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CREW PERFORMANCE REQUIREMENTS FOR EMERGING ARMOR WEAPONS SYSTEMS: STUDIES OF CREW SIZE AND METHODS OF FORECASTING HUMAN FACTORS

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The purpose of this research was to examine (a) the effects of operating a lightweight armor combat vehicle with crews of varying size, and (b) the effectiveness of two methods of forecasting human factors and training requirements for the same weapon system. These objectives were pursued in separate studies though both dealt with a conceptually new, lightweight, highly mobile, armor combat vehicle. The lack of good criterion performance data weakened the research and led to a reliance on questionnaire data.

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In Study I, experienced armor crewmen responded to questions about the impact on system performance of reductions in number of crewmen from four to three or two. The opinion data together with results of a literature review suggest that, if a combat vehicle design employs automation and control-and-display redundancy well, three men in a crew may not only be ample but perhaps superior to a four-man crew; a reduction to two men would, in the judgment of the experts, be too extreme, producing some degradation in system effectiveness and crewman confidence.

In Study II, estimates of personnel requirements for the experimental weapon system were made by armor experts who were provided documents descriptive of the system but who had no first-hand experience with it. Their estimates, regardless of the kinds of descriptive materials used, did not differ significantly from judgments of the same requirements made by crewmen experienced with the weapon system. In task areas where estimates of time to perform were compared with observed performance time, the armor experts tended to overestimate time to perform; the shorter the actual time, the greater the overestimate.

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PREFACE

This is the final report on Part I of a two part project: Research on Armor Weapon System Employment Parameters: Small Crew Performance Estimates and Moving Platform Stabilized Gunnery Training Techniques, ARI Contract No. MDA 903-80-C-0529. Much of the planning and development work on Part I preceding that reported here is covered in an earlier report, "Armor Weapon Employment Parameters: Human Factors Methodologies Applied to Small Crew Performance Estimates, an Interim Report" (Taylor, Harris, and Campbell, 1981).

Part II of the project was concerned with training techniques for moving platform stabilized gunnery. The specific objectives were to design, develop, and pilot test moving platform gunnery techniques. The principal results of Part II are reported in "Development and Evaluation of a Stabilized Gunnery Training Program" (Harris et al., 1982).

This work was performed at the Fort Knox Office of the Human Resources Research Organization (HumRRO) under Contract No. MDA 903-80-C-0529 with the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI). The Project Director was Dr. Elaine N. Taylor. HumRRO staff, other than the authors, who contributed to this part of the project were James H. Harris, Richard E. O'Brien, William C. Osborn and Susan N. Schmidt.

Dr. Robert W. Bauer of the ARI Field Unit at Fort Knox was the Contracting Officer's Representative. He monitored all phases of the work, arranged support from the Armor Combat Vehicle Technology (ACVT) Test Group, secured the participation of armor experts who provided the performance estimates, reviewed all plans and procedures, and advised on matters of practical and scientific concern.

Special acknowledgement is due the HSTV(L) Test Group, particularly LTC David Anstice (UK) and SFC Michael Ganoung, whose cooperation and support were consistent despite other demands on time and energies. And finally, the cooperation of the five test crews, Army and Marine, is what made the project possible.

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INTRODUCTION

Background

The Army has set three major goals for the 1980s: readiness, modernization, and sustainability. In recognition of these goals, a program of tank development was initiated in the early 1970s to determine what technological advances should be incorporated into a design of the next generation of tanks. The Armored Combat Vehicle Technology (ACVT) Program was established in 1972 to conduct studies aimed at exploring and exploiting the latest technology. More recently, in 1976, a formal understanding was reached by the Army, the Marine Corps, and the Defense Advanced Research Projects Agency committing them to a joint program of research and development. The advance in anti-armor capability has generated considerable interest in the development of tanks that are highly mobile and agile. In consequence, the ACVT program has devoted much effort to testing concepts of high mobility and agility.

One way to achieve high mobility and agility, presumably, is to design a small vehicle that requires fewer personnel than the conventional four-man crew of current tanks. Designing a vehicle for fewer crew members can result in a number of other advantages:

- A smaller vehicle with a lower silhouette and less target exposure area.
- Less weight.
- Lower fuel consumption.
- Fewer crew members at risk.
- Lower production cost.
- Simplification of air transport and increased strategic deployability.
- Lower training costs.
- Potential increase in total number of systems fielded.

While reduction in number of crewmen is an attractive opinion, many questions arise concerning the potential effectiveness of a vehicle manned with fewer than four crew members. Current U.S. tanks are manned by a tank commander, gunner, loader, and driver. If the crew is reduced to three members, which position should be omitted? Once omitted, how will the tasks performed by that crew member be allocated among the three remaining crew members? Is reduction beyond three crew members feasible? Can some of the tasks be performed by introduction of new equipment, e.g., an automatic loader? How can the resultant workload on individual crew members be assessed? This last is a vital question. It is anticipated that combat of the future may require continuous operations for 24 or 48 hours, or even longer. How effectively will fewer crewmen be able to sustain prolonged periods of operation?

Answers to such questions cannot wait until equipment is in production. Studies need to be performed throughout the development cycle of new equipment to provide program managers and design engineers with data that will help in making optimum decisions from among alternative design concepts. Such studies can help to avoid costly omissions and mistakes.

Obtaining such data requires a methodology for estimating human performance requirements in emerging man-machine systems. These estimates will aid in assuring that the man can operate the equipment efficiently and effectively and that the equipment has the least adverse effect upon the man. Unfortunately, no single, validated, or generally agreed upon methodology is available for making such estimates. Preliminary estimates for manpower, training and continuing deployment costs of new systems are required at the first stage of the development cycle, during the development of Mission Element Need Statements, and at the time a concept is approved for experimental development. Baker (1980) points out that 70% of the life-cycle decisions on a new equipment item will have been made by the time a concept is approved for experimental development.

During the course of this project, one of the vehicles being studied in the ACVT program was the HSTV(L) [High Survivability Test Vehicle (Lightweight)], a 19-ton vehicle equipped with a 75mm gun and an automatic loader. Since the HSTV(L) can be operated by either a two- or three-man crew, the testing of this vehicle provided an opportunity to study selected aspects of crew performance for two different crew sizes. In addition, information obtained from the vehicle operators could be used to validate methodologies for estimating manning and training requirements by subject matter experts who were familiar only with written and graphic descriptions of the vehicle.

Thus, reported here are the results of two studies: one pertaining to the number of crewmen needed to operate effectively lightweight armor combat vehicles, the other pertaining to methods of forecasting performance requirements for emerging armor systems. Despite empirical data shared between the two studies, they were conceived, planned and conducted to serve separate purposes and are therefore reported separately here.

STUDY I. CREW SIZE REQUIREMENTS FOR OPERATING LIGHTWEIGHT ARMOR COMBAT VEHICLES

The conceptually new weapon systems being developed by the ACVT program have reduced armor protection in order to increase mobility and reduce size. The HSTV(L) has, in addition to the relatively lightweight 75mm gun and automatic loader, a hunter-killer sight which will enable a commander to transfer his sighting of a target to the gunner or driver who will take the target under fire while the commander searches for another target. The vehicle can be operated by either a two- or three-man crew.

It is precisely this feature of the HSTV(L)--two- or three-man operation--that provided a useful opportunity to evaluate empirically the operational capabilities of the vehicle when operated by crews of different sizes. The ideal number of men in a tank crew has long been a matter of debate within the armor community and, while this debate is unlikely to be resolved in the near term, the HSTV(L) offered a ready test bed for its controlled exploration.

Purpose

The purpose of this study was to examine the advantages and disadvantages of operating a lightweight armor combat vehicle like the HSTV(L) with crews of varying size and configurations. Special emphasis was to be placed on comparing two- versus three-man operation and different combinations of two-man crew positions.

Method

A three-part approach was taken in studying the effects of crew size and configuration. First, the literature was reviewed on small, crew-served, lightweight armor systems; second, empirical data was collected comparing the performance of crews of varying size and configurations and third, the opinions of armor experts and experienced HSTV(L) crewmen were obtained.

Literature Review

The literature search was concentrated on the period 1970 to present, and keyed to two areas. The first was type standard vehicles, as well as developmental and test vehicles meeting three criteria: (a) weighed between 15 and 25 tons, (b) required no more than a crew of three to operate, and (c) possessed an anti-tank capability. The second area of focus was on literature pertaining to crew size.

Empirical Data

An extensive set of field comparisons of two-man versus three-man crew performance on the HSTV(L) was planned (see Taylor et al., 1981). These data were not collected, however, because of the commitment of the HSTV(L) to other priority tests.[1] Two crew performance tests were run, one on driving and one on preventive maintenance checks and services (PMCS).

Driving. An attempt was made to evaluate the effects of two- versus three-man crews on the ability to drive and maneuver the HSTV(L). Two crews made four runs of a one-mile course. The approximately oval course was about one-fourth hard surfaced dirt road with the remainder rolling, moderately vegetated, cross-country terrain with a 30-50 meter visibility. At two designated points on the course the crews were to stop the vehicle and move it into defilade; otherwise they were instructed to run the course as quickly as possible without violating safety restrictions. Following a familiarization run, each crew ran the course twice with a full (three-man) crew, once with the hatch open and once with the hatch closed, and twice with a two-man crew,[2] again once in each hatch position. The runs were timed and the crews were debriefed after all runs were completed.

PMCS. The effects of crew size on Preventive Maintenance Checks and Services (PMCS) were explored using M60A1 tanks[3] and crew sizes of four, three, and two crew members. The crews were instructed to perform the first 37 steps of before-operations PMCS following the TM and to record (but not correct) any deficiencies on a DA Form 2404 (Equipment Inspection and Maintenance Worksheet). Nine crews (three four-man, three three-man, three two-man--a total of 27 crewmen) performed PMCS on three M60A1 tanks. Three crews, one of each size, were assigned to each tank. The four-man crew consisted of a tank commander, gunner, loader, and driver; the three-man crew of a tank commander, gunner, and driver; and the two-man crew of a tank commander and driver. Records were kept of the time required to perform, completeness of number of entries on the 2404, and correctness of deficiencies recorded.

Opinion Data

A third source of data on crew performance as a function of crew size was the opinions of experienced armor crewmen.

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[1]These crew performance tests were planned with the expectation that the HSTV(L) would be made available on a dedicated basis for conduct of the tests. Later changes in ACVT program plans preempted this commitment of the vehicle to crew performance testing, and since collection of such data had to be scheduled around other priority ACVT tests, very little performance testing was done.

[2]The vehicle commander, though inactive, was present in the "two-man" configuration to act only in case of emergency.

[3]The M60A1 was used because of the limited availability of the HSTV(L).

Questionnaire. Questions pertaining to crew size and expected impact on various areas of crew performance were included in a questionnaire (Appendix A) designed for use in Study II of this report (see pages 23-25) for a description of questionnaire development and administration. For purposes of this study, only responses to 18 questions (number 21-30 and 35-42, Appendix A) were considered. These questions covered such issues as the anticipated effect of reducing crew size from three to two on command and control, communications, extended operation, and crew confidence. Examples of the questions asked are: "Place an x at the point on the scale that indicates how difficult command and control will be for two-man crews on the HSTV(L) during gunnery." Or "Given a two-man crew for the HSTV(L), how would you combine the operators?"

Respondents. Responses to the questionnaire were obtained from two groups of experienced armor crewmen. One group consisted of 40 E-6 and E-7 gunners and tank commanders with an average of about eight years experience on tanks who had been exposed to descriptions, in one form or another, of the HSTV(L). The other group comprised the 15 tankers (five three-man crews) assigned to the HSTV(L) test program, six (two crews) of whom were Army and nine (three crews) of whom were Marines. All HSTV(L) crewmen responded to the questionnaire on completion of their HSTV(L) service.

Results

Research findings on crew size and performance in lightweight armor combat vehicles are presented in three parts. Results of the literature search are presented first, empirical data second, and crewmen opinions third.

Literature Review

While much information was available on vehicles, almost all of it was of a technical or engineering nature. Performance data, where available, concentrated on hardware capability and design rather than crew use or performance. Very little information was found on the methodology of vehicle development and, again, what was available described hardware capabilities rather than performance of man and machine as a system. For example, elimination of the loader position from the conventional four-man tank crew appears to have come about because of technological advancements in the state-of-the-art of automatic loaders rather than an analysis of four- versus three-man crew functions.

Jane's Armor and Artillery. The 1979-1980 Annual Jane's Armor and Artillery provided the most up to date documentation on combat vehicles for countries of the world. From this document, 21 vehicles were identified that met the criteria outlined earlier on weight, crew size, and anti-armor capability. A twenty-second vehicle, the Swedish S-tank, though outside the guidelines on weight, was included in the review. Seventeen of the vehicles are for three-man crews, four for two-man, and one for one-man.

In addition to data on the 22 vehicles extracted from Armor and Artillery, five concept vehicles described in the "Armored Combat Vehicle Technology Study" (Puuri, Mottin, and Seyfert, 1980) and selected by the HSTV(L) test group were reviewed.

The summaries on the 22 vehicles and five concepts were reviewed in terms of five design aspects that could be viewed as advantages to the crew members. The original plan was to tabulate selected design features according to a division by year of initial development. However, Armor and Artillery does not provide exactly the same information for each vehicle. In quite a number of instances the presence or absence of a particular feature is not mentioned. For example, seven vehicle descriptions had no information on fording capability; five descriptions provided no information on the presence or absence of an NBC protective system. A summary of known advantages by design aspect by vehicles is given in Table 1.[1]

Protection from engine or operator compartment fires is provided on seven vehicles and automatic fire warning systems are present on three of these. In the event that an NBC environment is encountered, ten vehicles have a protective system against such conditions and three are equipped with automatic detectors. Duplication of displays and controls for driving operations are present on two vehicles, while duplication of displays and controls for target engagement is a design feature on eight. Thirteen vehicles can swim (some of them require a kit and advance preparation), and five can ford to a depth of at least one meter.

Each of the features included in Table 1 should improve the overall effectiveness of a combat vehicle and a number enhance the environment in which crew members are expected to operate. For crews of less than four men they may have particular impact. For example, automatic systems reduce the number of details that operators must otherwise monitor. The duplication of displays and controls has implications for rest-work cycles and for backup of one crew member by another.

The location of crew members for three-man vehicles was reported with sufficient consistency to do a simple analysis by time. The data on these vehicles were arbitrarily divided to provide nine vehicles designed prior to 1975 and eight designed after that date. Because armored personnel carriers, historically, have been considerd a means of transportation for troops intended to dismount for combat, a further division was made to compare these vehicles to "other" vehicles (see Table 2). Regardless of year of design or type of vehicle, the drivers have been located in the hull. There is some suggestion, in spite of the very small number of vehicles considered, that the location of commanders and gunners has changed in recent years. The clearest indication of this is found on armored personnel carriers; for the five vehicles designed most recently, both crew members are located in the turret. It should be noted, however, that before 1975 the designs for armored personnel carriers did not typically include turrets.

Armor Magazine. Twenty-one articles from Armor Magazine were reviewed. Although an official publication of the U.S. Army Armor Center,

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[1]The data in Table 1 focus on basic design features. Many listed vehicles have appeared in different versions or have been equipped with kits or modifications not reflected in the table.

TABLE 1

VEHICLES WITH DESIGN FEATURES IDENTIFIED AS ADVANTAGES TO HUMAN OPERATORS

VEHICLE	ENVIRONMENTAL SAFETY				NIGHT OPERATIONS		DISPLAY/CONTROL REDUNDANCY		WATER CROSSING CAPABILITIES		MISCELLANEOUS			
	Automatic Fire Extinguisher	Fire Warning System	NBC Protective System	NBC Detection	Driving	Gunnery	Driving	Gunnery	Amphibious	Fording (1 meter)	Air Conditioning	Protection for Reloading TOW Missiles	Rapid Engine Removal (30 min.)	Outside Ammunition Loading
Alvis Saladin FV601(C) (UK)	X	X		?	?	?		X		X				
AMX-13 (France)			?	?	?	?		X		?				X
AMX-10P (France)	X		X	X	?	?		X	X	?				
APE (Germany)			X	?	?	?			X	?				
EE-11 Urutu (Brazil)					X	?			X	?				
FV 436 (UK)			?	?	?	?			X	?				
HSTV(L) (USA)	X	X	X	X	X	X	X	X		X				
Jagdpanzer K 4KH7FA (Austria)			?	?	?	?		X		X				
LK10908 (ACVT-Concept 7) (USA)					?	?				?		X		
OT-64A (SKOT) (Czech)			X	?	?	?			X	?				
OT-64C (SKOT-2A) (Czech)			X	?	?	?			X	?				
OT-62 (Czech)	X		X	?	?	?			X	?				
PT-76 (USSR)			?	?	?	?			X	?				
Ratel 20 (South Africa)					?	?				X				
SA-6 (USSR)			X	?	X	?				X				
Saviem VAB (France)	X		X	?	X	X			X	?	X			
SIBMAS (Belgium)			X		?	?			X	?			X	
STRV 103S (Sweden)	X		?	?	X	?	X	X	X	?				
TOW ATOW (USA)			X		?	?			X	?				
X1A2 (Brazil)					?	?		X		?				
XM2 (USA)	X	X	X	X	X	X		X	X	?		X		

(?) indicates that the presence or absence of this feature could not be clearly determined from the literature reviewed.

TABLE 2

LOCATION OF CREW MEMBERS ON THREE-MAN VEHICLES BY YEAR OF DESIGN

Vehicle and Crew Position	Pre-1975		1975 and After	
	Hull	Turret	Hull	Turret
APC				
D	3	-	5	-
G[a]	1	1	-	5
C	3	-	-	5
Other Vehicles				
D	6	-	3	-
G[a]	1[b]	4[c]	2	1
C	2	4	1	2
APC and Other Combined				
D	9	-	8	-
G	2	5	2	6
C	5	4	1	7

[a]Gunner location not given for one vehicle in the Pre-1975 group.

[b]Radio Operator rather than a Gunner.

[c]Includes a Loader rather than a Gunner.

Armor Magazine does not necessarily reflect official position or endorsement of the articles by the Armor Center. It does, however, provide a forum for the exchange of ideas relating to armor and to the thinking on tank design within the armor community. The following provides a synopsis and conclusions of the review of pertinent armor articles relating to crew size from January 1970 through June 1980.

An examination of articles in Armor Magazine over the past ten years failed to provide explicit information on the role that crew size plays in tank development. It is unclear whether the number of people in a crew is determined by state-of-the-art design technology or whether crew size considerations are used to influence design. One thing is clear, however, in those articles in which a smaller number of crew members is discussed: A debate on light versus heavy tanks (and the ramifications on tank speed and agility attendant to this debate) inevitably follows. Ogorkiewicz (Jan-Feb 73) maintains that reducing the number of crew members increases tank agility by reducing reaction time. Shioritz (Nov-Dec 70), while maintaining that MBT weight must be reduced, states that four men are the minimum that can effectively operate an MBT. Ritgen (Nov-Dec 72) sees the greatest problems in tank design being centered around weight and the future MBT as a 40-ton vehicle with a two-man crew. Hunt (Sep-Oct 75) states that weight is not the decisive factor that others imply, that it is technically possible to have heavy tanks with superior mobility and that the main argument for a light tank lies in the cheaper cost.

Some writers propose specialty tanks. Two- and three-man crews are often considered for such speciality applications. While Riggs (Mar-Apr 70) defines speciality tanks in terms of terrain, most writers consider the speciality tank to be defined by function and the primary function put forth is that of a tank destroyer or infantry support vehicle. Turner (Sep-Oct 75) and Ogorkiewicz (Jul-Aug 75) see a requirement for the U.S. to develop lightweight tank destroyer vehicles with emphasis on evolutionary development.

Perhaps the best known light tank incorporating a three-man crew is the Swedish STRV 103S commonly referred to as the S-tank. Almost all who have discussed this vehicle, whether they are pro S-tank or not, describe the S-tank as innovative (Williams, May-June 75). Ogorkiewicz (Jul-Aug 75) is a particular booster of the vehicle because the adoption of a three-man crew allows a reduction in weight and silhouette. Berge (Mar-Apr 73), in a discussion of the technical characteristics of the tank, touches on the background of the design. In part, the design was a result of Sweden's reliance upon conscript service for self defense. This situation dictated that training time from mobilization to deployment be kept to a minimum. To accomplish this, a reduction in crew size as well as training time was needed. Elimination of the loader on the S-tank accomplished both. The S-tank has been operational since the early 1970s. The principal criticism of the S-tank concerns its fixed gun which requires that the vehicle be stationary and pointed directly toward a target for target engagement; Ogorkiewicz, however, considers that this problem has been exaggerated. It is in actuality a two-man tank with the capability of emergency one-man operation (Ogorkiewicz, Jul-Aug 75).

Williams (Mar-Apr 74) discusses some valuable "lessons learned" from his review on tank development. For example, growth allowances for weight and size at the concept stage are unrealistically low; on the average a tank's weight increases by 15% and its size by 13% during development. Helton (Jul-Aug 73) observes that early problems with the M551 stayed with the vehicle, by way of reputation, even after the problems were corrected. Starry (Jul 75-Feb 76) suggests that a nation's tank development tends to follow established trends and practices.

Foreign armor developments are of interest because most current lightweight and three-man tanks are foreign. The British experience with small, lightweight armored vehicles is considerable--they developed a whole family of such vehicles (Ogorkiewicz, Jan-Feb 70 and May-Jun 72) though the design is not without criticism (McArthur 1972). Starry (Sep 75-Feb 76) and Ogorkiewicz (Jul-Aug 75) both cite the speed, agility, low silhouette, and in some cases simplicity in French, Soviet, and British designs which have been achieved by small and lightweight configurations. However, these vehicles are not without their detractors. Luttwak (Jul-Aug 72) cites the Israelis' unfavorable experience with light tanks (AMX 13) in the 1967 war as evidence against further development of such vehicles.

A frequent criticism of tank concepts with fewer than four-man crews is that they will not be maintained properly. Bowen (Jan-Feb 80) disputes this. He suggests that a vehicle, if designed specifically for reliability and ease of maintenance, could be maintained by two crewmen. Ritgen (Nov-Dec 72) recommends a transfer of servicing and maintenance requirements to organizational maintenance to the extent that such requirements cannot be reduced through improved design, including components, changes in PM procedures and inspection and replacement philosophy. He proposes that maintenance come to the tank, rather than the tank going to a maintenance shop.

Empirical Data

Driving. Mean elapsed times for the eight runs of the driving course are shown in Table 3. The times ranged from 3 minutes 33 seconds to 4 minutes 45 seconds. The mean of the four runs by the three-man crews was 4:30 as compared to 4:00 for the two-man crews. This difference of nearly half a minute is not statistically reliable;[1] even if it were it could not be unequivocally attributed to crew size since all two-man runs came after those involving the three-man crews (counterbalancing the order of crew size was precluded by other testing considerations).

Crews in neither configuration experienced any particular problems with maneuver except in one situation where, during the two-man runs, the vehicle had to be backed out of a hull defilade position. In the two-man runs, outside assistance was needed in backing up because the HSTV(L) driver is completely blind to the rear.[2]

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[1] $t = 2.165$, $p < .05$

[2] The HSTV(L) has provisions for a rear-mounted television monitor which was not installed on the test vehicle.

TABLE 3

MEAN ELAPSED DRIVING TIMES (MIN:SEC) FOR TWO-MAN AND THREE-MAN HSTV(L) CREWS IN OPEN AND CLOSED HATCH OPERATIONS

Crew Size	Crew	Open Hatch	Closed Hatch	Total
Three-Man	Crew 1	4:40	4:18	4:29
	Crew 2	4:15	4:45	4:30
	Total	4:28	4:32	4:30
Two-Man	Crew 1	4:20	3:57	4:05
	Crew 2	3:33	4:15	3:54
	Total	3:56	4:06	4:01
Total		4:12	4:18	4:15

After all runs were completed the crews were debriefed. Preference for a three-man crew predominated. Drivers felt restricted without the "eyes" and guidance capability of the commander. This was expressed even by one driver whose commander did not normally interact extensively with him. There was no reported interaction between the driver and the gunner during the run of the course even though the HSTV(L) driver has restricted vision on the right (gunner) side.

PMCS. Time and quality of preventive maintenance checks and services as performed by crews of different size are summarized in Table 4.

TABLE 4

BEFORE-OPERATIONS PMCS AND CREW SIZE

	Crew Size		
Measure	Four-Man (N=3)	Three-Man (N=3)	Two-Man (N=3)
Mean Time to Complete PMCS (minutes)	22	38	38
Mean Number of 2404 Entries	4.33	12.67	3.00
Mean Number of Deficiencies Omitted	3.67	1.00	3.00

The four-man crews completed PMCS in an average of 58% of the time it took the three-man or two-man, a statistically reliable difference[1] in performance time. To evaluate the accuracy of the PMCS checks, the number of serious deficiencies (defects in the "Not Ready/Available" category) omitted were determined. Three such defects were determined for one tank, four for another, and six for the third. None of the four-man crews found all the known "Not Ready/Available" defects, nor did any of the two-man crews. And while two of the three-man crews located all the defects in this category, the difference in mean deficiencies omitted was not statistically significant.[2]

The total possible DA Form 2404 entries was not determined since many inspection items are so judgmental. It is generally true, however, that the greater the number of entries the more thorough the inspection; "false-negative" errors are few. Two of the three-man crews reported many more deficiencies than any of the other crews, which resulted in a larger (but not statistically so)[3] mean number of 2404 entries for three-man crews than for crews of two- or four-men.

Opinion Data

The 40 experienced armor crewmen (EAC) and 15 HSTV(L) crewmen responded to several items in the questionnaire pertaining to crew size. In nearly every regard a three-man crew was preferred to a two-man crew. When asked, for instance, which crew combination they would select for a combat environment, response overwhelmingly favored the three-man crew (Table 5). HSTV(L) crewmen as well as armor experts with only descriptive information on the HSTV(L) ranked the three-man crew significantly higher[4] (preferred) than any two-man crew combination. Both groups seemed to agree also that among the two-man combinations the Commander-Driver pair was the most preferred; differences in preference for the various two-man crew combinations were not evaluated for statistical reliability however.

When asked about the estimated difficulty of command and control on conventional tanks as compared to the three-man (HSTV(L), both groups of respondents indicated that command and control would be easier on the three-man HSTV(L) than on conventional tanks (Table 6). Reducing the HSTV(L) crew from three to two was seen as complicating the command and control process (Table 7), though only the EAC group mean was reliably different from the neutral or "no-difference-in-difficulty" point on the rating scale.

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[1] $F\ (2,6) = 8.6,\ p < .05$

[2] $F\ (2,6) = 1.96,\ p > .05$

[3] $F\ (2,6) = 4.60,\ p > .05$

[4] $\chi^2\ (4) = 38.8$ for EAC group and 17.9 for HSTV(L) group, both with $p < .05$

TABLE 5

MEAN RANKINGS[a] OF CREW COMBINATIONS FOR A COMBAT ENVIRONMENT

Group	n^b	Commander Gunner Driver	Gunner Driver	Commander Driver	Commander Gunner
EAC	37	1.05	3.22	2.53	2.97
HSTV(L)	13	1.23	3.0	2.62	3.15

[a]1 = most preferred; 4 = least preferred

[b]The smaller *n*s are a result of some respondents failing to answer this question.

TABLE 6

ESTIMATED COMMAND AND CONTROL DIFFICULTY ON CONVENTIONAL TANKS AS COMPARED TO HSTV(L) WITH A THREE-MAN CREW

Group	n	Mean[a]	*SD*	t^b	$t_{.975}$
EAC	40	8.6	2.39	-4.23*	± 2.02
HSTV(L)	14	9.2	2.04	-4.05*	± 2.16

[a]Scale of 1-13, where: 1 = more difficult on HSTV(L)
13 = less difficult on HSTV(L)

[b]Observed mean tested for difference from 7, the neutral point on the 13-point difficulty scale; asterisk indicates a significant difference at the .05 level using a two-tailed test.

TABLE 7

ESTIMATED COMMAND AND CONTROL DIFFICULTY ON THE HSTV(L) WITH A TWO-MAN CREW AS COMPARED WITH A THREE-MAN CREW

Group	n	Mean[a]	SD	t[b]	$t_{.975}$
EAC	40	5.17	3.12	-3.71*	$\pm$ 2.02
HSTV(L)	14	5.50	3.25	-1.73	$\pm$ 2.16

[a]Scale of 1-13, where: 1 = more difficult on HSTV(L)

[b]Observed mean tested for difference from 7, the neutral point on the 13-point difficulty scale; asterisk indicates a significant difference at the .05 level using a two-tailed test.

Command and control during HSTV(L) gunnery (Table 8) was judged to be slightly more difficult for a two-man crew than a three, though not reliably so by the group of HSTV(L) crewmen. This view was consistent regardless of the two-man combination being considered.

TABLE 8

ESTIMATED COMMAND AND CONTROL DIFFICULTY DURING HSTV(L) GUNNERY WITH A TWO-MAN CREW AS COMPARED TO A THREE-MAN CREW

Two-Man Crew	Group	n	Mean[a]	SD	t[b]	$t_{.975}$
Driver-Gunner	EAC	40	4.9	3.01	-4.41*	$\pm$ 2.02
	HSTV(L)	14	6.0	2.54	-1.47	$\pm$ 2.16
Driver-Commander	EAC	40	5.7	2.70	-3.04*	$\pm$ 2.02
	HSTV(L)	14	6.5	2.82	- .66	$\pm$ 2.16
Gunner-Commander	EAC	39	5.9	2.94	-2.34*	$\pm$ 2.02
	HSTV(L)	14	5.6	2.74	-1.91	$\pm$ 2.16

[a]Scale of 1-13, where: 1 = more difficult on HSTV(L)
13 = less difficult on HSTV(L)

[b]Observed mean tested for difference from 7, the neutral point on the 13-point difficulty scale; asterisk indicates a significant difference at the .05 level using a two-tailed test.

Both groups of respondents believed there would be fewer problems in handing-off targets between HSTV(L)s with three-man crews than between conventional vehicles but tended as groups to be less decisive on this question in comparing two-man HSTV(L)s with conventional vehicles (Table 9). Target hand-off between HSTV(L)s was seen as more likely to be problematic with two-man crews than with three-man crews (Table 10). Similar response was given to a question about problems expected in communicating between HSTV(L)s with three-man crews as opposed to two-man crews (Table 11); that is, as a group respondents foresaw no problems in communicating between three-man crews but were of mixed opinion when it came to two-man crews.

TABLE 9

ESTIMATED PROBLEMS IN TARGET HAND-OFF BETWEEN HSTV(L)S AS COMPARED TO CONVENTIONAL VEHICLES

		Three-Man HSTV(L)			Two-Man HSTV(L)		
Group	*n*	More Prob.	Less Prob.	$\chi^2(1)$	More Prob.	Less Prob.	$\chi^2(1)$
EAC	33	9	24	6.82*	17	16	.03
HSTV(L)	12	1	11	8.33*	8	4	1.33

*$p < .05$

TABLE 10

ESTIMATED PROBLEMS IN TARGET HAND-OFF BETWEEN HSTV(L)S WITH THREE-MAN VERSUS TWO-MAN CREWS

Group	*n*	More Problems With Three-Man	More Problems With Two-Man	$\chi^2(1)$
EAC	36	4	32	21.78*
HSTV(L)	11	0	11	11.0*

*$p < .05$

TABLE 11

EXPECTATION OF PROBLEMS IN COMMUNICATIONS
BETWEEN HSTV(L)S WITH THREE-MAN VERSUS TWO-MAN CREWS

		Prob. With Three-Man			Prob. With Two-Man		
Group	*n*	Yes	No	$\chi^2(1)$	Yes	No	$\chi^2(1)$
EAC	40	3	37	28.9*	14	26	3.6
HSTV(L)	13	1	12	9.31*	5	8	.69

*$p < .05$

When asked if they thought it would be possible to put a crew member off the vehicle on an outpost and maintain communications and weapon operations at a distance for up to eight hours, respondents indicated it would be possible with a three-man crew but may not be with a two-man (Table 12).

TABLE 12

JUDGED FEASIBILITY OF MAINTAINING VEHICLE SYSTEMS
AND SECURITY IN A STATIC LOCATION FOR AN EXTENDED PERIOD (8 HOURS)
WITH ONE CREWMAN DISMOUNTED

		Feasible With Three-Man			Feasible With Two-Man		
Group	*n*	Yes	No	$\chi^2(1)$	Yes	No	$\chi^2(1)$
EAC	40	37	3	28.9*	11	29	8.1*
HSTV(L)	13	12	1	9.31*	1	12	9.31*

*$p < .05$

Finally, while respondents tended to believe that a reduction in crew size from four to three would not adversely affect confidence in the weapon system, they were divided in their judgments of the effect of a further reduction to two-men (Table 13).

TABLE 13

JUDGED EFFECT OF REDUCTION IN CREW SIZE ON CONFIDENCE IN WEAPON SYSTEM

		From Four-Man to Three-Man Affect Confidence?				From Three-Man to Two-Man Affect Confidence?		
Group	*n*	Yes	No	$\chi^2(1)$	*n*	Yes	No	$\chi^2(1)$
EAC	40	5	35	22.5*	39	21	18	.23
HSTV(L)	13	1	12	9.31*	13	7	6	.08

*$p < .05$

Discussion

Opinions of crewmen, especially in their written comments, revealed strong preferences for crew sizes. The reduction of a tank crew from four to three men is seen by some as causing problems in target acquisition, maintenance and sustainability, and these problems are perceived to be exacerbated when further reduction to a two-man crew is considered. Additional concern with two-man crews was evidenced in the areas of command and control and reaction to casualties. On the other hand, however, several of the SMEE believed that with fewer crew members target engagement time would be less. Other perceived benefits in going to smaller crews were few; the majority of comments were negative. Yet it should be noted that in most functional areas these opinions were not based on actual experience with the smaller crews.

Comments also indicated that respondents are distrustful of technology. Many expressed concerns about systems reliability and durability. This is important because reduced crew size is most likely achieved by technological advances. Backup systems and, in particular, manual redundancies for systems were prime concerns. It appears that the more sophisticated the technology the more distrustful many are of its working properly. This reaction should hardly be surprising. Most NCO field experience has included experience with automotive, gunnery and mobility system failures brought on by the hard use, even misuse, given tanks, and they have experienced first hand the inadequacies of the maintenance system.

This skepticism is a legitimate area for study or training in the fielding of new high technology systems. At least one recent system, the M551 Sheridan, "failed" because of the common perception that the vehicle was "no good" when actual data were to the contrary. Hilton (1973) observed that tankers' previous experiences did not adequately prepare them for the M551; initial problems stayed with the vehicle by word of mouth even after they had been corrected. Such experience must be remembered. As one respondent commented on the questionnaire, "A three- or two-man tank will not work because people don't expect it to work."

These subjective reactions notwithstanding, there is little by way of hard data to shed light on the issue of optimal crew size for an armored fighting vehicle. That a vehicle like the HSTV(L) can be effectively manned by a crew of three is reasonably certain. Armor experts familiar with the HSTV(L) through either system descriptions or first-hand experience agreed that the vehicle with a three-man crew was probably more effective--at least from a command and control standpoint--than conventional vehicles with the traditional four-man crew. Preventive maintenance can probably be done as well but not as rapidly with fewer crewmen, but in the critical areas of target detection and target engagement no data--either analytic or empirical--were obtained on crew size.

One interpretation of the opinion data is that the armor experts prefer a three-man crew to either a four-man or a two-man crew: that somehow four are too many, complicating perhaps the coordination required among crewmen, and two are too few, a matter of not enough eyes and hands to handle the work load. This interpretation is plausible if one bears in mind that it is relative to the HSTV(L), a vehicle designed for three-man operation.

This is an important point: Judgments of optimal crew size cannot be made absolutely but must be made relative to the design, engineering and mission of a given armor vehicle. As the literature suggests, by automating some human functions and duplicating the displays and controls for others, crewman operations may at once be reduced in number and increased in flexibility. How far systems engineers can go in eliminating the human function depends of course on the nature of a system's requirements.

A vehicle like the HSTV(L), which was designed for experimental operation by a crew of either three or two, offered a unique opportunity to evaluate with some precision the need for the third crewman (or, viewed another way, the cost of deleting the third crewman). But, because controlled comparisons of three- versus two-man crew operations on critical gunnery and tactical tasks were not made, valid conclusions about the relative effectiveness of alternative manning levels cannot be drawn. We are left with experienced judgment which indicates rather reliably that an HSTV(L) with a three-man crew is superior to one with a two-man crew in areas such as command and control, communications, target hand-off, and crewman confidence. As accurate as these judgments may be, in the final analysis the question is not whether a three-man crew is better than a two-man, but whether it is enough better to justify the price one pays for the extra man. A vehicle like the HSTV(L) apparently can be operated by a crew of two, and assuming manpower to be the premium resource more two-man than three-man weapon systems may be fielded (the ratio, in fact, is three to two) per unit cost. Thus, if an HSTV(L) operated by two men cannot detect, engage, or hit targets as well as one operated by three men, then one needs to demonstrate that the disparity is substantial and not easily offset by the savings in manpower. This issue cannot be resolved by expert opinion. It requires empirical test, an approach intended but not realized in this work.

STUDY II. METHODS OF ESTIMATING CREW PERFORMANCE REQUIREMENTS

Methodological problems in estimating personnel and training requirements have been recognized for some time. Rupe (1963) quotes the Commanding General, US Continental Army Command from a 1961 issue of the "Army Information Digest": "When a new piece of equipment is developed, the user is concerned with how many men will be needed to operate it, how much training will be required . . ." In his report on predicting training requirements for future weapon systems, Rupe cites a number of others who have worked on this problem (Folley; Shapero; Powe, Carrier and Skandera; Miller; and Knowles).

Finley, Obermayer, Bertone, Meister and Muckler (1970) reviewed well over four hundred documents spanning more than three decades of research and development to evaluate methods and tests that could predict human performance in man-machine systems. As a result of this extensive review they conclude that methods for precise prediction of human performance in man-machine system tasks is a continuing and fundamental problem. They found the literature dealing with this problem to be unstructured and conceptually fragmented.

More recently, Finley and Muckler (1976) observe: "The problem is that very little research provides data on both operator/crew and system performance." Also: ". . . the methods for determining desirable function allocations and operator/crew workloads . . . leaves much to be desired."

Kurke (1961) provided a method, derived from engineering techniques such as operational process charts, for mapping behavioral requirements in task performance. This method of analysis, the Operational Sequence Diagram (OSD), provides a task analyst with information on discriminations, decisions, actions, and information exchange necessary to operate a mechanism. The method is useful for establishing sequence of operational requirements, elapsed time in task performance, and input-output rate load imposed upon operators. His presentation of the method illustrates its usefulness in making decisions on allocation of functional requirements to a human operator or to a hardware component.

Bauer and Walkush (1976) employed the OSD method of analysis to determine how many crewmen would be needed to perform weapons and leadership functions within a turret of an armored reconnaissance vehicle. They prepared OSD for three mission segments for two and one man concepts of the turret. Variants for each concept were also developed to reflect firing of a main gun or a missile. Comparisons of the OSD provided a sound basis for recommending the two-man turret concept, based upon differences in contact to strike time and large advantages in concurrent observation, reconnaissance and communication time.

Hughes (1979) investigated a method for predicting personnel requirements for two different tank systems by comparing their common and unique job characteristics. His method required the identification of basic functional performance requirements for each of the system tasks as opposed to their surface characteristics commonly specified in descriptive task analysis. Using a set of descriptors (stimuli; tools, instruments, controls; mediating processes; and overt responses) tasks were analyzed to obtain task characteristic profiles. Comparisons of task profiles were then made by plotting the total percentage of tasks containing a particular descriptor. Finally, a task by descriptor matrix was analyzed using a method of cluster analysis to produce prediction tables that reflected the basic structure of job performance for each tank system. Hughes makes a number of suggestions for improving the methodology and concludes that it can be useful to determine optimum job structure and to address selection and assignment policies for emerging weapon systems.

Each of the methods described above relies heavily on specialists such as psychologists or training experts. Sauer and Askren (1978) describe a method that relies upon subject matter experts to obtain predictions about manpower, maintenance and training requirements for new equipment. In their study, sixty technicians from two Air Force maintenance specialties were asked to provide estimates based upon an engineering description of a radar navigation system. The equipment description was limited to information that would be available at an early phase in design of the system. Because other navigation equipment selected for this study was in the Air Force inventory, criterion data could be obtained for comparison with the estimates. Based upon the comparisons, the authors concluded that experienced Air Force technicians can estimate the following with a satisfactory degree of accuracy: maintenance man-hours, crew size, skill level, career field, and task difficulty. However, they observed that the technicians seriously overestimated training time requirements. Estimates regarding requirements for training, training equipment and facilities and recognition of design features that might have adverse impact on maintenance capabilities were inconclusive.

Research is needed to develop, improve, and validate a methodology for forecasting minimum crew and training requirements during early design phases of lightweight, highly mobile armor weapon systems, and for providing early estimates of characteristics (e.g., driving and gunnery capabilities) of the weapon systems to preclude costly modifications during vehicle production phase.

Two candidate methods for assessing and projecting manpower, training, and operational requirements and other human factors aspects for lightweight armor vehicles were selected for modification and validation in this study. These were: (1) the Operational Sequence Diagram (OSD) method originally described and illustrated by Kurke (1961), and later modified by Bauer and Walkush (1976) to the solution of an armored vehicle manpower problem: and (2) the Subject Matter Expert Estimation (SMEE) method described by Sauer and Askren (1978). The two methodologies are described below.

Operational Sequence Analysis. The Operational Sequence diagram (or OSD) method of analysis is best summarized by Kurke (1961):

> "The OSD is a type of process chart modified for the peculiar needs of human factors work. Its primary use has been in determining man-machine interaction sequences, in analyzing communications requirements between groups of men and machines, and in coordinating information-decision-action sequences between interfacing subsystems. In its various forms the OSD can be used in several stages of system development."

Kurke's description can be extended to derive quantitative information from OSD of task performance. Each task can be described in terms of the number (or percent) of task steps representing requirements for action, transmitting information, receiving information, monitoring, recording, and decision making. Such data provide means for comparing the human performance demands of different tasks. An OSD also is useful in depicting the extent to which time-sharing enters performance, and in providing estimates of task performance time. Additional data can be derived from such analysis; for example, the need for perceptual-motor skills, finger dexterity, and fine visual discrimination, can be identified. Through development of OSD and especially through analysis on the vehicle, human factors problems and limitations become apparent. OSD provides a basis for allocating system functions between man and machine and for further subdividing the human functions among crew members. Moreover, the interplay between machine and crewmen or among crewmen--whether at the level of function, task or subtask--may be studied in some detail. Finally, OSD can provide a method for comparing the effect of different crew sizes on task performance responsibilities and task time.

An important variation on the OSD method was introduced in the present study. As applied by Kurke and later as applied by Bauer and Walkush, the OSD method relied on the use of psychologists, training experts or others in specialized disciplines to apply the OSD. During this study it was decided that the effort would focus on determining if the OSD method could be employed by individuals who possessed some related subject matter expertise in armor, but who were not particularly knowledgeable of or trained in the OSD method.

Subject Matter Expert Estimation. The SMEE method has been investigated in considerable detail by Sauer and Askern (1978). Briefly, the approach:

> ". . . requires relatively little in terms of external support and therefore represents a relatively low cost method for producing human resource estimates.
>
> The technique consists of five basic steps. First, an engineering description package is compiled for the equipment or system under study. This description is based on the engineering data and specifications available during early phases of system design. Second, a questionnaire is designed to collect the specific human resource estimates desired. The third step is to select the appropriate kinds and quantities of technicians to serve as expert estimators. The fourth step is . . . to collect the desired estimates. The fifth step is to analyze the data."

The expert estimation of manpower, training, and operational requirements of equipment systems does not depend on the availability of prototype or actual equipment. The method requires only an engineering description of the proposed system. The impact of alternative designs on human resources can be assessed using the SMEE approach.

Purpose

The purpose of this study was to evaluate the effectiveness of two methods of forecasting human factors and training requirements for a light, highly mobile armor weapon system, the HSTV(L). Specifically, the intent was to compare estimates made by armor experts using the two methods; comparisons were to be between methods, between each method and comparable estimates made by experienced HSTV(L) crewmen, and where feasible between the methods and actual system performance data.

Method

The general approach taken in this research was to obtain from armor experts, supplied with data on but no experienced with the HSTV(L), estimates of crew performance requirements for that weapon system, and then validate those estimates against criterion data derived from observed HSTV(L) performance or reports from experienced crewmen. The procedures for data collection included four activities:

1. Prepare engineering description.
2. Prepare operational sequence diagrams.
3. Prepare subject matter questionnaire.
4. Collect data.

The first three activities were performed concurrently. Detailed descriptions of these activities and the collection of estimation data from two groups using the engineering description and operational sequence diagrams are contained in Armor Weapon System Employment Parameters: Human Factors Methodologies Applied to Small Crew Performance Estimates (Taylor, Harris, and Campbell, 1981); only a brief summary of methodology used with these two groups is presented here. The third group from which data were collected was the HSTV(L) crews.

Estimation Methods

Engineering Description. The engineering description was modeled after one used by Sauer and Askren (1978) and was prepared in two volumes: one being an engineering description, predominantly textual, of the HSTV(L); the other consisting of the tables and figures referred to in the first. The material was separated to enable subjects to refer to tables and figures without leaving the text. The engineering description was prepared from three sources:

1. Preliminary Operation and Maintenance Manual for High Survivability Test Vehicle (Lightweight) HSTV(L), Parts I, II, and III, ER-10298A, AAI,[1] February 1980 with Change 1, April 1980.

2. HSTV(L) Fire Control System Training Manual, September 1980.

3. Conferences with Armored Combat Vehicle Technology (ACVT) test personnel and AAI technical representatives.

The engineering description contained sections on descriptions and data, primary driver's functions, primary gunner's functions, primary commander's functions, fire control system, communication system, preventive maintenance checks and services, and a general system description.

Operational Sequence Diagrams. The OSD were prepared to provide the OSD group of subject matter experts with a detailed understanding of crew performance of 16 driving and gunnery tasks. The tasks were analyzed for the three-man crew to reflect accessibility of subsystem components, controls and displays available to each crew member, and distribution of workload among the three crew members. These analyses were required to approximate an equally shared workload within the restrictions of the system and to maintain vehicle command and control functions traditional to the tank commander.

Preliminary OSD were prepared for each task depicting step-by-step performance by and interactions among crew members. These were reviewed by the HSTV(L) test group or the AAI technical representatives and revised on the basis of their comments.

When the OSD for the three-man crew were completed, the variants for two-man crews of driver-gunner, driver-commander and gunner-commander were developed. Tasks were analyzed for each two-man crew combination according to the guidelines used above; that is, taking into account readiness of access to parts of equipment and distribution of the workload of the missing crew member between the remaining crew members.

Subject Matter Questionnaire

The questionnaire was prepared by selecting the manpower, training, and operational aspects of interest and formatting questions to elicit the types of estimates required. The questionnaire (see Appendix A) comprises 42 questions in seven functional areas. A breakdown of the questions by area, including sample questions is presented in Table 14.

[1]AAI is the firm that built the HSTV(L).

TABLE 14

NUMBER AND TYPE OF QUESTIONS
MAKING UP THE SUBJECT MATTER EXPERT QUESTIONNAIRE

Functional Area	Question Numbers[a]	Sample Question (or Paraphrase)
Training	1-3	"Estimate the amount of time required for each crewman to be oriented on the HSTV(L)."
Driving	4-12	"Explain any difficulties you think a driver will have in a combat environment when the crew is engaging targets and the HSTV(L) is under enemy fire."
Maintenance	13-18	"Indicate in the space next to the preventive maintenance check or service, the crew member or members who should do the maintenance."
Gunnery	19-20	"The Hunter/Killer fire control system will enable crews to detect more available targets." (Yes/No)
Command and Control	23-27	"Place an X in the box to indicate which two-man crew combination permits the most effective command and control during moving firing vehicle gunnery."
Crew Requirements	21-22, 28-30, 35-42	"Put an X in the box under the two-man crew combination that will permit the most rapid target hand-off."
HSTV(L) Design	31-34	"How important is it to be able to slew the turret?" (Extremely Important - Moderately Important - Not Important At All)

[a]See questionnaire at Appendix A.

Data Collection

Data were collected from 40 highly experienced gunners and tank commanders (E-6 and E-7 Sergeants) over a ten day period. The participants were asked to review materials pertaining to the HSTV(L) and then to complete the questionnaire. The 40 subjects were divided into two groups, the first called the SMEE group and the second called the OSD group. The SMEE group received the engineering description for the HSTV(L) and a supporting document of tables, drawings and photographs. The OSD group received the same materials plus a description of the step-by-step performance and crew interactions for selected driving and gunnery tasks.

The questionnaire administrator briefed the participants on the purpose of the research project prior to giving verbal instructions for the questionnaire and evaluation. They were advised to read all the materials before making their estimates. They were also encouraged to refer to the materials as often as they wanted to during the session.

The questionnaire only was administered to a third group consisting of the 15 crewmen (two Army and three Marine crews) participating in the HSTV(L) testing ongoing at Fort Knox. This group was to serve as the initial criterion group (CRIT) against which SMEE and OSD group estimates were compared. These crewmen served from six to ten months with the HSTV(L) program, all completing the questionnaire at the end of their HSTV(L) service.[1]

Estimates made by experts using the OSD or SMEE methods were to be validated against two kinds of criteria, one being objective HSTV(L) performance data, the other being comparable subjective data obtained from HSTV(L) crewmen with first-hand experience in the functional areas covered on the questionnaire. With the exception of performance times for five tasks, objective HSTV(L) performance data in areas relevant to the questionnaire were not obtained for reasons already mentioned (see page 4). Thus the balance of the validation effort rested with the subjective criterion data.

Subjective data in the form of observations and judgments of those experienced in system operation is a weaker but more feasible criterion. The quality of the data can be enhanced by selecting judges experienced precisely in the content area being explored. Sauer and Askren (1978) used this type of source extensively. They established the credentials of groups of judges in different categories and then used the groups separately or in combination depending on their established credentials relative to a particular category. So, although the CRIT group completed the entire questionnaire, not all crewmen were qualified to provide criterion data on all items. The reasons for this included the following:

- The activities of the test crews (CRIT group) in the vehicle were very restricted. Firing was done under rigidly controlled conditions following a set procedure, down a predetermined

[1]One crew member departed early and did not return the questionnaire.

course, at known targets. No tactical exercises with the vehicle were attempted. Crew maintenance was not conducted. In short, only a limited number of the tasks or situations included in the questionnaire were actually performed by the crew during the test period.

- Crew members generally performed only in their designated roles; that is, drivers drove, gunners gunned, and commanders commanded. There was little if any cross training between duty positions.

- The crews always performed as full crews. Two-man or one-man crews were not tried in situations where three-man crews would normally perform.

For these reasons it was necessary to use data from the test crews selectively. Data to be analyzed were limited to (a) that pertaining to activities or tasks in the questionnaire that the crew was known to have performed or experienced during the test period, and (b) that obtained from respondents who actually served in the duty position referenced in a given question. Thus, responses for items pertaining to two-man crew operation, driving on snow or through wooded terrain, firing at moving targets, and handing off targets to another vehicle were not analyzed; nor were, for example, the driver responses to questions about TC activities. As a result, the CRIT group questionnaire results were limited primarily to the areas of training and performance times and driving difficulties.

Results

Results bearing on the overall validity of crew performance estimates are presented for the areas of training time, driving difficulty, and time to perform selected tasks. This is followed by an analysis of the comparative accuracy of the two estimation groups. Finally, participant reaction to the estimation methods are presented.

Validity of Estimates

Validities of performance requirement estimates was examined by comparing the SMEE and OSD groups' questionnaire results with those of the CRIT group and with actual performance data.

Questionnaire Data. The most complete set of comparative data was in the area of training time. Accuracy values (Sauer and Askren, 1978) were calculated as time estimated by the OSD or SMEE group divided by the time established by the CRIT group. Estimates that perfectly predicted the CRIT group training time have an accuracy value of 1.00. Estimates below the CRIT group training time yield accuracy values below 1.00 and estimates greater than the CRIT group yield accuracy values greater than 1.00.

Accuracy values were computed for estimates of time-to-train in a total of 13 task categories for each of the three duty positions. These values are presented for each of five levels of proficiency in Tables 15 through 19. Medians were used because of the many skewed distributions of estimated time.

TABLE 15

ESTIMATED TRAINING TIME REQUIRED TO FAMILIARIZE EXPERIENCED TANKERS

	(*n*)	Accuracy Value	Median (Hours)	Range (Hours)
		DRIVER		
OSD	(19)	3.53	4.1	1-720
SMEE	(19)	3.70	4.3	1-80
CRIT	(4)	--	1.2	1-2
		GUNNER		
OSD	(19)	1.50	7.8	1-720
SMEE	(19)	1.06	4.3	1-60
CRIT	(5)	--	4.0	1-336
		COMMANDER		
OSD	(19)	1.00	7.8	1-720
SMEE	(19)	.57	4.4	1-40
CRIT	(5)	--	7.8	2-80

$$\text{Accuracy Value} = \frac{\text{Median Estimated Familiarization Time}}{\text{Median Criterion Familiarization Time}}$$

TABLE 16

ESTIMATED TRAINING TIME REQUIRED FOR EXPERIENCED TANKERS TO LEARN BASIC OPERATION

	(*n*)	Accuracy Value	Median (Hours)	Range (Hours)
DRIVER				
OSD	(20)	2.78	4.2	.5-200
SMEE	(19)	2.67	4.0	1-20
CRIT	(4)	--	1.5	1-4
GUNNER				
OSD	(20)	1.93	7.7	.5-200
SMEE	(19)	1.10	4.4	0-24
CRIT	(5)	--	4.0	1-336
COMMANDER				
OSD	(20)	3.88	7.8	.5-200
SMEE	(19)	2.25	4.5	.5-29
CRIT	(5)	--	2.0	.5-40

$$\text{Accuracy Value} = \frac{\text{Median Estimated Time for Basic Operation}}{\text{Median Criterion Time for Basic Operation}}$$

TABLE 17

ESTIMATED TRAINING TIME REQUIRED FOR EXPERIENCED TANKERS TO BECOME PROFICIENT

	(*n*)	Accuracy Value	Median (Hours)	Range (Hours)
DRIVER				
OSD	(20)	3.13	12.5	1-40
SMEE	(19)	2.06	8.3	1-48
CRIT	(3)	--	4.0	2-5
GUNNER				
OSD	(20)	.50	20.0	1-72
SMEE	(19)	.22	8.6	1-72
CRIT	(5)	--	40.0	12-672
COMMANDER				
OSD	(20)	.23	18.5	1-72
SMEE	(19)	.11	8.6	1-34
CRIT	(5)	--	79.7	1-80

$$\text{Accuracy Value} = \frac{\text{Median Estimated Time for Proficiency}}{\text{Median Criterion Time for Proficiency}}$$

TABLE 18

ESTIMATED TRAINING TIME REQUIRED FOR INEXPERIENCED TRAINEES TO LEARN BASIC OPERATION

	(n)	Accuracy Value	Median (Hours)	Range (Hours)
DRIVER				
OSD	(20)	5.40	8.1	1-280
SMEE	(20)	5.45	8.2	1-40
CRIT	(4)	--	1.5	1-20
GUNNER				
OSD	(20)	.97	15.5	1-280
SMEE	(20)	.78	12.5	1-40
CRIT	(5)	--	16.0	1.5-960

$$\text{Accuracy Value} = \frac{\text{Median Estimated Time for Basic Operation}}{\text{Median Criterion Time for Basic Operation}}$$

Note: Commander position not evaluated.

TABLE 19

ESTIMATED TRAINING TIME REQUIRED FOR INEXPERIENCED TRAINEES TO BECOME PROFICIENT

	(n)	Accuracy Value	Median (Hours)	Range (Hours)
DRIVER				
OSD	(20)	10.67	32.0	1-272
SMEE	(20)	9.50	28.5	2-140
CRIT	(3)	--	3.0	1.5-25
GUNNER				
OSD	(20)	.46	36.5	1-272
SMEE	(20)	.32	25.5	2-140
CRIT	(5)	--	80.0	24-672

$$\text{Accuracy Value} = \frac{\text{Median Estimated Time for Proficiency}}{\text{Median Criterion Time for Proficiency}}$$

Note: Commander position not evaluated.

Overall, the OSD group overestimated the time required in eight of the 13 categories, underestimated in four and had perfect agreement in one. Similarly, the SMEE group overestimated in eight of the situations and underestimated in five. OSD overestimates ranged in accuracy from 1.50 (50% error) to 10.67 (967% error); underestimates ranged from .97 (3% error) to .23 (77% error). SMEE overestimates ranged from 1.06 (6% error) to 9.50 (850% error) and underestimates ranged from .78 (22% error) to .11 (89% error).[1] Discrepancies were computed as the average of the absolute values of the amounts of over- and underestimated. Overall, the OSD group had an average accuracy value of 2.77 and the SMEE group 2.29. So while the SMEE group was slightly more accurate in estimating training times, the discrepancies of both groups were large.

Driving was another area in which usable criterion data was available. But the experience of the CRIT group was limited to driving on dirt roads, so these data were accordingly restricted.

A comparison of the three groups is shown in Table 20. Overall, for the listed driving tasks the groups rated the HSTV(L) at the high (Extremely Easy) end of the scale as compared with other tanks, 4.8, 5.2, and 4.8 for CRIT, OSD and SMEE groups respectively. The SMEE group estimates were more accurate (1.02) across the driving tasks than were OSD responses (1.16), but only slightly so.

TABLE 20

DIFFICULTY[a] OF PERFORMING SELECTED DRIVING OPERATIONS ON DIRT ROADS AS COMPARED WITH OTHER TANKS

Driving Operations	Median Rating			Accuracy Values	
	CRIT (*n*=4)	OSD (*n*=20)	SMEE (*n*=20)	OSD	SMEE
Shift Gears	5.5	5.4	5.1	.98	.93
Steer, Normal	5.5	5.0	4.8	.91	.87
Brake	3.5	5.3	4.8	1.51	1.37
Maintain Steady Speed	4.5	5.2	4.8	1.55	1.07
Turn	5.0	4.8	4.4	.96	.88
Accelerate	4.5	5.3	4.8	1.18	1.07
Drive in Daylight	5.0	5.2	4.8	1.04	.96
Mean	4.8	5.2	4.8	1.16	1.02

[a]Rated on a scale of 1 = Extremely Difficult to 6 = Extremely Easy

[1]It should be noted that the use of accuracy values as a measure of discrepancies will tend to favor underestimates as appearing more accurate. The limit on underestimates is 100% (accuracy value of 0.00) while overestimate percentages are theoretically infinite.

Task Performance Times. The OSD group was asked to estimate the time required to perform 13 tasks using the task descriptions contained in the sequence diagrams. Five of these tasks were later performed by the crew under test conditions and actual performance times were obtained. Accuracy values were then computed (again using 1.00 for perfect agreement). As shown in Table 21, the OSD group grossly overestimates the times--up to 1400% in one case. Examination of the times shows that as the actual time to perform increases, the size of the discrepancy decreases. While the discrepancies are still large, time to perform the longer tasks is more accurately estimated than is time to perform the short tasks. Although the sample of tasks is too small for conclusive interpretation, the indication is that very short tasks are likely to be overestimated by a greater degree than longer tasks. This is offset somewhat by the fact that the absolute error is relatively small on short tasks.

TABLE 21

TIME TO PERFORM SELECTED TASKS

Task	Actual Time* (Minutes)	OSD Accuracy Value
Zero Muzzle Reference Sensor	1	15.00
Calibrate Vertical Reference Sensor	3	5.00
Boresight Fire Control System	4	9.50
Unload Ammunition		
5 rounds	6	2.50
26 rounds	21	2.14

$$\text{Accuracy Value} = \frac{\text{Median OSD Estimate Time}}{\text{Actual Time}}$$

*Times rounded

Comparison of Estimation Groups

While available criterion data for assessing the accuracy or validity of responses made by the two estimation groups were sparse, it is of interest to examine how the two estimation groups compared to one another.

The groups were homogenous in experience and background. Both were made up of armor experienced NCO in grade E-6 or E-7. All were assigned to the Armor Center, Fort Knox; some were school instructors, some OSUT instructors, and others were assigned to operational units. The OSD group had somewhat more armor experience than the SMEE group (mean of 98 months experience versus a mean of 90 months). The basic difference between the groups was one of methodology: the OSD group was given the sequence diagrams, the SMEE group was not. Other materials were identical. Thus it was assumed that any difference between the groups in their estimates of crew performance requirements would result from access to the sequence diagrams.

Questionnaire responses were compared for the two groups: analysis of variance F tests and t tests were used to analyze items requiring time estimates and ratings; chi-square for items requiring the selection of options. Results of the analyses are summarized in Table 22 by the major content areas of the questionnaire

TABLE 22

COMPARISON OF OSD AND SMEE RESPONSES
BY QUESTIONNAIRE CONTENT AREA

Content Area	Number of Items Analyzed	Results of Analyses
Training	five items	No significant differences between groups
Driving	five items	No significant differences between groups
Maintenance	four items	No significant differences between groups
Gunnery	one item (11 activities)	No significant differences between groups
Command and Control	seven items	Significant difference between groups on two of the seven items
Crew Requirements	seven items	Significant difference between groups on one of the seven items
Design	three items	No significant differences between groups

Approximately 80% of the items in the questionnaire were analyzed for group differences. Of these, less than 10% revealed significant differences between the two groups. The three items for which differences were found pertained to preferred two-man crew combinations. Over the three cases the SMEE groups tended to prefer the commander-driver team whereas the OSD group was divided in its preference between the commander-driver and commander-gunner.

Reactions to the Estimation Methodologies

The 40 respondents in the OSD and SMEE groups were asked to evaluate the materials they used to provide the estimates. Materials consisted of two types: an Engineering Description Volume and the Operational Sequence Diagrams Volume. As mentioned previously, the SMEE group was given only the former and the OSD group was given both.

The Engineering Description was rated only midway between Not Very Useful and Very Useful (6.8 on a 13-point scale). Likewise, the amount of detail in the Engineering Description was rated as "Sufficient," also the midpoint. When asked whether the Engineering Description was too long, about right or too short, 65% said about right and 33% said it was too short. Ninety percent of the two groups asked for more diagrams, illustrations, and photographs.

The OSD group was asked specifically about the Sequence Diagrams. Ratings indicated that they thought it was more useful than the Engineering Description (8.2 on a 13-point scale from Not Very Useful to Very Useful). However, the median ranking on the amount of detail in the OSD package (7.5 on a 13-point scale) indicated that some respondents felt too much detail was included.

When the OSD group was asked whether they used the Engineering Description or the Sequence Diagrams more in completing the questionnaire, 25% reported using the Engineering Description more, 5% the Sequence Diagrams more, and 70% reported using both equally.

Discussion

Estimates of training times from the OSD and SMEE groups, as well as from the CRIT group, varied too widely for any comparison to be made between estimated and criterion times. The poor quality of these data may in part be due to the difficulty of estimating anything as person- or situation-specific as training time but it may also be due to weaknesses in question format. First, the questions were of the free-response type; respondents could write in anything from minutes to months. Second, the questions required interpretation of terms such as "familiarization," "basic operation," and "proficiency," terms that are imprecise at best. This kind of latitude in interpretation and response may have aggravated the range of responses.

In contrast to the training time data, ratings of driving difficulty from the estimation groups were much closer to those from the CRIT group (see Table 20). All three groups described the driving activities on the HSTV(L) as easy, compared to driving on other tanks. It should be noted that the driving difficulty items restricted responses to one of six difficulty values (1 to 6). Thus the apparent accuracy of these responses as compared to those for training time may be merely the result of type of questionnaire items.

Observed times to perform five tasks (Table 21) were grossly overestimated by the OSD group, the indication being that time was overestimated more for short tasks than for long. Table 23 shows a comparison of actual task time with the percent of the overestimation.

TABLE 23

PERCENT OVERESTIMATION OF PERFORMANCE TIMES

Task	Actual Time (Minutes)*	Discrepancy (% of Overestimation)
Zero Muzzle Reference Sensor	1	1400%
Calibrate Vertical Reference Sensor	3	400%
Boresight Fire Control System	4	850%
Upload Ammo - 5 rounds	6	150%
Upload Ammo - 26 rounds	21	114%

*Times rounded

It is interesting to note that Sauer and Askren (1978) reported a tendency for judges to underestimate performance times. Tasks in that study took several hours to complete, substantially more than the longest times task in this study. Taken together these data suggest that judges tend to make greater errors of estimation at the extremes of the time-to-perform scale--overestimating at the low end and underestimating at the high--than in the middle where they are reasonably accurate. This phenomenon is not inconsistent with the typical ogival response curve found in psychophysical work. These errors of time estimation can probably be offset by (a) training judges to compensate for them, (b) restricting response options to a range of times nearer to that expected for actual task performance, or (c) both.

In comparing the two methods of estimation, few significant differences were found. It is not clear from a review of the Sequence Diagrams how they may have influenced estimates if indeed they did. The diagrams have the potential for giving the reviewer an insight into the effects of differing crew combinations. But in most cases variations in task performance are so subtle that they can be detected only after very careful comparison between the various crew compositions. There was no indication that OSD participants typically conducted the review in that detail.

Since the differences between the OSD and SMEE responses were relatively minor, little can be said about the effectiveness of Operational Sequence Diagrams. Whether the diagrams were superfluous to the Engineering Descriptions or whether for reasons of format or technical complexity they were unusable by the NCOs in the OSD group is not known. These possibilities should be examined in a more controlled way in any further evaluation of the OSD methodology.

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APPENDIX A

SUBJECT MATTER EXPERT QUESTIONNAIRE--
TEST CREW VERSION

Subject Matter Expert Questionnaire

Name ______________________________

Unit ______________________________

Phone # ___________________________

Date ______________________________

HSTV(L) Position __________________

HSTV(L) TEST PARTICIPANTS

Now that you have had even more experience with the HSTV(L), we would like you to give your estimates and opinions on training and operations questions once again.

This questionnaire is divided into three parts, as follows:

1. Training
2. Operations
3. Background questionnaire

Please read each question carefully before making your estimates; you may ask questions at any time while completing the questionnaire.

TRAINING

1. Estimate the amount of time required for each crewman to be familiarized on the HSTV(L) in his position. Give your estimates in hours and parts of hours to the nearest quarter-hour; for example: 1/2, 1, 1 1/4, 2 3/4.

Commander ____________
Gunner ____________
Driver ____________

2. If the HSTV(L) is introduced to the inventory, crewmen will be trai l to perform a primary job and the alternate crew jobs. Estimate the amount of training time required ıor each crewman to learn the location, function, and basic operation of displays and controls in his primary position and the alternate positions; then estimate how much time it will take to develop proficiency sufficient to perform in any position without direct supervision. Give your estimates in hours and parts of hours to the nearest quarter-hour; for example: 1/2, 1, 1 1/4, 2 3/4.

a. Consider Drivers (D), Gunners (G), and Commanders (C) with experience on other tanks.

	Training Time for:	
Train a:	BASIC OPERATION	PROFICIENCY DEVELOPMENT
D as D		
D as G		
D as C		
G as G		
G as D		
G as C		
C as C		
C as D		
C as G		

b. Consider Drivers (D), and Gunners (G) with no experience on tanks.

Train a:	Training Time for: BASIC OPERATIONS	PROFICIENCY DEVELOPMENT
D as D		
D as G		
D as C		
G as G		
G as D		
G as C		

3. What kinds of training problems did you or other operators have with the HSTV(L)?

a. For the Driver position?

b. For the Gunner position?

c. For the Commander position?

OPERATIONS

DRIVING

4. Estimate how difficult or easy it will be to do the following driving operations with the HSTV(L), compared with other tanks, in order to drive the vehicle over paved roads.

	EXTREMELY DIFFICULT	QUITE DIFFICULT	SLIGHTLY DIFFICULT	SLIGHTLY EASY	QUITE EASY	EXTREMELY EASY
a. Shift gears	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
b. Steer, normal	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
c. Steer, pivot	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
d. Brake	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
e. Maintain steady speed	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
f. Turn	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
g. Accelerate	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
h. Climb	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
i. Descend	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
j. Drive during daylight	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
k. Drive/limited visibility	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

5. Explain any difficulties you think drivers will have on paved roads:

6. Estimate how difficult or easy it will be to do the following driving operations with the HSTV(L), *compared with other tanks, in order to drive the vehicle over dirt roads.*

	EXTREMELY DIFFICULT	QUITE DIFFICULT	SLIGHTLY DIFFICULT	SLIGHTLY EASY	QUITE EASY	EXTREMELY EASY
a. Shift gears	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
b. Steer, normal	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
c. Steer, pivot	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
d. Brake	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
e. Maintain steady speed	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
f. Turn	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
g. Accelerate	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
h. Climb	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
i. Descend	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
j. Drive during daylight	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
k. Drive/limited visibility	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

7. Explain any difficulties you think drivers will have on dirt roads:

8. Estimate how difficult or easy it will be to do the following driving operations with the HSTV(L), compared with other tanks, in order to drive the vehicle across terrain that is primarily forest.

	EXTREMELY DIFFICULT	QUITE DIFFICULT	SLIGHTLY DIFFICULT	SLIGHTLY EASY	QUITE EASY	EXTREMELY EASY
a. Shift gears	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
b. Steer, normal	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
c. Steer, pivot	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
d. Brake	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
e. Maintain steady speed	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
f. Turn	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
g. Accelerate	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
h. Climb	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
i. Descend	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
j. Drive during daylight	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
k. Drive/limited visibility	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

9. Explain any difficulties you think drivers will have on terrain that is primarily forest.

10. Rank the difficulty of the following driving conditions for the driver of the HSTV(L). Place a 1 next to the condition which will be MOST DIFFICULT. Continue with 2 for the condition that is NEXT MOST DIFFICULT and so on until you place a 7 by the condition you feel will be LEAST DIFFICULT:

DRIVING CONDITION	DIFFICULTY
Paved Roads	____
Dirt Roads	____
Woodland & Scrub	____
Forest	____
Grassland	____
Forest & Grassland	____
Desert	____

11. Estimate how difficult or easy it will be to do the following driving operations with the HSTV(L), compared with other tanks, in a combat environment when the crew is engaging targets and the HSTV(L) is under enemy fire.

	EXTREMELY DIFFICULT	QUITE DIFFICULT	SLIGHTLY DIFFICULT	SLIGHTLY EASY	QUITE EASY	EXTREMELY EASY
a. Shift gears	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
b. Steer, normal	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
c. Steer, pivot	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
d. Brake	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
e. Maintain steady speed	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
f. Turn	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
g. Accelerate	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
h. Climb	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
i. Descend	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
j. Drive during daylight	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
k. Drive/limited visibility	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

12. Explain any difficulties you think drivers will have in a combat environment when the crew is engaging targets and the HSTV(L) is under enemy fire.

MAINTENANCE

13. A series of preventive maintenance checks and services has to be done on the HSTV(L) before the vehicle is driven. Indicate in the space next to the check or service the crew member or crew members who should do the maintenance.

> NOTE
>
> Use the following to indicate your selection:
> C = Commander
> G = Gunner
> D = Driver

a. _____ Check operation of exterior lights.
b. _____ Inspect suspension system.
c. _____ Inspect external fire extinguisher handles and safety wire.
d. _____ Check engine oil level.
e. _____ Inspect engine air filters for cleanliness.
f. _____ Check transmission oil level.
g. _____ Check transfer gear box oil level.
h. _____ Check hydraulic reservoir oil level.
i. _____ Inspect batteries.
j. _____ Check driving controls for binding or excessive play.
k. _____ Inspect fire extinguisher manual control handles.
l. _____ Inspect fire bottles.
m. _____ Inspect slip ring.
n. _____ Check escape hatches for proper operation.
o. _____ Check periscopes and vision blocks for cleanliness.
p. _____ Inspect CVC helmets.
q. _____ Inspect communications equipment.
r. _____ Check brake pressure.
s. _____ Check brakes (service, parking, and emergency).
t. _____ Check track tension.
u. _____ Inspect antennas.
v. _____ Inspect elevation and azimuth travel lock.
w. _____ Inspect trunnion access door.

14. Estimate the amount of time for a highly experienced crew to do the preventive maintenance checks and services on the HSTV(L). Consider only the items listed in #13 above.

> Minimum completion time ______________
> (hours-minutes)

15. Now estimate the amount of time for an inexperienced crew to do the preventive maintenance checks and services. Consider only those items listed in Question #13.

Maximum completion time ____________
(hours-minutes)

16. Now estimate the amount of time for a reasonably experienced crew to do the checks and services. Consider only those items listed in Question #13.

Normal completion time ____________
(hours-minutes)

17. Consider preventive maintenance checks and services performed on tanks. Place an X at the point on the scale that indicates how difficult PMCS will be on the HSTV(L) when compared to other tanks.

PMCS on the HSTV(L) will be

|____|____|____|____|____|____|

More Difficult Than — As Difficult As — Less Difficult Than

PMCS on other tanks

18. Explain any difficulties you think crews will have doing preventive maintenance checks and services on the HSTV(L).

GUNNERY

19. Estimates made in this section of the questionnaire are to compare, in terms of characteristics and capabilities, conventional fire control systems on tanks (for example, those on the M60A1, M60A1(AOS), M60A3, and the Hunter/Killer fire control system on the HSTV(L). To make your estimates, consider both the conventional fire control system(s) with which you are familiar and the Hunter/Killer fire control system on the HSTV(L) with a three-man crew. Gunnery on the HSTV(L) comprises four activities, as follows:

    1. Search and surveillance
    2. Target acquisition
    3. Target hand-off
    4. Target engagement

    Compared to the conventional fire control system(s) with which I am familiar, the Hunter/Killer fire control system:

	Yes	No
a. Will enable crews to detect more available targets	[ ]	[ ]
b. Will enable crew to identify more of the detected targets	[ ]	[ ]
c. Will reduce the time between target appearance and target detection	[ ]	[ ]
d. Will reduce the time between target detection and target identification by the TC	[ ]	[ ]
e. Will reduce the time between target identification by the TC and target hand-off to the gunner	[ ]	[ ]
f. Will reduce the time from target hand-off completion to target engagement	[ ]	[ ]
g. Will reduce the time from target detection to the end of target engagement (target kill)	[ ]	[ ]
h. Will permit more effective gunnery against a moving target	[ ]	[ ]
i. Will permit more effective gunnery when the firing vehicle is moving	[ ]	[ ]
j. Will permit more effective gunnery when both the target and the firing vehicle are moving	[ ]	[ ]
k. Will permit more effective gunnery during simultaneous engagements	[ ]	[ ]

20. Estimate the average time in seconds that it will take a three-man HSTV(L) crew to perform the following:

    d. Target appears until TC detects ___ sec.

    e. TC detects until he can identify as enemy ___ sec.

    g. Complete engagement: From the time the TC detects until the target is killed ___ sec.

CREW SIZE

21. The HSTV(L) crew compartments are designed so that driver functions can be performed from either the driver or the gunner position, and gunnery can be performed from the commander, gunner, and driver positions. This permits operation of the vehicle by two crewmen or by one crewman in an emergency. The purpose of this section is to estimate the effects on HSTV(L) operations of reducing the crew from three members to two members. The estimates are to be made for the three combinations of two-man crew positions (Driver-Gunner, Driver-Commander, Gunner-Commander). Please make any comments you think will clarify your response.

Put an X in the box under the two-man crew combination that:

	Driver/ Gunner	Driver/ Commander	Gunner/ Commander	Any Comments
a. Will permit more available targets to be detected	[ ]	[ ]	[ ]	
b. Will permit the most detected targets to be identified	[ ]	[ ]	[ ]	
c. Will permit the most effective driving in a combat environment	[ ]	[ ]	[ ]	
d. Will most reduce the time between target appearance and target detection	[ ]	[ ]	[ ]	
e. Will most reduce the time between target detection and target identification	[ ]	[ ]	[ ]	
f. Will permit the most rapid target hand-off	[ ]	[ ]	[ ]	
g. Will permit the most rapid time from the target detection to the end of target engagement (target kill)	[ ]	[ ]	[ ]	
h. Will permit more effective gunnery against a moving target	[ ]	[ ]	[ ]	
i. Will permit more effective gunnery when the firing vehicle is moving	[ ]	[ ]	[ ]	
j. Will permit more effective gunnery when both the target and the firing vehicle are moving	[ ]	[ ]	[ ]	
k. Will permit the most effective gunnery during simultaneous engagements	[ ]	[ ]	[ ]	
l. Will best enable preventive maintenance checks and services to be performed	[ ]	[ ]	[ ]	

22. Estimate the average time in seconds that it will take any two-man HSTV(L) crew combination to perform the following:

d. Target appears until crew detects ___ sec.

e. Crew detects until he can identify as enemy ___ sec.

g. Complete engagement: From the time a crewman detects until target is killed ___ sec.

23. Consider the difficulties encountered in maintaining command and control on tanks during gunnery engagements. Place an X at the point on the scale that indicates how difficult command and control will be on the HSTV(L) during gunnery when compared to other tanks.

a.

Command and control on the HSTV(L) with a <u>three-man crew</u> will be

More Difficult to Maintain Than			As Difficult to Maintain As			Less Difficult to Maintain Than

Command and control on other tanks

b. Explain any difficulties you think will be encountered in maintaining command and control on the HSTV(L) with a three-man crew.

24. Place an X at the point on the scale that indicates how difficult command and control will be for two-man crews on the HSTV(L) during gunnery. Each permissible two-man crew combination will be compared to command and control on the HSTV(L) during gunnery with a three-man crew.

a.

Command and control on the HSTV(L) with a Driver-Gunner crew will be

More Difficult to Maintain Than			As Difficult to Maintain As			Less Difficult to Maintain Than

Command and control on the HSTV(L) with a three-man crew

b. Explain any difficulties you think will be encountered in maintaining command and control on the HSTV(L) with a Driver-Gunner crew.

c.

Command and control on the HSTV(L) with a Driver-Commander crew will be

More Difficult to Maintain Than			As Difficult to Maintain As			Less Difficult to Maintain Than

Command and control on the HSTV(L) with a three-man crew

d. Explain any difficulties you think will be encountered in maintaining command and control on the HSTV(L) with a Driver-Commander crew.

e.

Command and control on the HSTV(L) with a Gunner-Commander crew will be

More Difficult to Maintain Than			As Difficult to Maintain As			Less Difficult to Maintain Than

Command and control on the HSTV(L) with a three-man crew

f. Explain any difficulties you think will be encountered in maintaining command and control on the HSTV(L) with a Gunner-Commander crew.

25. Now compare command and control for two-man HSTV(L) crews with command and control for three-man HSTV(L) crews.

a.

Command and control on the HSTV(L) with a <u>two-man crew</u> will be

More Difficult to Maintain Than			As Difficult to Maintain As			Less Difficult to Maintain Than

Command and control on the HSTV(L) with a <u>three-man crew</u>

b. Explain any <u>differences</u> in maintaining command and control on the HSTV(L) with a three-man vs. a two-man crew.

26. Place an X in the box to indicate which two-man crew combination on the HSTV(L) will permit the most effective command and control during moving firing vehicle gunnery.

Driver-Gunner [ ]
Driver-Commander [ ]
Gunner-Commander [ ]

27. Place an X in the box to indicate which two-man crew combination on the HSTV(L) will permit the most effective command and control during stationary firing vehicle gunnery.

Driver-Gunner [ ]
Driver-Commander [ ]
Gunner-Commander [ ]

28. Given a two-man crew for the HSTV(L), how would you combine the operators? (Put an X in the box next to the combination you prefer.)

Driver-Gunner [ ]
Driver-Commander [ ]
Gunner-Commander [ ]

29. Put a 1 in the box next to the HSTV(L) crew combination you would select for a combat environment. Then put a 2 in the box next to your second choice for crew combination; a 3 in the box next to your third choice, and finally, a 4 in the box next to the combination you least prefer.

Driver-Gunner-Commander [ ]
Driver-Gunner [ ]
Driver-Commander [ ]
Gunner-Commander [ ]

REST ARRANGEMENTS

30. Assume an HSTV(L) crew is on a sustained (48 hour) operation and it is possible for one crew member to rest on the vehicle during this time. Where should the crew locate themselves during the following rest situations?

a. For rest periods on an HSTV(L) with a three-man crew:

	Which vehicle position should		
Crew member(s) at rest	D be in	G be in	C be in
C			
G			
D			
C & G			
C & D			
D & G			

b. For rest periods on an HSTV(L) with a two-man crew:

		Which vehicle position should		
Crew members	Crew member at rest	D be in	G be in	C be in
C, G	C			
C, G	G			
C, D	C			
C, D	D			
G, D	G			
G, D	D			

HSTV(L) DESIGN

31. How important is it to be able to turn turret power on and off from the hull positions and from the turret?

Extremely Important			Moderately Important			Not Important At All

32. How important is it to be able to slew the turret manually from the hull positions and from the turret?

Extremely Important			Moderately Important			Not Important At All

33. How important is it to be able to fuel the vehicle without first having to slew the turret about 60 degrees counterclockwise?

Extremely Important			Moderately Important			Not Important At All

34. Describe any problems in the operation of the HSTV(L) that could be improved by changing particular features in its design. Consider the following functional areas:

Functional Area	Problems/Suggestions
a. Driving	
b. Search and surveillance	
c. Gunnery	
d. Command and control	
e. Any other problem areas	

SKILL LEVEL AND MOS

35. What skill level or rank do you recommend be used for crewmen on the HSTV(L)? Answer for a three-man crew and the three combinations of a two-man crew.

a. Three-man crew:

		SKILL LEVEL
	Commander	________
	Gunner	________
	Driver	________

b. Two-man crews:

		SKILL LEVEL
1.	Commander	________
	Gunner	________
2.	Commander	________
	Driver	________
3.	Gunner	________
	Driver	________

36. Should an HSTV(L) crew be identified by an existing job specialty or should a new job specialty be created for the HSTV(L)? If the job specialty is one that currently exists, please name it by number or title.

a. Three-man crew:

		Same Job Specialty	New Job Specialty
	Commander	________	________
	Gunner	________	________
	Driver	________	________

b. Two-man crews:

		Same Job Specialty	New Job Specialty
1.	Commander	________	________
	Gunner	________	________
2.	Commander	________	________
	Driver	________	________
3.	Gunner	________	________
	Driver	________	________

37. What role, mission, or type unit do you think the HSTV(L) should be assigned to?

a. In a three-man crew configuration ________________

b. In a two-man crew configuration ________________

38. This question is about "hand-off" between vehicles. Compared to conventional tanks, do you think there will be more or less problem in hand-off with the HSTV(L)?

a. With a three-man crew:

More ____________

Less ____________

Please explain your answer: ____________

b. With a two-man crew:

More ____________

Less ____________

Please explain your answer: ____________

39. This question is about "hand-off" between two HSTV(L) vehicles. Do you think there will be more or less problem in hand-off between two HSTV(L)s if they both have three-man crews than if they both have two-man crews?

More problem with a three-man crew ____________

Less problem with a three-man crew ____________

Please explain your answer: ____________

40. Do you anticipate problems in communicating to the commander (in another vehicle) in a timely manner?

a. In a three-man crew:

No ____________

Yes ____________

Please explain: ____________

b. In a two-man crew:

No ____________

Yes ____________

Please explain ____________

41. Will it be possible to put a crew member off vehicle on outpost and maintain communications and weapons operations at a distance for an extended period (1-8 hrs.)?

a. In a three-man crew:

No ________

Yes ________

Please explain: ________________________________

b. In a two-man crew:

No ________

Yes ________

Please explain: ________________________________

42. Will reduction of crew size from 4 to 3 or 2 cause a reduction in crew confidence in the weapon system?

a. With a three-man crew:

No ________

Yes ________

Please explain: ________________________________

b. With a two-man crew:

No ________

Yes ________

Please explain: ________________________________