Vehicle Systems Engineering and Integration Activities

A013 - Final Technical Report SERC-2012-TR-015-5

August 31, 2012

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Contract Number: H98230-08-D-0171 DO2, TTO2, RT0026

Report No. SERC-2012-TR-015-5
August 31, 2012

UNCLASSIFIED

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **31 AUG 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Vehicle Systems Engineering and Integration Activities**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Wayne State University,Mechanical Engineering,42 W. Warren Ave,Detroit,MI,48202**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**45**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Systems Engineering Research Center (SERC) under Contract H98230-08-D-0171. SERC is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology

RESEARCH TOPIC DESCRIPTION

TARDEC's mission is to conduct full service life cycle engineering support to the TACOM Life Cycle Management Command and the Program Executive Offices associated with it, for all DoD ground vehicle system acquisition and life cycle management. The TARDEC Systems Engineering Group is constantly looking for systems engineering methods, tools and procedures (MPT) to support this mission. TARDEC has found that many systems engineers from the automobile industry have significant experience in systems engineering (SE), but lack experience in some of the competencies deemed critical to systems engineering in the DoD workforce. This research will identify the differences between education needs of system engineers in both industry and the DoD workforce, and develop methods, processes and tools to address the shortfalls in educating SEs in the DoD workforce.

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1 Introduction

RT26 “Vehicle Systems Engineering and Integration Activities” was a SERC project sponsored by U.S. Army RDECOM/TARDEC in the period from 9/01/2010 to 6/30/2012. RT-26 was sponsored by the US Army RDECOM/TARDEC to develop Systems Engineering (SE) materials supporting the RDECOM/TARDEC SE Group. The project was executed with close coordination between WSU and RDECOM/TARDEC SE Group. During the course of the RT26 project, the RDECOM/TARDEC SE Group continued to develop and refine their SE practices and procedures. The specific focus and emphasis of the project evolved in coordination with developments in RDECOM/TARDECs SE practices and procedures.

RT26 was executed by Wayne State University (WSU) . The project consisted of four technical tasks:

1. Analyze TARDEC SE Needs
2. Identify SE Education Gaps
3. Conduct Case Studies Addressing the Needs and Gaps
4. Disseminate Results

Summaries of the results of each of these tasks follow. The major technical effort was devoted to two case studies, described in sections 2 and 3. Detailed research products are contained in the accompanying digital files, and referenced in the text. The two case studies were identified through the analysis of TARDEC SE needs and identification of SE education gaps. The first case study was a short (3 month) effort to develop formalization for physical reserve capacity requirements for versatile ground vehicles. The second case study was an extensive effort consisting of six phases over 15 months, to illustrate the evolution of the “Project Plan” for SE and project management, required by RDECOM OPORD 10-065 issued in August 2010, for Science and Technology (S&T) projects.

1.1 Task 1: Analyze TARDEC SE Needs

RDECOM/TARDEC is the research, development and engineering command supporting the AMC/TACOM life cycle management command (LCMC). TARDEC’s SE group supports TACOM by providing SE services and personnel for acquisition programs. TARDEC’s SE group develops SE policies, procedures, methods, tools and training materials within the context of RDECOM SE policy. TARDEC’s SE group performs SE for TARDEC Science and Technology (S&T) programs, and trains TARDEC personnel outside the SE group in SE practices.

From 2002 to 2009 the Future Combat Systems (FCS) acquisition program had been the Army’s capstone ground combat vehicle modernization program. TARDEC S&T projects were justified by supporting FCS. In 2009, the DoD cancelled the FCS program. Specific criticisms were cost growth, reliance on immature technologies in the expectation that they would become available in time for integration and fielding with the FCS, and a development timeline so long that the operational needs had changed so much that the FCS system requirements became irrelevant. In cancelling the FCS program, the Army was directed to eliminate the use of contractor Lead System Integrators (LSI), and instead to perform the LSI function internally.

In lieu of the FCS program, the TACOM was directed to develop a Ground Combat Vehicle (GCV) that would service the full spectrum of Army operations, would have the versatility to incorporate new capability packages in response to threat developments and/or technology maturation, would be a platform on which to base for a family of ground vehicle systems, and would be fielded in seven years.

The Army issued the set of requirements and Request for Proposal (RFP) for the GCV in November 2010. The GCV is now the Army's highest-priority ground vehicle modernization effort. The initial focus is for an Infantry Fighting Vehicle capable of providing protected mobility for a squad of 9 soldiers. The GCV concept is for a highly versatile system that will be able to integrate new, as-yet-undefined capability packages, and can be modified quickly and efficiently to create variant vehicles for different missions. Versatility as part of the acquisition strategy and incorporating versatility into the system requirement were novel actions. Traditionally, systems were developed to provide specific operational capabilities.

The GCV acquisition strategy created novel and unique challenges for SE with requirements intended to lead to a versatile and adaptable platform. Working with the TARDEC SE group, we identified that there was a critical SE need to develop approaches to formulate system requirements sufficient to ensure a versatile and adaptable platform. The focus of the case study was limited to requirements for reserve capacity. Modular design also contributes to versatility. Methods, procedures and tools (MPT) for design and analysis of modular architectures is an outstanding need, but was not included in the case study scope.

The first case study was designed to address this need. It consisted of an historical analysis of the design limitations that had to be overcome to achieve ground vehicle versatility, and from this derive what and how to require in terms of system performance. The first case study was limited in scope, and did not address evaluation of the level of versatility needed or methods to evaluate the versatility of a proposal.

The GCV acquisition program was also novel in that the requirements were "tiered": the first tier requirements were non-tradable, but the second and third tier requirements were tradeable, i.e., the bidder could select which to accept and which to reject, to meet cost and schedule objectives. Development time, unit production cost, and operating and sustainment costs had equal priority with the first-tier performance requirements. We identified a need for SE MPT for integrated cost, schedule and performance risk identification and analysis, to support requirements tradeoffs in the GCV program. This SE need was not selected for a case study.

In summary, we identified three critical needs for SE MPT, although only one was selected for a case study. The critical SE needs were:

- MPT to express requirements for infrastructure reserve capacity for versatile systems (selected)
- MPT to evaluate cost/schedule/performance risk tradeoffs in developing quantitative reserve capacity requirements for versatile systems (not selected)
- MPT for the design and analysis of modular architectures for complex systems with subsystem interactions on multiple dimensions (not selected)

1.2 Task 2: Identify SE Education Gaps

In August, 2010, RDECOM issued OPORD 10-065 "RDECOM Systems Engineering Policy" establishing an Organizational Standard Process (OSP) to apply rigorous Systems Engineering and Project Management to Science and Technology (S&T) projects, following the intent of the Weapon Systems Acquisition Reform Act (WSARA) of 2009. OPORD 10-065 includes a template and guidance for a Project Plan addressing Project Management (PM), SE and SE Management (SEM). OPORD 10-065 requires that the Project Plan be used on all Army Technology Objective-Demonstration (ATO-D) projects beginning in or after 1QFY11 (ATO-D projects are now called Technology Enabled Capability Demonstration – TECD – projects). The Project Plan is described as a living document to be maintained and updated over the course of the project to help assure quality and completeness of PM, SEM and SE activities. OPORD 10-065 requires each RDECOM component to have personnel who are trained and accountable to plan, coordinate, execute and assess the activities defined in the policy.

TARDEC initiated an effort to prepare to comply with the OPORD. The TARDEC SE Group has responsibility for developing methods, tools and procedures for applying the RDECOM Project Plan template to TARDEC TECD programs, to provide tools for project SE, and to provide trained personnel. TARDEC began developing internal policies, procedures, and guidelines to apply the OPORD, and began, in 1QFY11, to apply the OPORD policy to new TECD projects. Working with the TARDEC SE group, we identified a critical SE education gap being the lack of a specific example of a Project Plan as it evolves over the course of an S&T project to use for personnel training and as an example to follow.

The second case study was designed to address this gap by creating an example of the Project Plan, showing its evolution over the course of a project. TARDEC's policies and procedures to comply with the OPORD were being developed in parallel with the conduct of the second case study.

1.3 Task 3: Conduct Case Studies Addressing the Needs and Gaps

We conducted two case studies. The first case study, conducted in a 3-month period from January to March 2011, reviewed factors that limited and contributed to the versatility and adaptability of ground vehicle systems, developed a taxonomy of mechanical properties that are needed, and developed a formalism to express the requirements in a way that avoided unintentional conflicts with other performance requirements. The second case study, conducted over a 15-month period from April 2011 to June 2012, illustrated the evolution of the OPORD 10-065 Project Plan for a S&T project by producing snapshots of the Project Plan and accompanying technical documentation at six points in the project life cycle. The second case study was organized into six subcases, one for each of the six major technical reviews.

Ground Vehicle Versatility Systems Engineering Case Study

Ground vehicle versatility refers to the ability to produce variants of a vehicle to support the full Range of Military Operations from major combat operations to humanitarian assistance, across the spectrum of terrains and environments:

- Basing a product line of mission-variants on a common vehicle platform
- Integrating new capability packages addressing operational needs identified by commanders in the field, and to integrate new technologies as they mature.

Historically, the Army has produced versatile ground vehicles by an incremental, hit-or-miss evolutionary process in which vehicles are modified to overcome limiting physical characteristics.   Some vehicle designs turn out to be more conducive to expansion than others.

The objective of the case study was to develop guidelines and templates to define requirements that will lead to versatile ground vehicles at the initial design, bypassing the costly and time consuming process of incremental evolution. The resulting MPT had three components:

1. Identification of the critical physical system dimensions/parameters on which to require reserve capacity
2. Guidelines and methodology to analyze the physical architecture to identify subsystems for which to require reserve capacity
3. A grammar to express the requirements for reserve capacity, including derived interaction and compatibility requirements

The scope of this study was limited to defining requirements for physical characteristics that can limit or enable versatility. It did not include MPT to evaluate the tradeoffs among the level of reserve capacity, potential needs/risks, cost/schedule/performance tradeoffs. It did not include modular design and its role in system versatility. DoD acquisition regulation 5000.2 requires consideration of modular and open system architecture in system design. Existing guidelines and evaluation methods for modular design that are largely procedural and subjective (see Program Managers Guide: A Modular Open Systems Approach to Acquisition Version 2, Open Systems Joint Task Force, http://www.acq.osd.mil/osjtf/pmguide.html, 2004). Systems engineering research is needed to develop analytical and objective MPT tradeoffs between integral and modular design, modularity metrics, and MPT for modular physical and functional architectures are needed, but are outside the scope of this study.

The first case study is documented in section 2. The report on the case study is organized into four technical sections. Section 2.2 reviews the strategic motivation for versatile ground vehicles and DoD systems. Section 2.3 describes the systems engineering research approach. Section 2.4 presents the case studies and lessons for versatile design. Section 2.5 presents the findings and recommendations.

RDECOM OPORD 10-065 Project Plan Case Study

The Project Plan Case Study used as a concrete example a specific TARDEC S&T project that was nearing completion. The project preceded the OPORD 10-065 requirement, so no Project Plan had been prepared, but the project was current and the information was available with which to reconstruct what the Project Plan evolution would have been. The specific project was to develop a compact mast system to elevate antennas and a sensor pod for the Man-Transportable Robotic System (MTRS) PoR. The acquisition agent for the MTRS PoR is the Robotic System Joint Program Office (RS-JPO), under the TACOM Program Executive Office for Combat Support and Combat Service Support (PEO CS-CSS).

The case study produced snapshots of the Project Plan and accompanying technical annexes for each of the six major technical reviews:

1. Stakeholder Needs Review (SNR)
2. System Requirements Review (SRR)
3. System Functional Review (SFR)
4. Preliminary Design Review (PDR)
5. Critical Design Review (CDR)
6. Test Readiness Review (TRR)

The Project Plan template in OPORD 10-065 has 26 sections. Our case study included nine additional technical annexes with additional PM, SEM and SE content amplifying and detailing sections of the Project Plan

The scope of case study was to create a complete example application of the Project Plan policy over the life of an S&T project. We were not tasked to critique or make recommendations for the Project Plan template and guidance. In order to provide the most useful product for the TARDEC sponsor, we coordinated closely with the TARDEC SE group to ensure that our example would correspond to TARDEC's evolving policies, guidance and templates for implementing OPORD 10-065. The detailed reviews and feedback on the Project Plan iterations were invaluable for completing the case study and ensuring consistency with TARDEC SE policies and practices.

The second case study is described in section 3. Specific research products are contained in the accompanying files, and referenced in the text.

1.4 Task 4: Disseminate Results

The results of the first case study were presented to the SE community at the third SERC annual review. Further coordination of the first case study with RDECOM/TARDEC will take place at TARDEC's scheduling and request.

The snapshots of the Project Plan and technical annexes were provided to RDECOM/TARDEC for use as examples to help guide SE personnel in applying RDECOM OPORD 10-065 and associated TARDEC guidance. OPORD 10-065 specifies that each organizational Chief SE and project SE Leads will take the SE Advanced course (as well as the Technology Planning Continuous Learning Module offered by the Defense Acquisition University and be Systems Planning, Research Development and Engineering – Program Systems Engineer Level III certified). As of completion of RT-26 the SE Advanced course is still under development. The second case study artifacts – snapshots of the Project Plan and technical annexes – can potentially be used as part of the course material, however development of curriculum is outside the scope of the Systems Engineering Research Center (SERC) contract scope.

2 Case Study 1: Requirements Definition For Versatile Ground Vehicles

2.1 Introduction

Versatility in defense systems has become a strategic priority. Recent conflicts highlight the need for DoD to be able to field capabilities and systems responding rapidly to changing threats. The traditional material acquisition practice of defining specific point requirements for specific threats years before the system's initial use is unable to keep up with the pace of events and agility of adversaries. Systems of the future need to be flexible and adaptable to changing environments. Ground vehicle versatility is a central goal of Army Modernization. The primary benefit of ground vehicle versatility is the ability to rapidly field capabilities addressing operational needs identified by commanders in the field. Additional benefits include reduced logistics burden from common maintenance, equipment, and spares, reduced acquisition costs by retrofitting rather than new starts, lengthened inventory life, improved interoperability, reliability and maintainability.

Army material acquisition has successfully procured versatile ground vehicles. The M113, the Stryker, the HMMWV are good examples of vehicle product lines with many different mission-variants, and which have been quickly retrofitted to incorporate new or improved mission equipment. However these vehicles did not initially have this versatility, nor were they initially designed to meet versatility objectives. Instead, the vehicles evolved over time. When the vehicle was unable to accommodate a new mission configuration or equipment, the base design was changed to provide increased capacity. This eventually led to versatile platforms. Some basic designs were more conducive to being modified and expanded than others, leading to larger and more successful product lines.

The objective of this systems engineering initiative is to research methods, procedures and tools (MPT) to define ground vehicle requirements that will lead to versatile platforms, thereby avoiding the lengthy, inconsistent, hit-or-miss evolutionary processes. Historically, versatility has been achieved by trial-and-error discovery and correction of limiting factors. The goal of a systems engineering approach to requirements definition for versatile platforms is to design versatility in from the start, avoiding the lengthy and costly field-and-fix historical pattern.

Versatility is one of the core non-tradable requirements of the current Ground Combat Vehicle (GCV) program. The GCV performance specifications included requirements intended to provide the capacity for growth, flexibility and expansion. The objective of this effort is to provide a more complete and rigorous framework to define requirements for physical characteristics leading to versatility ground vehicle platforms. This research expands and refines the GCV approach to address other physical characteristics that limited the capacity for growth and expansion in the historical evolution of versatile ground vehicle platforms.

Two factors contribute to platform versatility: reserve capacity and modular design. This study is limited to requirements definition for reserve capacity in the physical characteristics of the design. The focus of this case study is to identify the dimensions on which to require reserve capacity and a formalism to express the requirement. MPT to recommend the level of reserve capacity or to evaluate cost/performance risks and tradeoffs are outside the scope of this initial case study. MPT to address tradeoffs between modular and integral design, metrics for modularity, and guidelines for modular design are outside the scope of this study.

The findings and recommendations include MPT to define the vehicle's physical architecture, a list of the critical physical characteristics than can limit or enable versatility, and generic, parametric statements of requirements for reserve capacity and subsystem compatibility. The MPT are independent of vehicle physical configuration, functions, and functional architecture. The formal results are illustrated with specific examples of the generic parametric requirements.

Ground vehicle versatility refers to the ability to produce variants of a vehicle to support the full Range of Military Operations from major combat operations to humanitarian assistance, across the spectrum of terrains and environments:

- Basing a product line of mission-variants on a common vehicle platform
- Integrating new capability packages addressing operational needs identified by commanders in the field, and to integrate new technologies as they mature.

Historically, the Army has produced versatile ground vehicles by an incremental, hit-or-miss evolutionary process in which vehicles are modified to overcome limiting physical characteristics. Some vehicle designs turn out to be more conducive to expansion than others.

The objective of this study is to develop guidelines and templates to define requirements that will lead to versatile ground vehicles at the initial design, bypassing the time consuming process of incremental evolution.

The scope of this study is limited to defining requirements for physical characteristics that can limit or enable versatility. Modular design and its role in system versatility are not addressed in this study. DoD acquisition regulation 5000.2 requires consideration of modular and open system architecture in system design. Existing guidelines and evaluation methods for modular design that are largely procedural and subjective (see *Program Managers Guide: A Modular Open Systems Approach to Acquisition Version 2*, Open Systems Joint Task Force, http://www.acq.osd.mil/osjtf/pmguide.html, 2004). Systems engineering research is needed to develop analytical and objective MPT tradeoffs between integral and modular design, modularity metrics, and MPT for modular physical and functional architectures are needed, but are outside the scope of this study.

The documentation is organized into four sections. Section 2.2 reviews the strategic motivation for versatile ground vehicles and DoD systems. Section 2.3 describes the systems engineering research approach. Section 2.4 presents the case studies and lessons for versatile design. Section 2.5 presents the findings and recommendations.

2.2 Motivation

Versatile systems are systems that can be quickly and efficiently adapted for different configurations and mission payloads. Benefits of versatile systems include

- Reduced time and cost to upgrade the system
- Reduced manufacturing change-over time and cost
- Reduced fielding time and cost
- Reduced logistics burden over the family of systems based on a common platform
- Faster and less costly response to adapt to changes in
- Threats
- Operational situations and needs
- DoD budget, force structure and system mix
- Technology capability developments and burdens

System versatility is a strategic objective of the Office of the Secretary of Defense for Research and Engineering: "The Office of the Deputy Assistant Secretary of Defense for Systems Engineering (ODASD(SE)) is leading the "**System 2020**" strategic initiative on behalf of the Office of the Assistant Secretary of Defense for Research and Engineering. Its objective is to fundamentally change the capabilities for the design, adaptation, and manufacture of defense systems. Recent conflicts have highlighted the need for DoD to be able to field capabilities and systems to respond rapidly to changing threats. The Department is exploring various approaches as alternatives to the typical practice of fielding systems that respond to specific point requirements that were defined years before the system's initial use. Current requirements-based systems tend to lead to "point solutions" designed to address specific threats, which in turn are assumed to evolve slowly in time. With the pace of events and agility of adversaries, systems of the future need to be far more flexible, adaptable to changing environments." (http://www.acq.osd.mil/se/initiatives/init_s2020.html).

The Army's vision for Force Modernization and force generation (AFOREN) emphasizes vehicle versatility as a way to response rapidly to changes in the operational environment and operational needs identified by commanders in the field. This vision and the central role of versatility were articulated in a presentation made in 2009 by LTG Vane (then Director of the Army Capabilities Integration Center and Deputy Commanding General, Futures) articulating the need for vehicle versatility to incorporate capability packages addressing needs identified by commanders in the field and to exploit technology spin-out.

The need for versatility is especially pronounced with respect to flexible armor solutions that can be tailored for the operational conditions. The Army's 2010 wheeled vehicle acquisition strategy observed that: "Without a front line, all vehicles proved to be targets of enemy fire, particularly emergent threats of improvised explosive devices that would drive the need for greater and greater protection levels across the truck fleet. The result was a fleet designed without the burden of armor protection and the corresponding automotive impacts that potential add-on armor would have on critical truck sub-components like the engine, suspension, transmission, and axles." The Long Term Armor Strategy response is to design and build tactical trucks with an A-kit, B-kit modular armor approach, allowing trucks to adjust their protection to the potential threats they will face in combat. The A-kit is designed to accept additional armor in the form of a B-kit. The A-kit/B-kit concept allows the Army flexibility in several areas: the armor B-kit can be taken off when not needed -- reducing unnecessary wear and tear on the vehicles; the Army can continue to pursue upgrades in armor protection -- adapting B-kits to match the threat; and the versatility of the B-kit enables the transfer of armor from unit to unit making armor requirements affordable by pooling assets versus buying armor that is only for one vehicle.

2.3 Objectives, Scope and Approach

The objective of this study is to produce methods, procedures and tools (MPT) to define ground vehicle requirements that will lead to versatile platforms, thereby avoiding the lengthy, inconsistent, hit-or-miss evolutionary processes. The goal is to provide a rigorous framework to define requirements for reserve capacity physical characteristics enabling platform versatility.

The specific objectives are to develop

1. a list of the critical physical characteristics than can limit or enable versatility,
2. MPT to define the vehicle's physical architecture for physical characterization, and
3. generic, parametric statements of requirements for reserve capacity and subsystem compatibility.

The MPT are independent of vehicle physical configuration, functions, and functional architecture. The formal results are illustrated with specific examples of the generic parametric requirements.

The research approach combines two elements. It builds on the approach to defining reserve capacity requirements taken in the GCV program. Versatility is one of the core non-tradable requirements of the GCV program, and the GCV performance specifications included some requirements intended to provide reserve capacity for growth, flexibility and expansion. It expands and refines the GCV approach to address other physical characteristics that limited the capacity for growth and expansion in evolution of historical versatile ground vehicle platforms. These case studies include the HMMWV, M113, Stryker, and several foreign tactical vehicles.

Two factors contribute to platform versatility: reserve capacity and modular design. The scope of this study is limited to requirements definition for reserve capacity in the physical characteristics of the design. MPT to address tradeoffs between modular and integral design, metrics for modularity, and guidelines for modular design are outside the scope of this study.

2.4 Cases and Lessons

2.4.1 GCV

The GCV is envisioned to be a class of vehicles that includes a range of specific platform capabilities by variant roles including an Infantry Fighting Vehicle (IFV), Reconnaissance, Command and Control, and General Support (e.g., Ambulance/Medical Evacuation, Engineering, Security/Convoy escort, and Armored Security). The GCV design is intended to

facilitate integration of new capability packages addressing operational needs identified by commanders in the field, and new technologies as they mature, replacing or complementing existing functional elements.
The GCV IFV Performance Specification contains a section on requirements for growth, expansion and flexibility. The requirements for excess capacity to handle increased mass addressed individual elements of the vehicle, not the vehicle system, e.g.

- The prime structures shall be designed for an X% weight growth
- The turret kinematic components shall be designed to meet all performance requirements with an X% weight growth
- The running gear shall be designed to meet all performance requirements with an X% weight growth
- The engine shall be designed to meet all performance requirements with an X% weight growth
- The thermal management shall be designed to meet all performance requirements with an X% waste heat rejection capacity.

These requirements statements assumed a functional architecture (prime structure, turret, running gear, etc.). Other sections of the Performance Specification used more general and concise statements of the form: The GCV shall perform its mission, meeting all performance requirements, under conditions XYZ. Ideally, the requirements definition can be expressed in a general way that is not tied to a specific functional architecture.

The Performance Specification also included requirements for reserve data processing capacity expressed in terms of data bus bandwidth, processor throughput, computer memory, additional card slots and I/O ports. Ideally, the requirements definition can be expressed in a general way that is not tied to a specific computer and data processing hardware approaches.

The GCV requirements addressed reserve card slots and I/O ports in each hardware item with a backplane architecture, but did not otherwise include requirements for reserve volume and surface area to mount additional components.

Lessons, insights, & observations: Versatility requirements include reserve capacity to accommodate increase in mass. The requirements should ensure that all subsystems whose performance is affected are able to accommodate the increased mass. The requirements should be expressed in terms of accomplishing functions to target levels, rather than the capacity of subsystems so that the requirements can be expressed independently of the allocated baseline (i.e., the allocation of physical subsystems to functions).

Vehicle Dynamics Data Sheets and Test Operating Procedures distributed with the GCV solicitation provide insight into additional physical characteristics that limit versatility. The Vehicle Dynamics Data Sheets contained the instruction "If the chassis has a turret and weapon system attached, and if these components will be moved to various fixed positions or continuously by a control system, then must be treated as individual rigid/flexible bodies with the same data requirements as the hull. Hull, turret, and weapon system should be parameterized as loaded for nominal operations with equipment, personnel, supplies, ammunition, etc. accounted for in the mass, CG and inertia data. The spatial location of the CG of the sprung hull, turret, elevating but not recoiling weapon body, and recoiling weapon body should be given with respect to a well defined point on each body. The mass and inertia matrix in a well defined coordinate system should be provided. Interconnectivity of adjacent bodies must be described. The axis of rotation between elevating and non-recoiling mass and the turret must be located. The locations of the hull of attachment points for roadarms and/or axels should be indicated."

The vehicle dynamics data sheets addressed physical properties were addressed in the data sheets that affect versatility, beyond those addressed in the Performance Specification. These factors directly affect vehicle mobility. Modifications to the vehicle will affect theses characteristics, and could reduce mobility unless the vehicle was required to meet all the mobility requirements despite some amount of change in these physical characteristics. These characteristics include:

- Mass
- Center of Gravity (CG) location
- Moment of inertia matrix
- Imbalance (distances between the GC location and the axes of rotation).

The vehicle dynamics data sheets also highlighted that these physical characteristics apply not just to the vehicle as a whole, but to each component that could be moved to alternate fixed positions or moved continuously.

Lessons, insights, & observations: Mass, CG location, angular moments, and imbalances are critical physical characteristics that can limit versatility. These characteristics apply to the overall vehicle and each component that rotates or can be set to different positions.

Test Operating Procedure "Physical Characteristics" TOP 1-2-504, 1972, U.S. Army Test and Evaluation Command, requires reporting dimensions, areas, volumes and carrying capacity by vehicle compartment.

Lessons, insights, & observations: Vehicle compartment volumes are critical physical characteristics that can limit versatility.

GCV solicitation included requirements for top-deck deconfliction: "The offeror's CAD Model as well as the narrative and intervisibility/interference plots submitted in response to L.4.1.1.3 and L.4.1.1.4, respectively, will be evaluated to assess the risks that the placement of weapons, sensors, communications and survivability subsystems meet the rooftop deconfliction requirements for Fields of View/Fields of Regard, elevation/depression angles, and ground intercepts as defined in Attachment 025." The requirement shows that surface space to mount components and for subsystem work envelope is a critical, potentially limiting resource.

Lessons, insights, & observations: Surface areas to mount components (with adequate work envelope without conflict) are a critical physical characteristic that can limit versatility.

2.4.2 HMMWV

HMMWV Evolution

AM General produces 15 different HMMWV variants with 44 interchangeable parts that are used in more than one position (see figure 1). The HMMWV is constructed on a steel frame with boxed frame rails and five cross members constructed from high-grade alloy steel. The aluminum body panels are riveted and bonded together with adhesives to provide additional strength. The body is designed to flex to accommodate off-road stresses.

Figure 1: HMMVW Variants

The history of the HMMWV evolution has been to increase the load. The A0 Series (1984-93) had 6.2L diesel engine with a 3 speed transmission, 2,500 to 3,632 lb payload, 7,700 lb gross vehicle weight. The A1 Series (1991-95) had an improved driveline and suspension, with 2,500 to 3,632 lb payload, 10,000 lb gross vehicle weight. The A2 Series (1994-present) had a 6.5 liter diesel engine, 4 speed electronic transmission, with 3,520 to 4,400 lb payload, 10,300 lb gross vehicle weight. The Expanded Capacity Vehicle (ECV, 1993-present) has a 6.5 liter turbo diesel engine, a suspension upgrade, is capable of carrying the armor upgrade kit, 1,800-5,100 lb payload, with gross vehicle weight 12,100. The wheel rating is 13,500 lbs.

Upgrade kits for the HMMWV series include add-on armor, an armor suspension improvement kit to handle the weight of the add-on armor, a winch kit, a central tire inflation kit, a water fording kit, a gunners cupola kit, and an auxiliary weapon station kit. The kits can be installed in the field. Some can be installed by the crew, some require special equipment and are installed by the maintenance unit.

A proposed ECV2 (not currently in production) has an improved 6.5 liter turbo diesel engine, a new transmission, improved suspension and frame for an increased armor capability, 1,800-4,400 lb payload and GVW 18,000 lbs. Other ECV2 enhancements include anti-lock brakes and active traction control, upgraded suspension, higher capacity drivetrain, heavier-duty tire/Wheel Assembly (22.5" rim, 40" tire), stronger frame (3 piece welded), integral "A" armor with attachment points for "B" armor kit, increased cab space (14 cubic feet), enhanced 6500 turbo diesel engine, higher capacity transmission, air induction system and exhaust systems.

Lessons, insights, & observations: To achieve versatility, vehicles need to be able to have reserve capacity in terms of volume, load bearing, and load mobility (propulsion, suspension, steering, braking, ground pressure). HMMWV evolved its versatility by increases to these. Note also that modifications are made at different maintenance levels. Versatility should be considered in terms of the maintenance level at which the changes can be made, i.e. unit, maintenance battalion, depot, and production line. Note also the use of standard interchangeable parts.

HMMWV Gunner's Cupola

The gunner's cupola includes the Gunner's Shield Kit (GSK, weight over 115 pounds) and the Gunner's Protection Kit (GPK, another 320 pounds), for a total of 430 pounds. The machine gun, its cradle, ammunition box, and other components add further weight. All the elements are shipped overseas as a kit where they are assembled in theater. It mounts on the standard HMMWV roof hatch.

The ring mount base allows the gunner to rotate the cupola a full 360 degrees. The Center of Gravity (CG) of the cupola is off-center from the axis of rotation, with the effect that additional force is needed to rotate the cupola "uphill" when the vehicle is on a slope. The force needed to overcome the combined effects of friction (mass times coefficient of resistance) and imbalance (mass times the distance between the CG and axis of rotation) is 106 pounds on a 30 percent slope.

To address this problem, engineers at the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) designed the Battery Powered Motorized Traversing Unit (BPMTU) to provide a HMMWV gunner with powered cupola operations. The BPMTU and its rear-mounted power supply, positioned to help counterbalance the weight of the gun, mount and shield.

Lessons, insights, & observations: The cupola had a large imbalance and angular moments. Both are limiting physical characteristics. The applicable requirements would need to be leveled on the rotating component, not the vehicle as a whole.

HMMWV Rollover

Another issue that surfaced as more and more mass was mounted on the top of the HMMWV was increased frequency of roll-over accidents. HMMWV roll-overs are the third leading cause of death in theater (after combat actions and IED explosions). Roll-over accidents increased with the advent of Up-Armored HMMWVs and the GPK/GSK. Factors combining to contribute to roll-overs include high CG, aggressive driving, and obstacle encounters (the HMMWV was designed to climb obstacles, not bulldoze them out of the way). Military safety teams investigated many of these accidents and looked at the need for roll-bars or other increased protection for the gunner position, to be factored into future equipment designs.

The additional armor and cupola raised the HMMWV's CG, increased the risk of roll-over. Increased moment of inertia degrades handling. On 9 November, 2010, the U.S. Marine Corps issued a request for information for the HMMWV roll-over stability control system (M6785411I5014). The announcement stated "Force protection requirements necessitate the addition of as much as 4800 pounds of armor to some HMMWV variants which significantly degrades the vehicle's dynamic performance. Additional payload or any off-road operational scenarios further diminish the vehicle's stability resulting in un-tripped, or maneuver-induced roll-over incidents. Un-tripped and maneuver-induced roll-over refers to events where roll-over is spontaneous and not initiated by contact between the tires and a tripping mechanism (such as a curb, a soft shoulder, a ditch, loose gravel, a guard rail, etc.). These events are often operator induced and/or exacerbated by excessive speed and large yaw inputs to the vehicle steering."

Lessons, insights, & observations: CG location and angular movements are limiting physical characteristics.

2.4.3 M113

M113 Development

The M113 Armored Personnel Carrier is in service with more than thirty armies throughout the world including the United States Army. More than 50,000 units have been produced covering 150 variants and versions during the last 20 years. Initial design work for the M113 dates back to 1956 when the US Army called for an APC cheaper and lighter than the M75 then under consideration. In response to these requirements, evaluation studies were undertaken on T113 of aluminum construction (3 prototypes) T117 of steel construction (5 prototypes).

The T113 was marginally lighter than the T117. The difference in weight was only one factor in the ultimate choice of vehicles since to obtain an equal degree of protection, aluminum armor had to be three times as thick as that of steel. However, rigidity of the aluminum hull was far greater which enabled a number of reinforcing structures to be eliminated, allowing more useable interior space.

Lessons, insights, & observations: Load bearing capacity of walls and structures are physical characteristic related t versatility.

M113 Variants

The evolution of the M113 Family of Vehicles (FOV) is illustrated in figure 2.

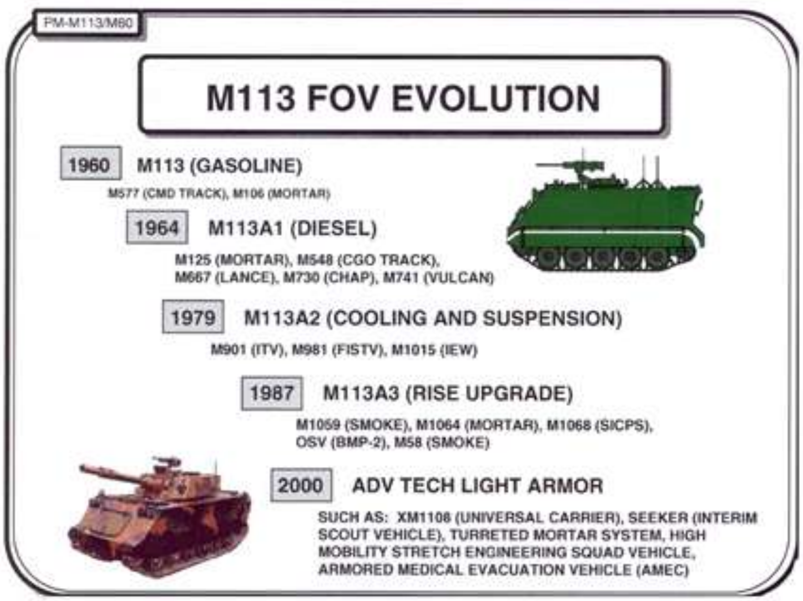

Figure 2: M113 Family of Vehicles Evoluttion

The first major upgrade came in 1964 with the introduction of the M113A1 package which replaced the original gasoline engine with a 212 horsepower diesel package. The new power train was soon incorporated into the existing vehicle family as the M113A1, M577A1, and M106A1, as well as several new derivative systems. Some of these new derivatives were based on the armored M113 chassis (the M125A1 mortar carrier and M741 "Vulcan" air defense vehicle) while others were based on an unarmored version of the chassis (including the M548 cargo carrier, M667 "Lance" missile carrier, and M730 "Chaparral" missile carrier).

Continuing modernization efforts led to the introduction of the A2 package of suspension and cooling enhancements in 1979. As with previous enhancements, these upgrades resulted in further proliferation of the FOV.

Today's M113 fleet includes a mix of these A2 variants together with other derivatives equipped with the most recent A3 RISE (Reliability Improvements for Selected Equipment) package. The standard RISE package includes an upgraded propulsion system (turbocharged engine and new transmission), greatly improved driver controls (new power brakes and conventional steering controls), external fuel tanks, and 200 AMP alternator with 4 batteries. Additional A3 improvements, include incorporation of spall liners and provisions for mounting external armor.

A major component of the RISE powertrain incorporated into the original M113A3 and M730A2 vehicles is the turbocharged 275 hp 6V53T engine from Detroit Diesel Corporation. Replacing the earlier 212 hp M113A2 engine with the turbocharged 275 hp model paved the way for improvements in performance as well as survivability enhancements such as the incorporation of spall liners and the possible addition of add-on armor. The improved performance and higher chassis load capacity has also opened the way for planners to consider additional M113 FOV derivatives.

The new engine packages have also been accompanied by improvements in the RISE transmission component. The RISE program was introduced with the X200-4 transmission from Allison Transmission. The X-200-4 transmission replaces the three component A2 vehicle drive train (transfer gear case, transmission, steering differential). The new transmission, designed to provide longer life than the previous configuration, has proven durability that is five times greater than the TX-100-1 transmission that it replaced.

The Model X200-4 Transmission went into production in 1986 for both the M113A3 and M730A2 RISE powered vehicles. It was designed for use in vehicles up to 32,000 pounds, a top speed of 41 mph, a maximum engine speed of 2800 RPM, and a power rating up to 275 hp.

Development of the Model X200-4A Transmission was prompted by the heavier derivative vehicles that will utilize the 300 hp and 350 hp engines noted above. The "4A" model features durability and performance improvements in 6 separate areas. It is capable of operating in vehicles up to 40,000 pounds with a top speed of 41 mph. Most importantly, the new model allows for vehicle power growth up to 350 hp. Because of its application from 275- 350 hp, the X200-4A has been phased into production and is the only transmission currently being produced for the M113A3 RISE variants.

Lessons, insights, & observations: Engine, transmission and suspension upgrades were needed to accommodate increased mass.

The M113A3+ mobile tactical vehicle light (MTVL) uses an M113 hull that is lengthened 34 inches and equipped with an additional road wheel (six on each side). The vehicle was developed as a "production-tooled demonstrator" with private-industry funding from United Defense.

Lessons, insights, & observations: The ability to modify the design to increase volume (length) and add a roadwheel to reduce the ground pressure due to increased mass are factors that enhance versatility. These changes are made at the production line, not unit, field or depot maintenance.

The M113A3+ ESV meets the Combat Engineer Squad requirements to transport an eight man engineer squad and all of their equipment while providing mobility and survivability equal to the maneuver force. The M113A3+ ESV supports the Engineer Squad in the performance of both offensive and defensive obstacle/counter-obstacle operations in support of the maneuver force. The vehicle can be adapted to fulfill other engineer mission objectives including: carrying the Volcano mine dispenser, the pathfinder marking system, and towing the MICLC trailer. The basic configuration provides:

- Ballistic survivability equal to the M2A2 IFV
- 30% more volume under armor than the M113A3
- 30% more payload capacity
- 50% greater cross country mobility (equal to M1/M2)

Lessons, insights, & observations: Payload capacity volume and weight are important physical characteristics for versatility.

2.4.4 STRYKER

There are two basic versions (the Infantry Combat Vehicle, ICV, and the Mobile Gun System, MGS) plus eight ICV variants (and seven up-armored versions with "double-Vee" hull for underbody blast protection):

- M1128 Mobile Gun System (MGS), adds a turret with 105 mm cannon
- M1126 Infantry Carrier Vehicle (ICV) with remote Weapon Station
- M1127 Reconnaissance Vehicle (RV)
- M1129 Mortar Carrier Vehicle (MC)
- M1130 Command Vehicle (CV)
- M1131 Fire Support Vehicle (FSV)
- M1132 Engineer Squad Vehicle (ESV)
- M1133 Medical Evacuation Vehicle (MEV)
- M1134 Anti-Tank Guided Missile Vehicle (ATGM)
- M1135 Nuclear, Biological & Chemical Reconnaissance Vehicle (NBC RV)

The Stryker was based derived from the Interim Armored Gun System, which was based on the Canadian LAV III, which was based on the Swiss MOWAG Piranha vehicle. When then turret and cannon were added for the MGS, the body was not strong enough to support the load and had to be redesigned. The ICV version of the Stryker could be configured for different mission variants because of the large volume in the passenger compartment and large upper deck area.

Slat side armor for RPG protection conflicts with external side storage. Figure 3 shows several configurations, including operational employment with the upper deck area consumed for stowage.

Figure 3: Syker Configurations

To meet urgent operational needs, Styker was tested, produced, fielded and fought in combat all in parallel. The operational tempo was much higher than planned for, the mix of on- and off-road user were in inverse ratio from the development operational mode expectations. The threat and operational environment were also much different from developmental expectations.

Lessons/insights/observations: Reserve load-bearing strength of the structure is needed for versatility, as are large "unused" volume, and reserve deck & exterior surface area.

2.4.5 PINZGAUER

The Swiss Pinzgauer platform is the basis for a variety of military and civilian utility vehicles in service with armed forces in 29 countries with at least 8 variants. The base vehicle (cab, powertrain, flatbed body) is produced in 4x4 and 6x6 configurations, and can be integrated with different shelter bodies and special equipment. It can be outfitted with standard wheel-tire running gear or tracked bogey wheels for greater mobility (see figure 4).

Figure 4: Pinzgauer Configurations

The first-generation Pinzgauer vehicle was manufactured in 710 4×4 and 712 6×6. BAE Systems introduced the Pinzgauer II, in 716 4×4 and 718 6×6 configurations. The new vehicle features an upgraded engine, enhanced suspension and flexible amour solutions. The height and width of the vehicle were increased for extra internal space.

Lessons/insights/observations: Large volume is needed for versatility. A design that can be stretched (4x4 and 6x6) enhanced versatility. Ability to swap wheels for bogey wheels to reduce ground pressure enhances ability to accommodate increased mass. Modular design of base vehicle with container or shelter is an approach to platform versatility.

2.4.6 YAK

The Rheinmetall Yak is an armored and mine-protected multi-purpose transport vehicle, based on the Swiss MOWAG Duro IIIP chassis. The Yak is based on two fixed components: (1) chassis with the cab, and (2) interchangeable modular shelter (see figure 5). It can be quickly modified to suit wide variety of missions.

Figure 5: Yak Flatbed and Flatbed with Shelter Module

Lessons/insights/observations: Large volume is needed for versatility. Modular design of base vehicle with container or shelter is an approach to platform versatility.

2.4.7 Boxer

The Boxer design is based on a modular structure selected to give the maximum flexibility for multi-purpose operation. Mission modules fit into the base vehicle. The base vehicle operates independently from the modules. The modules are interchangeable in less than one hour. The vehicle incorporates a high level of standardization and uses commercially proven automotive components. The 8x8 vehicle provides a load capacity to 8t and has an internal capacity of more than $14m^3$.

Add-on modular armor which provides protection against top attack bomblets, anti-tank and antipersonnel mines, 360° heavy machine gun fire and artillery fragments. Modular armor is sandwiched between the vehicle cell and the steel coat and all three elements are secured by fastening bolts.

Boxer has an integrated weapon station on which various weapons can be mounted, including 7.62mm or 12.7mm machine guns and 40mm grenade launcher.

Lessons/insights/observations: Modifications that can be made at the unit or field maintenance level contribute to versatility. Modular design of base vehicle with container or shelter, large free volume in shelter, and use of standard, interchangeable parts also contribute to versatility.

2.5 Findings and Recommendations

The physical characteristics of reserve capacity consist of mass properties, structural properties and computer/electronics properties (see figure 6). Critical mass properties are mass, CG location, angular moments, and imbalances. Critical structural properties are volume, internal and external surface mounting area, load bearing strength. Critical computer/electronics properties are bandwidth, throughput, I/O ports, card slots, and electrical power.

Mass Properties
- Mass
- CG location
- Angular moments
- Imbalances

Structure Properties
- Volume
- Surface mounting area
- Sructure load limit

Computer & Electronics Properties
- Memory
- Processor throughput
- Data bus bandwidth
- I/O ports
- Card slots
- Electrical power

Figure 6: Physical Characteristics for Reserve Capacity Enabling Versatility

The physical characteristics of reserve capacity apply to the vehicle as a whole, and its physical decomposition separated or separable parts (see the illustration in figure 7):

- Subsystems or components that can be moved to different fixed positions or continuously (e.g., chassis, turret, cupola, sensor pod, etc.)
- Groups of subsystems or components that can be moved independently but are physically connected (e.g. entire vehicle, chassis+turret, turret+cupola, etc.)
- Sequestered compartments (e.g., crew compartments, passenger/cargo compartments, engine compartment)
- Line Replaceable Units (LRUs), Line Replaceable Modules (LRMs), computer and electronics components

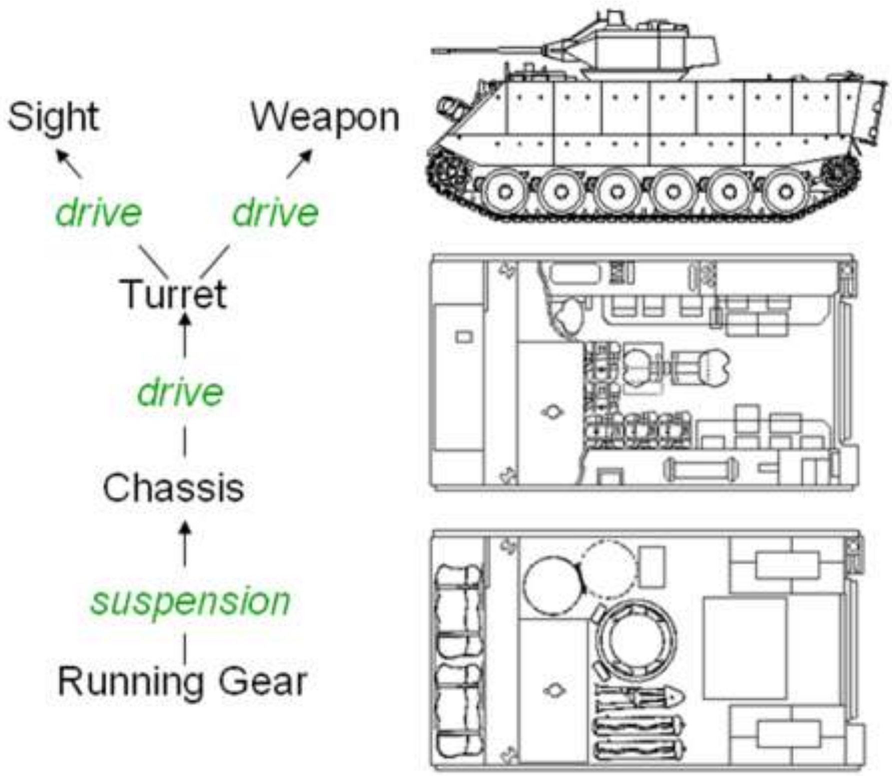

Figure 7: Illustration of Vehicle Physical Architecture Decomposition

The following examples illustrate requirements for reserve capacity:

- The system shall be meet all performance requirements with a change in vehicle CG location of 5% of vehicle dimension (i.e., longitudinal change 5% of length, lateral change up to 5% of width, elevation change up to 5% of height)
- The system shall be meet all performance requirements with a change in turret mass of 10%
- The turret shall have 20% upper deck surface area reserve capacity
- The chassis frame shall have 50% reserve load bearing capacity
- The computer/electronics hardware with backplane architecture shall have 10% reserve capacity for card slots
- The data buses shall have 50% reserve bandwidth
- The system and subsystems shall have 10% reserve capacity in memory, processing throughput, data bus bandwidth, expansion slots, and power supply in computer/electronics subsystems and components.
- The XYZ compartment shall have reserve volume able to add 1 component of size $H_1W_1L_1$ or 2 components of size $H_2W_2L_2$ or 3 component of $H_3W_3L_3$

The following four statements are the general form of the parametric requirements for physical characteristics enabling versatility:

- Subsystems shall be designed with compatible reserve capacities to enable the vehicle system to perform all functions effectively and meet system performance requirements with X% change in <mass property> of <decomposition element>
- The <decomposition component> shall have X% <structure property> reserve capacity
- The <decomposition component> shall have X amount of <structure property> reserve capacity
- The < computer/electronics component > shall have X% reserve capacity for <computer and electronics property>

The requirements statements are independent of the vehicle functions and functional architecture. The requirements for reserve capacity in physical characteristics are not independent of the physical decomposition. The amount of reserve capacity, by physical decomposition and physical characteristic are to be determined by the program systems engineers to meet operational requirements.

3 Case Study 2: Example Application of RDECOM Project Plan Template over the Course of a Science and Technology Project

In August 2010, TARDEC's parent agency RDECOM, issued new OPORD 10-065 "RDECOM Systems Engineering Policy" establishing an Organizational Standard Process (OSP) for rigorous Systems Engineering and Project Management to Science and Technology (S&T) projects, following the intent of the Weapon Systems Acquisition Reform Act (WSARA) of 2009. Appendix B to OPORD 10-065 contains a template and guidance to prepare and maintain the Project Plan to document Project Management (PM), SE and SE Management (SEM) organizations, procedures and status. OPORD 10-065 requires that the Project Plan be used on all Army Technology Objective-Demonstration (ATO-D) projects beginning in or after 1QFY11 (ATO-D projects are now called Technology Enabled Capability Demonstration – TECD – projects). The Project Plan is conceived as a living document to be maintained and updated over the course of the project to help assure quality and completeness of PM, SEM and SE activities.

The template and guidance for the Project Plan, Appendix B to OPORD 10-065, is contained in the accompanying file "Annex B to OPORD 10-065, SE Policy, RDECOM Project Plan Template.pdf". The guidance and template are generic, intended to be tailored and applied by all of RDECOM's subordinate command. TARDEC began an effort to develop more specific policy, procedures, guidance, forms and templates to comply with OPORD 10-065. TARDEC identified the need to produce an example of a completed project plan, and associated technical annexes, to provide a concrete example for training PM, SEM and SE personnel, an as an example to follow. The specific example is complements the descriptions of procedures and formats.

TARDEC policies, guidance, forms and templates for the Project Plan continued to develop and evolve in parallel with our activity to generate a specific example and it history of evolution. We held bi-weekly detailed technical reviews with TARDEC to help ensure that our example remained consistent with TARDEC's parallel development and refinement of policies and guidance. Our activity to apply TARDEC's policies and procedures provided feedback to TARDEC that in some cases resulted in refinement of the policies and procedures.

We created the example illustration of the Project Plan and its evolution for a current TARDEC S&T project that was nearing completion. The S&T project was the "MTRS Communications and Situation Awareness Mast" (MCSAM) project. MTRS stands for "Man Transportable Robot System." MTRS is a TACOM Program of Record (PoR). If successful, the MCSAM S&T project will produce a payload for the MTRS that will transition to the PoR at the end of the S&T project. The MCSAM project preceded OPORD 10-065. The Project Plan and associated technical annexes were not developed by the S&T project. We developed them in retrospect, as though they had been prepared during the course of the MCSAM project. We chose the

MCSM project, in consultation with TARDEC, because we had advised on the project and were familiar with the details and history of the project.

The Project Plan is conceived as a living document to be maintained and updated over the course of the project to help assure quality and completeness of PM, SEM and SE activities. To show how the project plan evolves over the course of a project, we generated snapshots of the Project Plan and associated technical annexes at six points in time over the course of the project corresponding to the six required technical reviews:

1. Stakeholder Needs Review (SNR)
2. System Requirements Review (SRR)
3. System Functional Review (SFR)
4. Preliminary Design Review (PDR)
5. Critical Design Review (CDR)
6. Test Readiness Review (TRR)

In addition to the main body of the Project Plan, we prepared examples of nine associated technical annexes:

Annex A: Readiness Levels and Assessment Criteria
Annex B: Technology Transition Plan
Annex C: Supplemental Checklists
Annex D: Technical Review Guidelines
Annex E: Technical Review Checklists
Annex F: Requirements Management Plan
Annex G: Configuration Management
Annex H: Risk Management Plan
Annex I: Backup Material

The information contents of the Project Plan main body and associated technical annexes are described in the remainder of this section. Files containing the six instances of the Project Plan and associated technical annexes are contained in the accompanying files, and referenced in the descriptions.

3.1 Project Plan Main Body

The six snapshots of the Project Plan main body for the MCSAM project are contained in the following files:

PP Main MCSAM SNR PP.docx
PP Main MCSAM SRR PP.docx
PP Main MCSAM SFR PP.docx
PP Main MCSAM PDR PP.docx
PP Main MCSAM CDR PP.docx
PP Main MCSAM TRR PP.docx

The template and guidance for the Project Plan, Appendix B to OPORD 10-065, is contained in the accompanying file "Annex B to OPORD 10-065, SE Policy, RDECOM Project Plan Template.pdf". The outline of the Project Plan is:

1 Purpose of Project Plan
2 Project Purpose & Scenario
3 Project Background
4 Project Scope Statement
5 Guidance Documents
6 Project Technical Status as of Date of Project Plan
7 Stakeholders and Responsibilities
8 Stakeholder Communication/Coordination
    8.1 Stakeholder Coordination Plan
    8.2 Conflict Management
    8.3 Organization Chart
    8.4 Meetings and Status Reporting
    8.5 Technical Reviews
9 System Capabilities, Requirement, and Design Considerations
10 Acquisition Strategy
11 Life Cycle Model
12 Resources and Schedule
    12.1 WBS Activities
    12.2 Schedule
    12.3 Basis of Estimate / Work Product Size Estimates
    12.4 Effort, Staffing, and Cost Estimate
    12.5 Engineering Environment
    12.6 Contractor Efforts
13 Project Training Needs
14 New Technology Pilots and Process Pilots
15 System Engineering Process
    15.1 Stakeholder Requirements Definition
    15.2 Requirements Analysis
    15.3 Architectural Design
    15.4 Implementation
    15.5 Integration
16 Product Evaluation
    16.1 Peer Reviews
    16.2 Verification
    16.3 Validation
17 Transition
18 Requirements Management
19 Interface Management

20 Process Assurance Plan
21 Configuration Management
22 Data Management
23 Project Deliverables/Work Products
24 Simulation Support Planning
25 Risk Management Plan
    25.1 Risk Management Process
    25.2 Risk Identification & Profile
26 Measurement and Analysis
    26.1 Technical Objectives
    26.2 Technical Analyses
27 Causal Analysis and Resolution
28 Decision Analysis and Resolution
29 Corrective Action Tracking
30 Security
31 Data Rights
32 List of Acronyms

3.2 Annex A: Readiness Levels and Assessment Criteria

This annex contains the definitions, descriptions, and verification questions for technical, integration, and manufacturing readiness levels (TRL, IRL and MRL). S&T projects are intended to advance the readiness levels of the subject technologies, to the point where the technology is ready for transition to a PoR. The MCSAM project had specific requirements to achieve TRL-7, IRL-7 and MRL-7 by the end of the project.

Annex A was prepared one time for the SNR. It was not changed or updated in subsequent reviews. Annex A is contained in the file "PP Annex A Readiness Levels.docx." The definitions, descriptions, and verification questions for the readiness levels were provided by TARDEC.

3.3 Annex B: Technology Transition Agreement

The Technology Transition Agreement is the agreement between the development agent and the acquisition agent for the target PoR. In the MCSAM project, the development agent was TARDEC and the acquisition agent was TACOM RS-JPO. The MCSAM project had a well-defined transition program and partner. TARDEC engaged in the MCSAM project at the request of RS-JPO. In this respect, the MCSAM project is somewhat atypical for S&T projects, and its Technology Transition Agreement is more specific and detailed than others might be.

The Technology Transition Agreement was developed initially for the SNR, then updated once at SRR. The two snapshots of the Technology Transition Agreement for the MCSAM project are contained in the files:
PP Annex B MCSAM Technology Transition Agreement SNR.docx
PP Annex B MCSAM Technology Transition Agreement SRR.docx

The contents of the Technology Transition Agreement are:

1. Introduction
   - 1.1 Purpose/Scope
   - 1.2 Summary
2. Basic Transition Agreement
   - 2.1 Technology Name
   - 2.2 Technology Description
   - 2.3 Target Acquisition Program
   - 2.4 Acquisition Program Technology Need
   - 2.5 Integration Strategy
   - 2.6 Program Manager/Project Officer
   - 2.7 Technology Manager
   - 2.8 Capability Requirement Basis
   - 2.9 Resource Sponsor/Requirements Officer
3. Technical Details And Programmatics
   - 3.1. Current Status of Technology
   - 3.2. Technology Development Strategy
   - 3.3. Transition Readiness
   - 3.4. Program Plan
4. References

Appendix A: Operational Requirements Document (ORD)

1. General Description of Operational Capability
   a. Overall Mission Area
   b. Type of System Proposed
   c. Operational Concept
   d. Support Concept
   e. Mission Need Statement Summary (MNS)
2. Threat
3. Shortcomings of Existing Systems
4. Capabilities Required
   a. System Performance
   b. Logistics and Readiness
   c. Critical System Characteristics
5. Integrated Logistics Support
   a. Maintenance Planning
   b. Support Equipment

    c. Human Systems Integration
    d. Computer Resources
    e. Other Logistics Considerations
6. Infrastructure Support and Interoperability
7. Force Structure
8. Schedule Considerations

3.4 Annex C: Supplemental Checklists

The Supplemental Checklists are spreadsheets forms. They are the means for documenting and tracing relationships among stakeholder needs, system requirements, system functions, configuration items and subsystems, and testing requirements. The checklist format was provided by TARDEC, and instantiated for the MCSAM project by WSU.

The Supplemental Checklists are updated at each technical review with (1) and new worksheet for the current review, and (2) updates to the sections filled in at the previous reviews. The updates illustrate the addition and refinement of needs, requirements and functions.

The Supplemental Checklists for the MCSAM project are contained in the following files:

PP Annex C MCSAM Supplemental Checklists SNR.xls
PP Annex C MCSAM Supplemental Checklists SRR.xls
PP Annex C MCSAM Supplemental Checklists SFR.xls
PP Annex C MCSAM Supplemental Checklists PDR.xls
PP Annex C MCSAM Supplemental Checklists CDR.xls
PP Annex C MCSAM Supplemental Checklists TRR.xls

The Supplemental Checklists consist of the following five worksheets (one worksheet serves both PDR and CDR):

Project Needs Checklist (SNR)
Project Requirements Checklist (SRR)
Functional Baseline Checklist (SFR)
Allocated/Product Baseline Checklist (PDR & CDR)
Test Readiness Review Checklist (TRR)

Project Needs Checklist (SNR). At SNR, each project need is documented on a row with the following information fields:

Unique ID Number
Rank Order
Project Need
Rationale
Type
Source Document

Link to Other Need Numbers
Agreed to by All Parties Check
Date Added or Changed

Project Requirements Checklist (SRR). At SRR, each project requirement is documented on a row with the following information fields:

Unique Requirement Number
Priority
Project Requirement
Type
Derived from Need Type
Rationale
Source Document
Validation Method/Test
Linked to Needs Numbers
Linked to Other Requirement Numbers
Singularized Check
Achievable Check
Affordable Check
Verifiable Check
Unambigious Check
Stated as a Shall Check
Agreed to by All Parties Check

Functional Baseline Checklist (SFR). At SFR, each function is documented on a row with the following information fields:

Unique Number
Level
System Level Requirements Linked
Function
Definition
Rationale
Derived Functional Requirements
Preconditions for Testing
Additional Interface Requirements
Notes & Outstanding Issues
Singularized Check
Achievable Check
Affordable Check
Verifiable Check
Unambigious Check
Stated as a Shall Check
Agreed to by All Parties Check

All Columns Filled Check

Allocated/Product Baseline Checklist (PDR & CDR). At PDR, each configuration item is documented on a row with the following information fields:

Unique Number
Level
System Level Requirements Linked
Configuration Item Name with Subsystem Product Specifications
Definition
Rationale
Validation Method/Test
Linked Interface Control Documents (ICDs)
Notes & Outstanding Issues
Singularized Check
Achievable Check
Affordable Check
Verifiable Check
Unambigious Check
Stated as a Shall Check
Agreed to by All Parties Check
All Columns Filled Check.

At CDR, the following additional fields are added:

ICDs Completed Check
Build Drawings Completed Check
75-90% Manufacturing Quality Check
Specifications Achievable with the Current Design Check.

Test Readiness Review Checklist (TRR). At TRR, each test is documented on a row with the following information fields:

Unique Test Number
Requirement Description
System Configuration Item or Subsystem
Test Procedure
Testing Preconditions or Equipment Needed, Duration of Scheduled Test and Date
Number of Test Articles
Safety Risks
Test Site
Site Properly Resourced Check
Site Properly Staffed Check
Site Booked and Available and Booked Check
Passing Test Risk, Expected Results
Pass / Fail Criteria

Notes & Outstanding Requirements
All Columns Filled Check

After the tests are completed, two additional fields are added: Test Passed or Failed, Actual Testing Results.

3.5 Annex D: Technical Review Guidelines

The Technical Review Guidelines were documented once at the SNR, and were not updated for the subsequent technical reviews. The Technical Review Guidelines are contained in the file "PP Annex D Technical Review Guidelines.docx", and were provided by TARDEC. The guidelines contain a section for each of the six required technical reviews, the following contents:

SNR
Purpose of review
Problem identification
Stakeholder identification
Documenting stakeholder needs
Stakeholder needs management
Entrance criteria checklist
Conducting the review
Review exit criteria
Definitions of terms

SRR
Purpose of review
Requirements analysis
Documenting requirements
Requirements management
Entrance criteria checklist
Conducting the review
Review exit criteria
Definitions of terms

SFR
Purpose of review
Functional decomposition
Linking system requirements to applicable functions
Developing lower level functional requirements
Documenting lower level functional requirements
Lower level requirements management
Developing other supporting documentation

Entrance criteria checklist
Conducting the review
Review exit criteria
Definitions of terms

PDR
Purpose of review
Completing the Work Breakdown Structure & identifying configuration items
Linking functions to subsystem configuration items
Developing internal and external interface control documents
Documenting lower level functional requirements
Creating subsystem product specifications
Subsystem product specification management
Technology maturity assessment & creating preliminary engineering drawings
Developing other supporting documentation
Conducting the review
Review exit criteria
Definitions of terms

CDR
Purpose of review
Completing product baseline information started at PDR
Completing the detailed design
System and subsystem product specification management
Completing the validation and test plan
Developing other supporting documentation
Conducting the review
Review exit criteria
Definitions of terms

TRR
Purpose of review
Completing test and evaluation specifications
Verifying system requirements are linked to testing specifications
Completing the Test and Evaluation Master Plan
Verifying testing resources identified, agreed to procedures and available
Failure reporting, processing for corrective action and/or deviation authorization
Other supporting documentation
Conducting the review
Review exit criteria
Definitions of terms

3.6 ANNEX E: TECHNICAL REVIEW CHECKLISTS

The technical review checklists document the status assessment, status description, expected completion date, and documentation references for entrance criteria, conduct of the review, and exit criteria for each of the six required technical reviews. The technical review checklists are the means for documenting and tracking execution of the technical reviews. The Technical Review Checklists are worksheets, with one sheet for each technical review. The MCSAM Technical Review Checklists are contained in the following files:

PP Annex E MCSAM Technical Review Checklists SNR.xls
PP Annex E MCSAM Technical Review Checklists SRR.xls
PP Annex E MCSAM Technical Review Checklists SFR.xls
PP Annex E MCSAM Technical Review Checklists PDR.xls
PP Annex E MCSAM Technical Review Checklists CDR.xls
PP Annex E MCSAM Technical Review Checklists TRR.xls

The formats of the technical review checklists were provided by TARDEC, and instantiated for the MCSAM project by WSU.

3.7 ANNEX F: REQUIREMENTS MANAGEMENT PLAN

The Requirements Management Plan was prepared one time at SNR, and was not updated. The Requirements Management Plan annex is referenced in the Project Plan main body, section 18, Requirements Management. The Requirements Management Plan annex F is contained in the file "PP Annex F MCSAM Req Mgmnt Plan.docx". The basic plan was provided by TARDEC and modified for the MCSAM project by WSU. The Requirements Management Plan annex contains the following content:

- 1.0 Introduction
  - 1.1 Background
  - 1.2 Mission
  - 1.3 Project Organization Description
- 2.0 Process
  - 2.1 Process Flow
- 3.0 Procedures
  - 3.1 Overview
  - 3.2 Requirements Management Process
    - 3.2.1 Create/Update Change Proposal
    - 3.2.2 Compile Change Proposals
    - 3.2.3 Requirements Change Control Review
    - 3.2.4 Update Requirements Baseline And Release New Requirements Baseline
    - 3.2.5 Update Project's Doors Module(s)
- 4.0 Metrics

4.1 Quarterly And Cumulative Tracking Of Proposals
4.2 Percentage Of Proposals Approved

3.8 Annex G: Configuration Management

The Configuration Management Plan was prepared one time at SRR, and was not updated. The Configuration Management Plan annex is referenced in the Project Plan main body, section 21, Configuration Management. The Configuration Management Plan annex G is contained in the file "PP Annex G MCSAM Config Mgmnt Plan.docx". The basic plan was provided by TARDEC and modified for the MCSAM project by WSU. The Configuration Management Plan annex contains the following content:

- 1.0 Introduction
  - 1.1 Scope
  - 1.2 Project Organization Description
- 2.0 Reference Documents
- 3.0 Concept of Operations and Acquisition Strategy
  - 3.1 Configuration Management Concept of Operations
    - 3.1.1 Configuration Management Objectives
  - 3.2 Configuration Management Acquisition Strategy
    - 3.2.1 Baselines
- 4.0 Organization
  - 4.1 Core Team
  - 4.2 Supporting IPTs, Sub-IPTs, and APMs
  - 4.3 Change Control Board
  - 4.4 Roles and Responsibilities
- 5.0 Data Management
  - 5.1 Configuration Item Naming Convention
  - 5.2 Format and Storage
- 6.0 Configuration Management Process
  - 6.1 Configuration Item Identification
  - 6.2 Configuration Item Change Process
    - 6.2.1 Configuration Manager Process Responsibilities
    - 6.2.3 Metrics
    - 6.2.4 Audits
    - 6.2.5 Future Configuration Management Planning

3.9 ANNEX H: RISK MANAGEMENT PLAN

The Risk Management Plan was prepared one time at SRR, and was not updated. The Risk Management Plan annex is referenced in the Project Plan main body, section 25, Risk Management. The Risk Management Plan annex H is contained in the file "PP Annex H MCSAM Risk Mgmnt Plan.docx". The basic plan was provided by TARDEC and modified for the MCSAM project by WSU. The Risk Management Plan annex contains the following content:

- 1.0 Approach
  - 1.1 Introduction And Overview
- 2.0 Organization, Roles, And Responsibilities
  - 2.1 Chief Systems Engineer
  - 2.2 Project Lead
  - 2.3 Project Systems Engineering Lead
  - 2.4 Risk Review Board
  - 2.5 Risk Manager
  - 2.6 Risk Recon Tool Administrator
- 3.0 Risk Management Reviews
  - 3.1 Risk Ipt Meetings
- 4.0 Risk Management Process
  - 4.1 Risk Identification
  - 4.2 Risk Analysis And Ranking
  - 4.3 Risk Mitigation Planning
  - 4.4 Risk Monitoring
  - 4.5 Integration With Other Program Management Processes
- 5.0 Risk Management Training

3.10 ANNEX I: BACKUP MATERIAL

The Backup Material annex contains additional project data supporting and referenced in the Technical Review Checklists. The Backup Material annexes are contained in the following files:
PP Annex I MCSAM Backup Material SNR.docx
PP Annex I MCSAM Backup Material SRR.docx
PP Annex I MCSAM Backup Material SFR.docx
PP Annex I MCSAM Backup Material PDR.docx
PP Annex I MCSAM Backup Material CDR.docx
PP Annex I MCSAM Backup Material TRR.docx

The Backup Material document contains a section for each of the six required reviews (SNR, SRR, SFR, PDR, CDR, TRR) with the following subsections:

1 Major Developments

2 Major Issues
3 Major Risks, Conditions, Consequences And Mitigations
4 Major Project Artifacts List
5 Major Objectives Prior To The Next Technical Review
6 Major Lessons Learned
7 Major Corrective Actions

APPENDICES

1. Project Plan Template
2. MTRS Communications and Situation Awareness Mast (MCSAM) Project Plan V6.1
3. MTRS Communications and Situation Awareness Mast (MCSAM) Project Plan Backup Materials
4. Project Plan Annex A Readiness Levels
5. Project Plan Annex B MCSAM Technology Transition Agreement
6. Project Plan Annex C MCSAM Supplemental Checklists
7. Project Plan Annex D Technical Review guidelines
8. Project Plan Annex E MCSAM Technical Review Checklists
9. Project Plan Annex F MCSAM Requirement Management Plan
10. Project Plan Annex G MCSAM Configuration Management Plan
11. Project Plan Annex H MCSAM Risk Management Plan