should set local fill rate performance requirements that support any assumptions made in the requirements determination process. Similarly, a level of wholesale spare parts performance could be specified. And one element of weapon system design that the Army can use as a lever for reducing the resource requirements necessary to provide a given level of parts support is part commonality.

THE CRITICALITY OF ASSUMPTIONS

To measure progress toward achieving the overarching goals, each of the potential standard metrics identified for defining equipment sustainment requirements needs to be decomposed into its root-level design elements. For example, pulse operational availability (A_o), which measures the percentage of time a system is available over the course of a combat pulse, is a function of two root metrics: the mission-critical failure rate and the total time required to return items to mission-capable status. For pulse A_o to be a viable metric, these root metrics have to be reliably estimable.

Producing reliable estimates, and the generation of effective sustainment requirements in general, depends critically on good assumptions. For example, calculating pulse A_o requires an assumption about the average total broke-to-fix time. An unrealistically optimistic broke-to-fix time assumption will lead to a much lower reliability requirement to meet a given pulse A_o and would produce a misleading assessment of pulse A_o. When fielded, such a system would then experience lower-than-desired pulse A_o.

ASSESSING THE MERITS OF MAKING EQUIPMENT SUSTAINMENT REQUIREMENTS KPPs

Given that equipment sustainment is so vital to Objective Force concepts, the question arises as to whether, and if so which, equipment sustainment requirements should be designated as KPPs. Such designation brings about congressional oversight and can trigger legally required program reviews. In general, KPPs should be those *precise* requirements (i.e., thresholds) that—if not met—should cause the managing service or DoD to consider dramatically changing or even canceling a program. To ensure that their use is aligned with this KPP concept, DoD and the Army have designed policy criteria for determining which requirements should be KPPs in terms of both intent and practicality. The intent criteria define what the KPPs are meant to represent from a theoretical standpoint (e.g., basic definition of a system, mission essentiality, sole means of achieving critical operational goal), while the practical criteria ensure that KPPs are useful and supportable in practice (i.e., technical and financial feasibility, existence of a justifiable threshold, and reliable assessability).

All four of the overarching logistics and readiness goals—pulse A_o, footprint, self-sufficiency, and life cycle sustainment costs—have potential merit as KPPs from an intent standpoint, while one-dimensional functional design requirements have less potential because they are typically not the sole means of achieving a critical operational goal. For example, pulse A_o would be a viable KPP if the mission need dictates that some minimum level of availability is necessary for mission accomplishment (the point at which a force becomes combat ineffective).

What the Army must decide is whether, for a given weapon system, one or more of these sustainability requirements are absolutely essential for it to have value. In addition, it should be remembered that the KPP decision is ultimately about which *feasible* characteristics are essential. As such, some requirements might only achieve KPP potential if their feasibility reaches a level that provides a whole new type of operational capability that produces a step change in overall performance. Thus a desire for an aggressive advance in performance should be reflected as a KPP only if the entire value of a system depends on whether such an aggressive advance can be achieved. Otherwise, the Army should rigorously pursue an increase in the feasible level through research investments and contractor incentives without making the program depend on achieving the "stretch goal."

THE ENTIRE TRADESPACE SHOULD BE CONSIDERED DURING CONCEPT DEVELOPMENT

Initially, the Army considered Objective Force concepts that would have required combat pulse self-sufficiency without any maintenance personnel in the maneuver force. To make such a concept feasible would require very high FCS pulse reliability—such as 90 to 95 percent for a three-day high-intensity pulse—to achieve desired levels of equipment availability.[5] To meet this goal even at an individual system level (let alone a networked system of systems), the Army would have to achieve dramatic improvement over current levels of reliability. Equipment availability performance at the National Training Center (NTC) illustrates the type of improvement needed. A seven-day pulse is used for comparison to account for the higher operating tempo envisioned for an Objective Force pulse. In five NTC rotations during fiscal years 2000 and 2001, the seven-day pulse reliability for M1A2s averaged 58 percent, which means that it would require a fivefold increase in the MTBCF for M1A2s to achieve a 90 percent seven-day pulse reliability operating at a NTC-like level of intensity. Over the past two years, battalions with NTC prepositioned M1A1s and home-station M1A1s averaged only 37 percent seven-day pulse reliability (with home-station M1A1s actually performing below this average) and would therefore require about a ninefold increase in MTBCF to reach 90 percent pulse reliability. And if combat damage were added to these failures as part of an overall suitability analysis, it would potentially drive the need for even greater reliability. Numbers for the somewhat simpler M2 Bradley have been a little better but still present a substantial gap, with the reliability of relatively new Bradleys just one-fourth that needed to achieve 90 percent seven-day pulse reliability at NTC.

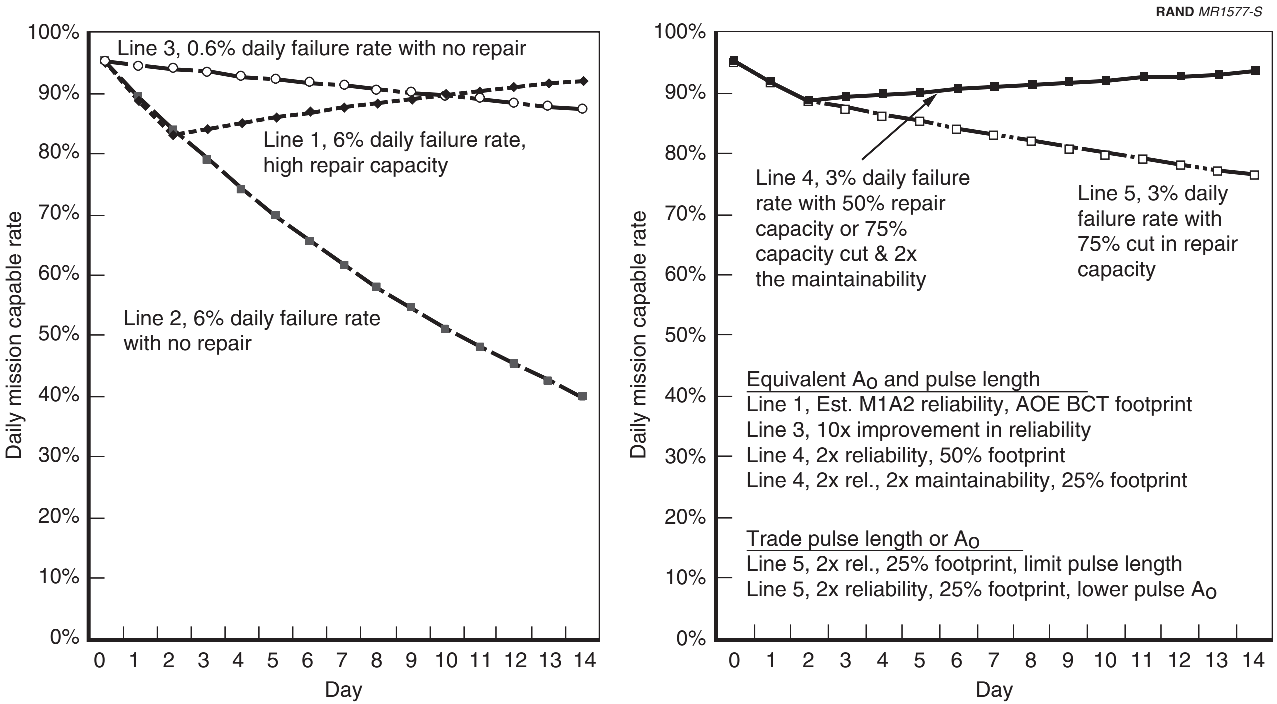
It will probably be difficult to close this gap in one generation of weapon system development, particularly because reliability im-

[5]Pulse reliability is defined as the probability that a system will remain mission capable for an entire combat pulse of defined length.

provements are typically process-driven rather than achieved through revolutionary “silver bullet” technological solutions. Dramatic improvements in reliability require improving a host of subsystems and thousands of dissimilar components (e.g., hydraulics, electronics, mechanical parts, and sensors). Technology solutions are certainly possible, but they could result in higher cost (expensive electronics, sensors, advanced materials, or redundancy) or weight (e.g., beefier suspension components), which could require tradeoffs in deployability or fuel efficiency.

The reliability gap between current systems and those needed to achieve the envisioned Objective Force concepts can begin to narrow if the Army were to allow for a broader “tradespace” to achieve availability goals by balancing overarching equipment sustainment goals against each other. For example, to achieve pulse A_o performance levels similar to those of the M1A2-equipped battalions at NTC over the course of a rotation (indicated by line 1 in Figure S.1)—but without any repair capability—an increase in reliability of an order of magnitude would be required, as illustrated by line 3. However, a similar pulse A_o could be achieved with a still substantial but more modest twofold MTBCF improvement and a 50 percent reduction in repair capacity (line 4). This balanced, and likely more feasible, approach would still reduce the maintenance footprint substantially. Moreover, maintainability improvements could further reduce the necessary repair capacity and footprint, perhaps to a level 75 percent lower than today’s, with this same MTBCF improvement. The Army should pursue aggressive improvements and innovations across several means of keeping equipment available, because it would be risky to rely on just one method to reach the high pulse A_o that the FCS should have while also reaching the other overarching goals. In fact, through this type of tradespace exploration, many in the Army are realizing the potential inherent in each of the sustainment levers. They have realized that this type of approach will probably be more effective than relying on reliability alone. Increasingly, attention is being focused more broadly on availability, with a recognition that reliability, maintainability, fleet life cycle management, and supply performance must all improve substantially to reach overall FCS goals.

In conclusion, adopting a standard set of potential requirements and associated metrics for consideration by every program will help the



Constant two-day repair time, constant failure rates

Figure S.1—Examining the Equipment Sustainment Requirements Tradespace

Army address the full spectrum of overarching goals and design objectives for equipment sustainment—provided that good assumptions are employed in the requirements determination process. In conjunction, the Army should review several overarching sustainability requirements to assess their desirability as KPPs. These requirements do not necessarily need to be limited to maintenance sustainment alone; they could include all sustainment requirements. Finally, beyond the option of designating one or more equipment sustainment requirements as KPPs, the Army should explore the potential value of additional policies and strategies to provide incentives for improved equipment sustainment performance.