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T AND E GUIDELINES FOR GROUND VEHICLE SYSTEMS

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T&E GUIDELINES FOR GROUND VEHICLE SYSTEMS

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FOREWORD

This report is an outgrowth of the work of the Defense Science Board Task Force on Test and Evaluation, and the checklists herein have been derived from the study of past major weapon system programs.

The T&E expert in reading this volume will find many precepts which will strike him as being too obvious to be included in checklists of this type. These items are included because examples were found where even the obvious has been neglected, not because of incompetence or lack of personal dedication by the people in charge of the program, but because of financial and temporal pressures which forced competent managers to compromise on their principles. It is hoped that the inclusion of the obvious will prevent repetition of the serious errors which have been made in the past when such political, economic and temporal pressures have forced project managers to depart from the rules of sound engineering practices.

In the long run, taking short cuts during T&E to save time and money will result in significant increases in the overall costs of the programs and in the delay of the delivery of the corresponding weapon systems to the combatant forces.

T&E GUIDELINES FOR GROUND VEHICLE SYSTEMS

The checklist items presented here are specifically applicable to ground vehicle testing and evaluation. It is suggested that the user of this volume also refer to the Report of the Defense Science Board on Test and Evaluation which contains general checklist items also applicable to this system T&E program. The checklist items presented here are organized into time phases of the acquisition process oriented to the DSARC cycle.

The checklists cover various aspects of the major activities that should be underway during a given time period. Hence, a checklist might cover the (1) evaluation of work that occurred in the previous phase, (2) conduct of tests planned in the previous phase and executed in the subject phase, and (3) plans and other preparatory actions for test schedules to be conducted in a subsequent phase. For reasons such as this, items on some subjects, such as development test plans, may appear in more than one phase. In addition, since the Services and the DSARC have flexibility in deciding how rapidly to progress in the Validation Phase, there may be cases where the Request for Proposals (RFPs), proposal evaluations, source selections, or contract negotiations may occur after the DSARC approves full-scale development instead of before. For this reason, it is recommended that previous checklists in the Validation Phase be reviewed when entering the Full-Scale Engineering Development Phase. The following are the phases used in this report.

CONCEPTUAL PHASE

The checklist items in this phase are for guidance in evaluating T&E activities during the Conceptual Phase of the acquisition of the system. This phase (often research and exploratory development) precedes the first DSARC milestone and is focused on the development of a weapon system concept that offers high prospects of satisfying an identified military need.

Although not called for in DoD Directive 5000.1 specifically, the objectives of this phase should be:

1. To verify that there is a military need for the proposed system.
2. To demonstrate that there is a sound physical basis for a new weapon system.
3. To formulate a concept, based on demonstrated physical phenomena, for satisfying the military need.
4. To show that the proposed solution is superior to its competitors in terms of potential effectiveness, probability of success, probable cost, impact on the U.S. military posture, and development risks.
5. To analyze the technology outlook and the military need to show that it is better to start advanced development now rather than to wait for future technological improvements.
6. To identify the key risk areas and critical issues that need to be resolved before full-scale development is initiated.

The most important product of this phase is the Development Concept Paper (DCP) or its equivalent. The DCP defines program issues, including special logistics problems, program objectives, program plans, performance parameters, areas of major risk, system alternatives, and acquisition strategy.

VALIDATION PHASE

The checklist items in this phase are for guidance in conducting T&E during the Validation Phase (the time between when the DSARC recommends approval of the DCP for the first time and when the DSARC recommends full-scale development of the system).

While these objectives are not spelled out in the DoD Directive 5000.1, the objectives of the Validation Phase should be to confirm:

1. The need for the selected system in consideration of the threat, system alternatives, special logistics needs, estimates of development costs, preliminary estimates of life cycle costs and potential benefits in context with overall DoD strategy and fiscal guidance.
2. The validity of the operational concept.
3. That development risks have been identified and solutions are in hand.
4. Realism of the plan for full-scale development.

In the pursuit of the above objectives, it is likely that advanced development T&E will be conducted to resolve issues. In some cases, an RFP for full-scale engineering development will be prepared, proposals will be received and evaluated, and contracts negotiated in preparation for seeking DSARC approval for the next phase. Therefore, some checklist items are included to help ensure that this work properly reflects the T&E interests in this and subsequent phases. For example, the RFP must include adequate guidance to ensure that sufficient resources and time are available so that engineering effort can properly support the initial DT&E with hardware, software, technical data, and training.

The primary emphasis of OSD/T&E activities is with items 3 and 4 above. Special attention should be given to the planning of IOT&E activity as it is incorporated in the engineering development contract as well as the DT&E associated with addressing the critical issues and areas of major risk identified in the DCP.

FULL-SCALE ENGINEERING DEVELOPMENT PHASE

The checklist items contained in this phase are for guidance in conducting T&E during the Full-Scale Engineering Development Phase. This includes the major DT&E and the IOT&E conducted prior to the major production decision. By this time, the system is well defined and is becoming a unique item and, hence, sound judgment must be applied in using these checklist items.

To enter the Engineering Development Phase, the DSARC will have:

- Confirmed the need in consideration of the threat, alternatives, logistic needs, cost, and benefits.
- Identified development risks.
- Confirmed the realism of the development plan.

Given the above, the primary objectives of the DT&E should be to:

1. Demonstrate that the engineering and design and development process is complete and that the design risks have been minimized (the system is ready for production).
2. Demonstrate that the system will meet specifications.

The primary objectives of the IOT&E should be to:

3. Assess operational suitability and effectiveness.
4. Validate organizational and employment concepts.
5. Determine training and logistic requirements.

In addition, the validity of the plan for the remainder of the program must be confirmed by the DSARC before substantial production/deployment will be recommended to the Secretary of Defense.

The level of OSD/T&E activity is highest during this phase. The IOT&E plan must be designed, the tests conducted, and the data analyzed to evaluate the inputs associated with the primary objectives. These tests should not be conducted until the primary objectives of the DT&E have been met. Thus, OSD/T&E activity is required to assess that the DT&E major milestone--the system is ready for production--has been achieved. Close monitoring of the T&E Service activity is required during the latter stages of this phase.

SUBSTANTIAL PRODUCTION/DEPLOYMENT PHASE

The checklist items contained in this phase are for guidance in conducting T&E after the substantial production decision has been made by the DSARC. This includes DT&E and follow-on OT&E to be conducted on the early production items.

To enter the Production/Deployment Phase, the DSARC will have reviewed the program to confirm:

- The need for the system.
- A practical engineering design with adequate consideration of production and logistic problems is complete.
- All technical uncertainties have been resolved and operational suitability has been determined by T&E.
- The realism of the plan.

The primary objective of the DT&E in this phase should be to:

1. Verify that the production system meets specifications.

The primary objectives of the follow-on OT&E should be to:

2. Validate the operational suitability and effectiveness.
3. Optimize organization and doctrine.
4. Validate training and logistic requirements.

At this point, the OSD/T&E activity is similar to that in the previous phase; however, much of the testing is verification that the production system performance is as expected. Hence, most of the items in the previous phase are appropriate to this phase, especially those related to OT&E.

I. CONCEPTUAL PHASE

The prime objective of the Conceptual Phase of a ground vehicle program is to verify the feasibility of the new concept. The genesis of the program is usually built on a growing threat or a new need where existing equipments have serious deficiencies, modification costs are excessive, and a more efficient or capable new system is proposed. The new system is usually based on studies, IR&D, exploratory or advanced development and technology indications. During the concept formulation phase, a DCP is normally proposed which develops a solution by presenting such matters as justification, a program plan, schedules, tradeoffs, costs, alternatives, risks, and issues.

This phase requires testing which will demonstrate the capability of the concept system or vehicle to meet the objectives and performance requirements which have been established. A preliminary test plan will be designed for use during the Validation Phase. Experience gained from problems encountered in previous programs should be applied at this point. The T&E checklist for this phase, portions of which may have continuing application in subsequent phases, includes:

1. Preparation of Test Plans
2. Validation Test Plans
3. Performance Characteristics Range
4. Operating Degradation
5. Test Personnel
6. Design Reviews
7. Prototype Vehicles
8. Test Facilities and Scheduling

1. PREPARATION OF TEST PLANS

It is necessary that a detailed evaluation criteria be established which includes all items that are to be tested.

Without such criteria the results of the tests may not provide the performance information needed by the developer and the user. In some instances in the past important data were not obtained in the initial tests and retesting was necessary or decisions were made in the absence of complete test data.

2. VALIDATION TEST PLANS

Prior to DSARC I, a plan should be prepared for an evaluation of the overall T&E program.

As part of this, a detailed test and evaluation plan for those tests to be conducted prior to DSARC II to validate the concept and hardware approach to the vehicle system should be developed. The objective of the validation test plan is to fully evaluate the performance characteristics of the new concept vehicle. This test plan cannot be developed, of course, until the performance characteristics are defined. Even at this early phase some effort should be planned to evaluate reliability. Plans to evaluate human factors, serviceability and maintenance should be included.

This test plan should include:

- Understandable description of the characteristics.
- How the characteristics will be evaluated.
- Facilities needed to make evaluations.
- Schedule of evaluations and facilities.
- Reporting procedure.
- Cost estimates.

Detailed evaluation criteria (e.g., a ROC supported by any additional necessary documentation) should be available prior to the start of testing of a system. Where practical, detailed quantitative goals are desirable (e.g., a tank shall have a minimum top speed of 35 mph and a minimum draw bar pull of 25,000 pounds on hard roads). Duplication and redundance of goals should be minimized (e.g., "truck should have a minimum fuel capacity of 50 gallons, minimum hard road efficiency of 6 miles per gallon and minimum hard road range of 300 miles" is redundant. Only two of the specifications are needed [operationally, only the range specification is meaningful]).

The interaction of contract requirements and test plans should be recognized. For instance, the contract incentive fee criteria may constrain the developer from exploring the full performance envelope, because of fear that failure will reduce payments or jeopardize continuation of the program, rather than encourage the developer to determine the full performance envelope at the earliest possible date.

For example, a vehicle with a specification requirement to travel at 35 mph (and which has satisfactorily demonstrated this capability) should be tested to determine its maximum achievable speed without any penalty to the developer if failures (e.g., of the engine) occur at the higher speed. Especially do not allow test criteria to be limited to a single evaluation criterion such as hit or miss of a target.

3. PERFORMANCE CHARACTERISTICS RANGE

Stated performance characteristics derived from studies should be measured early in the program.

Unrealistic performance requirements can lead to false starts and costly delays. In some past programs the mismatch of the performance called for in the requirement with that technically achievable has been the major cause of serious problems and delays in development programs. Performance characteristics specified on the basis of analytical and empirical studies conducted prior to DSARC I, in which the range of critical performance characteristics has been determined, should be measurable through bench and laboratory (which includes proving ground) testing. The test design and the number of tests should be adequate to provide results with confidence limits compatible with the statements of desired characteristics. For example, a demonstration that a 20 percent increase in suspension travel will permit a 10 percent increase in speed over a standard obstacle without increasing the g's experienced by the operator can be made with a very small number of tests. Testing in advanced development should be planned to explore the performance characteristics over a broad range so as to provide insight into system performance over the expected range of values and not just at a single point. For example, the development of a new type of armor plate would include firings at sample plate segments using a variety of types of projectile (kinetic energy, shaped charge) at various impact velocities and angles of incidence.

4. OPERATING DEGRADATION

System performance degrades under field conditions. Anticipated degradation must be considered during test and evaluation.

When a system must operate at peak performance during DT/OT to meet the specified requirements it then will likely perform at a lesser level when operated in the field. In several past programs vehicular systems were beefed up and stressed to meet DT/OT test conditions. When finally fielded, the performance was below the minimum needed.

The system concept and possible implementation must not hinge on the requirement for the vehicle system or subsystems to be finely tuned when the expected operational environment suggests that this will not be likely. The vehicle system should not degrade significantly as a result of detuning caused from expected operational usage. For example, if the cross-country mobility capability is expected to degrade with operational use* (and the ability to perform typical missions depends on this capability), then tests of the mobility capability should be conducted with the vehicle degraded to operational levels to establish the sensitivity to this factor.

*Causes might include loss of engine power due to normal engine wear, dirt in engine air filter and higher engine operating temperatures caused by accumulated deposits of dirt, grease, etc., loss of ground traction due to tread or track wear, loss of vehicle ride comfort due to normal wear of suspension components. In addition, performance losses may also be caused by environmental variations including variations in air temperature, humidity, ground moisture, etc.

5. TEST PERSONNEL

The test director and/or key members of the test planning group within the project office should have significant T&E experience.

If the requisite experience does not exist at the appropriate levels within the project office, test plans may be based on too shallow or too naive a conception of the role and potential utility of the T&E process. In a number of past programs key test personnel were assigned to T&E slots with little prior exposure to T&E or its management, and with inadequately experienced support as well. The test planning group should have personnel experienced in engineering testing, development testing and operational testing. Operational experience is also desirable (a test planner on a tank program should have armor, rather than helicopter, experience). This experience should be available early in this phase and all efforts should be made to encourage these people to remain with the system project office through the T&E phases of the program.

6. DESIGN REVIEWS

T&E factors and experience must influence the system design.

The application of knowledge derived from past experience can be a major asset in arriving at a sound system design. In a few instances desirable design features were overlooked by not capitalizing on lessons learned in previous programs.

The DT&E program initially will progress through a design stage. It is during this period that the detailed design will be put on paper and possibly mocked-up. At the formal design reviews, the T&E people and all interested parties will have an opportunity to view the hardware plans and to make recommendations. T&E related matters should be considered at these design reviews because changes are difficult to make later. For example, such factors as the layout of a tank turret, minimization of the number of connectors, convenience of communications equipment usage, ammunition positioning and accessibility for loading, and similar items should be examined at this time. In addition, previous programs should be examined for problem areas to identify potential areas of concern.

7. PROTOTYPE VEHICLES

When high technical risk is present, development should be structured around the use of one or more prototype vehicles designed to prove the system concept under realistic operational conditions before proceeding tc engineering development.

In most systems there are generally several subsystems which represent the major technical risks. It has not been uncommon for systems to be placed in full-scale development without adequate proof of available technology.

It is frequently desirable to take a risk; however, when an implied commitment to production is involved the technology should be operationally proof tested prior to commencing full-scale development. Avoid the temptation of thinking that any vehicle system, subsystem, or component is "state-of-the-art" until it is working in the field. Provide a sufficient number of prototypes to perform the necessary testing without delays caused by unavailability of test vehicles.

8. TEST FACILITIES AND SCHEDULING

Before DSARC I, test range and resource requirements to conduct validation tests should be identified along with a tentative schedule of test activities.

If inter-service testing is contemplated, preliminary plans for such testing should be coordinated with the cooperating service.

The applicability of the test ranges and the adequacy of the facilities and instrumentation should be verified insofar as possible alternative approaches (different ranges, etc.) and instrumentation improvements needed should be specified. Of prime importance are the constraints to be placed on the test because of the range and instrumentation. Evaluation of performance at 125° F ambient is difficult when ambient temperatures do not exceed 90° F. If range and instrumentation factors are found to cast significant doubt on the meaningfulness of the test data because of a lack of operational realism, the steps necessary to assure meaningful data should be identified and planned.

Some systems may require MCP (Military Construction Program) facilities for portions of the testing. The long lead times to obtain authorization, appropriations, and to construct or obtain facilities can pace a program. For example, many steps and considerable time are involved in getting facilities ready and test gear in place to start system tests. If the ability of a tank to travel through wooded areas containing trees up to 6 inches in diameter is to be evaluated, a location must be obtained where such trees may be knocked down and considerable damage done to the undergrowth.

Most of the steps to program, justify, and construct facilities must be done mainly in series so that a long time span is involved. The completion of DT&E and the operational testing may require the MCP facility. These matters must be considered in preparing and evaluating a test plan where MCP is involved.

In general, the OT&E plan should include engagements in the environments in which the new system is expected to operate. Testing may be addressed in several phases, such as (in the case of tanks):

(a) One-on-one testing against existing US tanks and available simulators of the assumed threat.

(b) Multiple tank testing in a multiple vehicle environment including mobile artillery, anti-tank weapons and aircraft.

(c) Comparative testing of the new tank system with existing systems to estimate the increased capability.

II. VALIDATION PHASE

In the Validation Phase the issues raised by the DCP may be resolved by conducting tests of the system. The development and operational plans will be defined in considerable detail.

Specific actions during this phase are:

- Verify that the vehicle system does satisfy the specified performance requirements.
- Analyze the characteristic behavior of risk components (those approaching or exceeding the limits of current state-of-the-art).
- Refine the preliminary requirements for performance, reliability, human factors, serviceability, and maintenance in the light of test results.
- Develop and refine the test plan for the engineering development phase.
- Develop design criteria information.

Guidelines from the previous phases may continue to apply and should be reviewed. The checklist for this phase is subdivided into the following categories:

1. Vulnerability
2. Gun and Ammunition Performance
3. Increased Complexity
4. Component Interfaces
5. Determination of Test Conditions
6. Test Plan Development
7. Demonstration Tests
8. Reliability Testing
9. Human Factors
10. Test Plan Scheduling
11. Test Failures

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1. VULNERABILITY

<u>The vulnerability of vehicles should be estimated on the basis of testing</u>.

E.g., fuel vulnerability tests should be performed on tactical vehicles. This includes flammability of the fuel/fuel tank combination (e.g., whether or not fuel cells are fitted) under various situations (e.g., kinetic energy penetration, including small arms fire, shaped charge jet exposure). Also included are any fire extinguisher systems, automatic or manual; for automatic systems, evaluation of the triggering mechanism and its sensitivity to, e.g., cigarette lighters, cigarettes, and reflected sunlight.

Vulnerability tests for tanks and other armored vehicles should include both plate evaluations (firings against plates of various thicknesses, materials, and obliquity angles) and firings against the complete ballistic hull and turret. Plate penetration, penetration through openings, and keying of moving joints should all be investigated. Analytical studies of hull performance (including considerations of factors such as angle of attack, penetration probabilities, effects of penetration, and type of kill--mobility [M], firepower [F], "K") should be performed concurrently.

2. GUN AND AMMUNITION PERFORMANCE

<u>Gun and ammunition development should be considered a part of overall tank system development</u>.

When a new gun tube, or one which has not previously been mounted on a tank chassis, is being evaluated, all ammunition types (including missiles) planned for use in that system should be test fired under simulated operational conditions. If the gun tube and ammunition have been proven, then any new ammunition types being considered should be test fired under simulated operational conditions, with particular emphasis on discovering any potential safety hazards.

Use of a realistic mockup in conjunction with hot firings should permit evaluation of shock and recoil loadings on the turret; combustion fume evacuation, and blowback into the loading area; physical space requirements; and internal environmental effects (noise, fumes, heat).

3. INCREASED COMPLEXITY

The addition of new capabilities to an existing system or system type will generally increase complexity of the system, and therefore increase the types and amount of testing required and the time to perform these tests.

E.g., the addition of a stabilized turret, a missile guidance system, and a night vision device to a tank system adds electronic complexities comparable to those in aircraft avionics suits. Appropriate electronic testing in addition to the conventional mechanical testing is therefore required.

4. COMPONENT INTERFACES

Prior to assembly in a prototype system, component subsystems should be assembled in a mockup and verified for physical fit, human factors considerations, interface compatibility, and electrical and mechanical compatibility.

This will guarantee, e.g., that the turret can be traversed with all equipment and personnel in operational configurations; that operation of the radio transmitter will not affect the fire control system, and operation of the fire control system will not affect the night vision equipment; that operation of the gun tube will not physically interfere with operation of other controls; that mutually interdependent systems do, in fact, operate as planned; and that operators can reach and use all controls in all operational modes.

5. DETERMINATION OF TEST CONDITIONS

Test conditions during validation should be determined by the primary objectives of that test, rather than by more general considerations of realism.

Whenever a non-tactical, non-operational configuration is dictated by test requirements, the results of the tests should not be challenged by the fact that that configuration was not tactical or operational. For example, if, in the development of a truck it is found that the undercarriage ground clearance is inadequate for operation over rough terrain,* it may be desirable, for a variety of reasons, to operate the vehicle only over smooth terrain until the problems of ground clearance are satisfactorily solved. On the other hand, demonstration and acceptance tests, as well as tests intended to evaluate performance under operational conditions, should always be conducted under conditions as close to those anticipated in practice as possible.

6. TEST PLAN DEVELOPMENT

The test plan developed by this point should be in nearly final form, and include as a minimum:

(a) A description of requirements, including:

- Performance
- Reliability
- Human Factors
- Serviceability
- Maintenance

(b) A test definition to evaluate the requirements, including:

- Performance; speed, brakes, cooling, steering, mounted attachments, missions, gradeability, stability, swim, mud, altitude, controllability.
- Reliability; structural, frame, axle housing, turret, articulated or oscillation joint, attachments, sheet metal.
- Components; engine, transmission, driveline, hydraulic system, control system, suspension system, steering system, brakes, tires, tracks.
- Human Factors; noise, heat, visibility, control location, ride, communication, function, space.

*If examination of the underside of a truck after preliminary drive-around exercises reveals indications (scratches, dirt deposits) of contact between the ground and the oil sump, then full-fledged cross-country testing (over rocks in particular) should not be attempted until a skid plate or other means of protection has been installed.

- Serviceability; component replacement time, component repair time.
- Maintenance; maintenance points, maintenance periods.

(c) The facilities needed to make evaluations, including:

- Number of complete vehicles; number of subsystems or components, spare parts support, comparable satisfactory models for comparison.
- Type of test facilities required; proving grounds to provide environmental considerations, instrumentation capability to measure loads, stresses, strains, temperatures, pressures, etc.; component laboratories for fatigue tests, simulated tests, accelerated tests; user command for actual mission evaluations.

(d) The schedule of evaluations and facilities, including considerations for each phase of development, each affected organization, and each significant development item.

(e) The reporting procedure, the objective of which is to communicate test results in an understandable format to all program echelons. This includes problem identification to the design groups; provision of data on stresses, loads, temperatures, etc., to design groups, component test laboratories, and system test laboratories; and result summaries as reported at milestone reviews to all levels.

(f) The Test and Evaluation Guidelines, which include: development of an endurance test course where the user helps establish the severity (this will be the main evaluation of reliability and will show any improvement obtained); continual user evaluation of all required missions; special tests which must be established to validate improvements; identification of repeated problems of critical items and/or failure to meet mission performance requirements which call for immediate evaluation by the program manager in development phase; and final testing which should be planned on first production units. An equivalent one year's operation on the endurance test course may prevent expensive retrofit.

(g) A further refinement of the cost estimates which were initiated during the conceptual phase.

7. DEMONSTRATION TESTS

Demonstration tests should show satisfactory meeting of success criteria which are meaningful in terms of operational usage.

In designing contractually required demonstration tests, upon whose outcome may depend large incentive payments, or even program continuation, it is essential to specify broader success criteria than simply hit or miss in a single given scenario. If this is not done, the entire program may be skewed to meet the requirements of the selected scenario, to the detriment of exploring the entire performance envelope. For example, the hit probability of a tank gun should not be stated solely for a single range and type of ammunition (e.g., 0.9 for APDS round at 1000 meters), but rather over a range of distances and types of ammunition (e.g., 0.5 at 2000 meters, 0.1 at 3000 meters, 0.8 for HEAT at 1000 meters, etc.) With too much weight attached to the hit/miss outcome, non-tactical hardware may be retained beyond the early stages of the program to enhance the probability of successful demonstration.

Demonstrations should be designed to measure overall performance, with statistical weighting to compensate for reduced probabilities of success at edge values of condition parameters.

Results of tests conducted during exploratory development and which most likely have been conducted on brassboard, breadboard, or modified existing hardware should be evaluated with special attention to items such as:

(a) The fabrication of the vehicle may significantly affect the performance characteristics so that the suggested proof of validation is inconclusive.

(b) Scaling laws may invalidate the findings or introduce new technology problems.

(c) The laboratory type environment in which the vehicle was tested may preclude the generation of data needed to validate that the concept and technology approach will be applicable to an operational environment.

(d) The tests may not include vehicle inputs representative of those that might be expected in an operational environment. For example, the ability of a ground vehicle to travel on side hill slopes must be evaluated as well as its ability to climb and descend slopes. In addition to obvious stability problems (if a side hill slope is too steep, the vehicle will tip over), factors such as lubrication (does the oil level drop below the oil pump pickup?) and fuel delivery (is the fuel level below the fuel pump pickup? Does the carburetor float level change excessively, either starving or flooding the engine?) must also be considered.

8. RELIABILITY TESTING

Reliability testing should be performed on component and subsystem assemblies prior to testing of the complete vehicle system.

Prior to full system testing viable component and subsystem tests should be conducted. Missile test adequacy studies show that almost all failures will be the kind that cannot be detected or prevented in full system testing. While this may not be as true for ground vehicles, all experience indicates that new systems will exhibit the "new system syndrome" and that by far and away the best return on test investment will come from applying substantial attention to component and subsystem level test effort. Detecting a subsystem or component failure at the full system test level puts them at the extremely high end of an exponential cost curve.

A wheeled or tracked weapon system (e.g., a tank) should be tested using the same sequential evaluations as any other weapon system. In particular, components (e.g., the gun tube, the turret stabilization system, the fire control system) should be bench tested, developed, and individually proven; interfaces should be examined; and system operation should be simulated prior to assembling a complete prototype system. Individual testing of engine, transmission, and suspension would be followed by testing of a turretless chassis. For example, suspension components (tracks, road wheels, shock absorbers, torsion bars, sprockets, idlers, suspension arms, return rollers, track pads, and track pins) should be tested individually (e.g., testing on a machine which will put complete movement cycles on a shock absorber at a high rate and accumulate operational life information in a short period of time) and characteristics matched by means of appropriate simulators prior to assembly on a test platform. Incorporation on a prototype should follow satisfactory test platform performance. Simultaneously, testing of the gun tube, stabilization system, and night sight would be followed by testing of a complete turret, perhaps mounted to a stripped or testbed chassis.

A preliminary stress survey (using stresscoat, strain gauges, and other appropriate techniques) should be made of all loaded parts in both static and dynamic (including fatigue) configurations. A recheck of design assumptions should be made wherever excessive stress levels are indicated, and potential problem areas, where practical, should be overloaded to failure to determine whether safety factors are adequate for anticipated use. Similarly, very lightly loaded parts, as indicated by the results of stress tests, may be subject to re-examination for over-design. Suspension and driveline components, frames, attachment points for auxiliary equipment such as blades (as well as the blades themselves), and ability of the turret and chassis to absorb repeated gun tube recoil, are normally the most critical areas. Basic strength evaluations should be done by the developer prior to submitting the prototype system for test. These types of analysis are not normally performed during service system test, so any significant structural modifications subsequent to original structural tests should be followed by additional checks as part of the development program. Only after this testing is finished should a complete tank be assembled and tested.

9. HUMAN FACTORS

In evaluating ground vehicles, human factors should be considered at all stages starting with the design of the prototype.

In particular, testing should be conducted to determine that

(a) The smallest operator (fifth percentile or other appropriate measure) and the largest operator (95th percentile) in full winter gear can utilize any passenger/operator location and are able to reach and operate all controls without difficulty.

(b) Operators and passengers are able to communicate as needed, and are able to travel in a reasonably comfortable fashion (seats padded and adjustable).

(c) Noise levels are not excessive (e.g., 95 pndb maximum, 80 pndb sustained).

(d) Vibration and shock transmission are controlled.

(e) Temperature environment is controlled (e.g., to between 30° F and 90° F regardless of ambient).

(f) Limited induction of dust and dirt and no engine, fuel, or exhaust fumes are allowed.

(g) Protection is provided from wind, rain, and other undesirable conditions.

(h) Controls are so designed and located that operation is straightforward and easy, and possibilities for confusion are minimized.

(i) Tracked vehicle controls are as similar as practicable to those of wheeled vehicles.

(j) Crew members are capable of functioning during cross-country operation of combat vehicles at maximum speeds.

(k) Crew comfort and operability in combat vehicles, space use optimization, and turret/chassis interface are considered in both open and buttoned-up conditions.

(l) Instruments and controls are appropriately lighted for night operations.

(m) Questions of safety, appropriateness of man-machine interfaces, and the number and skill levels of the personnel required are examined.

(n) The numbers of personnel required are validated against both operational and maintenance requirements.

Testing early versions in the "human acceptability and compatibility" environment is extremely important. This will also help to validate the manning requirements.

10. TEST PLAN SCHEDULING

Test plan scheduling should be tied to event milestones rather than to the calendar.

In evaluating the adequacy of the scheduling as given by test plans, it is important that milestones be tied to the major events of the weapon system (meeting stated requirements) and not the calendar. As a result, milestones should be flexible with respect to time. The acquisition process should be based on the achievement of major milestones and sufficient time and resources allowed between these milestones. Flexibility must not be hampered by the contracting mechanism. A system of effective bottoms up review at frequent phases of the program should be established. These reviews should be objective, in depth, and provide guidance on whether or not to commit to the next phase. It is inordinately expensive to commit to a test program before the hardware is ready. Component problems are much better worked at the component level than the system level. Contractors should be required to demonstrate successful accomplishment of technical milestones before proceeding to the next phase of development. For example, before the vehicle system is allowed to go into the IOT&E phase, all engineering tests should be complete; before the full-scale production phase is entered, the IOT&E of the total vehicle system should have been successfully performed by the using command; prior to deployment of the vehicle system to the user, successful completion of the acceptance testing of the initial production items must have occurred.

In evaluating test plans, look favorably on phasing where the OT&E is run in parallel with continued DT&E. A problem that becomes apparent in the operational testing can often be evaluated much more quickly and more completely with the instrumented DT&E hardware.

In general, DT and OT plans should make provisions for the occurrence of failures and in particular should include time and money necessary for investigating test failures and making provisions for elimination of the cause at the earliest possible date.

11. TEST FAILURES

The T&E schedule should be sufficiently flexible to accommodate failures and correction of problems which have been identified.

T&E schedules must provide for failures. A percentage of the total tests (sorties, runs, trials, experiments) should be allowed for retesting, over and above the minimum number required to successfully complete the program. This percentage must be related to the probability of achieving success as opposed to failure. On a "good" program, 70 percent of all testing may fall into the category of testing not contained in the original program test plan; on a program with problems, it may go higher. An early detection scheme for top government and contractor management should be established to indicate that a program may be becoming ill. At this time there may be a good possibility of recovery. Some of the indications of trouble during the engineering development phase which should be noted by the tester are:

(a) Any repetitive failure (e.g., repeated failure of U-joints).

(b) A revision of schedule or incremental funding that exceeds the original plan. Predicted downstream recovery may not have a realistic basis.

(c) Any relaxation of basic requirements such as less range, lower performance, etc. (e.g., lower maximum speed, higher allowable [or allowed] transmission and differential temperatures).

Adequate time must be allowed during all phases of testing to: (1) complete all necessary testing in a sequential fashion as required; and (2) allow the developer time to correct problems and make indicated changes. Changes or modifications to the system require some or all of the testing to be repeated, so corrections, once identified, should be expedited. In particular, changes incorporated as a result of pre-production or production vehicle testing should, wherever practical, be adequately tested prior to commitment to full scale production regardless of production delays.

III. FULL-SCALE ENGINEERING DEVELOPMENT PHASE

In the Full-Scale Development Phase, the engineering development and the IOT&E are to be conducted. Test plans prepared during the previous Validation Phase should be refined and the testing will be conducted in this phase aimed at demonstrating that a substantial production/deployment decision is warranted. The emphasis during this phase should be placed on the evaluation of the vehicle against the test plan requirements including:

- Performance
- Reliability
- Human Factors
- Serviceability
- Maintenance

Validation and full scale development phase checklist items are appropriate guidance for actions before the production decision DSARC. Again, guidelines from the previous phases may continue to apply and should be reviewed.

The full scale development checklist includes:

1. Planning the Operational Test
2. Pilot and Dry Run Tests
3. Comparison Testing
4. Simulations
5. Environmental Testing
6. System Vulnerability
7. Design Criteria Verification
8. System Critical Speeds
9. Electromagnetic Testing
10. System Strength Testing
11. Component Compatability
12. Human Interface
13. Serviceability Testing
14. Experienced User Critique
15. Troubleshooting During Tests

1. PLANNING THE OPERATIONAL TEST

Operational testing should be cost effective and provide meaningful results.

Operational testing is essential, but it is also expensive and time consuming. Be sure that the test plans are well thought out so that the value received is worth the effort expended and at least cost equivalent to the not-delivered systems. Think in terms of:

(a) Involving operational groups in test planning and in establishing measures of effectiveness, so that the outcome of the vehicle system tests will be accepted as being operationally significant.

(b) Determining whether the scope of the planned tests will provide sufficient data on the performance of the vehicle system to justify any change at all in the eyes of potential users.

(c) Comparing the scope of proposed tests against checklists of vehicle system issues frequently raised at major decision milestones, to assure that the data needed for such decisions will be forthcoming to the extent this is possible from testing alone.

(d) Recognizing in the formulation of test plans that major system decisions are judgments based on a wide range of qualitative considerations, as well as on statistical compilations, and that the outcome and limitations of operational tests must be comprehensive and meaningful to the decision makers as well as to the testing community. For example, if a major design consideration is a swim capability, then the results of OT&E should reflect vehicle performance in river crossings. Data should include depths, stream velocity, entrance and departure bank slopes, etc.

2. PILOT AND DRY RUN TESTS

A scheduled series of tests should be preceded by a dry run which verifies that the desired data will be obtained.

Before tests for demonstration of operational suitability and effectiveness are conducted, a pilot test should be held with the primary purpose of shaking down the test plan, the instrumentation concept and the data analysis plan. A secondary, but vital purpose should be to provide final training for the test participants. In general, a pilot test should be conducted sufficiently prior to the OT&E so that ample time is available to make the necessary changes to the OT&E as dictated by the results of the pilot test. A full-throttle full-load dry run test which indicates that the engine will overheat at ambient temperatures above 110° F indicates that testing at 125° F ambient should not be attempted.

Dry runs should be conducted for each new phase of testing. For example, simulation and other laboratory or ground testing could be conducted to predict the specific test outcome. The DT/OT tests should then be run to verify the test objectives. Evaluation of the simulation vis-a-vis the actual test results would help to refine the understanding of the system.

3. COMPARISON TESTING

The test program should include a detailed comparison of the characteristics of a new vehicle system with those of existing systems, alternate vehicle system concepts (if applicable), and those of any system(s) being replaced.

A portion of the test program should be devoted to comparison testing (side-by-side when practical) between the new vehicle and the actual observed characteristics of the vehicle(s) being replaced. When significant degradation in various measures of performance are found (e.g., slower acceleration, lower top speed, poorer fuel economy, poorer reliability, higher maintenance, increased operating costs, reduced payload weight, reduced payload volume, loss of mobility, loss of swimming capability, harder to operate), the degradation should be emphasized in the test report as well as the probable cause(s), (e.g., reduced payload volume due to smaller cargo bed); poorer fuel economy due to less efficient engine design (undesirable) or revised gearing to improve acceleration (a conscious trade-off decision). In many cases (e.g., fuel economy, cross-country mobility), there are multiple interacting factors to be considered, all of which should be identified. Contradictory results may be obtained (e.g., vehicle has excessive power resulting in undesirably high top speed on paved roads, but is underpowered for high mobility cross country), but the purpose of the testing is to identify, not cure, any potential problem areas.

4. SIMULATIONS

Simulation techniques and equipment should be utilized to enhance data collection.

Creation of histograms for each test course provides a record of conditions experienced by the vehicle during testing. Use of a chassis dynamometer can produce additional driveline endurance testing with more complete instrumentation coverage. Programmed engine dynamometers can provide accelerated engine and transmission endurance testing, and simulate extreme conditions (e.g., full throttle, full load, high coolant and lubricant temperatures) for extended periods of time* rather than depending on the length of the available grade and a high ambient temperature. Test course failures attributable to loaded component failures should be duplicated on the simulator to verify causes. Simulators are also valuable in estimating limits to the performance envelope (e.g., engine coolant temperatures reach unacceptable levels at a still air ambient of 127° F). Note that successful completion of a 20,000-mile endurance test (or an accelerated test to a shorter distance) on a simulator does not eliminate the need for field testing, but may reduce the number of test vehicles required.

5. ENVIRONMENTAL TESTING

Ground vehicles should be tested in environmental conditions and situations comparable to those in which they will be expected to perform.**

These should include tropical, desert, mud and jungle, cross country operations, including mountains, and elevations from sea level to in excess of 10,000 feet. Areas of particular concern should include:

(a) Mobility (Does the vehicle get stuck?)

(b) Engine Starting (Will it start at -40° F? +20° F?)

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*Extended periods of time and severity of conditions must be specifically defined for each system in terms of its intended application.

**Also, by implication, testing should not be required in environments in which the vehicle will not be expected to perform. A snowmobile would not be subjected to desert testing.

(c) Engine Performance (Will it pull rated loads up representative grades at high elevations?)

(d) Cooling (Does the engine coolant overheat under full-load, full-throttle conditions? Do engine, transmission, or differential lubricants overheat under heavy load conditions? Are there vapor lock problems?)

(e) Wear (Do brake linings wear very rapidly when operated in muddy conditions? Is track wear excessive on paved roads?)

(f) Crew Comfort (Is operator performance impaired because of excessively high or low internal temperatures, etc?)

(g) Maintenance Requirements (Does air cleaner require excessive servic: 'n dusty environments? Does radiator collect dust and dirt depo ? Are components too hot [or cold] to service, especially during field failures? Is servicing in rain, snow, dust, wind, high humidity undesirable?)

(h) Reliability (Do controls such as throttle and brake freeze up when vehicle is operated in slushy snow? Do switches corrode and become inoperable in high humidity or salt spray environments? Do wheel bearings fail prematurely when operated in very cold ambient temperatures? Do optical components fog up in high temperature, high humidity, environments?)

6. SYSTEM VULNERABILITY

For combat vehicles, some estimate of vulnerability to battle damage should be made.

If the operator is in an armor-protected position, he is protected from rifle fire and shell fragments, but may be vulnerable to a land mine explosion. The relative vulnerability of other "soft" components (radiator, fuel tank, fuel lines, coolant hoses, some engine components, tires) is a function of both the inherent protection of the item (a fuel line running inside a boxed frame rail is protected from many hazards; the same fuel line running along the bottom of the same frame rail is subject to damage by large rocks as well as a complete assortment of ordnance) and any special measures which are taken (armor protection; fuel cells inside fuel tanks; foam-filled tires; bullet and shell fragment deflecting radiator grilles). Tracks and suspension systems are vulnerable to damage that can immobilize tracked vehicles. Fire controls, particularly vision devices, are subject to damage that can destroy the effectiveness of combat vehicle weapons.

7. DESIGN CRITERIA VERIFICATION

Subsystem design criteria should be compared with actual characteristics.

E.g., a track may be designed to operate at a ground pressure of 4 psi, but if the actual tank weight is 25 percent higher than the original target weight, the track may be operating at a 25 percent increase in ground pressure, with corresponding effects on mobility. Similarly, a turret stabilization system may be designed for a specific turret moment of inertia; changes in the turret weight (and moment of inertia) may severely degrade the stabilization system performance.

8. SYSTEM CRITICAL SPEEDS

Critical speeds should be determined for all ground vehicles.

Critical speeds include, e.g., those at which resonant vibration frequencies are encountered. If tank fire control system optics encounter a resonance at an operational road speed, performance would be significantly degraded if either the system was not mounted using shock and vibration isolation techniques, or the tank was not modified as necessary to eliminate the resonance.

9. ELECTROMAGNETIC TESTING

Vehicle testing should include electromagnetic testing.

E.g., for a tank, this includes evaluation of: the electromagnetic signature of the tank as a function of which systems are operating;* internal system compatibility (e.g., does the radio transmitter affect the turret stabilization system at certain broadcast frequencies?); effects of external electromagnetic radiation (do fuzes detonate when a range-finding radar is trained on the tank?); and compatibility with other current and

*This includes optical and IR signatures, both day and night, with/without engine operating, before/after gun firing, etc.

proposed electromagnetic generating systems (tanks, aircraft, radars, etc.) during the contemplated operational time frame.

10. SYSTEM STRENGTH TESTING

In evaluating ground vehicles, early testing should verify intrinsic strength.

This implies operation with maximum anticipated loading, including trailed loads at maximum speeds and over worst case grades, secondary roads, and cross-country conditions for which the vehicle was developed or procured. This test is intended to identify deficient areas of design, not to break the machinery. Areas which should be examined for damage or incipient failure include: frame, tires, wheels, tracks, springs, shock absorbers, torsion bars, wheel bearings, suspension bushings, tie rods, drag links, king pins (or ball joints or other equivalent suspension components), U-joints, drive shafts, axle shafts, propeller shafts, transfer cases, transmissions, differentials, axle housings, engines, cooling systems, including radiators and hoses (both cooling capability and structural integrity are important), auxiliary drives, steering gear, tracks, sprockets, road wheels, and any other components which may be subjected to loading during severe operating conditions.* Any deficient components should be strengthened as needed prior to performing any further testing, which should begin with a check test of the entire system to verify the modified components. Testing may need to be repeated in the event of redesign or modification of a component for any reason.

11. COMPONENT COMPATIBILITY

Component compatibility should be checked through the duration of the test sequence.

Suspension components should be tested to verify, for example:

- That shock absorbers and springs are matched to produce the desired transient response to dynamic inputs.

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*A severe condition is defined in terms of a baseline set by an existing similar vehicle configuration.

- That wheel and suspension bearings are an adequate size for the loads imposed during testing and
- That tracks are compatible with suspension components.

The driveline--engine, transmission, axles, etc.--should be a balanced design, and the interfaces with other portions of the vehicle (e.g., motor and transmission mounts, spring hangers, shock absorber attachment points) should be checked for premature failure. Vibration testing on vibration fixtures to determine resonant frequencies of items such as fuel tank support brackets can be used to predict potential areas of fatigue failure.

Reverification of compatibility may be required in the event of any significant change in components or subsystems. The magnitude of this testing should be compatible with the magnitude of the change. If an engine is changed, almost the entire test program may require repetition, while if a rear view mirror or turn signal were changed most portions of the test would not need repetition (note that arctic testing might reveal that the mirror frame contracts and cracks the mirror, while desert testing may reveal that insulation in the turn signal softens under extreme heat, resulting in a short circuit. Simulation of these conditions [i.e., in a freezer and an oven] may reveal these problems without the need for a full environmental test. Note also that actual desert maximum temperatures [e.g., 125°F ambient plus solar heating loads], rather than extrapolation from lower temperature levels, are required to demonstrate this type of failure).

12. HUMAN INTERFACE

<u>Critiques of good and bad features of the vehicle should be made early in the prototype stage, while adequate time remains to make any indicated changes</u>.

Note this includes features which may not be spelled out specifically in the test plan; e.g., that an annoying resonance occurs at typical convoy speed, that engine surge is annoying, that headlight and windshield wiper switches can be confused, that the clutch chatters when engaged from rest on an uphill location, that the seat is extremely comfortable, that some controls cannot be reached if seat belts are used, that the external rear view mirror vibrates to an unusable extent and reflects the headlights of following vehicles at night with excessive glare, that rear vision while backing up is outstanding, that a fiberglass battery cover makes a convenient step but is not strong enough to sustain a man's weight, that the windshield wiper arm contacts a blackout light wire when operating and will eventually abrade the insulation, and that the hooks on the chains which hold the tailgate in the down position are inadequate to support a heavy load or a man standing on the tailgate. The need for, e.g., a step to aid climbing into the cab, would also be expressed at this time. Fire control layout in combat vehicles should be considered with regard for rapid operation under conditions of stress.

13. SERVICEABILITY TESTING

Ground vehicles should be tested and evaluated to determine the relative ease of serviceability, particularly with high frequency operations.

Test items should include answers to the following questions: Is it easy to change spark plugs or to clean and service injector pumps? Are there access points for diagnostic equipment? Can wearing parts, such as brake linings, be examined easily? Can oil level, coolant level, battery water level, and other fluid levels be checked easily? Can wheel alignment be checked and adjusted using available servicing equipment? Can starter, alternator, carburetor or injector system, distributor (if applicable), oil filter, and other engine accessories be reached, examined, and easily removed for servicing or replacement? Can all lubrication points be located and serviced easily? Are critical components (oil pan, coolant hoses, brake lines) protected from contact with rocks, etc., yet easily inspected? Can track tension be adjusted easily by crew members? Can a thrown track be remounted under field conditions?

14. EXPERIENCED USER CRITIQUE

Ground vehicle user opinions should be obtained early in the development program.

Test drivers with extensive experience frequently miss problems which most users identify fairly rapidly (e.g., a user who has been driving gasoline-powered automobiles with automatic transmissions may have initial difficulties starting and driving a standard transmission truck powered by a diesel engine. An experienced tester would make the necessary compensations for differences among various vehicles). Users should also enter into the maintenance evaluation (for example, the most efficient way to change starters may be to pull the engine; the user, who does not have an engine hoist in the field, may find that a revised frame cross member prohibits starter removal according to the scheme described in the maintenance manual). User maintenance must be capable of being performed on combat vehicles under all likely field conditions.

15. TROUBLESHOOTING DURING TESTS

Provisions should be made to identify subsystem failure causes.

Subsystems may exhibit failures during testing. Adequate provisions should be made to permit troubleshooting and identification of defective components and inadequate design. E.g., a turret stabilization system which includes a set of black boxes fails to operate. If test equipment and troubleshooting techniques are not provided, the tester has no way to distinguish among a fuse failure, a defective electrical component (capacitor, resistor, transistor, integrated circuit), and a defective design or assembly.

IV. SUBSTANTIAL PRODUCTION/DEPLOYMENT PHASE

The purpose of this phase is to verify production design utilizing early production vehicles. The lead time after the production decision and before full production is rarely less than 2 years, and may be 4 years or more; consequently, the detailed planning for OT&E can probably wait until after the production decision. However, prior to that time the basic OT&E plans should have been made for manning assignments, personnel training, hardware and software requirements and facilities.

Some of the full-scale development phase testing will be continued into this phase, and appropriate checklist items would also carry over. The checklist includes:

1. Performance and Reliability Testing
2. Lead-the-Fleet Testing
3. User Evaluation

1. PERFORMANCE AND RELIABILITY TESTING

The production first-article testing should verify the performance of the vehicle system and determine the degradation, failure modes, and failure rates.

The production, first-article testing and evaluation should be designed and conducted to confirm the adequacy of the vehicle system to meet specified performance requirements, to evaluate variation of critical performance parameters with time, and to determine failure modes and rates. These development tests, usually conducted first by the contractor and then by the service, should be functional at the subsystem level but should progress to the fully integrated system test leading to a service acceptance test. This activity should be followed by FOT&E.

In practice, the larger sample size available for distribution at the battalion level may reveal previously unidentified problems, and modifications made to enhance produceability may affect performance.

Ideally, operational testing of production items should be primarily an evaluation of reliability/maintainability/availability. Problems should also be anticipated in the fields of quality control and assembly procedure. The basic durability and performance should have been established previously, and inherent component and subsystem failures should not be encountered. If any of the latter types of problems are identified, there should be provision for stopping or modifying production until the causes are identified and cured.

2. LEAD-THE-FLEET TESTING

At least one production prototype or initial production model vehicle should be allocated to intensive testing so as to accumulate very high operating time in a short period.

The testing should be performed over the same test course used to define the reliability characteristics of the vehicle. It places the vehicle under the various stress and strain conditions to be expected of it during typical combat conditions (if it is a combat type vehicle), or under normal operating conditions (if it is a non-combat type vehicle.) This testing is not to replace or reduce the need for a standard endurance test but is an operational usage test of the total weapon system under normal conditions maintained at an accelerated pace so that problems can be identified and resolved very early in the production of the vehicle.

The lead-the-fleet concept is meaningful for a tank only when all systems are equally exercised at operational levels. Accumulation of chassis miles may be meaningful from the standpoint of power train evaluation, but it is not adequate for weapon systems evaluation. Gun tests (including accuracy), stabilization system performance, fire control system performance, ranging system performance, night vision system performance, and communications system performance, are all significant as well.

3. USER EVALUATION

User-reported shortcomings should be followed up to determine problem areas requiring correction.

After the new vehicle system is placed with the user, there are always problems. These problems are reported through materiel channels, e.g., as unsatisfactory equipment reports (UERs) or deficiency reports (DRs). To plan appropriate follow-on OT&E, these unsatisfactory conditions must be closely investigated so that corrections can be candidates for more complete evaluation in FOT, with redesign requirements to be determined. Identification of problem areas at this stage should not be considered to be a misapplication of equipment.