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AN ANALYSIS OF ARMY TRANSPORTATION
CAPABILITY TO SUPPORT THE
DISTRIBUTION OF LIQUID PROPELLANT
IN FIELD ARTILLERY APPLICATIONS

THESIS

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AFIT/GLM/LSM/91S-41

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THESIS

Presented to the Faculty of the School of Systems and
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With an open heart, I claim this thesis to be an outward sign of the love and teachings of Jesus Christ, our Lord and Savior, and the inspiration of the Holy Spirit. There were many times when I looked down to see just one set of foot prints in the sand. To this end, God, our Father, used many holy men and women as His instruments to guide and develop the research effort.

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Finally, I wish to acknowledge the support and patient understanding of my wife, Karen, and four children. Her steadfast strength and compassion as a single parent these past months have made this a rewarding experience:

> Strength and dignity are her clothing, and she laughs at the time to come. She speaks with wisdom, and the teaching of kindness is on her tongue. Her children arise and call her blessed; her husband also, and he praises her: "Many women do noble things, but you surpass them all." (Proverbs 31:25-29)

John S. Lenart, Jr.

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Abstract

This study applied a screening technique methodology to systematically obtain organizational consensus in the establishment and ranking of Army surface transportation performance measurement criteria and system design attributes. This model was then used to assess the feasibility of three potential liquid propellant logistics concepts.

A literature search identified the fundamentals of defining and measuring transportation capability, Departments of Defense and Transportation hazardous material classification, liquid propellant packaging and logistics concepts, and current distribution procedures for products of similar commodity characteristics.

A subjective (intuitive) research approach provided the means for constructing a descriptive performance evaluation model by surveying twenty-four subject matter experts from the Army's Transportation and Ordnance (Munitions) Corps. The application of systematic approaches in obtaining consensus provided an audit trail for the management problem solving process.

The methodology consisted of nominal-interacting group processes to develop ten system design attributes, repeated use of the paired comparison instrument to weight the six performance criteria and rank the ten attributes, and use of

a scoring model to rank order the ten attributes based on the weighted criteria. Four senior Army transportation managers were then asked to assess three proposed liquid propellant logistics concepts based on the ranked system design attributes.

Research findings supported the Army's qualitative commitment to ensuring environmental and personnel safety, to simultaneously improve the operational capability of logistics with the tactical capability of combat forces, and to reducing the logistics burden in support of highly mobile forces. Visual and statistical examination of the rankings revealed sufficient evidence that the two sampled populations have identical probability distributions and a high degree of positive correlation (consistency).

Discrete distribution was selected as the most feasible logistics concept. Major strengths of this system included high reliability and maintainability of both equipment and product packaging; flexibility in transfer, handling, speed, and mode compatibility; lot control; and compatibility with existing concepts. A major weakness of discrete distribution was the retrograde of empty containers; however, the use of disposable drums could eliminate this weakness.

AN ANALYSIS OF ARMY TRANSPORTATION CAPABILITY TO SUPPORT THE DISTRIBUTION OF LIQUID PROPELLANT IN FIELD ARTILLERY APPLICATIONS

I. INTRODUCTION

Background

> The Iran-Iraq War, in which over one million people may have died, is stark evidence of what conflict in the developing world can be. More than a dozen developing nations have 1,000 or more main battle tanks, and a similar number possess ballistic missiles or have access to technologies for their development (Rice, 1990:6).

The decade of the 1990s will pose unparalleled challenges and risks for the global interests of the United States and its allies. While recent events in the Soviet Union and Eastern Europe have reduced the risk of direct superpower confrontation, Soviet and Soviet backed forces around the world will continue to pose a significant security challenge. In addition, growing and increasingly sophisticated military capabilities in the developing world have given rise to a complex and dangerous global security environment (Rice, 1990:6). For example, it was technology alone that made a third-world country like Iraq a first-class threat to world political and economic stability.

To meet the challenges of deterring world-wide low to medium intensity conflicts on a high-technology battlefield, the Field Artillery Corps is developing its first new-generation 155mm Self-Propelled Howitzer (SPH) in over 30 years. The M109 series weapon system, shown in Figure 1, was designed as a medium-weight, self-propelled, air

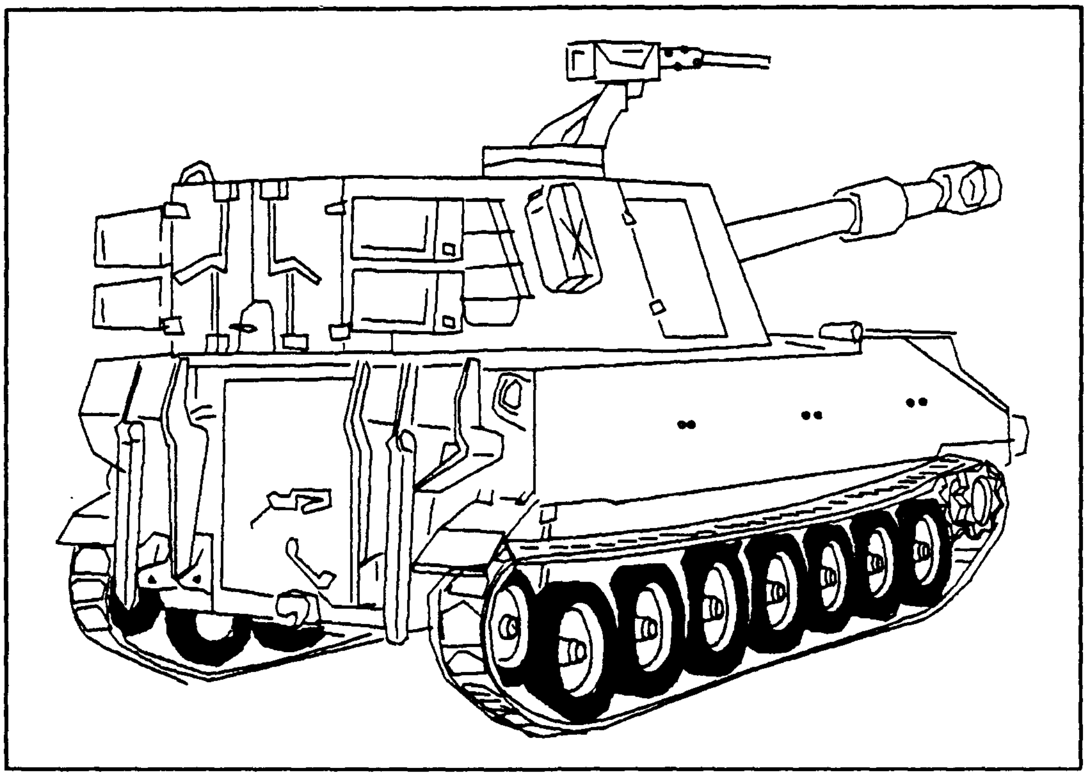

Figure 1. Self-Propelled Howitzer, M109A3

transportable carriage for the 155mm howitzer. Its mission is to provide mobile direct support (DS) artillery fire to mechanized, infantry, and cavalry units (Rodolfo, 1991). The M109 SPH requires a crew of six soldiers, has a maximum speed of 35 miles per hour, and a cruising range of 220 miles (TM 9-2350-311-10, 1991:1-7,8). Ammunition stowage includes 22 conventional projectiles, 12 chemical or illumination projectiles, and two Copperhead laser-guided projectiles. Propellant stowage allows up to 14 M4 solid bag canisters and 22 mixed canisters (TM 9-2350-311-10, 1991:E1 - E-8). Maximum range of the M185 main gun is 14,600 meters with zone seven charges, 18,000 meters with zone eight charges, and 23,500 meters for zone eight with rocket-assessed projectiles (TM 9-2350-311-10, 1991:1-1 - 1-18). Zones one through eight represent concentric circles of distance drawn from the weapon system. Firing within each zone requires the combination of a specific number of bag charges and a specific gun tube elevation.

The impetus for development of this new weapon system was both the Navy's development of a water soluble, salt-based liquid propellant and breakthroughs in advanced gun technology such as the regenerative liquid propellant gun (RLPG). Liquid propellants offer significant tactical and logistical advantages over the current system of solid bag powder. These benefits include increased firing range, increased stowed basic load, increased rate of fire, continuous zoning, enhanced personnel safety, greater survivability of the weapon system and the crew, decreased logistics burden, lower vulnerability of the propellant, reduced muzzle flash and blast, simplification of autoloading mechanisms, and significantly reduced production costs (Kelly, 1988:13; Watson et al, 1990:1).

AirLand Battle Doctrine

Army doctrine forms the basis for planning and conducting combat operations. This same doctrine also guides the modernization, technological development, and acquisition programs designed to maintain the force. The Army's cornerstone of operational and tactical doctrine, AirLand Battle, is applicable to all environments and provides for the most efficient and effective interservice integration of available combat power. Speed in mobility and maneuver and maximum utilization of resources is stressed in order to concentrate all available combat power at critical points on the battlefield.

AirLand Battle doctrine is founded upon the basic tenets of seizing and retaining the initiative, physical and mental agility to react quickly to changing developments, projecting combat power throughout the depth of the enemy formation, and synchronization of combat assets against a numerically superior enemy (FM 100-5, 1986:14-17). AirLand Battle doctrine envisions a very large and fluid battleground without a fixed front. It will not be possible to assume that airspace is safe or to distinguish linear battle lines (Russ, 1988:13). The concept directs simultaneous operations over the full breadth and depth of the battlefield in close operations to destroy enemy front line forces, deep operations to destroy enemy follow-on forces, and rear operations to retain freedom of action for sustainment of committed forces and the movement of reserves (FM 100-5, 1986:15).

Dynamic and continuously evolving, the Army's doctrine is designed to take full advantage of the quality and training of American soldiers and developments in new technology. In anticipation of future requirements, the Army is developing a new doctrine termed AirLand Battle-Future. This new concept will focus on the Army's participation in joint and combined operations and form the principles that the Army will adopt to guide its combat tactics beyond the year 2000 (Rice, 1990:22).

AirLand Battle-Future Doctrine

AirLand Battle-Future (ALB-F) represents the Army's changing orientation "from a concept of forward deployed-forward defense to one of forward deployed-forward presence" (Foss, 1991:20). ALB-F depicts the changing doctrine, training, equipment, and organizations necessary to deter and defeat a technologically advanced, highly capable threat force on the future battlefield.

ALB-F recognizes several important trends. First, while technological advancements have significantly increased the capability of modern weapon systems, these advancements also have been accompanied by increasing costs. The result will be a more sophisticated, smaller Army on the future battlefield (Foss, 1991:21). Second, improved intelligence sensors now can provide the corps commander with the ability to detect and monitor threat forces up to 400 kilometers forward of the battle area. Finally, improved target acquisition capability coupled with accurate long-range fires (artillery, multiple launch rocket system (MLRS), air, and attack helicopters) allow the corps commander to mass long-range fires and extend the battle zone up to 100 kilometers forward of the battle zone (Foss, 1991:22). This last point significantly increases the premium placed upon long-range, highly accurate, highly mobile weapon systems such as the M109 series SPH.

From these capabilities, the Army envisions a new battlefield structure as depicted in Figure 2. Smaller, highly mobile forces initially will be dispersed. Upon detecting the enemy force, the corps commander would mass and commit his long-range fire weapon systems, and maneuver units would form to fight a highly synchronized battle. Following contact with the enemy, friendly force would again disperse and reconstitute (Foss, 1991:22). Logistics units would be dispersed in the corps rear area.

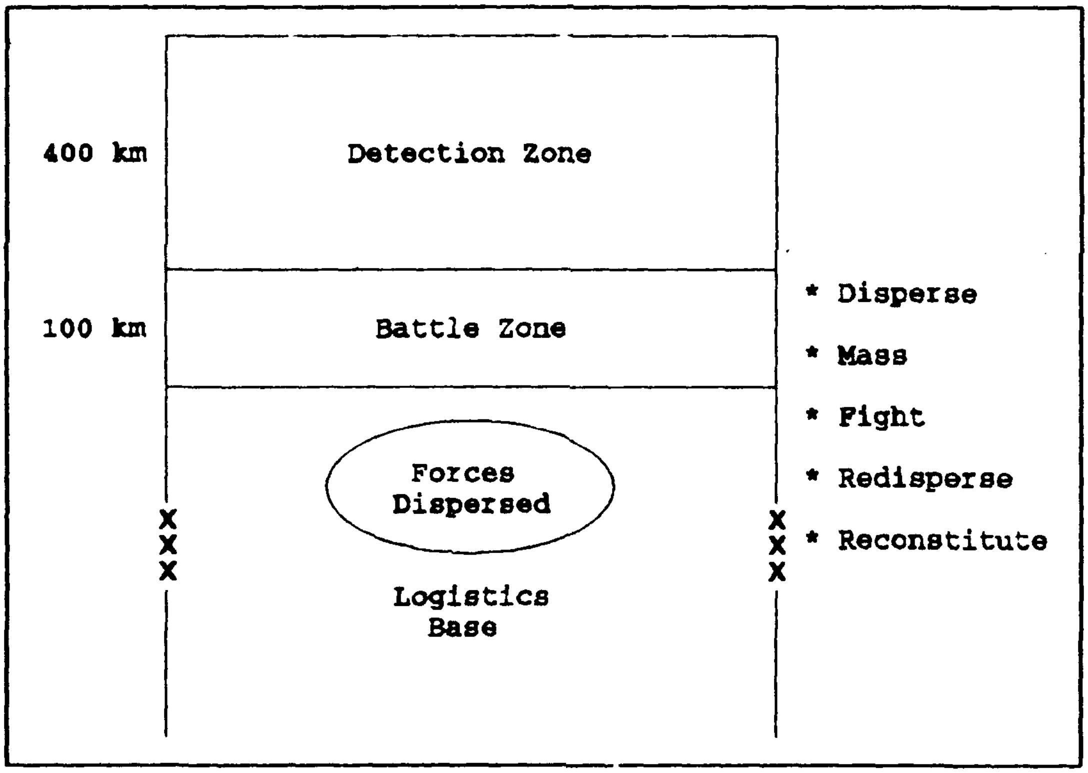

Figure 2. AirLand-Future Battlefield (Adapted form Foss, 1991:22)

<u>Field Artillery Corps Doctrine</u>

An important premise of AirLand Battle doctrine is that combat support units must be equally as mobile as the combat maneuver units (Infantry and Armor). Field artillery provides accurate, high volume direct (DS) and/or general support (GS) indirect fire to the maneuver units and counter battery fire for the destruction of hostile artillery emplacements.

These fire support roles range from "danger close" (within 600 meters of friendly forces) to a maximum range of 23.5 kilometers (zone eight charges with rocket-assisted projectiles) (Lewis, 1990). Throughout this range of distance, accuracy of the weapon system is paramount. In a danger close situation, accuracy is obviously important to defeat the enemy while ensuring the safety of friendly forces. Likewise, at maximum range, accuracy is critical to defeat pinpoint targets. Artillery fire is the Army's only immediate, on-call indirect fire ground support weapon system capable of attacking the enemy's follow-on echelons before they close with friendly maneuver forces (FM 6-20-1, 1990:2-17).

Field artillery supports all phases of an offensive operation. Through techniques of massive bombardment, artillery fire is used to isolate portions of the battlefield. Artillery fire missions can be substituted for a maneuver force against enemy positions in an economy of force role for limited periods (FM 6-20-1, 1990:2-2). This tactic of economy of force allows the tactical commander to mass limited combat maneuver forces in a superior ratio to the enemy at the point of attack. Massive, violent artillery fires targeted against the enemy's frontline defenses, observation posts, command and control, indirect fire weapons, and reserves are used to weaken an objective before the attack. In deep attacks that precede and accompany offensive operations, artillery fire support also can include the use of nuclear and chemical munitions (FM 6-20-1, 1990:2-20).

During the attack, artillery fire is used to neutralize and suppress enemy forces. Fire missions can be used to assist friendly aircraft providing close air support (CAS) by suppressing enemy air defense weapons; and, in conjunction with electronic warfare (EW), neutralize the enemy commander's ability to command and control his unit. (FM 6-20-1, 1990:2-2). During the battlefield consolidation phase following an attack, artillery support fires are used to protect reorganization and consolidation of the objective, break up counterattacks, and prevent enemy reinforcement (FM 6-20-1, 1990:2-4,5).

Finally, defense in AirLand Battle is not passive, but entails offensive operations by subordinate units. The ability of artillery fire to maintain flexibility and agility in controlling the tempo of the battle is critical to reseizing the tactical initiative for transition to offensive operations (FM 6-20-1, 1990:2-20).

Combat Service Support Doctrine

The mission of combat service support (CSS) is to maintain maximum combat power at theater and subordinate echelons from the port of debarkation forward into the covering force area (FM 100-10, 1983:Preface, 1-1). The three categories of CSS are personnel services, health services, and logistics (transportation, supply and field services, and maintenance). Together, these elements are responsible to man, arm, fuel, repair, supply, transport, and sustain the force.

"Forward support," founded upon the five sustainment imperatives of anticipation, integration, continuity, responsiveness, and improvisation, describes the character of combat service support under the AirLand Battle concept. CSS planners must anticipate the needs of the maneuver forces based both on future battle plans and on contingencies that may develop. To ensure unity of effort, support plans must be fully integrated into the operational and tactical plans of the combat commander. Quick and continuous support allows maneuver commanders to maintain the initiative on the battlefield. Support commanders must be responsive to meet the surge needs of the combat force and to relocate support bases in response to enemy and friendly action. Finally, support commanders must improvise unconventional support measures to overcome the unanticipated contingencies on the battlefield.

Ordnance Corps (Munitions) Doctrine. Munitions support in the theater of operations is supplied as far forward as transportation assets and the tactical situation permit (FM 100-10, 1983:1-7). The Theater Army Area Command (TAACOM) exercises command of assigned and attached ammunition units required for operation of theaterwide ammunition services. TAACOM responsibilities include ammunition service support to the theater, publishing the controlled supply rate (CSR) for major subordinate units in the communications zone (COMMZ), maintaining control of and dispersing COMMZ ammunition stocks, and planning for the rotation of stocks (FM 9-6, 1989:2-12).

The Theater Army Material Management Center (TAMMC) provides theaterwide retail management of ammunition, including direct requisition from the national inventory control point (NICP) located in the continental United States (CONUS) (FM 9-6, 1989:2-12). The TAMMC is a direct, subordinate unit of the Theater Army Commander. As the central commodity manager of ammunition, TAMMC prescribes the levels of supply to be held in the combat zone (CZ) and the COMMZ, determines the CSR for conventional ammunition, and establishes standards and policies for selection of sites and construction of ammunition service facilities (FM 9-6, 1989:2-12). The TAACOM Materiel Management Center (MMC), an extension of the TAMMC, is the ammunition commodity manager in the TAACOM.

Through its ammunition group(s), the TAACOM provides general support (GS) to the theater and corps areas by establishing theater support (TSA) and corps support (CSA) ammunition supply areas and direct support (DS) to divisions through ammunition supply (ASP) and transfer (ATP) points

(FM 9-6, 1989:1-4; 2-12). This overview is illustrated in Figure 3. The COSCOM Materiel Management Center (MMC) manages ammunition within the corps, and through its ammunition group, supplies ammunition to the corps combat divisions (FM 9-6, 1989:2-12).

Each division contains a Main Support Battalion (MSB) and three Forward Support Battalions (FSB). An FSB provides combat service support to a maneuver brigade. Each FSB operates one ammunition transfer point (ATP) designed to support a three to four battalion maneuver brigade with an assigned or attached direct support (DS) artillery battalion (FM 9-6, 1989:2-8 - 2-12).

The brigade ATPs are located between 15 and 30 kilometers from the forward line of own troops (FLOT). An additional ATP may be established in the division rear by the MSB. Each ATP is equipped to provide a capability of 450 to 600 short tons (ST) of ammunition per day (FM 6-20-1, 1990:7-31).

The Corps Support Command (COSCOM) establishes ammunition supply points (ASP) within each division zone of operations. COSCOM ASPs are located between 45 and 60 kilometers from the FLOT (FM 9-6, 1989:2-8,9). The number established is determined by demand and the number of direct support ordnance companies available to the corps. These ASPs must handle all of the division ammunition requirements not filled by the ammunition transfer points (ATP) and

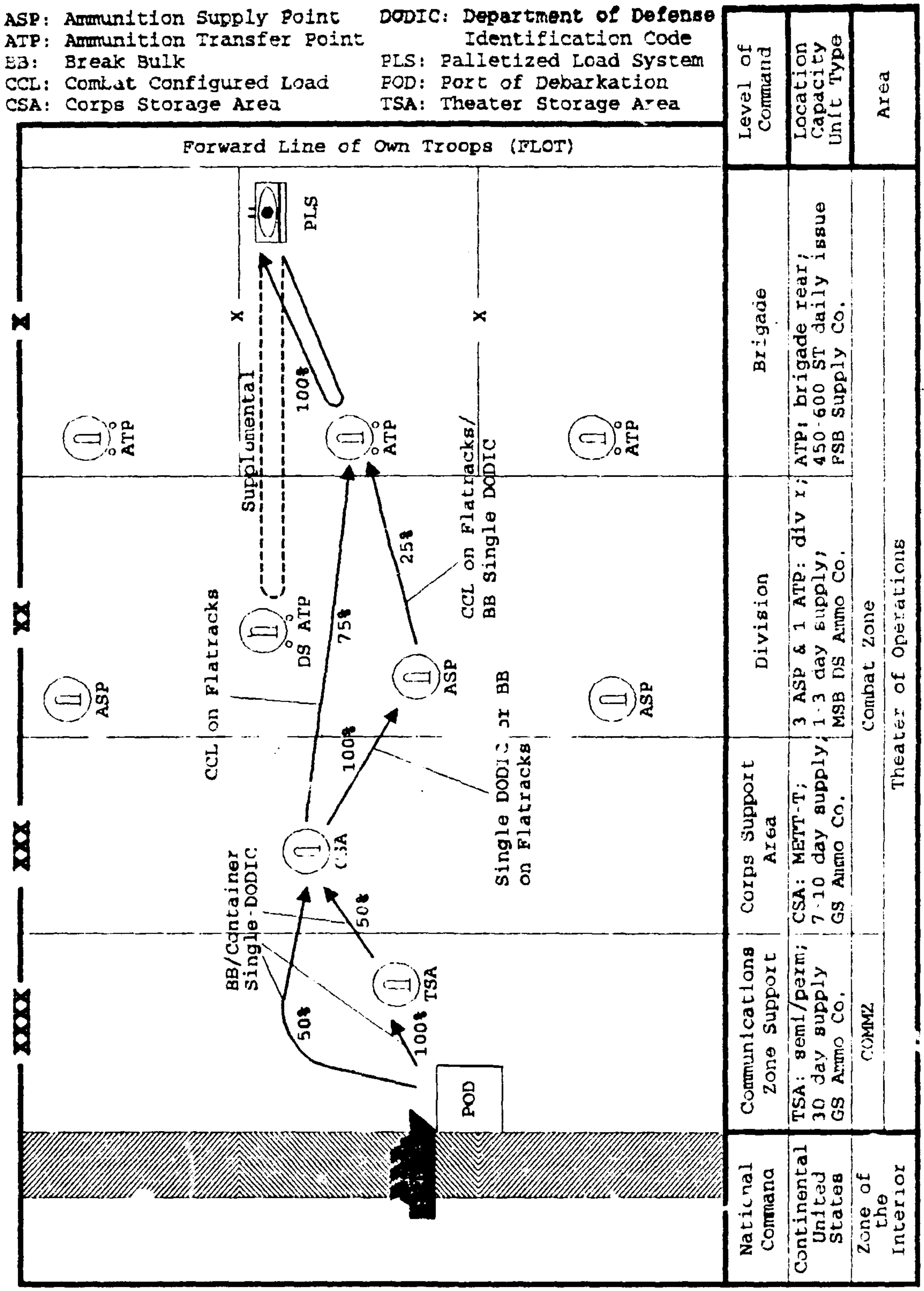

Figure 3. Ammunition Flow within the Theater Using the Maneuver Oriented Ammunition System (MOADS) (Adapted from FM 9-6, 1989:2-6; Brady, 1991: A-2)

satisfy up to 20 percent of the ATP demands (FM 9-6, 1989:2-9 - 2-12). Combined, the ASPs and ATPs supporting one division should be able to issue 4,000 ST of ammunition per day in support of above-average demands for limited periods of time (FM 6-20-1, 1990:7-32).

Transportation Corps Doctrine. The mission of the transportation system in a theater of operations is "the timely delivery to planned destinations of both effective combat forces and the means for their sustained support" (FM 100-10, 1983:1-10). Transportation requirements are assessed by point of origin, intermediate links and nodes, and destination. The quantity of supplies required to sustain the forward deployed force becomes a major work load factor against which the structure of the transportation system is defined (FM 100-10, 1983:1-7). Having determined the quantity of personnel, cargo, and equipment to be moved, these force increments are sequenced in order of desired arrival at destination (FM 100-10, 1983:1-10).

Movement within the transportation network is governed by four basic principles. These principles are centralized control, regulation, fluidity and flexibility, and maximum use of carrying capacity (FM 55-10, 1986:1-1). Control of transportation movements is centralized at the highest level capable of adequately exercising control, i.e., the commander tasked with providing integrated logistical support. Extensive regulation and coordination of movements are required to support highly mobile forces and to prevent congestion and conflict with competing users (allied forces, civilian commerce/refugees, etc.). The transportation system must possess the capability to divert or reroute movement to provide an uninterrupted flow of traffic. Finally, transportation capacity cannot be stored. Partially loaded or idle assets are both examples of wasted capacity.

As depicted in Figure 4, the theater Transportation Command (TRANSCOM) exercises command of assigned and attached Army transportation units required for the operation of theaterwide transportation services. TRANSCOM is functionally organized to support the theater and to provide the capability necessary to accomplish the transportation mission in the COMMZ. This capability may include motor transport groups, rail groups, terminal groups, and aviation battalions. While TRANSCOM commands the transport units of the COMMZ, these assets are managed and tasked by the Theater Army Movement Control Agency (TAMCA) (FM 55-10, 1986:5-1).

TAMCA provides theaterwide movement management services and highway traffic regulation within the theater and exercises centralized movement management within the COMMZ (FM 55-10, 1986:1-4, 4-1). The TAMCA is a direct, subordinate unit of the Theater Army Commander. As the central movement management agency, TAMCA provides coordination of U.S., allied, and host nation forces; prepares movement and port clearance plans and programs;

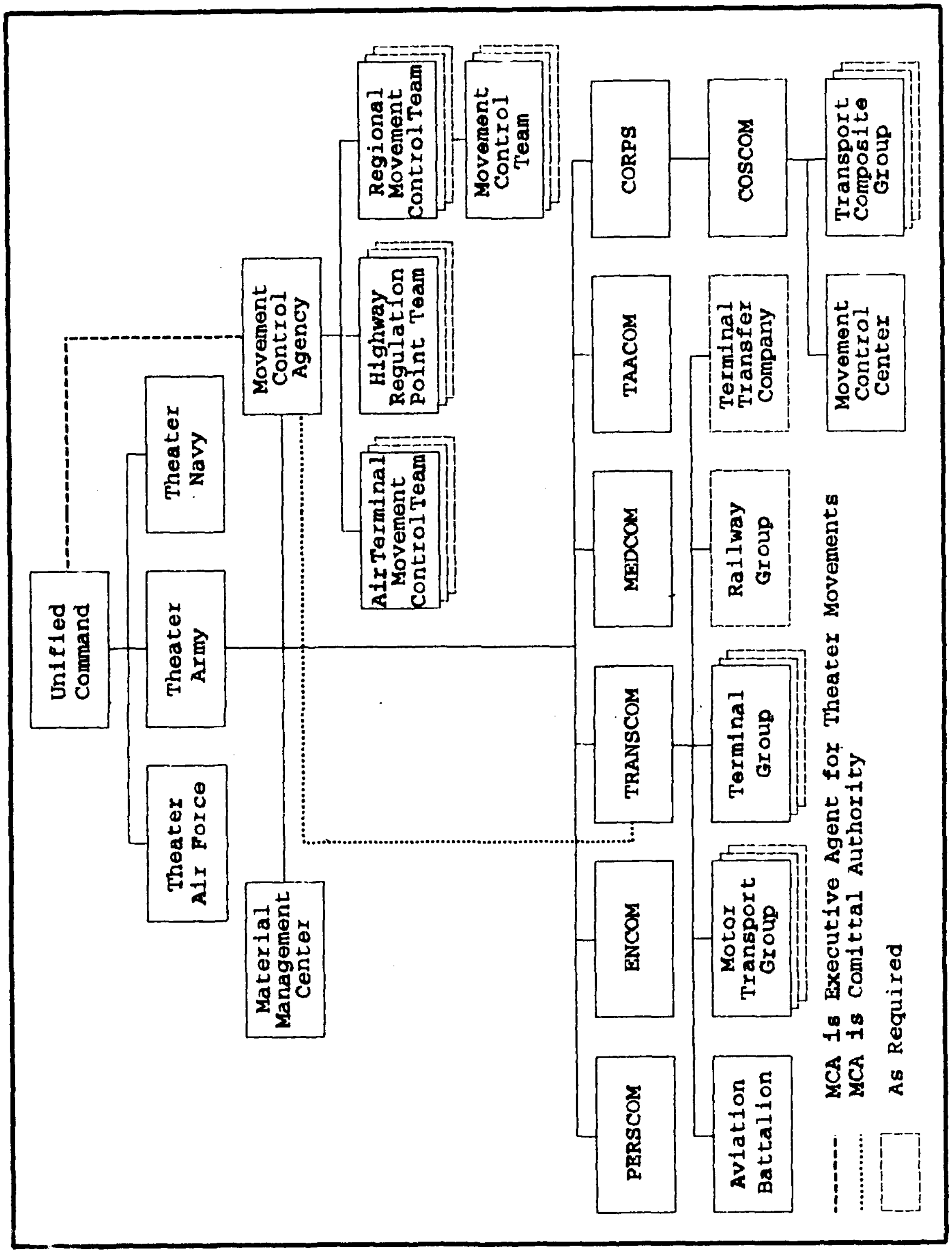

Figure 4. Transportation Organization in the Theater (Adapted from FM 55-1, 1984:2-3; FM 55-10, 1986:2-2; and FM 63-5, 1985:6-3)

controls movement control teams; and provides technical supervision of corps movement control centers (MCC) (FM 55-10, 1986:1-4, 4-1). Finally, the TAMCA is responsible for coordinating and monitoring the transport of all intransit shipments from the continental United States (CONUS) or the COMMZ from origin to final destination (FM 55-10, 1986:9-1, 9-2).

In the Corps area, centralized movement management is provided by the Corps Support Command (COSCOM) Movement Control Center (MCC) (FM 55-10, 1986:1-5). COSCOM MCC authority and responsibility are essentially identical to those of the TAMCA, but are limited by echelon of command, geographic area, and available resources (FM 55-10, 1986:6-1). The MCC coordinates the movement of Theater Army transportation assets operating in the combat zone (CZ) and coordinates retrograde movement from the CZ to the COMMZ with the TAMCA. All movements between the COMMZ and the corps area must be coordinated between the TAMCA and the corps MCC to prevent overloading of any segment of the transportation system (FM 55-10, 1986:1-5, 9-4).

Modernization

The Army is continuously modernizing its equipment to maintain the technological advantage over a threat force that is superior in numbers. While political changes are taking place within the Soviet Union and its allies, they still continue to modernize as they eliminate obsolete equipment and excessive troop strength. In the foreseeable future, Soviet forces will remain the major potential adversary against which the Army must measure its capabilities and readiness (Rice 1990:37).

Developing world countries dramatically have improved their forces in quantity and quality. A rising number possess capable forces with modern weapons that can influence regional balances of power and hold vital U.S. interests at risk. The recent crises of Operation Just Cause in Panama and Operations Desert Storm in the Middle East provide clear evidence of the dangers inherent in the unstable international environment. They demonstrate the need to continuously modernize, train, and maintain a ready Army (Rice, 1990:5).

Technology is the key to the Army's long-term force modernization, with less emphasis placed on marginal near-term advantages through modification of outdated systems (Rice, 1990:37-45). The goal is to invest in technologies that will enable the Army to provide its forces with the sophisticated and reliable equipment necessary to defeat increasingly capable threats around the world.

Liquid Propellant Technology

Solid propellant guns, using either bag or cartridge charges, have existed in their present form for almost 100 years (Future Close Combat Vehicle System Phase II, 1983:3-1). While periodic research efforts began investigating the application of liquid propellants as early as the end of World War II, only recently have developments in propellant and gun technology made such concepts practical for military application. High energy content was perceived, in the early studies, as the primary advantage for exploring liquid propellant concepts; however, more recent studies cited the propellant's fluid nature and more benign chemical characteristics as the principle factors in ascertaining military value (Morrison, et al, 1987:1).

The key problem with solid propellant is that it is actually a high explosive that must be formed into grains of specific size and geometry to obtain a controlled rate of gas release required by a particular caliber of gun. Even for a particular caliber of gun, the propellant design parameters have to be adjusted if the mass of the projectiles being fired varies significantly (Technology Assessment, 1983:3-1). Conventional gun designs control the rapid generation of the solid propellant charge through the linear burning rate and total burning surface of the propellant grains.

The loose granular propellant is sewn into silk bags which are hand-loaded separately behind the projectile in the gun tube. A standard package charge contains several bags, each one containing a different amount of powder. Velocity control is achieved by selecting which bags are used, i.e., bags are removed to achieve the necessary propellant combination for the zone of fire. Continuous range capability is achieved by varying the angle of fire for any particular charge weight.

Bag charges also have a number of operational disadvantages which have led to the development of alternative charge concepts. Several of these disadvantages are: all unused charge increments must be destroyed; a considerable amount of packaging material is used in transporting these charges; the hand-loading process is highly susceptible to human error; and the structural composition of the bags is such that automation of the loading process for the battlefield environment is extremely difficult (Stark, 1984:8).

Liquid propellant concepts overcome these disadvantages by forming the charge at the gun by metering a variable amount of propellant directly into the breach. Morrison, Knapton, and Klingenberg noted many potential advantages in the application of liquid propellant technology to a 155mm self-propelled howitzer system. These included a doubling of onboard ammunition storage, a simplification of auto-loader mechanisms, increased rate of fire, and enhanced stockpiling characteristics. Moreover, advantages specific to the use of a hydroxylammonium nitrate (HAN) based propellant and a regenerative liquid propellant gun (RLPG) were increased safety, continuous zoning, reduced vulnerability of the propellant, reduced muzzle flash and blast, and increased range for acceleration of sensitive projectiles (Morrison et al, 1983:2-10). However, perhaps the most significant advantage would be realized in the cost savings of propellant production. The packaged cost per pound of a HAN based propellant was estimated at approximately 10 percent of a conventional M3A1 solid propellant charge (Morrison et al, 1983:15).

Thus the Army's interest in liquid propellants for field artillery application is based on four factors: a single propellant without modification could be used in a wide assortment of guns; the realization of a much higher muzzle velocity; the possibility of eliminating the cartridge case in high performance ammunition; and the pumping of the propellant from a storage container remote from the gun (Future Close Combat Vehicle System Phase II, 1983:3-3, 3-6). In self-propelled artillery, remote pumping would allow formerly inaccessible interior spaces to be used for propellant storage and it would make possible "single chambering" of the complete round and thus automatic loading. Further, automation of the loading process could potentially reduce the number of personnel required and possibly the size of the weapon system (Technology Assessment, 1983:3-3).

Justification

> Logistics has been subordinated in past weapons developments. We have the best main battle tanks in the world - but how do we still load them? BY HAND THROUGH THE TURRET, ONE ROUND AT A TIME! This is a totally unacceptable when under fire. (Lewis, 1990)

The Army is continuously applying new technologies in the development and acquisition of advanced weapon systems to ensure that its numerically inferior forces will maintain the technological advantage on the battlefield. However, most new weapon systems have been designed without the co-development of a supporting logistics system. This subordination of logistics has later proven detrimental to combat effectiveness.

A classic example of this situation is the Army's M1 Main Battle Tank. Acquisition of the weapon system did not consider the need for a method of ammunition resupply while in a combat environment. As a consequence, the tank must be rearmed one round of ammunition at a time through the main hatch on the top of the turret. This can not be accomplished under conditions of fire and maneuver without placing the weapon system, personnel, bulk ammunition supply, and the ammunition resupply vehicle at considerable risk.

Research Objective

This thesis will analyze Army surface transportation performance measurement criteria and system design attributes for liquid propellants in Field Artillery applications. Transportation by motor vehicle, rail, and inland waterway (lighterage) will be analyzed. The Army, in a joint effort between the Army Armament Research Development and Engineering Center (ARDEC) and the Army Laboratory Command (LABCOM), is conducting an Advanced Development Program to evaluate a Liquid Propellant Gun and Ammunition System for the next generation Field Artillery application in the 155mm Self-Propelled Howitzer.

Development of the Regenerative Liquid Propellant Gun (RLPG) has yielded significant improvements in weapon system capabilities. However, development of logistics support doctrine was initially postponed pending determination, through operational testing, of the liquid propellant's inherent characteristics and the weapon system's operational requirements.

Problem Statement

No comprehensive analysis has been performed to identify the performance measurement criteria and design attributes of an Army surface transportation system necessary to support the distribution of liquid propellant in Field Artillery applications. The development of transportation doctrine is dependent upon the inherent characteristics of the propellant; the selected method of packaging; the operational requirements of the weapon system; and the cargo capabilities of the motor vehicle, rail, and inland waterway (lighterage) transportation assets currently available or emerging in the Army inventory.

Investigative Questions

1. What is transportation capability? What are the principles involved in measuring transportation capability?

2. What are the Departments of Transportation and Defense classification procedures for newly developed hazardous products?

3. What are the proposed liquid propellant packaging requirements and logistics fielding concepts, based on the

inherent characteristics and applicable hazard classification?

4. How have other organizations planned for the transport of liquid propellants and other products of similar commodity characteristics?

5. What are the relative strengths and weaknesses of the proposed logistics fielding concepts for liquid propellant in Field Artillery applications?

a. What are the relevant surface transportation performance measurement criteria for evaluating logistics fielding concepts?

b. What are the relevant system design attributes which must be considered for inclusion into the final selection of a liquid propellant logistics fielding concept?

Assumptions

Three propellants are currently under development by the Army: liquid propellant, unicharge, and electro-thermal. Based on the current research emphasis and the inherent limitations of electro-thermal and unicharge concepts, this thesis assumes that liquid propellant will be selected for the next generation field artillery application. The second assumption is that transportation capability must be assessed based on assets currently in the Army inventory or under acquisition. Funding for development of new transportation assets usually fairs less favorably than the primary weapons system (Kelly, 1988:67). Third, since liquid propellant and the primary weapon system are in the development and testing stage, assumptions must be made as to the final packaging configuration.

> The package may be a technical compromise based on the implications of the tentacles of packaging. All participants, from production through logistics to the user, must support the method of packaging. (Acton, 1990)

Scope and Limitations

Although there are many segments of the transportation pipeline, this thesis will analyze only Theater Army surface transport by motor vehicle, rail, and inland waterway (lighterage) from the port of debarkation to the brigade ammunition transfer point in the theater of operations. This will encompass analyzing each segment of the Theater transportation pipeline from the port to the Theater Army and Corps Support Command ammunition supply points, and ultimately to the Brigade Forward Support Battalion (FSB) ammunition transfer point. The European theater was selected for analysis because initial fielding of the liquid propellant and weapon system is programmed for fielding to units of the V and VII Corps.

Summary

Field Artillery operations are an integral component of the Army's AirLand Battle tactics, serving as a force multiplier and providing economy of force. Artillery provides accurate and high volume indirect fire support and counter battery fire support to the task force maneuver units. The Army has been working to develop safe and insensitive propellants to replace highly explosive propellants for gun propulsion systems. One such approach has been liquid propellants. Liquid propellants offer numerous benefits over the current system of solid bag powder, the most notable of which are increased range of the weapon system, reduced sensitivity of the propellant, and reduced production cost.

The purpose of this research study is to identify the most important performance measurement criteria and design attributes of an Army surface transportation system required to support the new generation of 155mm Self-Propelled Howitzer. This study will quantify the success-dependent qualitative characteristics of a surface transportation system necessary to sustain the desired level of customer service through the logistics chain and to the ultimate user.

Chapter II, Literature Review, provides a basic understanding of transportation capability and capability measurement, hazardous material classification, liquid propellant packaging and fielding concepts, and current planning procedures for the transport of liquid propellants. Chapter III, Methodology, describes the method of problem solution through field surveys and prioritization matrices. Chapter IV, Data Analysis and Findings, details the statistical and analytical results of the field survey. Finally, Chapter V, Conclusions and Recommendations, answers the research question for recommending selection of a liquid propellant logistics fielding concept.

II. Literature Review

Overview

The first four investigative questions of Chapter I provide the structure for performing both the literature search and experience surveys. The literature search provided background knowledge on previous research in the area of study. Recognizing that only a fraction of all knowledge in a field is documented, the experience survey was used to supplement the literature search by seeking information from persons knowledgeable in the field of transportation and liquid propellant technology (Emory, 1985:63). These persons helped to focus the research effort by contributing their thoughts on which were the important issues and aspects of the study. The experience survey also aided in providing insight into the relationships and variables under study (Emory, 1985:169-171).

This chapter begins by first defining transportation system capability and a discussion of two approaches to measuring system capability. Next, a review of the Department of Transportation (DOT) procedures for product classification is presented with an examination of Department of Defense (DOD) procedures for mandatory compliance with the DOT requirements. Third, an examination is conducted of the proposed liquid propellant packaging requirements and logistics fielding concepts. Fourth, an overview is presented of current planning procedures used by other organizations for the handling, storage, and transport of products with commodity characteristics which are similar to those of liquid propellant. Finally, this chapter concludes by presenting an assessment of the research maturation found in the literature search.

Transportation Capability Assessment

Manheim pictured a total transportation system as a single, multimodal system operating within an external environment (Manheim, 1979:11). The identification and analysis of a transportation system requires equal consideration for the characteristics of the product transported, the various modes upon which the product will be conveyed, and the network of modal facilities through which the product will be transported (Manheim, 1979:12-13).

User and operator options, or decision variables, affect mode selection within the transportation system (Manheim, 1979:15). The user specifies the required volume, delivery time/date, and destination based on actual and forecasted use. The transportation operator makes decisions on mode selection, routes, schedules, quantity of assets employed, and physical facilities used to achieve a desired level of user support.

Transportation mode selection also is affected by technology, assets, network characteristics, and organizational policies (Manheim, 1979:15-17). The development and procurement of new transportation technologies enables demand to be satisfied at lower costs, increased volume, and higher levels of user support. Also, each transportation mode has a finite number of assets available for use; and not all modes may be available at the same time, or to a single operating manager. This option also includes the number of assets available in the system and their characteristics (Manheim, 1979:16).

Network characteristics include the geographic location of the transportation links and nodes (Manheim, 1979:16). Nodes are the facilities, such as the port of debarkation, inland port terminals, intersections, trailer transfer points, and rail yards. Links are the rights-of-way, such as the highways, waterways, and rail lines. Finally, organizational policies include a wide variety of management, organizational, and institutional doctrines, as well as decisions about functional and geographic operational structures (Manheim, 1979:17).

The entire transportation system is composed of many components linked together as sets of subsystems. These subsystems are envisioned as a network of facilities for movement or transfer (Manheim, 1979:16). Analysis of the pattern flows in the transportation system (the origins, routes, destinations, and volumes of the product moving through the system) provides an understanding of system behavior and a means of predicting the effects of internal and external changes (Manheim, 1979:163-173). This is accomplished by focusing on those aspects of transportation that provide the greatest impact on system performance (Manheim, 1979:173).

Service is the most important aspect to the user, while assets required and resources consumed are the most important aspects to the operator. An analysis of technology, assets, network characteristics, and organizational policies is performed with the primary aim of understanding their impact on the level of service provided, assets used, and resources consumed by the transportation system (Manheim, 1979:163-173).

Hay defined a transportation system model as including two principal components: the physical elements of the system and the environmental or regional elements. Physical elements include vehicles, terminals, people, and activities. The environmental elements consist of factors such as location and climate (Hay, 1977:18). Hay also supported Manheim's approach of developing a model of a transportation system that can be represented graphically to show the capacity of the various factors and their relative relationships (Hay, 1977:540-542).

Manheim defined capability as a level of service, or the maximum number of items per unit of time that can be processed through a component of the system (Manheim, 1979:268-271). In quantitative analysis, this is known as the "critical path." Hay also defined transportation capability in terms of a level of service required to meet a volume of demand. The specific characteristics of a transportation system that provide service for a volume of demand include: capacity, speed, accessibility, flexibility, and frequency. According to Hay, the capacity of a transportation system is a function of vehicle capability, vehicle speed, and route capacity (Hay, 1977:265-267).

Measurement of Transportation Capability. Manheim defines capability as both physical capacity, the maximum volume of product that can be processed through the system per unit of time, and practical capacity, a lower level of volume that recognizes that delays of some magnitude are still tolerable (Manheim, 1979:271). Measurement of the maximum level of material processed through a system requires five types of mathematical models: service, resource, demand, equilibrium, and activity-shift (Manheim, 1979:30-31).

The service model calculates, based on a specific set of options, the achievable levels of service as various product-flows move through the system. Second, the resource model calculates the resources required to meet that level of service. Next, the demand model calculates volume of product demanded by the user at various levels of service. Fourth, the equilibrium model calculates the volume of product flowing in the total transportation system as a function of the level of service and user demand. Finally, the activity-shift model is a feedback loop designed to predict long-term changes in the distribution and structure of the transportation system resulting from the short-term equilibrium calculations (Manheim, 1979:30-31).

Hay measured capability by the quantity of product which can be moved per unit of time between two points by a given combination of fixed assets and facilities (Hay, 1977:538). Sources of traffic requirements are identified and evaluated for their maximum generated potential. Then, traffic routes, modes, volumes, capacities, vehicle trips, and destination points are determined and compared to required capacity (Hay, 1977:480).

Hay argued that no fully acceptable mathematical model has been developed to permit complete evaluation of a transportation system (Hay, 1977:538). Thus, the graphical representation must be broken down through analysis of the relationships between the subsystems. These relationships must be quantified and evaluated by minimizing cost to achieve maximum capacity for a given level of resources (Hay, 1977:538-539).

Both Manheim's physical capacity models and Hay's analysis of subsystem relationships for measuring transportation capacity are dependent upon the physical properties of the commodity. These characteristics determine the packaging, handling, transportation, and storage requirements of the product. The next section will examine the Departments of Defense (DOD) Transportation (DOT) mandatory hazard classification tests for newly developed hazardous products.

Department of Defense Explosives Hazard Classification Procedures

Background. Two hydroxyammonia nitrate (HAN)-based propellants, designated LP 1845 and LP 1846, are being tested as a potential replacement propellant in the 155mm Self-Propelled Howitzer. An explosive material normally is assigned an interim hazard classification for use during research and development, and then a final classification is assigned prior to the material's release into operational service inventory (Technical Bulletin 700-2, 1989:9-1). It is the responsibility of the Department of Defense component (DODC) sponsoring development of, or first adopting for use, an explosive material to generate the necessary test data to assign an appropriate hazard classification (TB 700-2, 1989:3-1).

Procedures for hazard classification of ammunition and explosive items are contained in Department of Defense Explosives Hazard Classification Procedures (Army TB 700-2, Navy NAVSEAINST 8020.8A, Air Force TO 11A-1-47, Defense Logistics Agency DLAR 8220.1). This publication establishes common DODC procedures for testing and interpreting the reaction of ammunition and explosives to specific "initiating influences" (TB 700-2, 1989:1-1). Based on the material's reaction, the manual prescribes the procedures for assigning the Department of Defense (DOD) Hazard Class/Division, DOD Compatibility Group, Department of Transportation (DOT) Hazard Class, DOT Shipping Description, DOT Label, United Nations (UN) Number, and North Alantic Treaty Organization (NATO) Standard Nation Agreement (STANAG) No. 4123 data (TB 700-2, 1989:3-1, 8-2).

However, TB 700-2 does not contain a formal methodology for the hazard classification of liquid propellants (Herrera, 1990:1). Instead, the manual prescribes that,

> In the case of liquid explosives/propellants, the sponsoring organization will convene a committee of experts to establish and assure performance of a test series to qualify the liquid for hazard classification which is analogous to that required by this document for solid explosives. Liquid explosives and propellants will be classified using test procedures established by the developing DODC and approved by the Department of Defense Explosives Safety Board (DDESB) on a by-case basis. (TB 700-2, 1989:1-1)

In the absence of a formal testing protocol, the two liquid propellants were assigned an interim hazard classification of 1.3 Class B Explosive (Herrera, 1983:1, 1990:13). This classification will remain in effect during the research stage of product development.

Hazard Class/Division. The hazard class is a numerical designator assigned to denote whether the propellant is either explosive or poisonous (toxic). In the United Nations publication, Transport of Dangerous Goods, a hazard class designation of 1 identifies explosives while 6 identifies poisonous (toxic) material (TB 700-2, 1989:4-1, 4-2). The hazard division is a numerical designator assigned to denote the character (aggregate physical features and traits), predominance of the associated hazards and potential for causing casualties or property damage. As illustrated in Table 1, there are five divisions within hazard class 1 (explosives) that indicate the type of hazard (TB 700-2, 1989:4-1).

Table 1

Hazard Class 1 Divisions (TB 700-2, 1989:4-1)

Hazard Class/Division	Hazards
1.1	Mass explosion
1.2	Non-mass explosion
1.3	Fragment producing
1.4	Moderate fire, no blast, or fragment
1.5	Explosive substance, mass explosion, or Ammunition article, unit risk

Also, when required to describe the hazard, a supplemental numerical designation will be placed to the left of the Hazard Class/Division for 1.1 through 1.3 (e.g., (12)1.1, (08)1.2, or (06)1.3). This designator is used to denote the minimum separation distance, in hundreds of feet, to ensure specified separation distance from hazardous fragments of firebrands produced by ammunition and explosive items. A minimum distance designator is mandatory for all items in hazard class/division 1.2 (TB 700-2, 1989:4-1). For all items in hazard class/division 1.1 and 1.3, a minimum distance designator is mandatory only where a minimum separation distance from limited quantities exceeds that specified by the applicable explosives quantity-distance table, DOD 6055.9-STD (TB 700-2, 1989:4-1).

Storage Compatibility Group. Ammunition and explosives are assigned to one of 12 storage compatibility groups (TB 700-2, 1989:4-1). Of these, only the first three groups, A, B, and C as presented in Table 2, are applicable to the liquid propellants under consideration by the Army.

Table 2

Storage Compatibility Groups (TB 700-2, 1989:4-1, 4-2)

Group	Description
A	Initiating explosives. Packaged initiating explosives that have the necessary sensitivity to heat, friction, or percussion to make them suitable for use as initiating elements in an explosive train. Examples are lead azide, styphnate, mercury fulminate, and tatracene.
B	Detonators and similar initiating devices. Items containing initiating explosives that are designed to initiate or continue the functioning of an explosive train. Examples are detonators, blasting caps, small arms primers, and fuses without two or more safety features.
C	Packaged propellants, propelling charges, and devices containing propellant with or without their means of ignition. Items that upon initiation will deflagrate or explode. Examples are single-, double-, triple-base, and composite propellants, rocket motors (solid propellant), and ammunition with inert projectiles.

United Nations Number. The United Nations publication Transport of Dangerous Goods, ST/SG/AC.10/1, lists four-digit numerical designations for the international transport identification of goods and materials. These codes also are listed in "Title 49," Code of Federal Regulations, Part 100 to 127, paragraph 172.102 (TB 700-2, 1989:4-2).

Classification Methodology for Liquid Propellant. Herrara conducted an in-depth literature search of past criteria, procedures, and tests used to classify solid propellants. He then made an assessment of the available published information to determine if the current procedures could equally be applied to the evaluation of liquid propellants (Herrera, 1983:1,2). From his findings, he selected the following documents to develop test procedures and a pass/fail criteria:

> North Atlantic Treaty Organization. Manual of Tests for Qualification of Explosive Materials for Military Use. NATO AOP-7. August 1986.
>
> United Nations. Recommendations on the Transport of Dangerous Goods: Tests and Criteria (First Edition). NY: United Nations, 1986.
>
> Department of Defense, Explosives Hazard Classification Procedures. TB 700-2. 1986.

Herrera used Technical Bulletin (TB) 700-2 as the principal model for establishing a hazard classification for liquid propellants. While NATO AOP-7 provided procedures and tests for classification, the corresponding acceptance criteria were omitted. The United Nations document prescribed procedures for testing and interpretation of data, but relied on the competency of the testing authority for discretion in interpreting the results. As with the NATO document, this manual also lacked criteria to establish hazard classification (Herrera, 1990:1).

TB 700-2 prescribed procedures, tests, and criteria for establishing a hazard classification for ammunition and explosives. The only modifications necessary were to the test equipment. HAN-based liquid propellants are sensitive to decomposition by transition metals and chemically incompatible with many other materials. Containment in compatible containers was incorporated where required (Herrera, 1990:1).

As illustrated in Figures 5 through 7, Herrera developed a methodology for hazardous classification that accounts for the various methods of ignition liquid

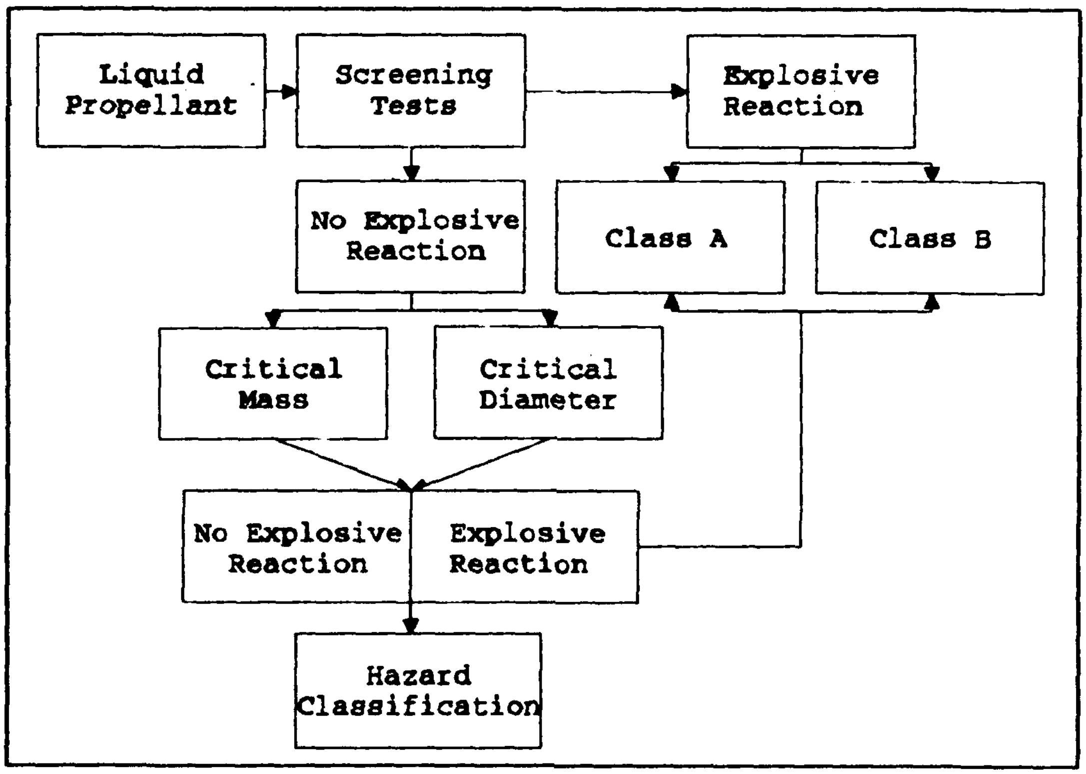

Figure 5. Hazard Classification (Herrera, 1983:13, 1990:3)

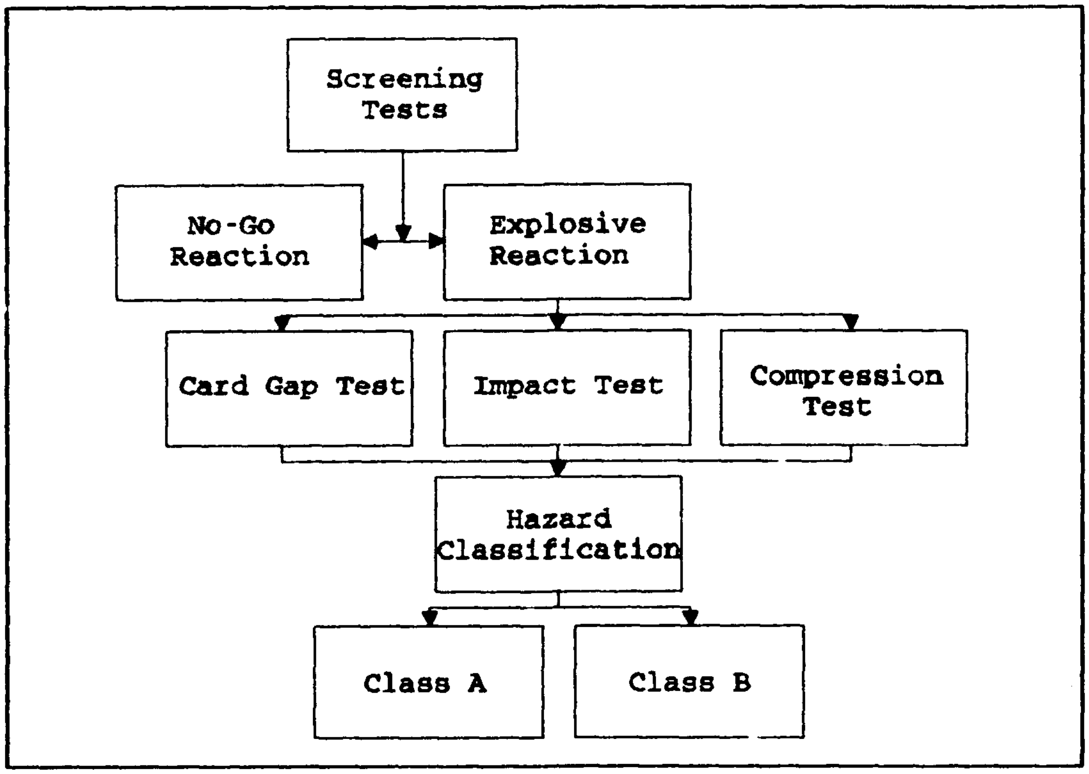

Figure 6. Explosive Reaction (Herrera, 1983:13, 1990:3)

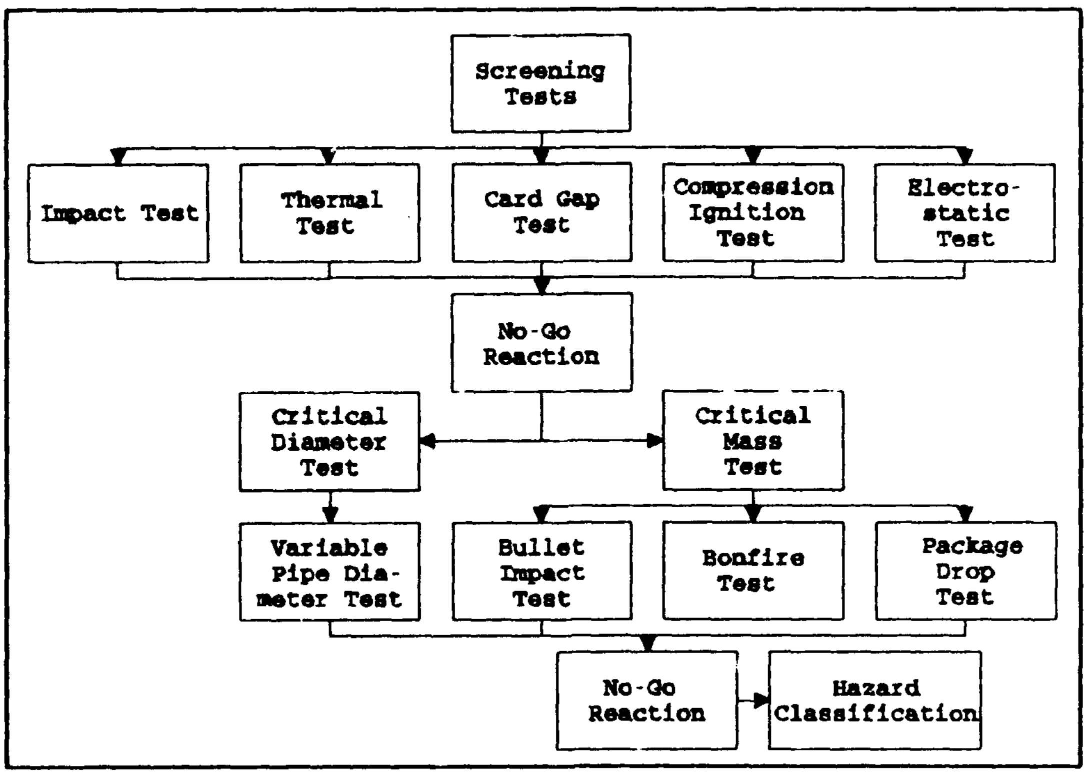

Figure 7. No-Go Reaction (Herrera, 1983:13, 1990:3)

propellant could potentially experience in its environment. Once a propellant displays a positive explosive reaction in any one of the laboratory screening tests, further testing is continued to determine if the propellant is a Class A or B explosive. Full-scale critical mass and diameter testing subsequently will confirm the laboratory classification of the propellant.

Department of Transportation Hazard Class, Marking, and Label Procedures

The procedures specified in "Title 49-Transportation," Code of Federal Regulations, along with the results of mandatory DOD and NATO testing will be used for assignment of appropriate Department of Transportation hazard class, shipping description, and label (TB 700-2, 1989:4-1). These tests and their respective results are described below.

Transportation Hazard Classification Testing. Mandatory interim classification testing, or screening tests, must be performed prior to full-scale packaged end item tests for approval of hazard classification (Herrera, 1990:3, 13). Full scale tests subsequently must be performed to test the sensitivity of the propellants under simulated conditions as encountered in manufacture, storage, transportation, and user environments. Under the shock of loading, liquids of all types generate hydraulic pressures. These pressures are contingent upon the critical mass, degree of confinement, and density of the liquid (Herrera, 1983:1). Mandatory testing is required by "Title 49," Code of Federal Regulations for transportation and by NATO STANAG No. 4123 and DOD for storage hazard classification (TB 700-2, 1989:5-1 - 5-7). These mandatory tests include:

1. Detonation
2. Ignition and Unconfined Burning
3. Thermal Stability
4. Impact Sensitivity
5. Card Gap

Detonation Test. The test apparatus is constructed as outlined in TB 700-2. A solid lead cylinder head, 1-1/2-inch diameter by 4-inches high, is placed upon one piece of mild steel plate, 1/2-inch thick by 12-inches square, SAE 1010 to 1030 (TB 700-2, 1989:5-3). The liquid propellant sample, housed in a decontaminated polyethylene bottle 2-inch diameter x 2-1/2-inches high, is placed on top of the lead cylinder (Herrera, 1990:6). A No. 8 blasting cap is placed perpendicular to and in contact with the propellant surface. The cap is detonated and reactions are recorded. If the lead cylinder is deformed in excess of 1\8-inch, detonation has occurred. The test is repeated five times or until detonation occurs (TB 700-2, 1989:5-3).

Table 3

Detonation Test Results (Herrera, 1990:11)

Sample ID	Detonation Reaction
LP 1845	None
LP 1846	None

The results of the detonation test are listed in Table 3. No detonation occurred during the test for either LP 1845 or LP 1846. The DOD regards this test as one of the most critical of the mandatory testing requirements (Herrera, 1990:11). Also, the absence of sympathetic detonation, which could lead to mass detonation, enhances the survivability of the weapon system and its crew. Had detonation occurred, the propellant would have been classified as a DOT Class A hazardous material with a DOD class/division 1.1 designation (mass detonable) (TB 700-2, 1989:5-9; Herrera, 1990:11).

Ignition and Unconfined Burning Test. This test is conducted in two phases, once with only one bottle of propellant and once with four bottles placed in a single row in contact with each other. Each phase is repeated twice to confirm the results. A 12 x 12 x 4-inch stainless container is filled to a level of 1\4-inches thick with kerosene-soaked sawdust (TB 700-2, 1989:5-3). The liquid propellant sample, housed in a decontaminated polyethylene bottle 2-inch diameter x 2-1/2-inches high, is placed in the center of the sawdust container (Herrera, 1990:6). The saw dust is ignited and reactions are recorded. The second phase of the test is conducted with four bottles of propellant placed in a row, each in contact with the next bottle (TB 700-2, 1989:5-3).

The results of the ignition and unconfined burning test are listed in Table 4. No reaction occurred for either LP

1845 or LP 1846 when exposed to burning sawdust soaked with kerosene (Herrera, 1990:11). This test simulates two conditions: a fire in a storage location and whether thermal heat transfer can initiate a detonation. If the test conditions had resulted in a detonation, the propellant would receive a classification of DOT Class A, Type 4 Explosive, and . . ."[would] not be shipped until instructions are received from the Office of Hazardous Materials Transportation, Department of Transportation" (TB 700-2, 1989:5-3).

Table 4

Ignition and Unconfined Burning Test Results (Herrera, 1990:11)

Sample ID	Detonation Reaction
LP 1845	None
LP 1846	None

<u>Thermal Stability Test</u>. This test is also conducted in two phases. The first phase screens for thermal instability by testing for ignition, explosion, or decomposition. The second phase screens for the severity of the thermal instability by measuring the extent of temperature rise in the sample. The second phase of the test is performed only if the first phase does not provide a definitive conclusion regarding sample stability (TB 700-2, 1989:5-3).

A decontaminated polyethylene bottle, 2-inch diameter x 2-1/2-inch high x 0.5-mil thick, is filled with propellant (Herrera, 1990:3). The bottle is then covered, weighed, and placed in a constant temperature, explosion-proof oven. The temperature of the oven is raised to 75 degrees centigrade and maintained for a period of 48 hours. Provided that neither ignition nor explosion has occurred, the bottle is removed, cooled, and weighed. A record is maintained of sample volatility (weight loss as a percent of the sample weight) that occurred during the test. The propellant is considered to have passed the test if no ignition, explosion, or decomposition (color change, fumes, weight loss, etc.) has occurred (TB 700-2, 1989:5-3).

Table 5

Thermal Stability and JANNAF Thermal Stability Test Results (Herrera, 1990:10)

Test	Sample ID	Reaction	Temp of Major Exotherm Onset (°C)
Thermal Stability[a]	LP 1845	None	
	LP 1846	None	
JANNAF Thermal Stability[b]	LP 1845		120
	LP 1846		122

a. 48 hours at 75°C in vented oven
b. Heat at constant temperature rate of 10°C/min

The results of the thermal test are listed in Table 5. If decomposition has occurred, the second phase of the test is performed. This test is performed like the first phase except with two samples (one test and one reference sample) and the addition of thermocouples (a sensor devise, composed of two dissimilar metallic conductors joined at their ends, used to electrically measure temperature) to measure the temperature differential (TB 700-2, 1989:5-3).

No reaction (detonation) occurred for either LP 1845 or LP 1846 (Herrera, 1990:10). This test is used by the Department of Transportation to identify "DOT Forbidden" materials for transportation. If the test conditions had resulted "in either a detonation, burning, or marked decomposition of the sample", the material would not have received certification for shipment (TB 700-2, 1989:5-9).

Impact Sensitivity Test. This test is not required if the propellant failed to detonate in the detonation test (TB 700-2, 1989:5-3). Impact tests are designed to assess compression ignition of propellants in a partially filled chamber. Drop weight tests are used to rate sensitivity of the material for combustion type environments and to assess behavior under rough handling and storage conditions (Strobie et al, 1988:1).

The device is first dropped from a height of 48 inches and at one-half increments thereafter until detonation occurs. If the steel diaphragm is punctured, the diaphragm is severely deformed, or the propellant is consumed, detonation has occurred. Again, the height reported, and therefore the impact sensitivity of the propellant, yields a

50% probability of detonation (Herrera, 1990:11). Also shown are the drop heights at which 0% and 100% detonation occurred.

Table 6

Impact Test Results (Herrera, 1990:11)

Sample ID	Drop Height (inches) 0%	50%	100%
LP 1845	28.0	30.0	31.0
LP 1846	29.0	30.5	33.0

The results of the impact test are listed in Table 6. The difference in drop height between LP 1845 and LP 1846 is only one inch. The one inch drop difference at zero percent between LP 1845 and LP 1846 is attributable to 3% more water in LP 1846. For the purpose of comparison, nitromethane, which is classified as a flammable liquid, has a drop height of 20 inches at 0% (Herrera, 1990:11). This test is used to determine if a detonable substance is DOT Class A, Type 4, and . . . "[would] not be shipped until instructions are received from the Office of Hazardous Materials Transportation, Department of Transportation" (TB 700-2, 1989:5-9).

As stated above, Herrara used a 1986 update of TB 700-2 to conduct his tests. The 1989 update of the publication requires only the conduct of 10 tests at 3-3/4-inch height using the Bureau of Explosives impact apparatus (TB 700-2, 1989:5-3, 5-5). If the test conditions result in impact sensitivity of less than 4 inches in more than 50% of the trials, the propellant would, as under the 1986 update criteria, receive a classification of DOT Class A, Type 4 Explosive (TB 700-2, 1989:5-9).

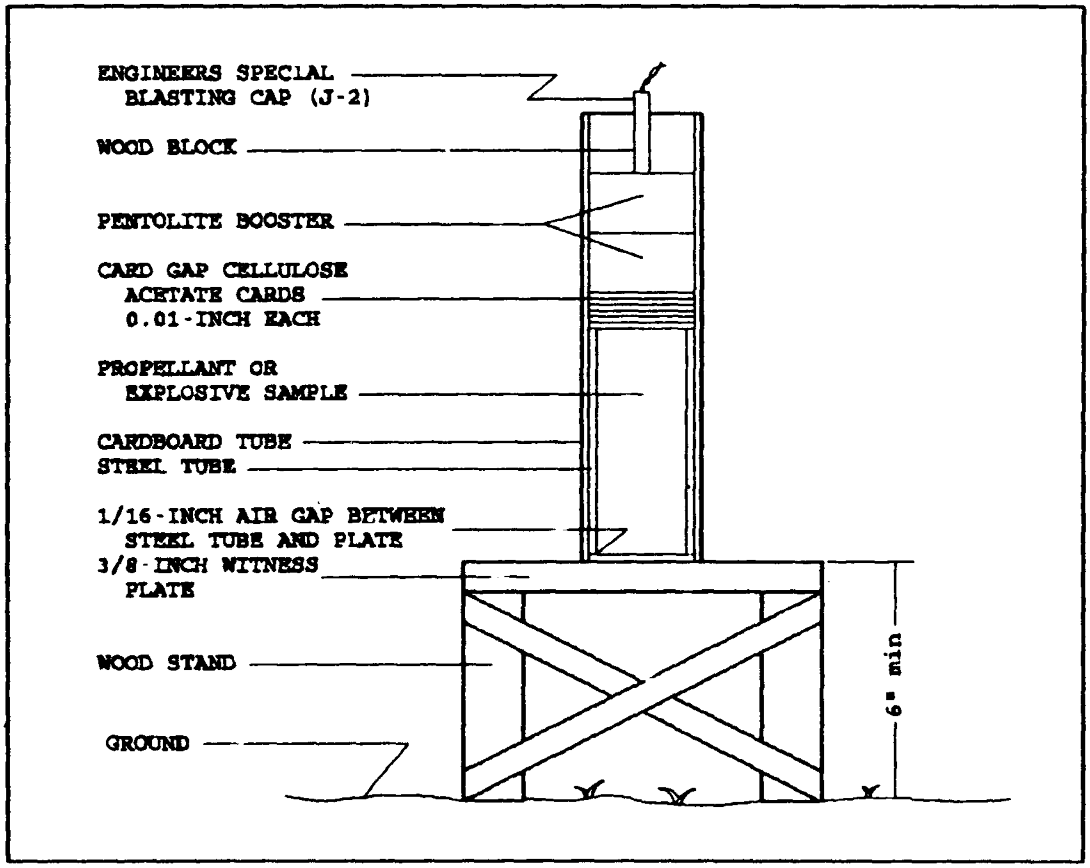

Figure 8. Card Gap Test Apparatus (TB 700-2, 1989:5-6; Herrera, 1990:4)

<u>Card Gap Test</u>. The test apparatus is constructed as outlined in TB 700-2. The device, as shown in Figure 8, consists of a series of chambers containing the boosters, cards, propellant, and witness plate. The acetate cards (0.01-inch thick) are used to measure the charge sensitivity

of the explosive. The greater the number of cards used, the more sensitive the propellant. A clean hole cut through the witness plate indicates detonation (TB 700-2, 1989:5-5).

The test is first performed using no cards. If no detonation occurs, the test is repeated two more times to confirm these results (TB 700-2, 1989:5-5). If a detonation occurs, the test is repeated using eight cards and then doubling the preceding number of cards on each successive trial (e.g., 8-16-32-64, etc.) until the number of cards prevents detonation. Then, the number of cards are reduced by one-half the previous addition until a 50% probability of detonation is obtained (TB 700-2, 1989:5-5). Propellant charge sensitivity is measured and expressed in terms of the number of acetate cards necessary to achieve a 50% probability of detonation.

Table 7

Card Gap Test Results (Herrera, 1990:11)

Sample ID	No. of Cards	Visual Observation
LP 1845	0	Witness plate deformed No holes in plate
LP 1846	0	Witness plate deformed No holes in plate

The results of the card gap test are listed in Table 7. Both propellants used zero cards (Herrera, 1990:10). Under the criteria of TB 700-2 for solid propellants, 70 cards or less or no reaction at zero cards would result in a DOT Class B classification. A result in excess of 70 cards would have classified the propellant as DOT Class A (TB 700-2, 1989:5-9). This is the standard test to determine the sensitivity of a material to the shock from a detonation (Herrera, 1990:10).

Storage Hazard Classification Testing. Full-scale end item tests are required by NATO STANAG 4123 and the DOD for storage hazard classification of ammunition and explosive materials as specified in TB 700-2. These tests include:

1. Single Package Test
2. Stack Test
3. External Fire, Stack Test

As illustrated in Figure 9, the type of ammunition or explosive and the results of preliminary testing together may permit a tailoring of full-scale classification testing. This is allowed to minimize the total resources consumed. For example, it is unnecessary to continue successive repetitions of the single package and stack tests if the first repetition results in detonation of the total contents. While each test should be performed on a hazardous material, it is possible, under certain circumstances, to curtail testing and thus save time and resources (TB 700-2, 1989:5-7).

The single package and stack tests are usually conducted for three repetitions to confirm the results. Although statistically insignificant (TB 700-2, 1989:5-7), this small sample testing does allow the test control

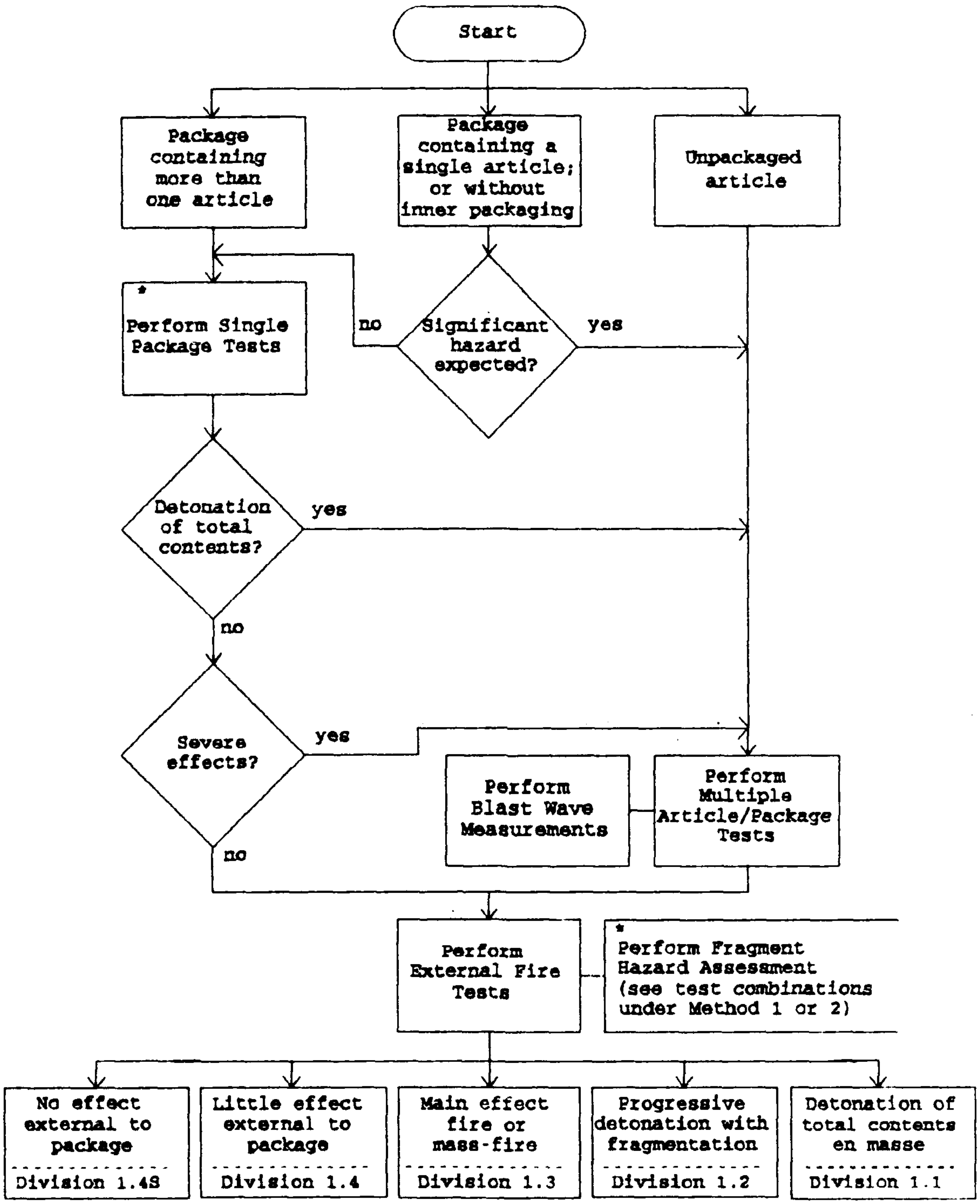

Figure 9. End Item Storage Hazard Classification Test Methodology (TB 700-2, 1989:5-8)

authority to detect errors made in testing procedure, exercise judgement in interpretation of the results, and assess the reproducibility of the test results.

Single Package Test. This test uses an integral (component of the product) source of ignition in an effort to cause the product to detonate or deflagrate (burn suddenly and violently). The stack test is designed to assess the external hazard to the field environment by measuring the extent of detonation or deflagration (TB 700-2, 1989:5-7). As indicated in Figure 8, there are two instances in which this test may be used as an inexpensive substitute for the stack test with multiple packages:

1) An outer package containing more than one article, and

2) A package containing a single article with no significant expectation of hazard.

The package containing the product(s) to be tested is placed on the ground. A confinement barrier, at least one meter thick, is constructed by placing bags or boxes filled with dirt or sand around and on top of the package (TB 700-2, 1989:5-7). An article near the center of the package is then "stimulated" by use of its own source of ignition or detonation. When the product does not ignite or detonate by its own integral source, an artificial source is used. The test is performed a minimum of three times, unless detonation of the total contents occurs on the first repetition (TB 700-2, 1989:5-8).

Multiple Article/Package Stack Test. The stack test also uses an integral source of ignition to cause the product to detonate or deflagrate. This test is designed to assess the external hazard to the environment by measuring the violence and extent of detonation when one article or package in a stack of five unpackaged items is initiated (TB 700-2, 1989:5-7). As indicated in Figure 8, there are four instances in which this test should be conducted:

1) An unpackaged article,

2) A package containing a single article or a package containing an article without inner packing where a significant hazard is expected,

3) A single package test which results in detonation of total contents, and

4) A single package test which does not result in detonation of total contents but where "severe effects" (effects short of a detonation of total contents but being so severe or directional as to question their effect in the stack) are observed.

A minimum of five packages or unpackaged articles are stacked on the ground and arranged in a manner that would most likely cause rapid, natural transmission of the explosion from one item to the next. A confinement barrier, at least one meter thick, is constructed by placing bags or boxes filled with dirt or sand around and on top of the package (TB 700-2, 1989:5-9). An article near the center of the package is then stimulated by use of its own source of ignition or detonation. When the product does not ignite or detonate by its own integral source, an artificial source is used. The test is performed a minimum of three times, unless detonation of the total contents occurs on the first repetition (TB 700-2, 1989:5-9).

Blast pressure measurements are used with this test. Fragmentation hazard assessment, while not mandatory, is encouraged to acquire additional information about the product hazard. However, when the test control authority has determined to assign the material to DOD class/division 1.1, DOT class A, for risk of mass detonation, a repetition of the stack test may be conducted without the confinement barrier. This test modification may be used for fragmentation hazard assessment as a substitute for the external fire stack test (TB 700-2, 1989:5-9).

External Fire Stack Test. This test is designed to assess the effect of an external fire on the articles or packages. If the fire does cause detonation or deflagration, this measures the intensity of the force, extent of the propagation, and the external hazard to the field environment (TB 700-2, 1989:5-7). Fragmentation and blast pressure measurements are performed as part of this test; however, blast measurements may be omitted when the expected reaction is other than mass detonation (TB 700-2, 1989:5-7).

A minimum of five packages or unpackaged articles are stacked on a wooden platform approximately one meter above the ground. A steel band is placed around the stack to maintain its integrity during the test. Air dried kindling (less than 30mm thick) is placed beneath the platform and around the stack of packages to at least 0.5 meter thick. The kindling is saturated with 15 gallons of diesel fuel or kerosene, then the kindling is ignited on two sides. This test, unlike the single and multiple stack tests, is usually performed only once (TB 700-2, 1989:5-9).

Blast Pressure Measurement. Blast pressure measurements are used to evaluate the output of an explosive blast wave, relative to a TNT equivalent, for products as they are packaged and stored and for ammunition components, to assess the contribution to total energy release (TB 700-2, 1989:5-9, 6-1). For example, liquid propellant, when assembled with the projectile (a mass detonating ammunition) as a combat configured load (CCL) under the Maneuver Oriented Ammunition Distribution System (MOADS), may augment the overall explosive yield.

A collection system for recording and measuring blast overpressure as a function of time is used to measure the blast yield. The test equipment used to measure the results consists of a transducer (an electromechanical or electronic device which measures one type of energy, such as a blast wave, then converts and retransmits it in another energy, such as electrical), signal conditioning equipment, and recording equipment (TB 700-2, 1989:6-1).

Fragmentation Hazard Assessment. Analysis of fragment field dispersal, area density, and individual fragment weight are used to determine the minimum separation distances for fragment hazard to personnel (TB 700-2, 1989:6-1). The fragment field produced by a test stack is characterized by the number of fragments emitted from the stack per unit of angle, and the distribution of the number of fragments with respect to individual fragment weight. Risk of injury to exposed personnel is determined by fragment density at the target, and whether injury of a specified level of severity (a function of fragment mass and impact velocity) occurs in the event of a strike (TB 700-2, 1989:6-1). Based upon the results of single package testing, one of two methods will be used to perform fragment field sampling.

The first method is followed if single package testing reveals the risk of mass detonation, or if the external fire stack test is expected to result in mass detonation of the total contents of the package (TB 700-2, 1989:6-6). In the first situation, fragmentation sampling may be conducted during the multiple article/package stack test, while in the latter instance, sampling may be conducted in conjunction with the fire stack test. If single package testing reveals that the risk of mass detonation is negligible, and therefore the external fire stack test is not expected to result in mass detonation, fragmentation sampling will be performed in conjunction with the ex rnal fire stack test (TB 700-2, 1989:6-8).

Additional Testing Requirements. Based upon the applicable hazardous material, the following additional tests may also be required by the Department of

Transportation to assess transportation and storage requirements (Herrera, 1990:1):

1. Adiabatic Compression
2. Critical Diameter
3. Flash Point
4. Minimum Pressure for Vapor Phase Ignition
5. Electrostatics

Adiabatic Compression Test. Adiabatic compression testing examines the sensitivity of compression ignition. Compression ignition is a potential sources of secondary ignition hazard (any ignition due to source other than the desired direct initiation). Secondary ignition may occur from hot spot development associated with bubble collapse under compressive loading from hydrodynamic surge pressure waves (Herrera, 1990:2).

The results of the adiabatic compression test are listed in Table 8. No detonation occurred for either LP 1845 or LP 1846 during confined pressure/heat testing to 260,000 psi (Herrera, 1990:11).

Table 8

Adiabatic Compression Test Results (Herrera, 1990:12)

Sample ID	Reaction at 260,000 psi/sec
Control (water)	None
LP 1845	None
LP 1846	None

Critical Diameter Test. Critical diameter is the minimum diameter at which a cylindrical charge of an explosive will sustain a steady-state detonation. Since detonations will not occur in a charge smaller than the applicable diameter, a large critical diameter is desirable. The results of the critical diameter test are listed in Table 9. Detonation probes indicated that detonation occurred with LP 1845 in the 4-inch diameter cylinder and with LP 1846 in the 5-inch cylinder. As in the impact test, the difference in sensitivity between LP 1845 and LP 1846 is attributable to 3% more water in LP 1846 (Herrera, 1990:12).

Table 9

Critical Diameter Test Results (Herrera, 1990:12)

Sample ID	Baffles*	Detonation Reaction
LP 1845	No	Apparent reaction at 4 in.
LP 1846	No	Apparent reaction at 5 in.
LP 1845	Yes	Apparent reaction at 4 in.
LP 1846	Yes	Apparent reaction at 5 in.

*Whiffle ball-type polyethylene spheres occupying approximately 12% of the canister volume

Table 10

Flash Point Test Results (Herrera, 1990:12)

Sample ID	Reaction*
LP 1845	None
LP 1846	None

*Propane flame at 75°C

Flash Point Test. The results of the flash point test are listed in Table 10. Since the formulation of each propellant contains 16.8% (LP 1845) and 20.0% (LP 1846) water, the vapor above each liquid is primarily water vapor. It was therefore expected that there would be no flash point for either propellant (Herrera, 1990:12).

Minimum Pressure for Vapor Phase Ignition. The propellants began to decompose as the incremental temperature increases reached 120°C. This test and the Flash Point test results confirmed that there was no minimum pressure for vapor phase ignition for either propellant (Herrera, 1990:13).

Table 11

Minimum Pressure for Vapor Phase Ignition Test Results (Herrera, 1990:13)

Sample ID	Reaction
Water (control)	None
LP 1845	None (material decomposed)
LP 1846	None (material decomposed)

Electrostatic Test. No reaction occurred during the test for either LP 1845 or LP 1846. This was as expected since the oxidizer, hydroxyammonium, and the fuel, triethanolammonium nitrate, are nitrated salts that are completely ionized in the water portions of the compound. The electrostatic charge build-up is therefore quickly dissipated and cannot reach a sufficient level to hazardous discharge (Herrera, 1990:13). The results of the electrostatic test are listed in Table 12.

Table 12

Electrostatic Test Results (Herrera, 1990:13)

Sample ID	Reaction*
LP 1845	None
LP 1846	None

*1 uf and 12.5 Joules at 5 kV

Table 13

Container Criteria, Specification 34, BOE-6000-F (Ekman, 1989:4-10)

1. Polyethylene for the material of construction of individual containers.

2. 150 to 160 gallon capacity consisting of three or four individual containers with inlets and outlets manifolded with plastic (PVC, CPVC, or polyethylene) tubing. The number of individual containers will be determined by the configuration of the forward ammunition resupply vehicle (FARV).

3. Quick disconnect male half-fittings on inlet and outlet ports.

4. Pressure relief capability will be incorporated.

5. 2500 lbs (maximum) for palletized containers when filled with liquid propellant (STANAG 2828).

6. All pallet and support materials of construction will be polyethylene or metals which can be decontaminated.

Storage and Transport Containers. Final design of a liquid propellant container can not be determined until final hazard classification testing has been completed. It is anticipated that final classification will allow shipment in accordance with Specification 34 (178.19) of BOE-6000-F, Hazardous Materials Regulations of the Department of Transportation (DOT) (1 November 1986) (Ekman, 1989:4-10). If this reclassification is obtained, the LP shipping container should meet the criteria listed in Table 13.

Table 14

Liquid Propellant Component Test Program
(Ekman, 1989:4-5)

Test	Pump	Disconnect	Container	Plumbing
Endurance (Life Cycle)	X	X	X	X
Compatibility	X	X	X	X
Efficiency*	X	X		
Contamination	X	X		
Leakage	X	X	X	X
Durability* (Handling)			X	X
Performance*	X	X	X	X
Palletization			X	X
Manifolding			X	X

*NORMAL (+70°F), high (+160°F), and low (-60°F)

Testing of the LP shipping container design will be conducted to verify capability with DOT Specification 34 or as determined by the hazardous classification tests. A detailed presentation of the performance testing requirements are presented in Table 14 and Figure 10 (Ekman, 1989:4-13). The performance testing requirements, as outlined below, will be conducted to determine container utilization capability under field conditions:

1. Compatibility with LP during long-term storage.

2. Performance during filling and emptying with setup as shown in Figure 10.

3. Cleaning.

4. Durability.

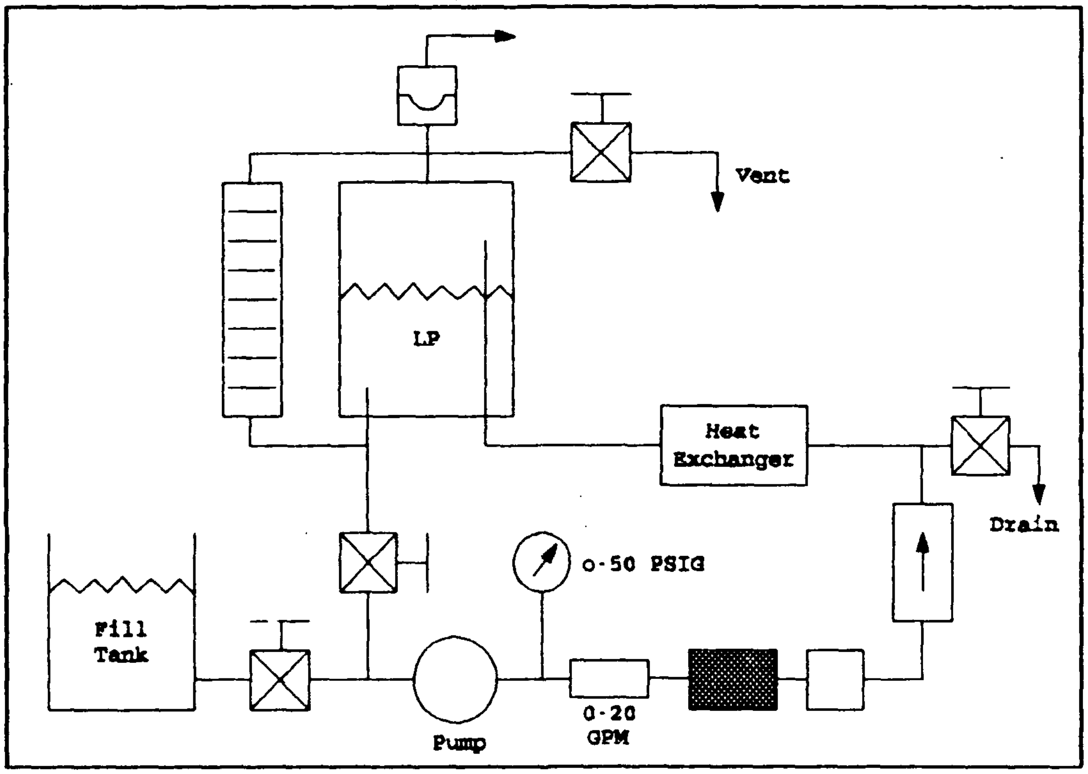

Figure 10. Liquid Propellant Performance Test Schematic (Ekman, 1989: 4-6)

<u>Demilitarization and Disposal of Liquid Propellants</u>. Potential scenarios may involve the disposal of liquid propellants. Several of these are:

1. Disposal of the propellants at the end of its useful life.

2. Disposal of contaminated liquid propellant.

3. Disposal of water used to flush spillage or extinguish a fire involving stored liquid propellant.

4. Disposal of contaminated soil resulting from propellant spills during transportation or use. (Graham, 1990:4-1)

The liquid propellant currently being developed for military application consists of a mixture of an oxidizer, hydroxylammonium nitrate (HAN), a fuel, triethanolammonium nitrate (TEAN), and water. During the manufacture of TEAN, the chemical reaction may produce a hazardous impurity, N-nitrosodiethanolamine (NDELA). This substance is an organic compound known to be toxic and a carcinogen, posing an exposure hazard to workers manufacturing the TEAN (Graham, 1990:1-2, 3-1). Studies have shown that specific manufacturing techniques and the HAN component of liquid propellant can markedly reduce the NDELA formed during manufacturing (Graham, 1990:3-2) and eliminate the NDELA hazard in the final liquid propellant product (Klein, 1991).

When a HAN-based propellant is no longer useable for its designed purpose, it must be disposed of as a waste product. When disposal is required, the propellant becomes a regulated waste under the Resource Conservation and Recovery Act (RCRA) (Graham, 1990:7-1). Propellant not contaminated with NDELA may be treated and demilitarized under RCRA using either water or salt (NaCl) (Klein, 1991). Water is effective because liquid propellant, an aqueous solution, loses its energy content as additional water is added. Salt (NaCl) is effective because the chlorine atoms react with the transients to suppress the flammable properties, thus not permitting the propellant to burn (Klein, 1991). Further, under RCRA regulations, a treated non-NDELA propellant may then be flushed into the public sewer system and to a community wastewater treatment facility (Graham, 1990:7-2).

Three techniques have been identified as being potentially useful for demilitarization and disposal of large quantities of liquid propellant. These techniques include thermal destruction, biological treatment, and photolytic degradation. These three technologies were selected based on the six criteria of technical feasibility, cost effectiveness, potential for full-scale implementation, applicability in remote areas, potential for adverse environmental impact, and potential for compliance with environmental regulations (Graham, 1990:1-4).

Biological treatment has the greatest potential for the disposal of HAN-based liquid propellant residues in an economical, safe manner in a wide variety of environments. The primary disadvantage of thermal destruction was a lower level of compliance with environmental regulations, while the main disadvantage of photolytic degradation was its high capital cost. Microbial degradation methods are currently being used for the disposal of various organic compounds, including explosives. Available biological treatment systems that may be applicable for the degradation of liquid propellants include composting, aerobic bioreactor, rotating biological contactor, fluidized bed reactor, and trickling filter treatment.

Liquid Propellant Logistics Concepts

Three liquid propellant logistics concepts are currently be studied as potential candidates for liquid propellant technology (Beaudet, 1989:I-5). Each concept was designed to be compatible with development of both the Maneuver Oriented Ammunition Distribution System (MOADS) and the Palletized Loading System. These three concepts are:

Discrete. Liquid propellant (LP) is loaded at the load, assembly and pack (LAP) facility and transferred through the entire logistics chain to the battalion reload/rearm point (BARP) in palletized 30-50 gallon sealed plastic containers. At the BARP, the LP is pumped from the rearm vehicle directly into the self-propelled howitzer's (SPH) LP reservoirs (Beaudet, 1989:I-5).

This concept continues to use existing logistics chain (solid propellant) transportation and transfer equipment. A winch or lifting device will be required to upload containers into the rearm vehicles (Beaudet, 1989:IX-1). Containers are palletized on existing standard size pallets and shipped in break-bulk containers. At the ATP container pallets are broken-down and individual containers are loaded onto user rearm vehicles. The LP is pumped from the rearm vehicle into the SPH reservoir tanks (Beaudet, 1989:IX-1).

The 30 and 50 gallon containers are not man-portable (a 30 gallon container at 12.5 pounds per gallon weighs 375 pounds) but are easily palletized on existing pallets and could be handled and stored in the resupply vehicle in an efficient manner (Beaudet, 1989:A-2). A 50 gallon container was selected because it can be easily compared to a current 55 gallon POL drum for which ample data is available concerning manufacture, strength, handling, transport, and cost of various container material.

<u>Bulk</u>. At the LAP facility, LP is loaded into 1,800 gallon stainless steel tanks which are either trailer-mounted or are on integrated skids/pallets for truck or palletized load system (PLS) transfer. The LP is transferred to the forward ATP and pumped into the rearm vehicle. The LP is then pumped from the rearm vehicle into the SPH LP reservoirs at the BARP (Beaudet, 1989:A-2). The transporting and transfer of the 1800 gallon tanks is handled in a manner similar to POL products. The total weight for one tank is 10-11 tons. "Four of these containers will supply one day's battalion requirement at 300 rounds per day per gun" (Beaudet, 1989:A-2).

<u>Combination</u>. At the LAP facility, LP is loaded into bulk 1,800 gallon stainless tanks, which are trailer-or skid mounted and transferred as far forward as possible. The propellant is then down-loaded at this location into discrete containers (30-50 gallons or 150 gallons). The discrete containers are uploaded into the rearm vehicle, and the propellant is then pumped from the discrete containers into the SPH reservoirs at the BARP (Beaudet, 1989:A-2).

This logistics concept uses Bulk POL type transfer from the wholesale to the retail supply location (CSA, ASP, or ATP). At this interface, the liquid propellant is then pumped into discrete containers.

Propellant Characteristics

The Phase I study (Ekman, 1989) concludes that the components (and questions for further study) of the LP logistics system can be grouped into two broad categories: containers, including palletization of discrete containers (less than 150 gallons) and containerization for larger containers; and, transfer systems used to transfer LP between storage tanks, containers, and the howitzer.

The three logistics concepts do not require new vehicular material handling equipment (MHE); however, modifications may be necessary to supply power to the transfer components (Beaudet, 1989:II-3). Suitable containers and transfer components are commercially available. Satisfactory compatibility of the products is achievable by using various combinations of stainless steel and plastics (Beaudet, 1989:II-3). Final selection of each is dependent upon final identification of the physical properties and hazard classification of the propellant.

Safety is a high-priority concern, including both explosive hazards and toxicity. The numerous preliminary and ongoing hazard classification tests have placed LP in DOT Class B, with Class C a possibility after appropriate full scale testing is concluded.

Testing has shown that unconfined propellant is relatively insensitive. The drop weight sensitivity test results were 29 inches for LP 1845 and 31 inches for LP 1846. Most solid propellants have averaged a sensitivity range of 10 inches (Beaudet, 1989:VI-40). LP will not burn at atmospheric pressure and can be safely stored under low pressure. While the exact threshold pressure that will sustain combustion has not been determined, bonfire tests indicate that LP decomposes and gives off large amounts of toxic brown fumes of mixed nitrogen oxides (Beaudet, 1989:VI-40). The card gap test also records detonation sensitivity. Both LP 1845 and LP 1846 tested at zero cards.

Propellant vulnerability tests also demonstrate the relative insensitivity of the propellant. Hot spall tests (steel balls heated to various temperatures and dropped into containers of propellant) reveal that red hot steel balls dropped into small containers fizz and give off yellow fumes. Dropped into large containers of propellant, the heat capacity of the LP was sufficient to stop the reaction. Next, a rifle bullet failed to cause a reaction when shot into a gallon container of LP (Beaudet, 1989:VI-41). A 5-inch shaped charge shot into a polyethylene container did result in a violent explosion; however, this reaction was suppressed by using small (38mm) hollow plastic balls as baffles (consuming only 8% of the container volume). In subsequent testing, the 5-inch shaped charge jet penetrated the LP container and ignited the aluminum plate behind the container, and the LP stream following the jet quenched the white hot burning aluminum (Beaudet, 1989:VI-42).

Toxicity of liquid propellant is relatively low. When handling LP, goggles should be worn and water resistant protective clothing is recommended. Absorbed through the skin, LP will cause a typical nitrate poisoning reaction by attacking the red blood cells. If washed off immediately, tests have shown it to be an irritant with reversible effects. Splashed in the eye, tests have also shown it to be an irritant. In tests on laboratory animals (rabbits), washing

> . . . at 30 seconds alleviated the conjunctival and iritic symptoms and prevented the development of corneal lesions. Immediate washing at 10 seconds after dosing was even more successful at alleviating the symptoms. (Justus and Korte, 1988:9)

There is no vapor hazard from LP (the vapor above the liquid is water); however, an aerosol stream from a broken pumping line would pose an inhalation hazard (Beaudet, 1989:VI-41).

The major environmental impacts are in the manufacture, transportation, and disposal of LP. In the logistics chain, there is always the possibility of a spill. Small spills can be washed away with water. The resulting effect on the environment would be the same as an overdose of fertilizer (Beaudet, 1989:VI-42). A large spill would require remediation. Nitrate ion concentrations (below 2 ppm concentration requirement) in water can lead to methoglobinemia in infants (blue babies) (Beaudet, 1989:VI-42). A protocol for handling large spills has not been developed.

Transport of Liquid Propellants with Similar Commodities Characteristics

A search was made of published literature to identify liquid propellants with chemical and physical properties similar to HAN-based propellants. This search revealed Otto Fuel II, used by the Navy as a torpedo propellant, as the only nitrate-based propellant with physical characteristics similar to those of LP 1845 and LP 1846. Otto Fuel II is also classified as a Class B explosive propellant. The following aspects of Otto Fuel II will be assessed: physical characteristics; environmental and personnel safety; transfer operations; packaging; transportation; and disposal.

Physical Characteristics. Otto Fuel II is a stable, noncorrosive liquid monopropellant composed of nitrate ester in solution with a desensitizing agent and a stabilizer. The propellant has an extremely low vapor pressure which minimizes the hazards usually associated with other monopropellants. Otto Fuel has a high flame point, an extremely low vapor pressure, and is relatively safe to handle (Jensen, 1978:22-1). Storage and transfer areas must be kept neat and clean and absolutely free from combustibles. All leaks and spills must be flushed away at once with large amounts of water. These areas will be inspected frequently and safety regulations must be strictly enforced.

Environmental and Personnel Safety. An adequate water supply will be available for firefighting, flushing, and for personnel showers and eye baths. A cold-water eye bath and approved safety-type personnel showers must be properly located for immediate use in a emergency (Jensen, 1978:22-1).

All personnel engaged in the handling, storage, or transfer of Otto Fuel II shall be thoroughly briefed on:

1. The chemical nature and physical properties of Otto Fuel II.

2. The primary toxic symptom of exposure to the fuel.

3. The availability and mandatory use of appropriate safety equipment.

4. The employment of forced air ventilation systems where gross spillage is probable.

5. The compatibility of construction materials.

6. The safety precautions to observe. (Adams, 1966:507; Jensen, 1978:22-3 - 1)

Transfer Operations. At least two operators will be assigned during all handling, storage, and transfer operations. After all transfer connections have been made, both inlet and outlet valves will be inspected before transfer operations begin. After transfer is completed, the piping will be drained to prevent the fuel from being trapped between closed valves (Jensen, 1978:22-3). If a pressure system is used, aluminum piping segments will be installed on each side of the transfer pump to provide protection against detonation propagation (Jensen, 1978:22-8).

Only fully trained personnel will perform logistics operations with Otto Fuel II. All operations will be controlled by standardized procedures and checklists. The standard procedures will be available to and strictly followed by all personnel. Spilled fuel will not be flushed into common drainage systems (Adams, 1966:524). An adequate supply of water will be available for safety showers for personnel and flushing spills. All personnel will wear the applicable approved protective clothing and safety equipment. All valves, pumps, switches, etc. must be clearly identified and labeled (Jensen, 1978:22-8).

Packaging. When shipping in small quantities (55 gallons or less), the fuel must be packed in a 5 gallon polyethylene drum overpacked in a steel drum, epoxy lined or coated with a material impervious to the Otto Fuel II. Quantities in excess of 5 gallons but not exceeding 55 gallons, must be packed in a polyethylene inner container (1/16 inch thickness). The inner container must fit snugly in a 55 gallon (removable head) steel drum. After emptying, containers may be reused onstation. They shall not be shipped to another activity for reuse (Jensen, 1978:22-9).

Quantities in excess of 55 gallons are considered bulk shipments. For bulk shipments, Otto Fuel II will be classified as "Propellant Explosive (Liquid), Class B" (Jensen, 1978:22-9.1.2.a; Table 22-5). Only Department of Defense approved carriers shall be utilized for bulk shipments. The consignor is required to inspect the transport tank for contamination and seal the tank lid after filling. The consignee must unload the fuel by gravity flow or by the application of up to 50 psi air pressure (Jensen, 1978:22-9.1.2.e). After unloading, the transport tank must be resealed (with no attempt made to clean-up or decontaminate) and delivered to an approved DOD decontamination site for cleaning prior to reuse (Jensen, 1978:22-9).

Transportation. The shipping and storage containers must not be filled to more than 95 percent capacity (Jensen, 1978:22-9.a). All shipping and storage containers must be provided with some means to prevent internal pressures in excess of 60 psi (Jensen, 1978:22-9.b). Shipments may be transported by rail, motor, water, or trailer-on-flatcar (TOFC). Air shipments are authorized by Military Airlift Command (MAC), Logistics Air (LOGAIR), Quick Transport (QUICKTRANS), or Priority Air Dispatch, Inc. (PAD). When offering this material for shipment, a copy of the Otto Fuel II transportation accident procedures shall be attached to all shipping papers (Jensen, 1978:22-9).

Disposal. The recommended disposal procedures for large quantities of Otto Fuel II are dumping in deep water at sea or burning in port. The disposal site in port should have a radius of 100 feet (Jensen, 1978:22-11.1). Disposal of small quantities, such as amounts accumulated from minor spills, shall be disposed of by absorbing the fuel in sawdust, rags, or cotton waste. This contaminated material shall be transported to a disposal area in an airtight metal container and then burned (Jensen, 1978:22-11.2).

Research Maturation

The research maturation model of Schendel and Hofer (1970) was adopted as an aid in conducting the literature review. This model specifically aided in cataloging the source documents and examining the developmental state of research work already accomplished in the field. To establish a sense of order, the literature review was conducted using a two step approach: first, each topic was grouped according to its respective investigative question; then, each topic was indexed according to the developmental state of the research work.

Research Maturation Model. A field of research progresses from a beginning to its present state along a certain developmental path. This advancement is achieved through use of a research methodology which is used to focus research energies, organize facts, and explain phenomena (Schendel and Cool, 1988:27). However, Schendel and Cool contend there is a distinct absence of a paradigm, or central organizing model, to track the advancement of research. In fact, they argue that the lack of a central methodology is owed substantially to the inability or reluctance of researchers to employ a scientific methodology toward research (Schendel and Cool, 1988:27).

Schendel and Cool's model of research maturation has been adapted for use as a means of focusing the research energies of this thesis. As depicted in Figure 11, research is classified into one of four cells, or phases. The model provides a means of examining the maturity of the research work previously accomplished. The arrow describes the direction in which research progresses with advancement in research maturity (Schendel and Cool, 1988:27).

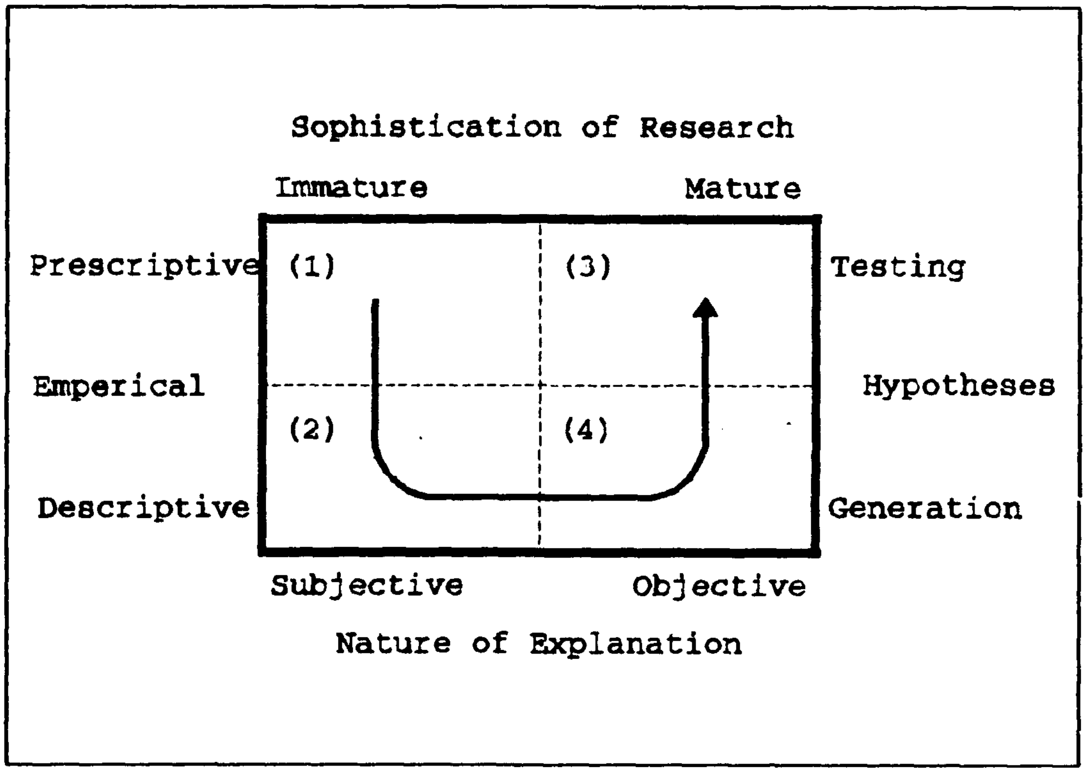

Figure 11. Research Maturation Matrix, Scientific Method (Adapted from Schendel and Cool, 1988:28)

Cell (1) contains the prescriptive works of practice and experience. The term prescriptive is defined as "acquired by, founded on, or determined by prescription or by long standing custom" (Mish, 1988:1048). While these works are of some value, they seldom move beyond practice and experience to advance serious questions about cause and effect (Schendel and Cool, 1988:28). Schendel and Cool summarize the prescriptive cell as:

> . . . the worst of all research worlds depicted, [where] much work, mostly embodied in the form of untested, or worse, untestable, statements [lie]. (Schendel and Cool, 1988:28)

Research generally begins with a subjective attempt to describe the field of study and to define and label the problem area (cell (2)). The term descriptive is defined as "referring to, constituting, or grounded in matters of observation or experience" (Mish, 1988:359). The descriptive process requires personal insight, judgement, and creativity. Schendel and Cool assert that "conceptual development is needed to define the boundaries of a field" (Schendel and Cool, 1988:28). Research maturation through the subjective descriptive phase then leads to the objective generation of hypotheses.

The objective generation of hypotheses, cell (3), depicts the meticulous, accurate description of problem area phenomena (Schendel and Cool, 1988:28). Research work contained in this phase include excellent field research, complete data bases, and careful classification of phenomena. This quadrant progresses from an understanding of the field and comprehension of the problem to generation of precise hypotheses. These hypotheses are intended to test cause and effect relationships and identify possible treatment methods (Schendel and Cool, 1988:27-30).

Adams '66 Adday '89 Berman '87 Brady (undated) CFR 49 '90 FM 6-20-1 '90 FM 9-6 '89 FM 100-10 '83 Goddard '81 Klein '91 LP Logistics '89 Morrison '83/87 Rodolfo '91 Haddow '87 Jensen '78 Seals '88 Spekman '88 TB 700-2 '89 Tech Assess '83 TM9-2350-311-10 '91	Bensinger '87 Costello '89 Herrara '83/86/90 Strobie '88
Acton '90 Bergquist '90/91 Crosby '90 Decker '86 Gough '87 Graham '90 Kelly '88 Knapton '90 Lewis '90	Doyle '88 Stark '86 Ekman '89

Figure 12. Relationship of Liquid Propellant Literature to Research Maturation in Scientific Method (Adapted from Schendel and Cool, 1988:28)

Hypotheses testing, cell (4), is the final and optimal phase of the research maturation model. Schendel and Cool summarize the hypotheses testing cell as:

> . . . research orientated toward testing hypotheses, developing causal models, and ultimately with validating prediction theory. It is, or should be, the outcome of all research to develop such predictive theory, theory which can guide practice and explain results achieved (Schendel and Cool, 1988:29).

These four phases outline the maturation of research through the various stages of development using the scientific method.

Research Sophistication. Figure 12 illustrates the state of the research reviewed in the development of liquid propellant technology and logistics doctrine. Most of the research literature was subjective; that is, the literature was both prescriptive and descriptive in nature. This was expected due to the present research and development stage of work in the field of liquid propellants. Very little research has progressed to the generation of hypotheses and hypotheses testing phases.

The subjective assignment of this literature is difficult and not always clear-cut. It is not unusual for many works to exhibit characteristics of more than one research phase (McCauley, 1991). However, each literature source was categorized to only one quadrant in an effort to simplify the process, organize the source literature, and to focus research energies.

Summary

This chapter began by defining transportation system capability and discussed two approaches to measuring system capability. Next, a review of the Department of Transportation (DOT) procedures for product classification was presented with an examination of DOD procedures for mandatory compliance with the DOT requirements. Third, an examination was conducted of the proposed liquid propellant packaging requirements and logistics fielding concepts. Fourth, an overview was presented of current planning procedures used by other organizations for the handling, storage, and transport of products with commodity characteristics which are similar to those of liquid propellant. Finally, the chapter concluded by presenting an assessment of the research maturation found in the literature search.

Chapter III will proceed by describing the data collection techniques used in this research. This literature review provided the background information and firm foundation upon which to build the data collection instruments and conduct the case study analysis of the three proposed liquid propellant logistics concepts.

III. Methodology

Overview

Chapter III describes the methodological approaches employed to answer the investigative questions formulated in Chapter I. The research design executed in this study encompassed three major phases. The first phase involved exploratory research including both a detailed literature search and an experience survey. This established a basic understanding in the areas of transportation capability and capability measurement; hazardous material classification; proposed liquid propellant packaging requirements and logistics delivery concepts; and current planning procedures for the handling, storage, and transport of liquid propellants.

The second phase comprised the construction of a subjective, descriptive surface transportation performance evaluation model based upon performance measurement criteria and system design attributes.

The third phase validated the model through the application of a paired comparison survey and scoring model. This involved a subjective approach of prioritizing surface transportation system design attributes based on weighted performance measurement criteria. A case study analysis was then conducted based on the weighted system design attributes. These three phases provided the qualitative data necessary to answer the investigative questions posed in Chapter I.

Research Technique for Investigative Question One

Investigative question one asked, "What is transportation capability?" and "What are the principles involved in measuring transportation capability?" A detailed literature search was conducted to examine the areas of transportation capability and capability measurement. Marvin L. Manheim, editor for the Center for Transportation Studies of the Massachusetts Institute of Technology, and William W. Hay, Professor of Railway Civil Engineering at the University of Illinois, provided comprehensive definitions of transportation capability and effectively explained the principles involved in measuring system capability. These principles were presented in Chapter II.

Research Technique for Investigative Question Two

The second investigative question asked, "What are the Departments of Transportation and Defense classification procedures for newly developed products?" Research for this information was performed through a literature search of published manuals and reports from the Departments of Transportation and Defense. These documents were acquired through the Defense Technical Information Center (DTIC) and the Interlibrary Loan Service. A summary of the requirements and procedures, as applicable to liquid propellant classification, were thoroughly discussed in Chapter II.

Research Technique for Investigative Question Three

The third investigative question asked, "What are the proposed liquid propellant packaging requirements and logistics fielding concepts, based on the inherent characteristics and applicable hazard classification?" A literature search was conducted of liquid propellant research and development (R&D) contractor progress reports. These documents were acquired through DTIC and the Jet Propulsion Laboratory (JPL), California Institute of Technology. These concepts were fully discussed in Chapter II.

Research Technique for Investigative Question Four

The fourth investigative question asked, "How have other organizations planned for the transport of liquid propellants and other products of similar commodity characteristics?" A review was made of Joint Army, Navy, NASA, Air Force (JANNAF) Propulsion Committee documents for nitrate-based liquid propellants with commodity characteristics similar to those of the liquid propellant under development by the Army.

This inquiry eventually focused upon Otto Fuel II, a liquid torpedo propellant used by the Navy, as a prototype for examining the handling, storage, and transportation of HAN-based propellants. Otto Fuel II is a nitrogen-based, Class B Explosive propellant with commodity characteristics similar to LP 1845 and LP 1846. These findings were presented in Chapter II.

Research Technique for Investigative Question Five

The fifth investigative question asked, "What are the relative strengths and weaknesses of the proposed logistics fielding concepts for liquid propellant in Field Artillery applications?" "What are the relevant surface transportation performance measurement criteria for evaluating logistics fielding concepts?" "What are the relevant system design attributes which must be considered for inclusion into the final selection of a liquid propellant logistics fielding concept?" To evaluate this question, it was necessary to construct a transportation performance evaluation model. This model was developed with an applicable focus toward the research and development (R&D) aspect of proposed logistics concepts. The output of the model, prioritized system design attributes, was then used in a case study analysis to evaluate the relative strengths and weaknesses of the proposed logistics fielding concepts.

Model Selection

The role of analysis in the managerial decision-making process can best be understood by the flow diagram illustrated in Figure 13. All decision making processes include both qualitative and quantitative analyses. In qualitative analysis, the decision maker draws primarily upon intuitive judgement and experience to summarize and evaluate the situation in order to reach a decision. Emphasis is placed on qualitative analysis when solving unstructured problems characterized by high uncertainty, long time horizons, or when the decision maker must draw upon experience from solving similar problems. (Anderson, et al, 1985:3; Hicks, 1987:23).

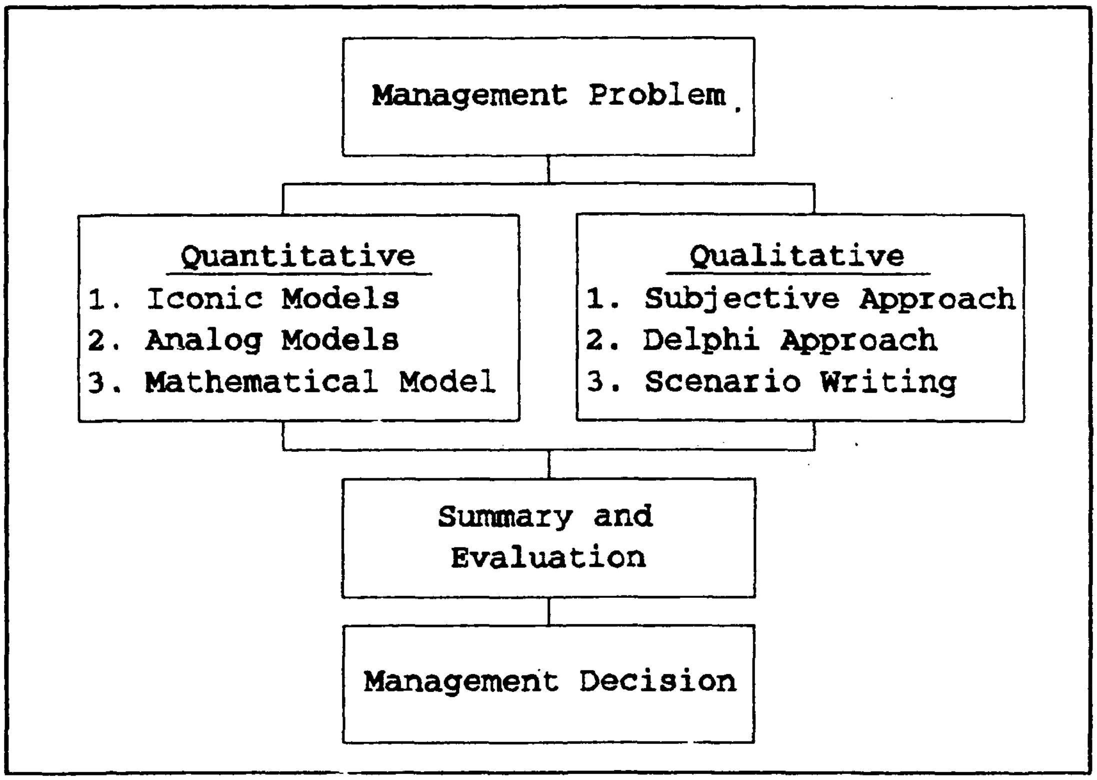

Figure 13. The Decision-Making Process (Adapted from Anderson, et al, 1985:3)

It was critically important to carefully screen and select an appropriate evaluation model. A model has value to the extent that it enables the researcher to draw conclusions about a real situation through study and analysis. Quantitative models, such as iconic, analog, and mathematical models, are useful in analyzing historical numeric data (Anderson, et al, 1985:6), while qualitative models, such as Subjective approaches, the Delphi study, and scenario writing, are appropriate to analyze language and thought data. This is especially appropriate when historical data is unavailable or questionable (Anderson, et al, 1985:598).

As with development of liquid propellant, research and development (R&D) project selection decisions are characterized as relatively unstructured problems that are concerned primarily with the allocation of organizational resources (Baker and Pound, 1964:124). Perhaps having the greatest influence on the decision process is the inherent uncertainty associated with the R&D process (Moore and Baker, 1969:B-212).

Subjective Qualitative Approach. A subjective, or intuitive, approach was selected in this research effort. A subjective analytic approach is based upon the inherent ability of the mind to think logically and creatively in identifying system elements and establishing relative relationships among them. These inherent abilities are to communicate what is observed, determine the relative intensity of the relationships, and synthesize these relationships for comprehensive understanding (Saaty and Kearns, 1985:19).

The subjective paired comparison technique was selected because: 1) there is complete control over the survey process as the researcher and the group of expert respondents are physically collocated; 2) the face-to-face iteration process develops consensus rapidly and fosters teamwork and enthusiasm within the group (Souder, 1980:72); 3) there is no delay between group input and individual receipt and feedback of that input; 4) the technique uses a hybrid nominal-group interaction process in which dynamic, open-group discussion is used to establish the variables for consideration, and individual, anonymous assessments to determine the judgements; and 5) qualitative judgements are expressed in absolute numbers based on relative comparisons. These relative judgements are made as part of a rigorous derivation of an estimated underlying ratio scale (Saaty, 1980:66-70).

A subjective survey approach conducted prior to the implementation phase of system design provides the benefit of comments in a realistic environment, i.e., from the field. This eliminates the proliferation of computer generated "war game" solutions and thus program specifications which are typically created in isolation of realism (Lewis: 1990).

Souder contends that the paired comparison method focuses careful thinking and eliminates irregulaties in decision making (Souder, 1980:32). For a planning and problem solving process in which there is no measurement scale to validate the result, Saaty also argues that paired comparison is the appropriate technique (Saaty, 1980:6). In the absence of specific quantitative measures, Lawshe and

Balma state that the pairwise comparison technique is one of the best measures of successful performance. Unlike other structured group decision-making approaches, a formal value assessment method such as the paired comparison method "is used to bridge vocabularies and lend credibility to each individual's rankings" (Souder, 1975:680).

The paired comparison technique, nominal-interaction process, and scoring model mechanisms enhance decision making and provide a systematic approach in obtaining consensus, provide an audit trail, and provide an effective communication and decision making device sufficiently rigorous to focus discussion on the alternatives rather than the process used to derive the alternatives (Harrington, 1989:13; 1991:91). The tools are simple and easy to implement, yet sufficiently rigorous to solicit individual and group judgements in a systematic manner (Harrington, 1989:15). For example, the ordinal rankings produced from multiple objectives can then be used as inputs to multiple objective mathematical programming models, such as goal programming (Harrington, 1989:15).

Moore and Baker (1969) conducted a computational analysis to compare the behavior of multiple criteria scoring models to that of economic and linear programming models. Using an analytical approach, their goal was to investigate whether scoring models, given the same input data and alternatives, provide results consistent with those of the other models. Both additive and multiplicative indices for computing the scoring models were investigated.

Their analyses revealed first that the rank-correlation coefficients were high enough to confirm the assertions of Brandenberg (1964):

> . . . that a significant and positive correlation exists between the project rankings by the scoring model and those resulting from the economic and linear programming models. (Moore and Baker, 1969:B-219)

Second, their analyses found that ". . . the additive scoring model index consistently provided a higher degree of rank-order consistency than the multiplicative index (Moore and Baker, 1969:B-220). Third, the additive index actively incorporated all observations including those at both extremes of the scale, while the multiplicative index favored alternatives which received average rankings (Moore and Baker, 1969:B-220).

Outline of Methodology

The methodology, as shown in Figure 14, was instituted in four phases. During the preliminary phase, problem definition, population definition, and sample selection were accomplished.

During the second phase, paired comparison surveys were administered to the sample groups. This required two separate days of field work. The first day involved criteria selection, nominal group interactive process (open discussion with individual selection) to develop surface transportation system design attributes, and a paired comparison survey to weight the criteria. The researcher

START

Problem Definition

Define Population

Select Sample Size
(determine expertise required)

Overview Briefing

Select the Criteria
(nominal group interactive process)

Weight the Criteria
(paired comparison technique)

Select the Attributes
(nominal group interactive technique)

Compare the Attributes for each Criteria
(paired comparison technique)

Scoring Model - Attribute Rank Order
(weight attributes to all criteria)

Data Analysis
(nonparametric statistics)

Case Study Analysis
(logistics concept(s) feasibility)

Compile Final Report

Figure 14. Methodology Procedure

then coded the survey responses into a prioritization matrix to derive the weighted score and significance level for each criteria. On the second day, an attribute paired comparison survey was completed for each criteria that achieved a minimum consensus weighted level (explained later in this chapter).

During the third phase, the researcher transcribed the survey responses into a scoring model to weight the attributes and perform a statistical analysis of the rank-order probability distributions. Phase four culminated the methodology with a case study analysis which evaluated the strengths and weaknesses of the three proposed liquid propellant logistics concepts based upon the weighted attributes.

The methodology was designed as a decision aiding tool to provide: 1) qualitative surface transportation performance criteria and system design attributes from expert field operators; 2) reliable information to transportation planners to communicate with Army Logistics Center (LOGCEN) and Training and Doctrine Command (TRADOC) planners concerning logistics concept performance; and 3) consensus input to the logistics concept selection process.

Preliminary Phase. This phase problem included definition of the management problem, population definition from which to draw the sample group, and selection of the sample size.

Problem Definition. No comprehensive analysis has been performed to identify the performance measurement criteria and design attributes of an Army surface transportation system necessary to support the distribution of liquid propellant in Field Artillery applications. The problem facing the researcher involved selecting and rank-ordering the criteria and attributes being used in the case study analysis, since the ranking would obviously influence the decision.

Population Definition. The population of the paired comparison field survey respondents comprised all Majors (Grade 04) and Captains (Grade 03) of both the Army Transportation and Ordnance Corps and vesselmaster senior chief warrant officers (Grade CW4/3) of the Transportation Corps. Table 15 segments the population under consideration for this study. Vesselmaster senior chief warrant officers from the transportation corps were included in the survey population because they are the operators for the Army's watercraft career field. Watercraft, rail, and highway modes provide the Army's surface transportation triad.

Table 15

Transportation and Ordnance (Munitions) Corps Officer Population (Gilgallon, 1991; Brown, 1991)

Transportation Corps:*	04, 88A00	273	
	03, 88A00	595	
Watercraft:	CW4, 880A2	16	
	CW3, 880A2	10	897
Ordnance Corps:+	04, 91D00	199	
	03, 91D00	465	
Munitions:	CW4, 910A2	6	
	CW3, 910A2	31	701
Total			1,598

* Corps inventory dated January 1991
\+ Corps inventory dated August 1990

Sample Selection. Interviews were conducted with the Directors, Directorate of Combat Development, Transportation and Ordnance (Munitions) Corps, to select a list of survey respondents. A respondent selection criterion of greater than eight years experience in their respective career fields and assignment in strategic planning or doctrinal instruction was set. These interviews were necessary to identify respondents both knowledgeable in their respective areas of combat service support logistics and capable of contributing to the final decision of selecting the transportation concept for the liquid propellant logistics system.

In identifying respondents to participate in a paired comparison survey, it is recommended to select 9-14 knowledgeable persons who are subject matter experts in the field being studied (Baker and Pound, 1964:125). Otherwise, the number of participants becomes cumbersome. Twenty-four respondents were selected (Appendix A) by the Directors of Combat Developments, twelve from each corps, to participate in the survey. All those selected participated through both days of surveying (100 percent response rate). Table 16 details the composition of the respondent group. While every effort was made to achieve equal experience and functional representation, obvious differences existed between the two corps in composition of the Directorates and personnel structures.

The sample respondents from the Transportation Corps included one senior Master Warrant Officer from the Office of the Chief of Transportation (OCT), four senior company and field grade officers and two senior Chief Warrant Officers from the Directorate of Combat Developments (DCD), two senior company and field grade officers and two senior civilians from the Professional Development Division (INSTR), and one senior Chief Warrant Officer vesselmaster from the operational watercraft field (OPER). The sample respondents from the Ordnance (Munitions) Corps included one senior field grade officer from the Office of the Chief of Ordnance (OCO); one senior field grade officer and three senior civilians from the Directorate of Combat Developments (DCD); and three senior company and field grade officers, three senior civilians, and one senior noncommissioned officer from the Professional Development Divisions (INSTR).

Table 16

Survey Respondents by Corps and Directorate

Corps/Office	OCT/O	DCD	INSTR	OPER	Total
Transportation	1	6	4	1	12
Ordnance (Mun)	1	4	7		12
Total	2	10	11	1	24

<u>Phase Two</u>. This phase two involved days of field work to select the surface transportation performance measurement

criteria and system design attributes, and paired comparison surveys to weight the criteria and compare the attributes.

Overview Briefing. To ensure respondent cooperation, an overview session was conducted to explain the problem definition, objectives, and methodology for development of surface transportation performance measurement criteria and system design attributes. The briefing explained the need and purpose of the ranking process, the importance of the data, and the significance of the outcome to the logistics system.

The participants were told that their rankings would be kept strictly confidential. Since the results were anonymous, minority opinions and less experienced participants would not be subjected to "specious persuasion" of loud, persuasive, or dominant group members (Souder, 1980:72). The respondents were briefed on the mechanics of the ranking process and questions were answered. Each participant was provided a brief yet thorough glossary of definitions (Appendix A) to ensure a common understanding of each criterion and attribute under consideration (Juran, 1988:61-63).

Select the Criteria. Criteria selection built upon previous research conducted by the Jet Propulsion Laboratory (JPL), California Institute of Technology (Beaudet, et al., 1989:V-4). In the Report on Liquid Propellant Logistics System Study, Phase I (1989), a logistics attribute ranking questionnaire had been employed to determine the critical performance measurement criteria for the first iteration down-select phase (performed by JPL) from sixteen proposed liquid propellant logistics concepts to six candidate concepts. The author selected these six logistics attributes used in the previous questionnaire as the surface transportation performance measurement criteria to be used in this study. These criteria are listed in Table 17.

Each criterion was reworded to actively reflect the desired outcome. For example, the third criterion should read, Increase Personnel and Environmental Safety, not Safety/Environmental (Brassard, 1989:111-105). This "active" rewording was necessary to express the criteria in terms of delivery, quality, and other performance measures for evaluating surface transportation capability (Harrington et al, 1991:86-87; Spekman, 1988:75-80). The list of criteria was confirmed for accuracy by the Technical Group, JPL, and the Directorate of Combat Developments, U.S. Army Transportation Center and School.

Table 17

Surface Transport Performance Measurement Criteria for Liquid Propellant Technology (Ekman, et al., 1989:I-5)

1. Reduce Logistics Burden
2. No Customized Technology
3. Increase Personnel and Environmental Safety
4. Increase Operational Capability of Logistics
5. Increase Tactical Capability of Users
6. Low Cost to Implement

Weight the Criteria. The paired comparison booklets were developed based on the work of C. H. Lawshe and Newell C. Kephart (Lawshe and Balma, 1966:375-390). The criteria and were paired, four to a sheet, in accordance with a Random Order of Pairs Table (Lawshe and Balma, 1966:379-389). This randomized format served to remove respondent bias caused by continuous sequencing. The sheets were cut into individual strips to contain only one pair, and then the strips were assembled into a booklet. This booklet arrangement thus allowed the rater to visualize and consider only one pair at a time (Lawshe and Balma, 1966:377).

To conduct the criteria paired comparison survey, each member of the respondent group was given a criteria paired comparison booklet and a glossary outlining common definitions of the criteria. Both the booklet and the glossary are reproduced in Appendix A. Each group member was directed to individually and anonymously judge whether each criteria pair was equal in importance/preference or whether one criterion was significantly or extremely more important/preferred. As demonstration in Figure 15, if the two criteria were "Equally Important/Preferred," the single center box would be marked. However, if the rater made a relative judgment that one criterion was "Significantly" or "Extremely More Important/Preferred," that appropriate criterion's box would be selected.

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Reduce Logistics Burden		[ ]	[ ]
	[ ]		
Low Cost to Implement		[X]	[ ]

Figure 15. Paired Comparison of Surface Transportation Performance Measurement Criteria

The pairwise grouping of the criteria was accomplished using a Random Order of Pairs Table to eliminate order as a source of bias in the testing instrument (Lawshe and Balma, 1966:379-389). The rater made a relative judgment about each pair (skipping none) in the order in which the pairs were presented in the booklet.

Following completion of the criteria paired comparison booklets by the respondents, the researcher transcribed each individual relative comparison to a numerical raw score using the values shown in Table 18. This broad ranking scale provided for a rigorous ordering of the criteria (Saaty, 1980:66).

Table 18

Pairwise Comparison Ranking Scale (Brassard, 1989:108)

10	=	Extremely more important/preferred
5	=	Significantly more important/preferred
1	=	Equally important/preferred
1/5	=	Significantly less important/preferred
1/10	=	Extremely less important/preferred

		1	2	3	4	5	6	Row Totals	
1	Reduce Logistics Burden		5	10					
2	No Customized Technology	1/5							
3	Increase Personnel and Environmental Safety	1/10							
4	Increase Operational Capability of Logistics								
5	Increase Tactical Capability of Users								
6	Low Cost to Implement								
	Column Totals							Grand Total	

Figure 16. Ranking the Criteria, Pairwise Comparison Matrix Instrument (Brassard, 1989:110)

Next, the researcher constructed a criteria prioritization matrix. The criteria were listed in the column headings in any order from left to right, then entered in the same order along the row headings of the matrix as shown in Figure 16. The total of the individual raw scores for each comparison was entered in the appropriate row-column intersection of the matrix with the reciprocal score entered in the reciprocal column-row intersection. The matrix is interpreted by reading first across a row, and then up the column. For example, in Figure 16, the first criterion, Reduce Logistics Burden, has been judged significantly more important/preferred than second criterion, No Customized Technology.

To tabulate the individual criterion weighted value, the total group score in each row-column intersection was converted to a decimal value and then row and column totals were added to form the "Row/Column Totals." Next, the column totals were added together for a "Total Across Columns Grand Total." Each row total was then divided by the grand total to obtain a percentage (Brassard, 1989:109). This percentage formed the weighted (normalized) score that was used as the criterion weight, or multiplier, in the final scoring model. The final step in completing the criteria paired comparison was to establish a minimum acceptance level of 10 percent for each criteria rank. The system design attributes will be evaluated only upon criteria above this consensus level.

A built-in check of the group's logic and the researcher's tabulation is provided in two ways by the symmetry of the completed matrix instrument around the diagonal (Souder, 1980:31): (1) the grand total of the row summations must equal the grand total of the column summations; and, (2) the column entitled "As a % of Grand Total" must equal 1.0000 (or 100%).

Select the Attributes. An initial list of sixteen performance-based system design attributes, Table 19, were chosen by the researcher and presented to the group for consideration. These attributes were selected from the discussions, findings, and recommendations contained in the Report on Liquid Propellant Logistics Systems Study, Phase I and II (1989), by the Jet Propulsion Laboratory (JPL), California Institute of Technology, and academic principles contained in the Practical Handbook of Distribution/Customer Service (1985), by Warren Banding, and Strategic Logistics Management (1987), by James R. Stock and Douglas M. Lambert. This was done to provide a basis for beginning the group discussion with attributes that were supported in research and academic literature and to save valuable time.

Table 19

Surface Transport Design Attributes for Liquid Propellant Technology (Blanding, 1985:129-162; Ekman, et al., 1989:3.1-84; Beaudet, et al., 1989:V.1-VII.44; Stock and Lambert, 1987:264-7, 723-4)

1. Provide HazMat Containment Training
2. Streamline HazMat Documentation
3. Provide HazMat Contingency Equipment
4. No Additional MOS Training
5. No Increase in Manpower
6. Design Flat Racks for Multipurpose Use
7. Design Pallets for Easy Access Top and Bottom
8. High Reliability and Maintainability
9. Use Current Handling/Transport Equipment
10. Compatible between Modes of Transport
11. Compatible with Allied Equipment
12. Capable of Automated and Manual Handling
13. Quick Transfer Speed at POD, TSA, and CSA
14. Quick Transfer Speed at ASP and ATP
15. High Package Integrity to Minimize Damage
16. Lightweight/Low Cube Packaging

The transportation group reviewed the initial list of attributes through open discussion, making additions and deletions until consensus was attained. Discussions were controlled by the members, who could participate as much or as little as each desired. A list of sixteen attributes was reached in one nominal group session. The group's final list of system design attributes was subsequently reduced to ten items.

The major problem encountered in using the paired comparison technique to develop a ranking system was the time required to rank the pairs (Lawshe and Balma, 1966:47). The number of pairs increased rapidly as the number of variables increased. Ranking 4 variables would require 6 pairs, 16 variables would require 120 pairs, and 100 variables would require 4,950 pairs. The number of paired comparisons for any group of variables is determined by the formula $C = N(N-1)/2$, where N is the number of variables under consideration and C is the number of resulting paired comparisons (Tiffin and McCormick, 1965:233). While methods for partial pairing of larger groups have been developed (Lawshe and Balma, 1948; McCormick and Bachus, 1952; McCormick and Roberts, 1952), these techniques were not used to ensure full coverage of the selected variables.

An iterative ballot technique was used to reduce the list of attributes to a manageable number. The list of attributes was reduced by presenting each member with a separate list of the attributes and directing them to anonymously select the ten items considered most important. The researcher collected the lists and compiled a summary of the group's ten most important attributes. Each member was then given the second list and directed to reassess their top ten attribute choices in light of the group consensus.

The researcher collected these results and compiled a final list of the ten most important attributes for paired comparison.

Compare the Attributes. Each member of the respondent group was given an attribute paired comparison booklet for each criterion judged as significantly important and a glossary outlining the common definitions of the criteria and attributes. Both the attribute booklet and the glossary are attached in Appendix A.

Judge the relative importance/preference based on the criteria: **REDUCE LOGISTICS BURDEN.**

(6-5)

	Equally Important/ Preferred	**Significantly** More Important/ Preferred	**Extremely** More Important/ Preferred
Use Current Handling and Transport Equipment		☐	☐
	☐		
High Reliability and Maintainability		X	☐

Figure 17. Paired Comparison of Surface Transportation System Design Attributes

The respondents were directed to complete one booklet for each criterion, based only upon that criterion. As before, each group member was directed to anonymously judge whether the attribute pair was equal in importance/preference or whether one attribute was significantly or extremely more important/preferred based on each criterion. This is illustrated in Figure 17.

As with the criteria, the pairwise grouping of the attributes was accomplished using a Random Order of Pairs Table to eliminate order as a bias in the testing instrument (Lawshe and Balma, 1966:379-389). Once again, the respondent made a relative judgment about each pair (skipping none) in the order in which the pairs were presented in the booklet.

Following completion of the attribute paired comparison booklets by the group members, the researcher scored and converted each relative comparison to a numerical raw score using the values shown in Table 3. Next, the researcher constructed an attribute prioritization matrix. The attributes were listed in the column headings in any order from left to right, then entered in the same order along the row headings of the matrix as shown in Figure 18. The total of the individual raw scores for each comparison was entered in the appropriate row-column intersection of the matrix with the reciprocal score entered in the reciprocal column-row intersection.

As with the criteria matrix, individual raw scores were entered in each row-column intersection and totaled, the total group score was converted to a decimal value, and then row and column totals are added together to form the Row/Column Total. Next, the column totals are added together for a Total Across Columns Grand Total. Each row total was then divided by the grand total to obtain a percentage (Brassard, 1989:109). This percentage formed the

		1	2	3	4	5	6	7	8	9	10	Row Totals
1	Provide HazMat Containment Training											
2	Provide HazMat Contingency Equipment											
3	No Increase in Manpower											
4	Design Flat Racks for Multipurpose Use											
5	High Reliability and Maintainability											
6	Use Current Handling and Transport Equipment											
7	Compatible between Modes of Transport											
8	Compatible with Allied Equipment											
9	Capable of Automated and Manual Handling											
10	Quick Transfer Speed at ASP and ATP											
	Column Totals											Grand Totals

Figure 18. Ranking Attributes by Individual Criterion. Pairwise Comparison Matrix Instrument (Brassard, 1989:113)

weighted (normalized) score that would be used as the attribute multiplier in the final scoring model matrix. The final scoring model matrix will compare each attribute based on all criteria for a final weighted attribute rank ordering.

Phase Three. During the third phase, the researcher transcribed the survey responses into a scoring model to weight the attributes. Nonparametric statistical analyses were then performed on the rank-order probability distributions. Statistical procedures are covered later in this chapter.

Scoring Model. The researcher constructed a scoring model to prioritize the transportation system design attributes based on all significant, weighted criteria (Brassard, 1989:114-116). A scoring model is a screening technique which provides a means of constructing a descriptive decision aid for prioritizing the surface transportation system design attributes based on known weighted performance measurement criteria (Brassard, 1989:99; Harrington et al, 1991:83).

Screening techniques are used in logistics to make strategic decisions where judgement remains an important part of the analysis process (Ballou, 1985:346). Screening techniques also are used in the feasibility analysis of a structured system development (Harrington, 1991:8). White states the principal advantage of using a scoring model approach is that:

> . . . it makes the process of weighing variables explicit: because it forces us to formalize the important elements of the . . . decision, it helps us bring our tacit assumptions to the surface and questions our intuitive or habitual priorities. (White, 1978:11)

The scoring model incorporates absolute scales for ranking the relative worth of each item to every other item in the data set. The scores are then combined into one ordinal value number, using the formula:

$$T_j = \sum_{j=1}^{n} C_i A_{ij} \qquad i,j=1,2,\ldots,n$$

where T_j is the combined value of the j^{th} system design attribute, C_i is the relative weight of the i^{th}

performance criterion, and A_{ij} is the relative attribute score derived based on each individual criterion. The value for A_{ij} is found by the formula:

$$A_{ij}=\frac{\sum_{k=1}^{n} s_i}{\sum (\sum_{k=1}^{n} s_j)} \qquad i,j,k=1,2,\ldots,n$$

were s_{ijk} is the vector score of the j^{th} attribute on the k^{th} criterion.

The criteria used as a basis for comparing the attributes were entered in the column headings in any order and the attributes were entered along the row headings in the same order as in the attribute paired comparison matrices as shown in Figure 19. Next, the weighted score from each attribute matrix was entered and multiplied by each criterion weighted score. An additive scoring model index was use to compute the individual column and row scores to form the "Row/Column Totals," and column totals were added to form the "Total Across Columns Grand Total."

Finally, each attribute raw score was divided by the grand total to obtain a percentage (criteria-weighted). This formed the final weighted (normalized) score for each system design attribute. These overall rankings determined the relative, perceived standings of each system design attribute against the field of ten attributes. To provide a final ranking that was easier to interpret, the author

	Criteria #1	Criteria #2	Criteria #3	Criteria #4	Row Total	% of Total	Scale 0-100
Provide HazMat Containment Training							
Provide HazMat Contingency Equipment							
No Increase in Manpower							
Design Flat Racks for Multipurpose Use							
High Reliability and Maintainability							
Use Current Handling and Transport Equipment							
Compatible between Modes of Transport							
Compatible with Allied Equipment							
Capable of Automated and Manual Handling							
Quick Transfer Speed at ASP and ATP							
Column Totals					Grand Totals		

Figure 19. Ranking Attributes by all Criterion. Scoring Model (Brassard, 1989:116)

converted criteria-weighted attribute percent scores to a scale of 0-100 using the formula $(A_i - A_l)/(A_h - A_l)$, where A_i is the attribute percent score being converted, A_h is the highest attribute percent score, and A_l is the lowest attribute percent score.

It should be noted that these six criteria and ten attributes were selected by the group of expert transportation managers as the most important for consideration in the survey. Thus, the attribute with a score of zero (0) does not indicate unimportance of a criteria-weight attribute, only that it is considered the least important of the field of ten selected attributes. While such scores give no indication of absolute zero of merit, they do enable the estimation of the relative size of the steps or intervals between the variables. The survey is limited to a given range of items, and merely allows the range to be divided between the highest and lowest items and to locate every other item within this range (Woodworth and Schlosberg, 1954:255).

Data Analysis. Bureaucracy and functional specialization may create dissimilar perceptions of organizational goals (Thompson, 1968:487) and can hinder the achievement of organizational consensus (Souder, 1975:68). For these reasons, it was deemed necessary to survey respondents from both the transportation and the ordnance corps in order to make certain inferences about validity and consistency of the surface transportation performance evaluation model and the resulting criteria and system design attributes.

Nonparametric statistical test methods are used to compare two or more populations that are based on a rank-ordering of the sample measurements corresponding to their relative magnitudes (McClave and Benson, 1988:945). The rank order probability distributions must be evaluated to determine whether the two samples came from the same population of logisticians. If hypotheses testing confirms high correlation and identical frequency distributions, inferences can be made about the two corps populations.

This section identifies the statistical tests for evaluation probability distributions of the two sampled populations. There are two categories of data for which the t and F tests are unsuitable. The first is data which do not satisfy the basic assumptions of normal probability distributions and equal variances. The second is data in the form of "responses that are not susceptible to measurement but that can be ranked in order of magnitude" (McClave and Benson, 1988:946).

Thus nonparametric tests must be used to compare the probability distributions of the sampled populations using relative ranks. This is accomplished through comparison of the sample observations rather than with actual numerical numbers (McClave and Benson, 1988:946). The weighted attribute scores from the two respondent groups were statistically compared to determine 1) if the probability distributions associated with the two populations were equivalent; and, 2) the strength of the linear relationship between the two population distributions.

Rankit Plot. First, a visual evaluation of the attribute rankings was conducted by producing a Rankit Plot. This test indicates whether the plotted variable corresponds to a normal distribution.

Wilcoxon Rank Sum Test for Independent Samples. Second, the Wilcoxon Rank Sum Test for Independent Samples was computed to examine if the two sampled populations have identical probability distributions (McClave and Benson, 1988:967). The Wilcoxon Rank Sum Test is the nonparametric equivalent of the small sample paired t test used when the population relative frequencies conform to the normal distribution. This test bases its comparison on the rank sums (totals of the ranks) of the data (McClave and Benson, 1988:948).

The null and alternative hypotheses are:

H_o: The two sampled populations have identical probability distributions

H_A: The probability distribution for the transportation corps population has shifted to the left or the right of that for the ordnance corps

The decision rule to reject the null hypothesis is:

Reject H_o of $p <$ alpha of 0.05 significance level

Spearman's Rank Coefficient Correlation. Spearman's Rank Coefficient Correlation r_s was computed as a nonparametric measure of the strength of the linear relationship between two variables (McClave and Benson, 1988:980). Spearman's Coefficient is the nonparametric equivalent of the Pearson's Product Moment Coefficient of Correlation **r** Test used when the population relative frequencies conform to the normal distribution. The correlation coefficient is essentially a measure of the degree to which individual differences in the sample items vary together (Lawshe and Balma, 1966:276). Thus, r_s is comparable to the least squares slope and computed from the same values; however, unlike the slope, r_s is a scaleless rank order measure of magnitude (McClave and Benson, 1988:514).

The null and alternative hypotheses are:

H_o: The **p** = 0 (no population correlation between ranks)

H_a: The **p** > 0 (population correlation between ranks)

The decision rule to reject the null hypothesis is:

Reject H_o of r_s > alpha of 0.05 significance level

As a caution, it should be noted that high correlation does not presuppose causality. "The only safe conclusion when a high correlation is observed in the sample data is that a linear trend may exist between x and y" (McClave and Benson, 1988:515-516).

Phase Four. This phase completes the methodology with case study analyses which evaluated the strengths and weaknesses of the three proposed liquid propellant logistics concepts based upon the criteria weighted system design attributes.

Logistics Concept Feasibility. To determine the feasibility of each liquid propellant logistics delivery concept, case study analyses were conducted four senior Army Transportation managers. These managers were selected in the same manner as the survey respondents. The only modification to the selection criteria was that the respondent has had at least battalion level command experience.

The case study analyses were coordinated by telephone. Each respondent was then provided in advance, by facsimile machine (FAX), an introductory briefing, list and glossary of the rank ordered system design attributes, description of the proposed logistics concepts, and decision matrix. This allowed the respondent the necessary time to thoroughly read and understand the concepts and develop a response.

A case study analysis was used to evaluate the three proposed liquid propellant logistics concepts. The background briefing was mailed to each respondent. This briefing contained a description of the three concepts, a listing of the weighted criteria and prioritized attributes, and a step by step format for conducting a case study. This complete briefing is reproduced in Appendix A.

Summary

In summary, this methodology involved nominal group interactive (open discussion) processes to develop surface transportation performance measurement criteria and system design attributes, a paired comparison technique to systematically weight the criteria and prioritize the attributes, a scoring model to weight the attributes to all significant criteria, and a case study analysis to evaluate how each proposed logistics concept would perform against the weighted attributes.

This chapter addressed the research techniques used to answer the investigative questions posed in Chapter I. These techniques included a detailed literature search and experience survey, the administration of a transportation performance evaluation model, and a case study analysis. Chapter IV proceeds to describe the model development, model application, and data analysis and findings.

IV. Data Analysis

Overview

This chapter describes the results attained during development and administration of the surface transportation performance evaluation model, the findings and statistical analysis of the inclusive scoring model, and the liquid propellant logistics concept decision matrices analysis. The analysis and findings are presented in the same sequence as the model development in Chapter III, Methodology.

Data Collection

Data collection required close coordination to ensure that valuable resource in time and travel funds were not wasted. Telephone coordination was made with the Directorate of Combat Developments, U.S. Army Transportation Center, and the Training and Doctrine (TRADOC) Munitions System Manager Directorate, U.S. Army Missile and Munitions Center.

Despite every effort to explain the purpose of the research and the use of the data, problems developed with the TRADOC Munitions Manager's office. Upon arrival at Redstone Arsenal to administer the paired comparison surveys, the TRADOC Munitions Manager unexpectedly declined to support the research. This resulted in a second visit being required to the Munitions Center. Subsequent coordination was accomplished directly with the Missile and Munitions Center Director of Combat Developments.

Initial coordination was followed by written correspondence (Appendix A). The Directors of Combat Developments from each Corps responded with their support and a list of twelve survey respondents in accordance with the predetermined selection criteria (Appendix A).

Paired Comparison Survey. The purpose of the paired comparison survey was to rank order the most important performance measurement criteria and design attributes of an Army surface transportation system required to support the new generation of 155mm Self-Propelled Howitzer. The results would quantify by rank order the success-dependent qualitative characteristics of a surface transportation system necessary to sustain the desired level of customer service through the logistics chain to the ultimate user.

The technique used was primarily based on Harrington's (1989) vendor performance model. The author embellished this method based on technical improvements employed by Lawshe and Balma (1966) and Brassard (1989). The survey respondent group consisted of twelve knowledgeable experts from the Army Transportation Corps and twelve from the Army Ordnance (Munitions) Corps. The respondents were individually selected by the directors of the Corps' respective Directorates of Combat Development. Selection letters and biographical sketches are included in Appendix A to substantiate each respondent's selection.

As stated in Chapter III, to overcome the major limitation of the paired comparison technique - large number of comparisons - a consensus level of .10000 was established to identify and eliminate insignificant criteria from the model. Only criteria above this predetermined consensus level would be carried forward to succeeding stages of the model's development. The survey consisted of two separate paired comparison questionnaires.

Criteria Survey Results. The response rate for the criteria paired comparison survey was 100% participation from 12 of 12 respondents from both corps' proponency, combat development, and professional development logistics experts.

The first questionnaire (Appendix B) contained six surface transportation performance measurement criteria. These criteria (Table 20) were provided by the researcher. A paired comparison booklet was constructed to derive the criteria weights in a rigorous and systematic manner. The questionnaire construction and criteria validation were explained in detail in Chapter III.

Table 20

Performance Measurement Criteria

1.	Reduce Logistics Burden
2.	No Customized Technology
3.	Increase Personnel and Environmental Safety
4.	Increase Operational Capability of Logistics
5.	Increase Tactical Capability of Users
6.	Low Cost to Implement

Each respondent was required to anonymously (the nominal portion) consider each independent pair and make a subjective judgement about the relative importance of one criteria over the other. Figure 20 shows the results of the transportation respondent group's survey, and Figure 21 the Ordnance group's results. The results were used to eliminate nonconsensus criteria and weight the attributes.

	Criteria	1	2	3	4	5	6	Row Totals	
1	Reduce Logistics Burden		34.4	19.8	12.6	20.6	43.6	131.0	0.1361
2	No Customized Technology	15.2		9.0	2.6	8.5	30.8	66.1	0.0687
3	Increase Personnel and Environmental Safety	39.6	73.2		49.5	39.6	67.0	268.9	0.2793
4	Increase Operational Capability of Logistics	37.2	86.0	24.6		39.6	54.2	241.6	0.2510
5	Increase Tactical Capability of Users	35.6	62.2	19.8	19.8		30.0	167.4	0.1739
6	Low Cost to Implement	19.0	25.4	3.7	10.1	29.4		87.6	0.0910
	Column Totals	146.6	281.2	76.9	94.6	137.7	225.6	Grand Total 962.6	1.0000

Figure 20. Transportation Corps Criteria Paired Comparison Survey Results

	Criteria	1	2	3	4	5	6	Row Totals	
1	Reduce Logistics Burden		42.4	20.5	18.8	14.9	30.4	127.0	0.126
2	No Customized Technology	28.3		2.0	2.1	9.3	25.2	66.9	0.066
3	Increase Personnel and Environmental Safety	40.6	80.0		39.8	25.7	72.0	258.1	0.256
4	Increase Operational Capability of Logistics	53.6	75.0	24.5		28.8	63.0	244.9	0.243
5	Increase Tactical Capability of Users	49.4	58.2	30.5	38.7		68.2	245.0	0.243
6	Low Cost to Implement	16.0	34.2	3.6	4.5	9.1		67.4	0.067
	Column Totals	187.9	289.8	81.1	103.9	87.8	258.8	Grand Total 1009.3	100.00%

Figure 21. Ordnance (Munitions) Corps Criteria Paired Comparison Survey Results

Both respondent groups independently selected the same four criteria as significant. Each ranked High Reliability and Maintainability as the most important performance criteria. An interesting intermediate finding was that criteria two and three were selected in reverse order by the two groups. The munitions group ranked Increase Tactical Capability of Users second, while the transportation group 2ranked Increase Operational Capability of Logistics second. Perhaps this is because the primary customer of the munitions activity is the tactical user, while the primary customer of the transportation activity is other logistics services.

Attribute Survey Results. The second questionnaire (Appendix B) consisted of ten surface transportation system design attributes. These attributes were selected by the Transportation Corps respondent group using group interaction. An initial list of sixteen attributes was provided by the researcher to save time and begin the group discussion. Validation of the initial attribute list was provided in Chapter III.

Through brainstorming techniques, the group developed a list of sixteen attributes believed to be important as standard system design attributes for a surface transportation system. Two separate iterative rounds of balloting reduced the list of attributes to a manageable size of ten (Table 21).

Table 21

System Design Attributes

1.	Provide HazMat Containment Training
2.	Provide HazMat Contingency Equipment
3.	No Increase in Manpower
4.	Design Flat Racks for Multipurpose Use
5.	High Reliability and Maintainability
6.	Use Current Handling and Transport Equipment
7.	Compatible between Modes of Transport
8.	Compatible with Allied Equipment
9.	Capable of Automated and Manual Handling
10.	Quick Transfer Speed at ASP and ATP

The attributes selected by the transportation respondent group has support in doctrine and academic literature. Seven of ten attributes stressed equipment performance-based system design standards reflecting reliability, maintainability, and interoperability. The remaining three attributes emphasized a concern for adequate operator training and containment material to ensure environmental and personnel safety.

The second paired comparison survey randomly paired the ten attributes into forty-five pairs, viewed individually in succession. The respondent was required to anonymously consider each independent pair and make a subjective judgement about the relative importance of one attribute over the other. Each respondent completed one attribute paired comparison survey for each consensus level criterion.

Prioritization Matrices and Scoring Model. Following completion of the paired comparison surveys, the researcher coded the surveys into separate ASCII text files (Appendix D and E). The data files, one for each respondent group, were then read into a microcomputer spreadsheet which calculated the prioritization matrices.

From these matrices, the spreadsheet scoring model then calculated a rank order scoring model by individually weighting each attribute by the consensus level performance measurement criteria. This scoring model provided the final scores of the system design attributes (Table 22) for statistical and qualitative analysis. This procedure has been fully explained in Chapter III.

Table 22

Weighted Scores of System Design Attributes

	ATTRIBUTE	TRANS	ORD
1.	Provide HazMat Containment Training	69	71
2.	Provide HazMat Contingency Equipment	56	63
3.	No Increase in Manpower	0	0
4.	Design Flat Racks for Multipurpose Use	2	30
5.	High Reliability and Maintainability	100	100
6.	Use Current Handling and Transport Equipment	54	27
7.	Compatible between Modes of Transport	85	47
8.	Compatible with Allied Equipment	45	25
9.	Capable of Automated and Manual Handling	45	42
10.	Quick Transfer Speed at ASP and ATP	62	81

Qualitative Assessment Survey

Once the criteria had been weighted and the attributes rank ordered, a small group of senior Army transportation officers were asked to complete qualitative assessments of the three logistics concepts based on each surface transportation system design attribute (Appendix C). This group was then asked to complete a simple Decision Matrix Survey (Appendix C, Attachment 4) to compare their qualitative and quantitative judgements.

The purpose of the qualitative assessments and the decision matrix was to evaluate the relative strengths and weaknesses of the three proposed logistics concepts (discrete, bulk, and combination). The senior respondents included the Commander, 8th Transportation Brigade (Training); the Deputy Commander, 7th Transportation Group (Terminal); Commander, 71st Transportation Battalion (Training), and the Commander, Sunny Point Ammunition Port. Their biographical sketches are included in Appendix A.

Table 23

Attribute Rank Order by Logistics Branch

	ATTRIBUTE	TRANS	ORD
1.	High Reliability and Maintainability	100	100
2.	Compatible between Modes of Transport	85	47
3.	Provide HazMat Containment Training	69	71
4.	Quick Transfer Speed at ASP and ATP	62	81
5.	Provide HazMat Contingency Equipment	56	63
6.	Use Current Handling/Transport Equip	54	27
7.	Capable of Automated/Manual Handling	45	42
8.	Compatible with Allied Equipment	45	25
9.	Design Flat Racks for Multipurpose Use	2	30
10.	No Increase in Manpower	0	0

Data Analysis

The relative rank-order scores (Table 23) of the two populations were examined to evaluate the validity and consistency of the surface transportation performance evaluation model and the resulting criteria and system design attributes. The population scores were evaluated for visual linearity, equivalency of probability distributions, and strength of population correlation.

Data Populations. As described in Chapter III, nonparametric tests were used to compare the probability distributions of the sampled populations and the strength of the linear relationship between the two distributions. The data test involved four steps. First, the rank order data sets were visually examined with Rankit Plots to determine whether the variables conformed to a normal distribution. Second, the Wilcoxon Rank Sum **T** Test for Independent Samples was computed to examine if the two sampled populations have identical probability distributions. Third, Spearman's Rank Coefficient Correlation r_s Test was performed, noting the Chi-squared approximation, to examine if there was a population correlation between the two ranks. Finally, the test results are evaluated and the decision is made whether to reject the null hypothesis.

Rankit Plot. Statistix produces a Rankit Plot of the variable and calculates an approximation of the Wilk-Shapiro normality statistic. The Rankit Plot for the Army transportation group is shown in Figure 22, and the plot for the Army Munitions group in Figure 23. Except for random variation, if the data conforms to a normal distribution, the plot of the rankits against the data sample, reordered

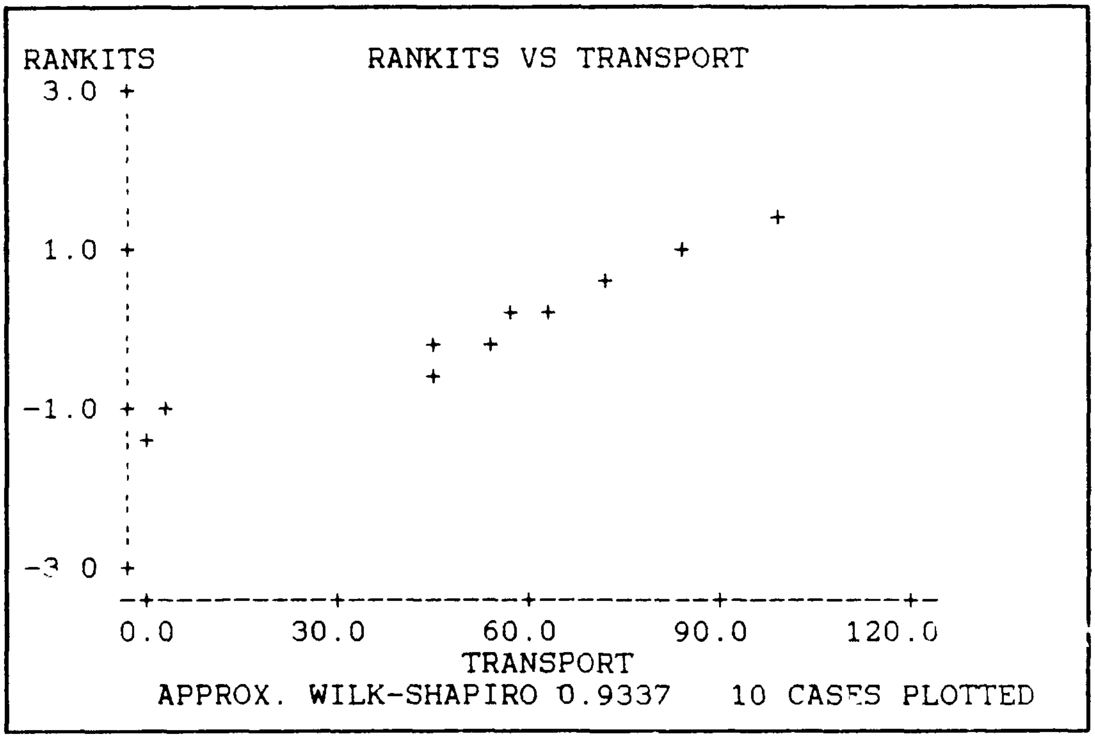

Figure 22. Rankits versus Transportation Group Rankings

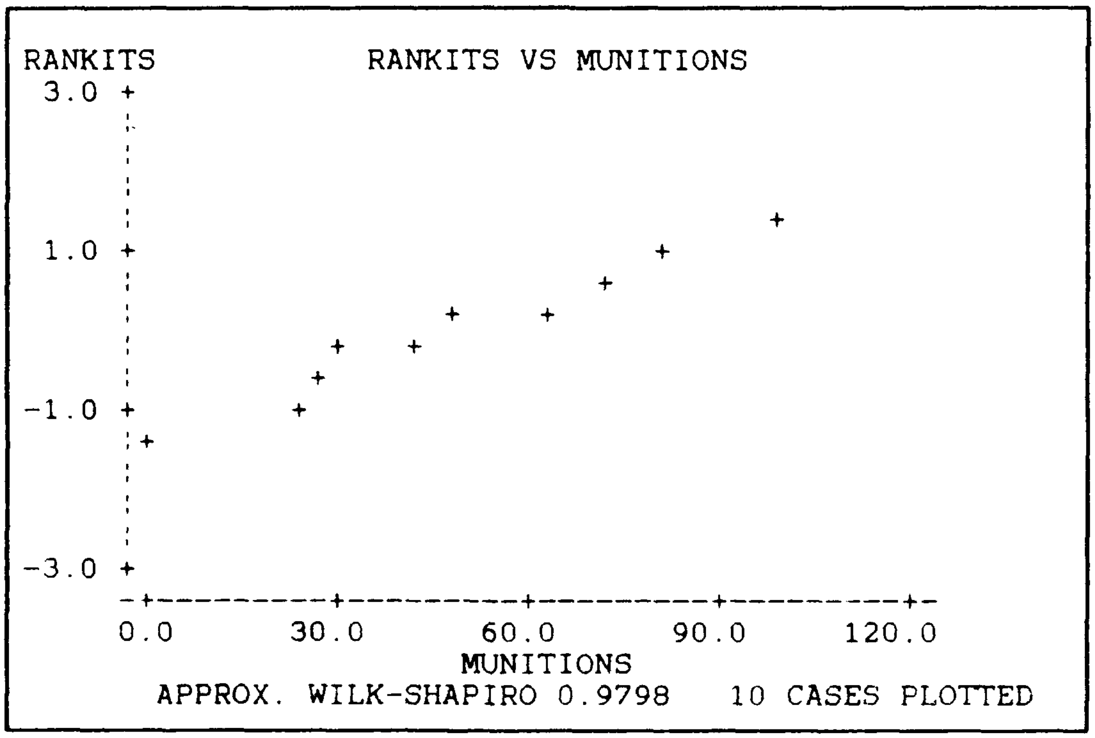

Figure 23. Rankits versus Munitions Group Ranking

by rank, should produce a straight line. As illustrated, the general shape of each curve is linear and the Wilk-Shapiro approximation is very high in both plots. These results combine to indicate a normal distribution.

Wilcoxon Rank Sum Test. The nonparametric Wilcoxon Rank Sum Test for Independent Samples (Figure 24) was computed to examine if the two sampled populations have identical probability distributions based its comparison on the rank sums (totals of the ranks). It evaluates whether the system design attribute means were drawn from identical distributions.

WILCOXON RANK SUM TWO SAMPLE (MANN-WHITNEY) TEST FOR
SCORE = CORPS

CORPS	RANK SUM	SAMPLE SIZE	U STAT	AVERAGE RANK
1	110.0	10	55.00	11.0
2	100.0	10	45.00	10.0
TOTAL	210.0	20		

EXACT PROBABILITY OF A RESULT AS OR MORE EXTREME
THAN THE OBSERVED RANKS (1 TAILED P VALUE) 0.8295

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION 0.340
TWO TAILED P VALUE FOR NORMAL APPROXIMATION 0.7337

TOTAL NUMBER OF VALUES WHICH WERE TIED 6
MAX. DIFF. ALLOWED BETWEEN TIES 1.0E-0005

CASES INCLUDED 20 MISSING CASES 0

Figure 24. Wilcoxon Rank Sum Two Sample Test

Chapter III illustrated the null and alternative hypotheses, and the decision null for rejecting or failing to reject the null hypothesis. The observed level of significance (alpha) and decision rule whether to reject or fail to reject the null hypothesis is:

Reject H_o if $p < $ alpha of 0.05

An observed significance level of 0.05 indicates the Type I error that the researcher is willing to accept. This implies the acceptance of a one in twenty chance of incorrectly saying the populations have identical probability distributions when in fact they differ Since the p-value equals 0.3400 (Figure 24) and is greater than 0.05, we fail to reject the null hypothesis. These results are confirmed by noting that the two population Rank Sums (110.0 and 100.0) (Figure 6) both fall within the upper and lower critical values (T_L = 79 and T_U = 131) of Table XI, Statistics for Business and Economics (1988). Therefore, there is insufficient evidence to indicate the probability distributions differ.

Spearman's Rank Coefficient Correlation. Spearman's rank coefficient correlation r_s is computed as a nonparametric measure of the strength of the linear relationship between two variables. The correlation coefficient is essentially a measure of the degree to which individual differences in the sample items vary together. A value of r_s near or at 0 indicates little or no linear relationship between the sample variables; a value near +1 and -1 implies a strong relationship. The r_s value of

0.8389 in Figure 25 indicates a strong positive correlation between the two population rankings.

SPEARMANS RANK CORRELATIONS, CORRECTED FOR TIES

	MUNITIONS	TRANSPORT
MUNITIONS	1.0000	
TRANSPORT	0.8389	1.0000

MAXIMUM DIFFERENCE ALLOWED BETWEEN TIES 1.0E-0005

CASES INCLUDED 10 MISSING CASES 0

Figure 25. Spearman Rank Correlation Coefficient

Chapter III illustrated the null and alternative hypotheses, and the decision for rejecting or failing to reject the null hypothesis. With p_s defined as the population Spearman rank correlation coefficient, the decision rule to reject the null hypothesis is:

H_0: The $p_s = 0$ (no population correlation between ranks)

Since the r_s-value equals 0.8389 (Figure 7), we reject the null hypothesis and conclude that the population rank correlation coefficient, p_s, differs from 0. These results is confirmed by noting that the r_s (Figure 25) exceeds the critical value of 0.564 of Table XVI, Statistics for Business and Economics (1988). Thus, there is sufficient evidence to indicate the probability distributions are strongly correlated. This test result also indicates the degree of rank order consistency between the two sample groups (Moore and Baker, 1969:B-218).

Again, as stated in Chapter III, a caution should be noted that high correlation does not presuppose causality. "The only safe conclusion when a high correlation is observed in the sample data is that a linear trend may exist between x and y" (McClave and Benson, 1988:515-516).

The Null Hypothesis. Using an observed significance level (test statistic) of 0.05, the Wilcoxon Rank Sum Test **p**-value of 0.3400 strongly indicates that the mean ranks for the groups are similar enough to conclude that the rankings are similar. We therefore fail to reject this test's null hypothesis that the **p** probability distributions are identical.

The Spearman's rank correlation coefficient r_s value of 0.8389 makes a strong argument for rejecting that test's null hypothesis that p_s equals 0. We conclude that the population rank correlation coefficient p_s differs from 0. There is a strong evidence of positive correlation between the ranks.

These results confirm that both population sample distributions are from the same population. Inferences can be made with consistency and confidence about the surface transportation system design attributes in analyzing the three liquid propellant logistics concepts.

Summary

This chapter described the results of the paired comparison survey, the scoring model, and the decision matrix. The paired comparison survey provided a qualitative assessment of surface transportation performance measurement criteria and system design attributes from twenty-four expert logisticians from the transportation and munitions corps. The scoring model rank ordered the attributes based on weighted consensus-level criteria.

Statistical analysis revealed very strong positive correlation between the two corps' rankings. High correlation indicates strong consistency of the results. The tests further showed that the two rankings have identical probability distributions. From these results, it can be inferred that the two sample respondent groups belong to the same population. Finally, the decision matrix provided a qualitative assessment of the relative ranking of the three logistics concepts. Chapter V summarized the qualitative and quantitative findings of the research questions and Chapter VI presents recommendations for further research.

V. Findings

Overview

A subjective research approach, using nominal group and paired comparison techniques, provided a means of constructing a descriptive surface transportation performance evaluation model by surveying knowledgeable logistics experts. This methodology achieved a qualitative level of consensus for surface transportation performance measurement criteria and system design attributes for analysis of proposed liquid propellant logistics concepts.

The validity of the descriptive model was assured by participation of selected logistics experts using the nominal group interaction process with immediate feedback. Selection of the sample respondent groups by the respective Directors, Directorates of Combat Developments, in accordance with pre-established criteria, substantiated the level of expertise possessed by the survey participants.

Statistical Findings

This methodology was administered to sample groups from the Transportation and Ordnance (Munitions) Corps. A level of rank-order consensus was achieved on performance measurement criteria and system design attributes for analysis of proposed liquid propellant logistics concepts. Data analysis, performed in Chapter IV, established sufficient statistical evidence that the system design attribute rank-order results from the two samples have identical probability distributions and high positive correlation (consistency). Thus it can be concluded that performance criteria and system design attributes (standards of measurement) have value in analyzing the performance of the proposed liquid propellant logistics concepts. The combination of nominal-interacting group processes and the paired comparison technique provided a valid methodology for assessing the qualitative (noneconomic) characteristics of a logistics distribution concept.

The final step in assessing the strengths and weaknesses of the proposed liquid propellant logistics concepts involved case study analyses by four senior Army transportation officers. The officers were asked to complete, based upon the ten rank-ordered system design attributes, a case study analysis and a decision matrix of the three proposed logistics concepts for the distribution of liquid propellant. These results provided the necessary data to answer investigative question five as proposed in Chapter I.

Research Findings

The research goal of Chapter I was to perform a comprehensive analysis to identify the performance measurement criteria and design attributes of an Army surface transportation system necessary to support the distribution of liquid propellant in Field Artillery applications. This analysis required a review of transportation capability and capability measurement, hazard classification procedures, feasible packaging and fielding concepts, and current distribution procedures to answer the final research question.

Investigative Question One.

> What is transportation capability? What are the principles involved in measuring transportation capability?

Capability is a level of service required to meet a volume of demand. This capacity is the maximum volume of product which can be moved per unit of time between two points by a given combination of modal assets and network facilities. The specific characteristics of a transportation system include internal asset capacity, speed, accessibility, flexibility, frequency, and external route capacity. The user views level of service as the most important system characteristic, while assets required and resources consumed are the most important aspects to the operator.

Transportation mode selection is influenced by technology, assets, network characteristics, and organizational policies. Operator and user decision variables affect mode selection within the transportation system. The user specifies the required volume, delivery time/date, and destination based on actual and forecasted use, while the transportation operator makes decisions on mode selection, routes, schedules, quantity of assets employed, and physical facilities used to achieve a desired level of user support. The development and procurement of new transportation technologies enables demand to be satisfied at lower costs, increased volume, and higher levels of user support.

The principles involved in measuring system capability focus upon analysis of the relationships between the transportation subsystems. Subsystem relationships must be quantified and evaluated by minimizing cost to achieve maximum capacity for a given level of resources. Analysis of subsystem relationships for measuring transportation capacity are dependent upon the physical properties of the commodity. These characteristics determine the packaging, handling, transportation, and storage requirements of the product.

Investigative Question Two.

What are the Departments of Transportation and Defense classification procedures for newly developed hazardous products?

The two liquid propellants under development by the Army have been assigned an Department of Transportation (DOT) interim hazard classification of 1.3 Class B Explosive for laboratory analysis. Figures 5, 6, and 7 accurately represent the hazard classification procedures of liquid propellant for full-scale production and fielding. The physical properties of LP 1845 and LP 1846 have not been fully determined, and classification testing is in progress. Preliminary findings of these tests indicate that DOT Class C designation, with resulting storage and transportation quantity/distance advantages, is a possibility.

Laboratory test results reveal neither a detonation (detonation, thermal stability, and card gap tests) nor ignition/burning (ignition/unconfined burning and impact sensitivity tests) reaction for either propellant. Supplemental test results also indicate no reaction (adiabatic compression, flash point, vapor phase minimum pressure, and electrostatics tests) for either propellant. Critical diameter reaction was recorded at 4-inches (LP 1845) and 5-inches (LP 1846).

Investigative Question Three.

> What are the proposed liquid propellant packaging requirements and logistics fielding concepts, based on the inherent characteristics and applicable hazard classification?

Packaging. Design of a liquid propellant container can not be determined until final hazard classification testing has been completed. It is anticipated that final classification will allow shipment in accordance with Specification 34 (178.19) of BOE-6000-F (Bureau of Explosives), Hazardous Materials Regulations of the Department of Transportation (DOT).

Appropriate testing of the LP shipping container design will be conducted for verification of capability to meet DOT Specification 34 or as determined by the hazardous classification tests. In addition, a proposed verification test program, listed in Tables 13 and 14, will be conducted to determine container utilization capability under field conditions.

Logistics Concepts. Three liquid propellant logistics concepts have been proposed as potential candidates for liquid propellant technology. Each concept was designed to be compatible with development of both the Maneuver Oriented Ammunition Distribution System (MOADS) and the Palletized Loading System. These three concepts are:

Discrete. Liquid propellant (LP) is packaged at the load, assembly and pack (LAP) facility in 30-50 gallon sealed plastic containers. Individual containers are palletized on existing standard size pallets and shipped in break-bulk containers. These palletized containers are transferred throughout the logistics pipeline to the user's battalion reload/rearm point (BARP). At the BARP, the pallets are broken down and individual propellant containers are transferred to the rearm vehicle. The liquid propellant is pumped from the rearm vehicle directly into the self-propelled howitzer's (SPH) LP reservoirs.

This concept continues to use existing logistics chain (solid propellant) transportation and transfer equipment, except for the inclusion of a winch or lifting equipment to upload containers into the rearm vehicles. The 30 and 50 gallon containers are not man-portable but are easily palletized on existing pallets and could be handled and stored in the resupply vehicle in an efficient manner.

Bulk. Liquid propellant is packaged at the LAP facility into 1,800-gallon stainless steel tanks which are either trailer-mounted or are on integrated skids/pallets for vehicle transfer. The propellant tanks are transferred to the BARP and pumped into the storage containers on the rearm vehicle. The LP is pumped from the rearm vehicle directly into the SPH's LP reservoirs.

The transporting and transfer of the 1800 gallon tanks is handled in a manner similar to bulk petroleum products. The total weight for one 1,800 tank is 10-11 ST (12.5 pounds per gallon). Four of these size containers would supply one day's battalion requirement at 300 rounds per day per gun.

Combination. Liquid Propellant is packaged at the LAP facility into bulk 1,800 gallon stainless tanks, which are trailer-or skid mounted and transferred as far forward as possible. The propellant is then down-loaded at this forward location by pumping into discrete containers (30-50 gallons or 150 gallons). The discrete containers are then uploaded into the rearm vehicle at the BARP, and finally pumped from the discrete containers into the SPH's reservoirs. This logistics concept uses bulk petroleum type transfer from the wholesale (LAP facility) to the retail supply location.

Investigative Question Four.

> How have other organizations planned for the transport of liquid propellants and other products of similar commodity characteristics?

Joint Army, Navy, NASA, Air Force (JANNAF) Propulsion Committee documents revealed Otto Fuel II, a liquid torpedo propellant used by the Navy, as the most likely candidate for examining the handling, storage, and transportation of

HAN-based propellants. Otto Fuel II is a nitrogen-based, Class B Explosive propellant with commodity characteristics similar to LP 1845 and LP 1846.

Otto Fuel II is a stable, noncorrosive liquid monopropellant composed of nitrate ester in solution with a desensitizing agent and a stabilizer. The propellant has an extremely low vapor pressure which minimizes the hazards usually associated with other monopropellants. Chapter II presents a summary of Otto Fuel II's physical characteristics, environmental and personnel safety considerations, transfer operation procedures, packaging and transportation requirements, and disposal guidelines.

Investigative Question Five.

> What are the relative strengths and weaknesses of the proposed logistics fielding concepts for liquid propellant in Field Artillery applications? What are the relevant surface transportation performance measurement criteria for evaluating logistics fielding concepts? What are the relevant system design attributes which must be considered for inclusion into the final selection of a liquid propellant logistics fielding concept?

This section will address the criteria and attribute paired comparison surveys and logistics concept analyses by senior Army transportation managers.

Survey Findings. The criteria paired comparison survey involved an analysis of surface transportation performance measurement criteria. This survey provided rank-order feedback on the relative importance of the six criteria for evaluating a proposed logistics concept.

Each group ranked High Reliability and Maintainability as the most important performance criteria (Figure 1 and 2). Two criteria, No Customized Technology (0.0687) and Low Cost to Implement (0.0910), failed to meet the minimum weighted score of 10 percent. These were eliminated from subsequent stages of the model.

An interesting intermediate finding was that the criteria rank-ordered as two and three, Increase Operational Capability of Logistics and Increase Tactical Capability of Users, were selected in reverse order by the two groups. The munitions group ranked Increase Tactical Capability of Users second, while transportation group ranked Increase Operational Capability of Logistics second. The ordering of the criteria may be due to the fact that munitions personnel, as the final link in the ammunition logistics chain, are in direct contact with the tactical user, while transportation personnel are "up-stream" in the logistics pipeline, and thus insulated to some degree from the user.

Next, the attribute paired comparison survey involved an analysis of surface transportation system design attributes based on the consensus-significant performance criteria. This survey provided rank-order feedback on the relative importance of the ten attributes, individually weighted by the criteria, for evaluating a proposed logistics concept. Table 24 shows the weighted rank-order scores from the transportation respondent group, and Table 25 shows the scores from the ordnance group.

Table 24

Transportation Group Weighted Attribute Scores

1.	High Reliability and Maintainability	100
2.	Compatible between Modes of Transport	85
3.	Provide HazMat Containment Training	69
4.	Provide HazMat Contingency Equipment	56
5.	Quick Transfer Speed at ASP and ATP	62
6.	Use Current Handling and Transport Equipment	54
7.	Compatible with Allied Equipment	45
8.	Capable of Automated and Manual Handling	45
9.	Design Flat Racks for Multipurpose Use	2
10.	No Increase in Manpower	0

Table 25

Ordnance Group Weighted Attribute Scores

1.	High Reliability and Maintainability	100
2 .	Quick Transfer Speed at ASP and ATP	81
3.	Provide HazMat Containment Training	71
4.	Provide HazMat Contingency Equipment	63
5.	Capable of Automated and Manual Handling	42
6.	Compatible between Modes of Transport	47
7.	Design Flat Racks for Multipurpose Use	30
8.	Use Current Handling and Transport Equipment	27
9.	Compatible with Allied Equipment	25
10	No Increase in Manpower	0

Both respondent groups ranked "High Reliability and Maintainability" as the most important attribute. This is a design and manufacturing concept of fielding logistics equipment that will require less maintenance and is easily repaired when it does break. Reliability reduces dependence on spare parts and increases the capability and survivability of the logistics pipeline. Maintainability reduces dependence on personnel with highly specialized diagnostic skills.

On the opposite end of the spectrum, both groups ranked "No increase in Manpower" as the least important of the ten attributes. This last ranking, combined with the first ranking for high reliability and maintainability, calls into question the current policy of reducing logistics manpower wherever possible. There is a preoccupation with increasing the operational capability of the combat service support structure by advances in equipment technology while simultaneously reducing the manpower requirement. New systems such as the Palletized Load System vehicle/trailer are being designed for operation by only one driver. It is assumed that one operator will drive the vehicle for twenty hours a day and still be able to maintain, service, and repair the vehicle. We further assume that it will be easy to replace this highly skilled vehicle operator.

The transportation group understandably ranked "Compatible between Modes of Transport" as second most important, while the ordnance group ranked "Quick Transfer Speed at ASP and ATP as second. These two rankings reflect the unique aspects of each corps' daily mission. The transporter is aware of the intermodal nature that a logistics concept must adopt, while the ordnance person is aware of the need for increasing survivability and reducing target signature of the ammunition point in the combat zone.

Both groups surprisingly ranked "Provide Hazardous Material Containment Training" and Provide Hazardous Material Contingency Equipment" as number three and four respectively. This reflects a keen awareness for protection of personnel and the environment from the dangers of hazardous/explosive material. George Haddow (1987) argues that training of personnel is an important component of safe transportation of hazardous material. "It is ultimately the skills, knowledge, and, above all, the attitude of the men and women who operate the trucks and trains that plays the most significant safety role" (Haddow, 1987:315). The Office of Technology Assessment found that human error accounts for 62 percent of hazardous cargo accidents. A Federal Highway Administration report further concluded that 94.5 percent of preventable accidents were the result of driver failure (Haddow, 1987:315).

Logistics Concept Analyses. All three concepts appear to be very analogous to the transport of Class III (Petroleum Products) (Kubiszewski, 1991).

Discrete. Discrete distribution was judged very high in terms of reliability and maintainability of both the delivery vehicle and the product container. Commercially available drums are reliable, and the use of disposable drums would further enhance the concept by eliminating the requirement for retrograde operations (Featherston, 1991). Drums would allow more flexibility in the distribution and issue of liquid propellant (Chalkley, 1991). Discrete containers could be moved forward with ammunition and would require no additional breakdown at the ASP (Featherston, 1991).

Discrete would require no additional manpower. Drums could be handled like existing ammunition and only require "breakdown" (like other ammunition) for movement forward (Featherston, 1991; Chalkley, 1991). Discrete would allow numerous options in container design: weight; fit in rearm vehicles; capacity of the howitzer reservoirs; ability to resupply the weapon system directly from the drum when the threat allows; production lot control; etc. (Featherston, 1991; Kubiszewski, 1991; McWard; 1991).

There are inherent weaknesses in adopting the discrete concept. First is the environmental impact of empty drums. Drums tend to be scattered about, and could cause containment problems if there was a spill. It would be more difficult to demilitarize or dispose of thirty-six 50-gallon drums than one 1800-gallon tank. The discrete concept would also require more storage space than tankers (Featherston, 1991; Chalkley, 1991).

Bulk. The bulk concept also ranked high in reliability and maintainability. Commercially available tanks, like drums, are also very reliable (Featherston, 1991). Tank storage possesses the ability to store larger quantities of LP at one location. Again, it would be much easier to demilitarize one 1800-gallon or thirty-six 50-gallon drums (Featherston, 1991; Chalkley, 1991). Emergency equipment could be stored on the tank in some way, where it would not be feasible with pallets (Featherston, 1991).

Employing bulk packaging from the load and pack facility (LAP) to the battalion rearm point (BARP) would enhance the speed and survivability of resupply, thus reducing the enemy's ability to detect logistics nodes (McWard, 1991).

Experience drawn from several REFORGER exercises have proven that large quantities of Class III (Liquid Petroleum) can be moved forward to the user beyond the ATPs, thereby minimizing the deadtime due to transfer of fuel at various nodes (McWard, 1991). Experience shows that the less you handle the product, the less likelihood for spillage problems. Bulk distribution directly to the user would be easiest on the logistics pipeline because it requires less transfer and handling (Kubiszewski, 1991).

Manual handling, however, was a major deficiency of bulk transport. If bulk is used, someone would have to manually perform the transfer in the ASP (Featherston, 1991). It appears that a gas station type operation would be required in the ASP or BARP if 1800-gallon tanks are used. Current organizational structures would have to be adjusted to handle the distribution of the LP if dispersed from 1800-gallon tanks to users (Featherston, 1991).

It appears that the addition of a new component to existing rounds would increase manpower requirements to move the LP through the system. Ordnance companies do not have equipment to disperse the LP. Field Artillery units also would require additional transport to move LP in their area, or reduce the ammunition capability of their rearm vehicles (Chalkley, 1991). If tankers or trailer mounted tanks are used, the ASP would require "yard-dogs" inside the ASP to shuffle tankers, or increase the requirements for trailer transfer detachments (Featherston, 1991).

Equipment compatibility will have to be coordinated with the allies. Specific areas to examine for compatibility are: hose connections; drum size; rack size; pumps; etc (Featherston, 1991). All concepts would support flat racks as long as a "special" flat rack for LP is not developed. The containers should be developed to fit common flat racks for maximum use of space, but not restrict common use of flat racks (Featherston, 1991).

Combination. Advantages of the combination concept include allowing the flexibility to meet surge requirements with bulk and incremental demands with discrete (Featherston, 1991). Management of transport modes could also be improved by controlling the mix of assets dedicated to the transportation of liquid propellant and ammunition (Chalkley, 1991; McWard, 1991). Pumping would allow for quick transfer speed at the forward ammunition supply point (ASP) and reduce the requirement for retrograde of empty discrete containers (Chalkley, 1991).

The combination concept was, however, eliminated for obvious reasons by the majority of the respondents. First, the concept requires additional resources in both personnel and equipment (Featherston, 1991). Second, the concept presents a lucrative interdiction target to threat forces (this would render the entire weapon system ineffective, theater-wide), and the theater tactical commander should receive all sustainment supplies in an immediately useable form (McWard).

Summary

This chapter analyzed the findings of the investigative questions, statistical tests, paired comparison survey, scoring model, and logistics concepts case analyses. The findings of the investigative questions presented definitions for transportation capacity and capacity measurement; procedures for hazardous material classification and the results and implications of preliminary laboratory testing; three proposed liquid propellant logistics concepts; and the storage, handling, and transportation procedures for a similar commodity.

Once a preliminary understanding of the underlying background and constraints of liquid propellant distribution were examined, the paired comparison survey and scoring model established a rank-order of performance criteria weighted system design attributes for analysis of surface transportation logistics systems. Finally, the logistics concepts case analyses presented the strengths and weaknesses of the three proposed concepts, selecting discrete as the most feasible distribution concept.

VI. Conclusions and Recommendations

Overview

The changing world political situation, economic realities of a smaller military, and the acquisition of technologically advanced weapon systems are presenting unprecedented challenges in strategic defense planning. The fall of communism in the Soviet Union and the Warsaw Pact Alliance, bilateral reduction in military forces, and the development of increasingly lethal, mobile weapons systems, combined to present military planners with a level of uncertainty that significantly compounds the planning and problem solving process.

Continuous modernization remains one of the Army's six guiding imperatives. Modernization, discussed in Chapter I, is undertaken to enhance warfighting capability by providing the best equipment available. Military research and development programs, with their inherently high economic cost and high degree uncertainty, require a statistically reliable qualitative decision model that is able to capture noneconomic relationships to supplement cost-benefit models.

The Army's expanding emphasis on total quality management has resulted in efforts to involve the soldier in systems development. This thesis developed and implemented a formal surface transportation performance measurement model. The circumstances leading to model construction included the uncertainty surrounding the introduction of liquid propellant in the Army inventory, development of the next generation Self-Propelled Howitzer, and the obvious need to capture years of training and experience from expert logisticians.

The performance measurement model was developed using nominal-interacting processes to develop performance criteria and system design attributes, paired comparison surveys to weight the criteria and prioritize the attributes, a scoring model to rank-order the attributes based on all consensus-significant criteria, and case analyses of the candidate logistics concepts based upon the rank-order system design attributes. Results of the case analyses identified strengths and weakness of each concept and a recommendation for selection of one potential system for further development.

Research Limitations

The original research charter was given by the Directorate of Combat Developments, U.S. Army Transportation Center. This charter expressed the requirement to examine developments in liquid propellant technology and to make doctrinal and procedural recommendations for surface transportation of the product within the theater of operations.

It was not possible to completely fulfill this charter. Product packaging design and selection depend on the Departments of Transportation and Defense classification of the product. Further, transportation, storage, handling, and procedures ultimately depend on the packaging concept. The physical and hazard characteristics of liquid propellant have not been determined, although prototype and full-scale testing is in progress. Therefore, the original charter could not be realized until product testing and classification are completed and product packaging has been selected.

Research Conclusions

This purpose of the research was modified to provide a descriptive framework for systematically identifying surface transportation performance criteria and standards for measuring performance.

1. First, the logistics performance criteria established by the Jet Propulsion Laboratory were verified by two sample groups of Army logistics experts. A high level of group consensus was attained through systematic use of a rigorous paired comparison survey. These criteria further quantitatively validated the Army's qualitative commitment to ensuring environmental and personnel safety, co-developing the operational capability of logistics with the tactical capability of combat forces, and reducing the logistics burden in support of highly mobile forces.

2. Second, surface transportation system design attributes were established by the transportation sample group and verified by the ordnance sample group. A high level of group consensus was attained through systematic use of nominal interacting group processes and repetitive use of

rigorous paired comparison surveys. These standards, used to evaluate transportation performance, correlated with the Army's qualitative doctrine for logistics system design and employment. The imperatives of AirLand Battle Future doctrine specifically emphasize a highly flexible, responsive logistics force to sustain the mobile warfighting capability of the tactical commander.

3. Third, the system design attributes were rank ordered by magnitude. This final score quantified the qualitative standards by which to measure potential and fielded logistics concept performance. This was accomplished through the use of a rigorous scoring model which compared each attribute base on all weighted criteria.

4. Fourth, a high level of organizational consensus was achieved in establishing the performance criteria and system design attributes. As previously stated, the model was implemented using two sample groups, one Transportation and one Ordnance (Munitions), of knowledgeable subject matter experts. Subsequent statistical testing revealed high correlation (consistency) and identical probability distributions for the two sample groups. These findings indicated sufficient evidence for having achieved a high level of organizational consensus for surface transportation performance measurement criteria and system design attributes for analysis of proposed and fielded liquid propellant logistics concepts.

5. Fifth, both respondent groups ranked "High Reliability and Maintainability" as the most important attribute, and "No increase in Manpower" as the least important of the ten attributes. This finding indicates a need to reevaluate the doctrine of increasing operational capability of logistics by increasing the size and technology of equipment while simultaneously reducing the manpower requirement. New systems such as the Palletized Load System (PLS) vehicle/trailer are being developed for operation by only one driver. It is assumed that 1) one operator can drive the vehicle for twenty hours a day and still be able to maintain, service, and repair the vehicle; and, 2) this highly skilled "Super Driver" can be easily replaced.

6. Sixth, high rankings for "Provide Hazardous Material Containment Training" and "Contingency Equipment," along with historical information on hazardous material traffic accidents, indicate a strong concern for ensuring adequate skills, knowledge, and above all, the attitude of the soldiers who operate the modes of transportation.

7. Seventh, a high ranking for "Compatible between Modes of Transport" parallels the commercial growth in intermodal transportation. The emergence of intermodal distribution recognizes the importance of achieving an optimal mix of available transportation modes to attain maximum flexibility at least total cost.

8. Eighth, discrete distribution was selected as the most feasible logistics concept. Four senior Army transportation managers assessed three proposed liquid propellant logistics concepts (discrete, bulk, and combination) using the system design attribute rankings. Major strengths identified included very high reliability and maintainability of both equipment and product packaging, flexibility and speed, lot control, and compatibility with existing concepts. A major weakness of discrete distribution was the retrograde of empty drums; however, the use of disposable drums could eliminate this weakness.

<u>Recommendations for Further Research</u>

During the application of this research project, several recommendations for policy-makers and further research were identified.

1. Future research based on the descriptive model developed in this thesis should include validation of the surface transportation performance measurement criteria and system design attributes. The criteria used in this research were incorporated from a previous study to ensure some degree of comparability. The system design attributes, as developed, were scaled down to a list of only ten to alleviate the size constraint of the paired comparison instrument.

2. Future research should be conducted to investigate the performance measurement criteria and system design attributes for each mode of surface transportation. This

research presented a general descriptive model of surface transportation. Future research should individually investigate highway, rail, marine terminal, and watercraft modes of transportation. The limited, although general, treatment of strategic transportation planning was a function of the inherent time and resource constraints of the thesis effort.

3. Resident and nonresident courses of transportation instruction should include periods of instruction on the transportation performance criteria standards for measurement (attributes) to broaden the students analytical knowledge and to ensure a common understanding of the terminology and concepts.

4. Selected resident courses of transportation instruction should include a period of instruction in which feedback, in the form of performance criteria and standards of measurement as presented in this research, is solicited from the students. This process would provide departments responsible for developing transportation doctrine, equipment, and organizations with continuous group-consensus feedback from field operators.

5. Strategic transportation managers and planners at the U.S. Army Transportation Center should consider employing the methodology and findings of this research. The methodology was designed for use by middle and upper management as a problem solving decision aid. The techniques are simple and easy to implement and understand.

A technique for classroom implementation of this research methodology has been formulated by Dr. Thomas C. Harrington, Judgement and Screening Models in Logistics: from the Classroom to the Boardroom (1991), Department of Information Systems and Decision Sciences, University of Florida at Fort Myers, Florida 33919 (813-432-5520).

Summary

The purpose of this research effort was to develop a qualitative surface transportation performance evaluation model for assessing proposed liquid propellant logistics concepts. Strategic logistics decisions usually transcend organizational boundaries and contain a high degree of uncertainty. Research evidence indicates that managers often rely on judgement models such as various screening techniques and decision matrices.

Through the use of a nominal interacting group process, paired comparison surveys, and scoring model, group consensus was quickly attained. Criteria weighted system design attributes were then ranked in order of magnitude. These attributes were finally used to assess three proposed logistics concepts. The methodology described in this thesis has great potential for assessing the noneconomic characteristic of a proposed or fielded logistics concept. Subjective approaches to management and problem solving processes should be used as a supplement to cost-benefit models to provide a complete analysis of logistics decisions.

Appendix A: Respondent Selection. Field Surveys

Cover Letter, Transportation Corps

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OH 45433-6583

Director, (Colonel Toney)
Directorate of Combat Developments
U.S. Army Trasnportation Center and School
Fort Eustis VA 23604

Dear Colonel Toney

At the School of Systems and Logistics, graduate students apply their conceptual academic knowledge to "real world" problems. Our thesis program ensures students effectively apply and execute acceptable research methodologies in a Department of Defense setting. With assistance of organizations like yours, students have had great success in providing their sponsors with useful research findings.

Request assistance in the thesis effort of Capt John S. Lenart, Jr., a graduate student working on his Master of Science degree in Transportation Management. His unclassified research examines surface transportation performance measures and system design attributes for liquid propellant technology in Field Artillery application. To conduct his research, Capt Lenart requires the participation of twelve officers, selected by your office as knowledgeable experts in the field of surface transportation management, to complete a paired comparison survey.

Capt Lenart has coordinated his specific survey and data requirements with MAJ Larrabee. For further information on this thesis effort, please have your staff contact Capt Lenart at AUTOVON 785-8989, or write to AFIT/LSM, Wright-Patterson AFB, OH 45433-6583, ATTN: Capt John S. Lenart, Jr. I appreciate your cooperation in this matter.

PHILLIP E. MILLER, Lt Col, USAF
Head, Dept of Log Mgt
School of Systems and Logistics

STRENGTH THROUGH KNOWLEDGE

Respondent Selection Letter, Transportation Corps

DEPARTMENT OF THE ARMY
U. S. ARMY TRANSPORTATION SCHOOL
FORT EUSTIS, VIRGINIA 23604-5399

REPLY TO
ATTENTION OF

Combat Developments Directorate

Captain John S. Lenart, Jr.
AFIT/LSM
Wright Patterson Air Force Base, Ohio 45433-6583

Dear Captain Lenart:

I have received your request for thesis research assistance. You requested that my office identify twelve knowledgeable experts in the field of surface transportation management to complete in a paired comparison questionnaire. My office will support your research survey effort in any way possible.

I have identified the following twelve managers, in accordance with your selection criteria, as recognized knowledgeable experts in the field of surface transportation management. These managers were selected from within the Directorate of Combat Developments and the Professional Developments Division, U.S. Army Transportation Center and School, and the 7th Transportation Group, U.S. Army Forces Command:

NAME	RANK	AUTOVON
BENFER, Dennis E.	LTC	927-6005
BISHOP, Floyd C., Jr.	DAC	927-6906
BREWSTER, Charles S.	CW4	927-5453
D'ATELLO, James V.	CPT	927-6163
EDSEL, Andreas	CPT	927-5323
ELMORE, Richard M.	CW4	927-5523
GENTRY, Thomas E.	CW4	927-4622
LARRABEE, Scott	MAJ(P)	927-6730
MCGEE, James T.	DAC	927-6958
WAGNER, Stanley	MAJ	927-6075
WATERS, Brian F.	CPT	927-3878
WEHRLI, Frederich N.	CPT	927-6700

I have appointed Captain Colon, AUTOVON 927-6967, as my action officer to assist you in further coordination efforts. Captain Colon will coordinate the time and place for you to conduct your survey, and ensure the above personnel are available to participate. Good luck on your masters program and thesis.

Sincerely,

for: Elijah Toney
Colonel, U.S. Army
Director of Combat Developments

Cover Letter, Ordnance (Munitions) Corps

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OH 45433-6583

Director, (Colonel Raymont)
Directorate of Combat Developments
U.S. Army Munitions Center and School
Redstone Arsenal AL 35897-6500

Dear Colonel Raymont

At the School of Systems and Logistics, graduate students apply their conceptual academic knowledge to "real world" problems. Our thesis program ensures students effectively apply and execute acceptable research methodologies in a Department of Defense setting. With assistance of organizations like yours, students have had great success in providing their sponsors with useful research findings.

Request assistance in the thesis effort of Capt John S. Lenart, Jr., a graduate student working on his Master of Science degree in Transportation Management. His unclassified research examines surface transportation performance measures and system design attributes for liquid propellant technology in Field Artillery application. To conduct his research, Capt Lenart requires the participation of twelve officers, selected by your office as knowledgeable experts in the field of munitions management, to complete a paired comparison survey.

Capt Lenart has coordinated his specific survey and data requirements with Mr. Dennis and Dr. Crooks. For further information on this thesis effort, please have your staff contact Capt Lenart at AUTOVON 785-8989, or write to AFIT/LSM, Wright-Patterson AFB, OH 45433-6583, ATTN: Capt John S. Lenart, Jr. I appreciate your cooperation in this matter.

PHILLIP E. MILLER, Lt Col, USAF
Head, Dept of Log Mgt
School of Systems and Logistics

STRENGTH THROUGH KNOWLEDGE

DEPARTMENT OF THE ARMY
U.S. ARMY ORDNANCE MISSILE AND MUNITIONS CENTER AND SCHOOL
REDSTONE ARSENAL, ALABAMA 35897-6000

REPLY TO
ATTENTION OF

Director, Combat Developments

Captain John S. Lenart, Jr.
Attention: AFIT/LSM
Wright-Patterson Air Force Base, Ohio 45433-6583

Captain Lenart:

I have received your request for thesis research assistance. You requested that my office identify twelve knowledgeable experts in the field of munitions management to complete a paired comparison questionnaire. My office will support your research survey effort in any way possible.

I have identified the following twelve managers, in accordance with your selection criteria, as recognized knowledgeable experts in the field of munitions management. These managers were selected from within the Directorate of Combat Developments and the Command and Staff Department, U.S. Army Ordnance Missile and Munitions Center and School.

NAME	RANK	DSN
Aguilera, Robert	CPT	788-9845
Barnes, Lowell	DAC	746-7995
Brady, Timothy W.	DAC	788-2867
Ford, Robert M.	DAC	788-9845
Francis, Linda	CPT	746-3817
Gates, Howard R.	DAC	788-2865
Goodman, Phillip J.	DAC	746-9846
Harrison, Rex A.	CPT	788-9855
McEnroe, Loughlin K., Jr.	SFC	788-9843
Randall, Richard R.	MAJ	788-2870
Rupp, David R.	MAJ	788-9855
Watkins, Raymond F.	DAC	788-2868

Dr. Crooks, DSN 746-2820, will serve as the U.S. Army Ordnance Missile and Munitions Center and School point of contact to assist you in further coordination efforts. He will coordinate the time and place for you to conduct your survey and will ensure the above personnel are available to participate. Good luck on you masters program and thesis.

Sincerely,

RICHARD J. RAYMONT
Colonel, Ordnance Corps
Director, Combat Developments

Copy Furnished:

Dr. Crooks, Command and Staff Department

Biographical Sketches

Biographical sketches were furnished by each survey respondent. Twenty-eight sketches are enclosed. Twenty-four sketches, twelve from each corps pertain to the paired comparison survey respondents, and four sketches pertain to the decision matrix survey respondents. The intent was to substantiate, through training and assignments, the credibility of these individuals as knowledgeable experts in the fields of transportation and munitions management. These persons were individually selected to participate in the survey by their respective branches. The selection process was thoroughly described in Chapter III, Methodology.

Transportation Corps Paired Comparison Survey Respondents.

Benfer, LTC Dennis E. Lieutenant Colonel Dennis E. Benfer is Chief, Professional Developments Division, U.S. Army Transportation Center and School, Fort Eustis, Virginia. He is the course manager for the Transportation Officer Basic and Advanced Courses, Pre-Command Courses, and six processional development courses. His division is responsible for developing and presenting programs of resident academic and professional instruction for highway, rail, and marine terminal transportation operations to selected military and civilian personnel of the Army, Department of Defense, foreign military, and other designated civilian personnel.

LTC Benfer received a commission through the Army Reserve Officer Training Corps and his Bachelor of Arts degree in History in 1972 from the Western Kentucky University, and received his Master of Arts in Education from the Western Kentucky University in 1973. His military education includes the Infantry Officer Basic Course and Transportation Officer and Advanced Course.

LTC Benfer's career spans over 18 years of active military service in highway and marine terminal management planning and operations. His key assignments include Infantry and Support Platoon Leader and Battalion Maintenance Officer. As Commander, 363rd Transportation

Company (Medium Truck), Fort Dix, New Jersey, his unit transported ammunition, supplies, and all other classes of supplies throughout the eastern United States. As the Director, Terminal Operations, Plans, and Security, Transportation Terminal Command Europe (TTCE), LTC Benfer was responsible for coordinating marine terminal operations throughout the European and Mediterranean theaters. His duties included coordinating ammunition vessel operations conducted at Nordenhau, Germany, Zeebrugge, Belgium, and Berry Wales. As Executive Officer, 6th Transportation Battalion (Truck), Fort Eustis, Virginia, he provided staff supervision and coordination of over 970 personnel and 500 major items of equipment. He deployed as the battalion's Task Force Commander for both Bright Star 90 (Egypt) and Ocean Venture 90 (Puerto Rico). His task force duties included coordinating and conducting local- and line-haul resupply to divisional units and operating the Arrival/Departure Airfield Control Groups.

Bishop, Floyd C., Jr. Floyd C. Bishop, Jr. is Chief, Rail Instruction Branch, Professional Developments Division, U.S. Army Transportation Center and School, Fort Eustis, Virginia. His branch is responsible for developing and presenting rail and traffic management academic and professional instruction for rail transportation operations. He is also responsible for writing Army rail operations doctrine within the Department of Defense.

Mr. Bishop received his Bachelor of Arts degree in Business and Transportation in 1971 from Jacksonville University. His career spans over 29 years in rail management planning and operations. He began his career with the Seaboard Coast Line in operations and accounting, progressing to assistant agent, yardmaster, auditor, and finally assistant director of accounting. In 1977 he accepted an appointment with the Interstate Commerce Commission as a Railroad Service Agent, and finally as Special Agent in charge of Rail Investigation. In 1982, he accepted his current position with the U.S. Army Transportation Center and School.

Brewster, CW4 Charles S. Chief Warrant Officer Charles S. Brewster is Systems Chief, Contractor Training Development, New Systems Training Office, Directorate of Combat Developments, U.S. Army Transportation Center and School, Fort Eustis, Virginia. He is responsible for coordinating Integrated Logistics Systems (ILS) development for Army watercraft with contractors.

CW4 Brewster received his Bachelor of Science degree in Nautical Science in 1967 from the California Maritime Academy, and received his Master of Arts in Business Management and Administration from Central Michigan University in 1983. His military education includes the Harbor Craft Deck Officer Course, both the Marine Warrant

Officer Basic and Senior Courses, and both the Transportation Officer Basic and Advanced Courses.

CW4 Brewster's career spans over 29 years in watercraft and marine terminal management planning and operations. He has sailed as an Ordinary Seaman, Able-Body Seaman, Third Mate, Second Mate, Second Assistant Engineer, and Master on board U.S. flag vessels ranging from 65-foot passenger/cargo ferry boats, ocean-going tow boats, break-bulk freighters, combination break-bulk/container vessels, containerships, and tankers.

In 1970, he received a Navy commission, serving in positions from Division Officer through Executive Officer, Surface Division 1-29 Division Officer, MSO 411, USS Exultant. In 1974, he accepted an appointment as a U.S. Army Warrant Officer. His key assignments include Vessel Master of both Landing Craft Utility and Large Tug Boats; Second Mate and then First Mate of the U.S. Army Vessel Page; First Mate of the U.S. Army Vessels McHenry and Betsy Ross; Acting Commander, 469th Transportation Detachment, U.S. Army Vessel Sutton; Marine Evaluator, U.S. Army Transportation Center and School; Harbormaster/Port Operations, Azores; Marine Instructor, U.S. Army Transportation Center and School; and U.S. Army Reserve Advisor.

<u>D'Attelo, CPT James V.</u> Captain James V. D'Attelo is a Doctrine Analyst, Directorate of Training and Doctrine, U.S. Army Transportation Center and School, Fort Eustis, Virginia. His duties include management and coordination of the development or revision of Army transportation doctrine.

CPT D'Attelo received a commission through the Army Reserve Officer Training Corps and his Bachelor of Science degree in Finance in 1980 from Providence College. His military education includes both the Transportation Officer Basic and Advanced courses, Combined Arms Services Staff School, Transportation Stowage and Hazardous Material Course, and the Officer Maintenance Course.

CPT D'Attelo's career spans over 10 years of active military service in highway and marine terminal management planning and operations. His key assignments include Platoon Leader, Terminal Service Company (Breakbulk), Terminal Operations Officer, Military Traffic Management Command, Livorno, Italy; Battalion S-4 Logistics Officer, 6th Transportation Battalion (Truck); Commander, E Company, 71st Transportation Battalion (AIT); and Transportation Advisor, Saudi Arabian National Guard, Operations Desert Shield/Storm.

<u>Edzel, CW4 Andreas</u> Chief Warrant Officer Andreas Edzel is a Senior Watercraft Instructor, Marine Rail Branch, Technical Training Division, Directorate of Instruction, U.S. Army Transportation Center and School, Fort Eustis, Virginia. His duties include Developing and presenting

programs of resident academic and professional instruction for navigation and seamanship, the Warrant Officer Entry Course, A-2 Certification Course (Army Unlimited Masters License), and the Senior Warrant Officer Course.

CW4 Edzel received his Associates degree in General Studies in 1976 from St Leo College. His military education includes both the Marine Warrant Officer Basic and Senior Courses, the Marine Warrant Officer Advanced Course, and the Warrant Officer Technical Certification Course (U.S. Coast Guard).

CW4 Edzel's career spans over 27 years in watercraft and marine terminal management planning and operations. His assignments key include Vessel Master of both Landing Craft Utility Large Tug Boats; Second Mate and then First Mate of Large Tug Boats; and First Mate and then Vessel Master of a Large Tug Boat, Azores.

Elmore, CW4 Richard M. Chief Warrant Officer Richard M. Elmore is the Commander, 335th Transportation Detachment, Logistics Support Vessel Besson, 10th Transportation Battalion (Terminal), Fort Eustis, Virginia. His duties include both Detachment Commander and Vessel Master. The detachment self-deployed to the Persian Gulf in support of Operation Desert Shield, providing inter- and intra-theater movement of ammunition and equipment.

CW4 Elmore received his Associates degree in General Studies in 1988 from St. Leo College. His military education includes both the Marine Warrant Officer Basic and Advanced Courses. CW4 Elmore's career spans over 15 years in watercraft and marine terminal management planning and operations. He began his career as an Ordinary Seaman on tug boats on Puget Sound and the west coast of the United States, accepted a Warrant Officer appointment with the Army National Guard in 1978, and then finally entered active duty. His key assignments include Vessel Master of both Landing Craft Utility and Large Tug Boats, Third Mate and then Second Mate of the U.S. Army Vessel Sutton, and First Mate of the U.S. Army Vessel Page.

Gentry, MW4 Thomas E. Master Warrant Officer Thomas E. Gentry is the Chief, Marine Safety Office, Office of the Chief of Transportation, U.S. Army Transportation Center and School. His duties include the Army's Marine Certification License Program Manager, Career Sea Pay Program Manager, and Marine Safety Program Manager.

MW4 Gentry received his Bachelor of Arts degree in 1981 from St. Leo College. His military education includes the Harbor Craft Deck Officer Course, both the Marine Warrant Officer Advanced and Senior Courses, and the Master Warrant Officer Course.

MW4 Gentry's career spans over 32 years in watercraft and marine terminal management planning and operations, with 15 years as a Vessel Master. His credentials include an

Unlimited Motor Vessels Upon Oceans License, Radar Observer Certification, and Harbor/Coastal Pilot Certification.

His key assignments include Vessel Master of both Landing Craft Utility and Large Tug Boats; Second Mate and then First Mate of the U.S. Army Vessel Page; Coastal Pilot, Vietnam; First Mate of the U.S. Army Vessels McHenry and Betsy Ross; Acting Commander, 469th Transportation Detachment, U.S. Army Vessel Sutton; Control Officer, Joint Logistics Over the Shore exercise; Marine Evaluator and Projects Officer, U.S. Army Transportation Center and School; Harbormaster and Port Operations Officer, Azores; Marine Instructor, U.S. Army Transportation Center and School; and U.S. Army Reserve Group Advisor.

<u>Larrabee, MAJ(P) Scott</u> Major(P) Larrabee is the Deputy, Concepts and Studies, Directorate of Combat Developments, U.S. Army Transportation Center and School, Fort Eustis, Virginia. His duties include supervising the development and design of future Army Theater Transportation Force Structure.

MAJ(P) Larrabee received a commission through the U.S. Army Military Academy at West Point in 1974, and received his Master of Science in Transportation Management from the Florida Institute of Technology in 1983. His military education includes the Infantry Officer Basic Course, Transportation Officer Advanced course, Logistics Executive Development Course, and Command and General Staff College.

MAJ(P) Larrabee's career spans over 17 years of active military service in highway and marine terminal management planning and operations. His key assignments include Infantry Platoon Leader; Battalion Adjutant and S-1 Officer; Battalion Maintenance Officer; Assistant Operations S-3 Officer, Division Support Command, 2nd Armored Division; Commander, 567th Transportation Company (Terminal Service), J-4 Transportation Officer, U.S. Forces Korea; Chief, Operations Center, Inland Traffic Division, Military Traffic Command Headquarters; Plans Officer, Assistant Chief of Staff, 2nd Corps Support Command; and Executive Officer, 229th Movement Control Center, 7th Corps.

<u>McGee, James T.</u> James T. McGee is a Transportation Management Officer, Transportation Analysis Branch, Transportation Engineering Activity, Military Traffic Management Command, Newport News, Virginia. His duties include developing and presenting rail and traffic management academic and professional instruction for rail transportation operations, Rail Instruction Branch, Professional Developments Division, U.S. Army Transportation Center and School, Fort Eustis, Virginia.

Mr. McGee received a commission through the Army Reserve Officer Training Corps and his Bachelor of Arts degree in History in 1971, a Master of Arts in History in 1973 and a Master of Science in Transportation Management from the Florida Institute of Technology. Mr. McGee holds a U.S. Army Reserve commission as a Major. His military education includes both the Transportation Officer Basic and Advanced Courses, Strategic Mobility Planning Course, and Command and General Staff College.

Mr. McGee's career spans over 20 years in highway and rail management planning and operations. He began his career as an Army Transportation Officer. His key military assignments include Platoon Leader of a light truck platoon; U.S. Army Reserve Training and Readiness Officer; Transportation Movements Officer, Karsruhe, Germany; Movements Officer, Bremerhaven, Germany; and Instructor, U.S. Army Transportation Center and School. In 1984, he accepted an appointment as a Trainmaster with Consolidated Rail Corporation. In 1986, he accepted his current position with the U.S. Army Transportation Center and School.

Wagner, MAJ Stan Major Wagner is the Transportation Plans and Operations Officer, Directorate of Combat Developments, U.S. Army Transportation Center and School, Fort Eustis, Virginia. His duties include project manager for the development and design of future Army Theater Transportation Force Structure.

MAJ Wagner received a commission through the Army Reserve Officer Training Corps and his Bachelor of Science degree in Education in 1978 from the Indiana University of Pennsylvania, and received his Master of Science in Transportation Management from the Florida Institute of Technology in 1990. His military education includes both the Transportation Officer Basic and Advanced Courses, Combined Arms Services Staff School, and Command and General Staff College.

MAJ Wagner's career spans over 15 years of active military service in highway and marine terminal management planning and operations. His key assignments include Platoon Leader of a light truck platoon; Commander, 365th Transportation Company (Light Truck); Movement Services Officer, NATO SHAPE Support Group; Logistics Officer, NATO Support Activity Brussels; Assistant Forward Area Support Coordination Officer; Commander, 594th Transportation Company (Medium Truck), 101st Airborne Division; Battalion Assistant Operations S-3 Officer; and Battalion S-4 Logistics Officer.

Waters, CPT Brian F. Captain Brian F. Waters a Combat Developer, Directorate of Combat Developments, U.S. Army Transportation Center and School, Fort Eustis, Virginia. His duties include developing the requirements and specifications for Army wheeled vehicles.

CPT Waters received a commission through the Army Reserve Officer Training Corps and his Bachelor of Arts degree in Political Science in 1981 from The Citadel. His military education includes the Transportation Officer Basic and Advanced courses, Combined Arms Services Staff School, and Strategic Mobility Planning Course.

CPT Waters career spans over 10 years of active military service in highway management planning and operations. His key assignments include Platoon Leader of a truck platoon, Battalion Maintenance Officer, Commander, 109th Transportation Company (Petroleum), Battalion Adjutant/S-1, Training with Industry, CSX Transportation (Rail Transport Group).

Wehrli, CPT Friedrich N. Captain Friedrich N. Wehrli is an Instructor/Writer, Tactical Transportation Branch, Department of Instruction, U.S. Army Transportation Center and School, Fort Eustis, Virginia. His duties include developing and presenting traffic management academic and professional instruction for both the Transportation Officer Basic and Advanced Courses.

CPT Wehrli received a commission through the Army Reserve Officer Training Corps and his Bachelor of Arts degree in Latin American Studies in 1982 from the University of Connecticut. His military education includes both the Transportation Officer Basic and Advanced courses and Combined Arms Services Staff School.

CPT Wehrli's career spans over 10 years of active military service in highway and marine terminal management planning and operations. His key assignments include Platoon Leader of a medium truck platoon; Commander, Headquarters Detachment, 106th Transportation Battalion (Truck), and Commander, 551st Transportation Company (Cargo Transfer).

Ordnance (Munitions) Corps Paired Comparison Survey Respondents.

Barnes, SGM(R) Lowell Mr. Barnes is an Instructor/Writer, Munitions Concepts and Studies Division, Command and Staff Department, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include developing and presenting munitions management academic and professional instruction for Officer and Noncommissioned Basic and Advanced Courses. He is responsible for writing Army munitions operations doctrine within the Department of Defense. He designed and implemented the Commander's Field Module for Munitions Officer Advanced Course, and has served as a Hazardous Devices Training Instructor.

Mr. Barnes received his Bachelor of Science degree in Business Administration in 1985 from Athens State College. His career spans over 35 years of ammunition management planning and operations. His key military assignments include three tours in Vietnam as an ammunition manager; several assignments in Explosive Ordnance Disposal; Chief Ammunition NCO, Headquarters, Korea Military Advisory Group; Sergeant Major, Assistant Chief of Staff, Ammunition, Headquarters, 19th Support Brigade, Korea; Sergeant Major, Directorate of Training, U.S. Army Missile and Munitions Center and School.

Brady, Timothy W. Mr. Brady is a Combat Developments Specialist, Munitions Branch, Concepts and Studies Division, Directorate of Combat Developments, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include planning, developing, and accomplishing conceptual studies for the development of Army logistics doctrine for conventional, chemical, and munitions items. He is the AirLand Battle (ALB) Concepts Officer, responsible for integrating all ammunition logistics elements into AirLand Battle operations. These elements include Combat Configured Loads (CCL), required and continuous ammunition resupply rates, materiel requirements, Force Structure, movements and all related Combat and Combat Support requirements.

Mr. Brady received a commission through the Army Reserve Officer Training Corps and his Bachelor of Arts degree in International Studies in 1974 from Widener University, and received his Master of Science in Contracting and Acquisition Management from the Florida Institute of Technology in 1987. He is a graduate of both the Ordnance Officer Basic and Advanced Courses, Service Ammunition Officer Course, and Conventional Ammunition Course.

Mr. Brady's career spans over 17 years of active military service in conventional and unconventional ammunition management planning and operations. His key assignments include Platoon Leader, U.S. Logistics Detachment, Turkey; Commander, Headquarters Company and then Ammunition Technical Officer, 6th Ordnance Battalion (Special Ammo); Chief, Chemical Munitions, Depot Property, Toole Army Depot; Deputy Commander, U.S. Army Ammunition Plan, Milan, Tennessee; and Munitions Instructor, Directorate of Professional Development, U.S. Army Munitions Center and School.

Ford, 1SG(R) Robert M. Mr. Barnes is Chief, Munitions Branch, Command and Staff Department, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include supervising the development and presentation of resident academic and professional instruction for ammunition to selected military and civilian personnel of the Army, Department of Defense, foreign military, and other designated civilian personnel. He directed the design and development of several ammunition training programs, including the Standard Army Ammunition System (SAAS) for automated accounting and the Ammunition Officer Branch Transfer Course.

Mr. Ford received his Bachelor of Arts in Sociology in 1974 from the State University of New York, and received his Master of Arts in Administrative Science from the University of Huntsville in 1980. His career spans over 29 years of ammunition management planning and operations. His key military assignments include three tours in Vietnam as an ammunition manager establishing forward Ammunition Supply Points (Direct Support); several assignments in Explosive Ordnance Disposal; Battalion Operations Sergeant; First Sergeant of a nuclear weapons ammunition company in Germany; Chief of Ammunition, Panama; and bilingual Instructor for ammunition logistics at the School of the Americas, Panama;

Francis, CPT Linda Captain Linda Francis is an Instructor/Writer, Officer Advanced Course Branch, Logistics Management Division, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. Her duties include developing and presenting conventional munitions management academic and professional instruction for both the Ordnance Officer Basic and Advanced Courses.

CPT Francis received a commission through the Army Reserve Officer Training Corps and her Bachelor of Arts degree in English, Linguistics, and Accounting in 1982 from The Ohio State University. Her military education includes both the Ordnance Officer Basic and Advanced courses, Combined Arms Services Staff School, and Marine Command and Staff School.

CPT Francis' career spans over 9 years of active military service in ammunition management planning and operations. Her key assignments include Ammunition Accountable and then Control Officer, 44th Ordnance Company (Conventional Ammo); Commander, Headquarters Detachment

84th Ordnance Battalion DS/GS (Conventional Ammo); and Ammunition Technical Officer, 84th Ordnance Battalion. The 84th Ordnance Battalion provides ammunition direct support to the 8th Infantry Division, 2nd Armored Division (Forward), and storage of 150,000 tons of preposition war reserve munitions.

Gates, SFC(R) Howard R. Mr. Howard R. Gates is a Combat Development Specialist (Munitions), Munitions Branch, Concepts and Studies Division, Directorate of Combat Developments, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. As a Projects Officer, his duties include planning, developing, and accomplishing conceptual studies for the development of Army logistics doctrine for conventional, chemical, and munitions items. He was responsible for developing the Maneuver Oriented Ammunition Distribution System utilizing the Palletized Load System.

Mr. Gates' career spans over 34 years of ammunition management planning and operations. His key military assignments include Noncommissioned Officer in Charge (NCOIC), Ammunition Supply Point, 101st Ordnance Battalion (Conventional Ammo); NCOIC, Ammunition Supply Point, XVIII Airborne Corps, Fort Bragg; and Ammunition Manager, Headquarters, Materiel Assistant Command, Republic of Vietnam.

Goodman, MGS(R) Phillip J. Mr. Phillip J. Goodman is an Instructor/Writer, Munitions Concepts and Studies Division, Command and Staff Department, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include developing and presenting munitions management academic and professional instruction for Officer and Noncommissioned Basic and Advanced Courses. He is responsible for writing Army munitions operations doctrine within the Department of Defense.

Mr. Goodman received his Bachelor of Science degree in History in 1977 from Athens State College. His career spans over 36 years of ammunition management planning and operations. His key military assignments include Platoon Leader of a conventional ammunition company; Ammunition Officer (Forward), 3rd Marine Division; Ammunition Stock Chief, 1st Marine Division, Instructor, Ammunition School, 1st Marine Division; and Instructor, Marine Corps Ammunition School, Quantico, Virginia.

Harrison, CPT Rex A. Captain Rex A. Harrison is an Instructor/Writer, Officer Advanced Course Branch, Logistics Management Division, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include developing and presenting conventional munitions management academic and professional instruction for both the Ordnance Officer Basic and Advanced Courses.

CPT Harrison received a commission through the U.S. Army Military Academy at West Point in 1985. His military education includes both the Ordnance Officer Basic and Advanced courses and Combined Arms Services Staff School.

CPT Harrison's career spans over 8 years of active military service in ammunition management planning and operations. His key assignments include Ammunition Operations Officer, 583rd Ordnance Company (Special Ammo) and Commander, Headquarters Company, 83th Ordnance Battalion (Conventional Ammo), Akizuke, Japan.

Libby, MAJ(P) Edmund W. Major(P) Edmund W. Libby is a Doctoral Candidate, School of Engineering, Air Force Institute of Technology, Wright Patterson AFB, Ohio. He received his Bachelor of Science degree in Chemical Engineering in 1975 from University of California at Berkley, and received a Master of Science in Guided Missile Engineering in 1983 from the Air Force Institute of Technology. His military education includes the Infantry Officer Basic Course, Ordnance Officer Advanced Course (Missile/Munitions) and Command and General Staff College.

Prior to entering active duty, MAJ Libby worked as a engineering technician at the Navy's China Lake Naval Weapons Center, California, where he designed and tested components of the rocket motors for the 5-inch cannon-launched guided projectile.

After commissioning in 1975, MAJ Libby served in Germany from 1976-79 as the Ammunition Technical Officer of the 84th Ordnance Battalion (Conventional Ammo). His responsibilities included ammunition direct support to the 8th Infantry Division, 2nd Armored Division (Forward), and most REFORGER/2+10 Units, as well as storage of 150,000 tons of propositioned was reserve munitions. He subsequently commanded the Army's only maintenance company for Warsaw Pact ordnance materiel, and served as a System Engineer on a major missile program in the Strategic Defense Initiative.

In 1987, MAJ Libby returned to Germany where he served as the Chief of Missiles, Munitions, and Armament for the VII Corps Materiel Management Center. In this capacity, he was responsible for management of all munitions operations in the Corps and played a key role in planning for Corps operations for wartime. In particular, he maintained an extremely close relationship with the Corps Movement Control Center and other transportation activities regarding their functions in support of munitions movement.

McEnroe, SFC Loughlin K. Sergeant First Class Loughlin is an Instructor/Writer, Munitions Concepts and Studies Division, Command and Staff Department, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include developing and presenting munitions management academic and professional instruction for the Ordnance Officer Basic Course, Warrant Officer

Certification Course, and Noncommissioned Officer Advanced Course.

SFC Loughlin is pursuing his Bachelor of Science degree in General Studies at Columbia College. His career spans over 19 years of ammunition management planning and operations. His key military assignments include Assistant Team Chief and Gunner, 105mm Towed Howitzer; Assistant Team Chief, Special Weapons (Nuclear), Maintenance and Assembly; Ammunition Supply Advisor, Materiel Office (MATO), 6th Ordnance Battalion (Conventional Ammo); and Platoon Sergeant, Maintenance Reconfiguration (Disposal), Chemical Weapons, Johnston Island, Pacific.

Randall, MAJ Richard R. Major Richard R. Randall is the Chief, Munitions Branch, Concepts and Studies Division, Directorate of Combat Developments, U.S Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include supervising the planning, developing, and accomplishing conceptual studies for the development of Army logistics doctrine for conventional, chemical, and munitions items.

MAJ Randall received a commission through the Army Reserve Officer Training Corps and his Bachelor of Arts degree in Mathematics in 1974 from the Northeastern University. He has two Master of Science degrees, Computer Information Systems and Computer Resource Management, and a Masters of Business Administrate degree. His military education includes both the Ordnance Officer Basic and Advanced Courses and Combined Arms Services Staff School.

MAJ Randall's career spans over 16 years of active military service in ammunition management planning and operations. His key assignments include Technical Escort for the disposal of chemical munitions, U.S. Army Escort and Disposal Agency; several assignments with Explosive Ordnance Disposal; Ammunition Accountable Officer (Conventional), Miesau Army Depot, Germany; Data Analyst, Field Command, Defense Nuclear Agency Inspector General; and 2nd Corps Support Command Ammunition Planning Officer during Desert Shield/Storm.

Rupp, MAJ David R. Major David R. Rupp is the Chief, Officer Advanced Course Branch, Logistics Management Division, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include supervising the development and presentation of conventional munitions management academic and professional instruction for both the Ordnance Officer Basic and Advanced Courses.

Major Rupp received a commission through the Army Reserve Officer Training Corps and her Bachelor of Arts degree in Government in 1978 from the University of Texas at Austin. His military education includes both the Ordnance Officer Basic and Advanced courses, Combined Arms Services Staff School, Command and General Staff College.

MAJ Rupp's career spans over 13 years of active military service in ammunition management planning and operations. His key assignments include Platoon Leader, Magazine Control Officer, and Class V Control Officer, 63rd Ordnance Company (Conventional Ammo), Fort Lewis and Yacima Training Area, Washington; S-4 Logistics Officer, 80th Ordnance Battalion (Conventional Ammo); S-2/3 Operations Officer, 6th Ordnance Battalion (Conventional Ammo); Surety Officer, Korean Ammunition Management System, Korea; Executive Officer, Kansas Army Ammunition Plant; Executive Officer, Sunflower Ammunition Plant; Commander, Headquarters Company, 196th Ordnance Battalion (Conventional Ammo); Executive Officer, 196th Ordnance Battalion.

Watkins, MSG(R) Raymond F. Mr. Raymond F. Watkins is a Logistics and Munitions Training Specialist, Concepts and Studies Division, Directorate of Combat Developments, U.S. Army Missile and Munitions Center and School, Redstone Arsenal, Alabama. His duties include developing and writing operational and organization plans for the Standard Army Ammunition System (SAAS) configuration.

Mr. Watkins received his Bachelor of Arts degree in Business Administration in 1971 from Athens State College. His career spans over 33 years of ammunition management planning and operations. His key military assignments include Operations Sergeant, 529th Ordnance Company (Special Weapons); Maintenance Crew Chief (Special Weapons), Seneca Army Depot; Maintenance Platoon Sergeant, 619th Ordnance Company (Special Weapons); Research and Analysis Sergeant, Special Weapons Packaging and Transport Survivability, U.S. Army Air Defense Board, Fort Bliss, Texas; Senior Instructor and Special Weapons Instructor, U.S. Army Ordnance Center and School, and First Sergeant of the 619th Ordnance Company (Special Weapons).

Transportation Corps Logistics Concept Analyses Respondents.

Featherston, COL Michael S. Colonel Michael S. Featherston, a native of Arkansas, entered active duty as a Regular Army Officer through the Army Reserve Training Program (DMG) in May of 1965, upon graduation from Henderson State College, Arkadelphia Arkansas. His initial assignment was with the Infantry, culminating as a Platoon Leader in the 1st Battalion, 18th Infantry, 1st Infantry Division in the Republic of Vietnam. Upon completion of his combat arms detail, Colonel Featherston was transferred to the Transportation Corps.

He has served in numerous troop assignments to include Company Commander, Battalion S-3 and Executive Officer, and Deputy Commander of the 7th Transportation Group (Terminal) at Fort Eustis, Virginia. Colonel Featherston's second Vietnam assignment was as the Brigade Transportation Officer of the 3rd Brigade (Separate), 1st Cavalry Division. He also has served several assignments with the Military Traffic Management Command (MTMC), including Operations Officer at Military Ocean Terminal, Sunny Point and Izmir, Turkey, Commander, Transportation Battalion (Terminal) Baltimore, Deputy Project Manager, Transportation Coordinator - Automated Command and Control Information System (TC ACCIS) and Brigade Commander, Military Ocean Terminal, Sunny Point and the MTMC Mid Atlantic Sub Area Commander. He also served at the Army Military Personnel Center and as Chief, Transportation Management Division, Office of the Deputy Chief of Staff, Logistics, Department of the Army. He is presently the Deputy Director of Distribution (Support) for the Army and Air Force Exchange Service.

Colonel Featherston holds an MA from Central Michigan University and is a graduate of the Army Command and General Staff College, Armed Forces Staff College, and the Industrial College of the Armed Forces. He also served a tour in the Training With Industry (TWI) Program at the Alabama State Docks, Mobile Alabama. Colonel Featherston's awards include the Bronze Star Medal for Valor (with four Oak Leaf Clusters), Purple Heart, Defense Meritorious Service Medal (with Oak Leaf Cluster), Meritorious Service Medal (with two Oak Leaf Clusters), Air Medal, Joint Service Commendation Medal (with Oak Leaf Cluster), Army Commendation Medal (with Oak Leaf Cluster), Army Achievement Medal, Vietnamese Cross of Gallantry with Bronze Star, Combat Infantryman Badge, and the Parachute Badge.

McWard, COL Robert G. Colonel Robert G. McWard was born in Lakehurst, New Jersey, and was raised in Phoenix, Arizona. He attended college at the University of Arizona in Tucson, where he earned his commission through the Army Reserve Officer Training Corps. Branched as a Transportation Officer, he entered active duty at Fort Eustis, Virginia, in the fall of 1967.

His assignments include Platoon Leader, 513th Transportation Company, 38th Transportation Battalion and Company Commander, 41st Transportation Company, 181st Transportation Battalion (Truck) Mannheim, Germany (1977-1969); S-4 and S-1, 71st Transportation Battalion (Terminal), Republic of Vietnam (1969-1970); S-4, S-1, and Executive Officer, 3d Battalion 26th Field Artillery (TA) and Battery Commander, Headquarters Battery, 214th Field Artillery Group, Fort Sill, Oklahoma (1970-1973); Operations Officer, Military Traffic Management Command Terminal Greece, Piraeus, Greece (1974-1977); Executive Officer, U.S. Army Transportation Center, Fort Eustis, Virginia (1980-1983); Commander, 181st Transportation Battalion (Truck), Mannheim, Germany (1984-1986); Director of the Office of the Chief of Transportation, U.S. Army Transportation Center, Fort Eustis, Virginia (1987-1988); and Director of the Department of Professional Development at the U.S. Army Transportation School (1988-1990). Colonel McWard assumed command of the 8th Transportation Brigade, Fort Eustis, Virginia, July 1990.

He is a graduate of the Transportation Officer Basic and Advanced Courses, the U.S. Army Command and General Staff College, and the U.S. Army War College. He also holds a Baccalaureate Degree in Political Science from the University of Arizona and a Masters Degree in Guidance and Counseling from Ball State University.

His awards and decorations include the Bronze Star Medal, the Meritorious Service Medal (with two Oak Leaf Clusters), the Joint Service Commendation Medal, and the Army Commendation Medal (with Oak Leaf Cluster).

<u>Chalkley, LTC James R.</u> Lieutenant Colonel James R. Chalkley entered the Army in Many 1973. A distinguished military graduate from the Virginia Military Institute, he was commissioned a Regular Army Transportation Corps Officer with a Combat Branch detail in the Field Artillery.

LTC Chalkley holds a Bachelors Degree in History from Virginia Military Institute and a Masters Degree from the Florida Institute of Technology. He is a graduate of the Field Artillery Officer Basic and Transportation Officers Advanced Courses, the Army Command and General Staff College, and the Navy Command Staff College.

LTC Chalkley's assignments include: Forward Observer, C Battery, 2/320th Field Artillery; Platoon Leader, 594th Transportation Company (Medium Truck); Assistant Division Transportation Officer, 101st Airborne Division (Air Assault); Chief, Air Traffic Coordinating Office, Ramstein Air Base, Germany; Commander, 69th Transportation Company (Medium Truck); Assistant Professor of Military Science, University of Richmond; Lieutenant and Captain Assignment Officer, Military Personnel Center; Personnel Action Officer, Office of the Deputy Chief of Staff for Personnel, the Pentagon; Assistant S-3, 7th Transportation Group (Terminal); Executive Officer, 24th Transportation Battalion (Terminal); Executive Officer to the Commanding General, U.S. Army Transportation Center at Fort Eustis; and Executive Officer, 7th Transportation Group (Terminal).

LTC Chalkley's awards and decorations include the Bronze Star Medal, the Meritorious Service Medal (with 5 Oak Leaf Clusters), the Army Commendation Medal (with 2 Oak Leaf Clusters), the Army Achievement Medal (with 1 Oak Leaf Cluster), the National Defense Service Medal, the Southwest Asia Service Medal, and the Department of the Army Staff Identification Badge.

Kubiszewski, LTC Robert Lieutenant Colonel Robert Kubiszewski was born on 31 July 1949 in East Chicago, Indiana. He received a Bachelor of Science Degree in Chemistry from Indiana University and was commissioned through the Army Reserve Officer Training Corps in 1972. LTC Kubiszewski received his Master of Science in Operations Research Systems Analysis from Case Western Reserve University in 1978. LTC Kubiszewski is a graduate of the Transportation Officer Basic and Advanced Courses, and the Command and General Staff College.

His assignments include: Company Commander of the 372nd Terminal Transfer Company and Assistant S-2/3, 19th Transportation Battalion (Truck), Fort Campbell, Kentucky; Systems Analyst for the Patriot Management Office, Redstone Arsenal, Huntsville, Alabama; Technical Advisor for the NATO Patriot Management Office and S-2/3 of the 181st Transportation Battalion (Truck), Federal Republic of Germany; Executive Officer of the 6th Transportation Battalion (Truck); and Chief, Army Driver Standardization Office, United States Army Transportation School, Fort Eustis, Virginia.

Decorations awarded to LTC Kubiszewski include the Meritorious Service Medal (with Oak Leaf Cluster), the Army Commendation Medal (with Oak Leaf Clusters), and the Army Achievement Medal (with Oak Leaf Cluster).

Appendix B: Paired Comparison Field Survey

Paired Comparison Briefing Paper

Good morning, and thank you for taking valuable time out of your busy work schedule to participate in this survey. My name is Captain John S. Lenart, Jr., and I am an Army Transportation Corps officer. I am a graduate student pursuing a Masters of Science degree in Transportation Management at the Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio.

This morning you will be participating in a paired comparison survey of surface transportation performance measurement criteria and system design attributes for liquid propellant technology in Field Artillery application. The liquid propellant logistics system is being developed by the U.S. Army Research Development and Engineering Center (ARDEC), Picatinny Arsenal, and the Jet Propulsion Laboratory, California Institute of Technology. A similar but much broader study was conducted during the first "down-select" phase in which sixteen logistics systems were narrowed to three candidate systems. These three systems are discrete, bulk, and combination discrete/bulk.

This survey is being administered to a select group of logistics "experts;" therefore, your response is extremely important. You were selected to participate in this research effort because your experience and knowledge qualify you as a logistics transportation "expert". Your ratings will be combined with those of other experts to develop a prioritization model describing the relevant performance measurement criteria and system design attributes for consideration toward final selection of the liquid propellant logistics system.

To identify and prioritize the criteria and attributes, this survey uses a series of paired comparison prioritization matrices. The Prioritization Matrix, a form of scoring model, is a screening technique which provides a means of constructing a descriptive decision aid for prioritizing tasks, issues, time, product/service characteristics, resource allocation, etc., based upon the weighted criteria. Screening techniques are used in logistics to make strategic decisions where judgement remains an important part of the analysis process.

Your ratings will be kept strictly confidential. The reliability of the findings depends heavily on my receiving a complete response from each person in the sample. Responses from all participants will be combined to form composite scores for statistical analysis and interpretation. A summary of the survey results will be provided to you upon completion of my work.

This survey consists of three phases. Phase I consists of two parts. First, each of you anonymously will complete a paired comparison questionnaire of the six performance measurement criteria. Your results will be scored and used for determining the relative weight of each criterion and selecting which criteria will be used during Phase II. Second, you will be presented with an initial list of sixteen system design attributes that I compiled and from several liquid propellant logistics studies and academic literature. In open discussion, you will be asked to agree upon a final list of attributes. This process of achieving group consensus through open discussion is called the nominal group interactive technique. Once a final list of attributes has been agreed upon, each you will select the ten most important attributes for use during the second phase of the survey. This final attribute selection process will be accomplished by anonymous ballot in two rounds. In the first round, each individual will select what he/she considers to be the ten most important attributes. These ballots will be collected and tabulated. The original attribute list and results of the first ballot will be redistributed and each will be asked to reevaluate his original selections based upon the group consensus of the first round ballot. The second ballot will then be tabulated, and a final list of the ten most important attributes will be selected.

During Phase II, each of you anonymously will complete a paired comparison questionnaire of the ten system design attributes based on each criterion that was selected during Phase I. Your results will be scored and used for determining the relative weight of each attribute.

Phase III will be completed by the researcher. During this phase, the weighted, normalized score of each attribute will be weighted by the normalized score of each criterion to identify the total relative prioritization and importance of each attribute. This relative importance will indicate the attribute's impact on the logistics system for liquid propellant technology. Now I want to draw your attention to the instructions for completing the paired comparison questionnaire.

Paired Comparison Survey Directions

You will complete a questionnaire booklet to individually compare six surface transportation performance measurement criteria. The criteria are as follows:

1. Reduce Logistics Burden
2. No Customized Technology
3. Increase Personnel and Environmental Safety
4. Increase Operational Capability of Logistics
5. Increase Tactical Capability of Users
6. Low Cost to Implement

Each pair of criteria will be rated on the basis of relative importance of each criterion as compared to every other criterion. This is illustrated below. If the two criterion are judged to be "Equally Important/Preferred," the single center box will be marked. However, if you make a relative judgment that one criterion is "Significantly" or "Extremely More Important/Preferred," the appropriate criterion's box will be selected. For example, if "Low Cost to Implement" was judged to be "Significantly More Important/ Preferred," the following selection would be made.

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Reduce Logistics Burden		[ ]	[ ]
	[ ]		
Low Cost to Implement		[X]	[ ]

The pairwise grouping of the criteria has been accomplished using an "Order of Pairs" table. Therefore, you are to make a relative judgment about each pair (skipping none) in the order in which the pairs are presented in the booklet. **Consistency in judgment is unimportant; what is needed is your unbiased judgment on each pair of criteria independent of your judgement on previous pairs**. Once the relative importance of each of the criterion has been established, each system design attribute must be judged on how completely it meets each of the criterion.

Next, you will review an initial list of sixteen system design attributes. In group discussion, you are asked to review the validity and completeness of the list, adding and subtracting as agreed upon by group consensus. Once consensus has been achieve, two rounds of anonymous ballots will be used to reduce the list to the ten most important attributes.

Finally, the ten system design attributes will be compared against each of the significant criteria. The paired comparison booklets in this final part of the survey are identical to each other. However, the attributes in each booklet must be rated based on each of the criterion being applied. For example, the first attribute booklet is compared based on the criterion "Reduce Logistics Burden," the second booklet based on the criterion "No Customized Technology " etc.. Each respondent should refer to the attached glossary to attain a common understanding of the criteria and attributes.

If you have any questions about the survey, please call Major Robert McCauley at (513) 255-4149 (AV 785-4149) or Captain John S. Lenart, Jr. at (513) 254-1062. Thank you very much for your help.

THANK YOU FOR PARTICIPATING IN THIS SURVEY

Surface Transportation Performance Measurement Criteria

Six criteria have been defined to provide a common understanding of the performance measure concepts. These criteria were selected from the Report on Liquid Propellant Logistics Systems Study, Phase I, published by the Jet Propulsion Laboratory, California Institute of Technology. Each definition provides a short outline of the term's meaning for use in completing the paired comparison ratings.

Criteria

1. Reduce Logistics Burden. The criteria concerned with the increased or decreased logistics burden associated with the introduction of a new technology into the Army's weapon inventory. A decreased burden implies reduction in supply, transportation, maintenance, production, and/or cost requirements.

2. No Customized Technology. The criteria concerned with the operation, use, technical approaches, problems, applicability, solutions, and application of selected systems, components, and equipment at the logistics links and nodes. The system should incorporate only current and emerging equipment; any new equipment requirements should be satisfied with off-the-shelf purchases.

3. Increase Environmental and Personnel Safety. The criteria concerned with a thorough understanding of the toxicological effects of LP and the consequences of disregarding them. It addresses the safe handling, exposure, treatment, demilitarization, and environmental impacts from spillage or accident from threat action of the known hazard.

4. Increase Operational Capability of Logistics. The criteria concerned with the operational environment such as host nation support and operating conditions in particular areas of operation. Conflict in undeveloped areas or where security of developed ports can not be assured will require increased use of logistics-over-the-shore (LOTS) and host nation support. It addresses the capability of transportation to respond to surge quantities from significantly higher demand rates during general mobilization and conflict, operate in varying climatic conditions such as extreme cold or heat and desert conditions, quickly and efficiently relocate ammunition stocks at logistics nodes as the fluid nature of the battlefield dictates, and the durability and flexibility of the transport system to maneuver for cover and concealment from threat action. The logistics system must support all phases of combat and the various combat operations and must

be able to degrade (equipment losses and manual handling) gracefully, survive, and still support the combat units.

5. Increase Tactical Capability of Users. The criteria concerned with trade-off analyses and technical compromises which favor tactical capability of users over logistics considerations. It addresses the capability of the user to support desired rates of fire, reduce crew vulnerability, and improve weapon system survivability. Tactical capability is used to assess functions of force multiplication, combat interface, and support capabilities.

6. Low Cost to Implement. The criteria concerned with the use of current and emerging handling and transport equipment; cheap, durable, and disposable package (container), and the ability to fill, seal, and discharge LP in a non-contaminating manner. It addresses container and pallet losses and retrogrades at various nodes, container palletization and break bulk, downloading from large to small containers, and costs associated with materials (containers and pallets) and operations (handling, break bulk, download, and retrograde). Cost is defined as cost in dollars per pound of liquid propellant.

Paired Comparison Survey of Surface Transportation Performance Measurement Criteria

(1-2)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Reduce Logistics Burden	☐	☐	☐
No Customized Technology		☐	☐

(5-1)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Increase Tactical Capability of Users	☐	☐	☐
Reduce Logistics Burden		☐	☐

(6-5)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Low Cost to Implement	☐	☐	☐
Increase Tactical Capability of Users		☐	☐

(4-2)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Increase Operational Capability of Logistics	☐	☐	☐
No Customized Technology		☐	☐

(3-4)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Increase Personnel and Environmental Safety	☐	☐	☐
Increase Operational Capability of Logistics		☐	☐

(1-4)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Reduce Logistics Burden	☐	☐	☐
Increase Operational Capability of Logistics		☐	☐

(6-2)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Low Cost to Implement	☐	☐	☐
No Customized Technology		☐	☐

(3-6)

	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Increase Personnel and Environmental Safety	☐	☐	☐
Low Cost to Implement		☐	☐

(4-6)	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Increase Operational Capability of Logistics		☐	☐
	☐		
Low Cost to Implement		☐	☐

(2-3)	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
No Customized Technology		☐	☐
	☐		
Increase Personnel and Environmental Safety		☐	☐

(1-3)	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Reduce Logistics Burden		☐	☐
	☐		
Increase Personnel and Environmental Safety		☐	☐

(6-1)	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Low Cost to Implement		☐	☐
	☐		
Reduce Logistics Burden		☐	☐

(2-5)	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
No Customized Technology		☐	☐
	☐		
Increase Tactical Capability of Users		☐	☐

(5-3)	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Increase Tactical Capability of Users		☐	☐
	☐		
Increase Personnel and Environmental Safety		☐	☐

(4-5)	Equally Important/ Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Increase Operational Capability of Logistics		☐	☐
	☐		
Increase Tactical Capability of Users		☐	☐

Surface Transportation System Design Attributes

Ten attributes have been defined to provide a common understanding of the system design concepts. These attributes were selected from the Report on Liquid Propellant Logistics Systems Study, Phase I, published by the Jet Propulsion Laboratory, California Institute of Technology. Each definition provides a short outline of the term's meaning for use in completing the paired comparison ratings.

Attributes

1. Provide HazMat Containment Training. Provide LP containment training for immediate response in the event of spills or leakage. Training should include immediate first aid treatment methods for exposure to liquid propellant (LP).

2. Streamline HazMat Documentation. Simplify documentation, labeling, and placarding of LP shipments.

3. Provide HazMat Contingency Equipment. Provide supplies and equipment for the handling, containment, and/or limited demilitarization of LP to render non-functional as a propellant or explosive in an emergency situation. Equipment should include first aid supplies for exposure to LP.

4. No Additional MOS Training. No additional training is required at MOS schools (however, may require unit training through correspondence extension course training).

5. No Increase in Manpower. No increase in manpower required to transport LP. An important guideline for the study of LP technology is the capability to reduce manpower in the logistics pipeline.

6. Design Flat Racks for Multipurpose Use. Design flat racks for the transport of multiple/alternative products and classes of supplies. Includes adaptability for use in retrograde operations.

7. Design Pallets for Easy Access Top and Bottom. Concerned with the access to the pallet for all sides, top and bottom. Includes the need for side posts (top access) designed to collapse for empty stacking and transport efficiency.

8. High Reliability and Maintainability. Reliability is defined as the probability that an item will perform its intended function for a specified interval under stated conditions. In the simplest sense, reliability means how

long an item will perform its intended function without a breakdown. Maintainability is defined as the ability of an item to be retained in, or restored to, specified condition when maintenance is performed be people having specified skill levels, using prescribed procedures and resources. In the simplest sense, maintainability means when it does break down, how difficult is it to troubleshoot and repair?

9. Use Current Handling/Transport Equipment. The LP logistics system should interface with current handling and transport equipment. The system should incorporate only current and emerging equipment; any new equipment requirements should be satisfied with off-the-shelf purchases.

10. Compatible between Modes of Transport. Package configuration should be compatible with the physical characteristics of MHE, lighterage (watercraft), rail, and truck. The package must contain and protect the contents against the dynamic fluid conditions inherent with each mode.

11. Compatible with Allied Equipment. France, Germany, and Great Britain are currently studying LP technology. LP logistics system must include capability to supply and be supplied by allied equipment in a multinational force structure.

12. Capable of Automated and Manual Handling. Packaging designs that enable manhandling in order to sustain logistics chain support in the event of material handling equipment (MHE) unavailability due to malfunction, threat action, etc.

13. Quick Transfer Speed at POD, TSA, and CSA. Nodes located in the Communications Zone (COMMZ). Transfer times need to be reduced as much as possible with equipment that is easy to maintain and operate. Anticipated higher munitions expenditure rates and greater mobility requirements on the future battle field necessitate a logistics system that is both responsive and efficient.

14. Quick Transfer Speed at ASP and ATP. Nodes located in the Combat Zone (CZ). Transfer times need to be reduced as much as possible with equipment that is easy to maintain and operate. Anticipated higher munitions expenditure rates and greater mobility requirements on the future battle field necessitate a logistics system that is both responsive and efficient.

15. High Package Integrity to Minimize Damage. Considers the need to minimize damage at user destination (weapon system).

16. Lightweight/Low Cube Packaging. Addresses utilization of space and weight limitations on mode of transport. Also reduces material handling costs.

Paired Comparison Survey of Surface Transportation System Design Attributes

(1-2)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Containment Training			
Provide HazMat Contingency Equipment			

(10-5)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Quick Transfer Speed at ASP and ATP			
High Reliability and Maintainability			

(7-9)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible between Modes of Transport			
Capable of Automated and Manual Handling			

(1-4)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Containment Training			
Design Flat Racks for Multipurpose Use			

(3-6)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
No Increase in Manpower	☐	☐	☐
Use Current Handling/ Transport Equipment		☐	☐

(8-2)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible with Allied Equipment	☐	☐	☐
Provide HazMat Contingency Equipment		☐	☐

(2-9)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Contingency Equipment	☐	☐	☐
Capable of Automated and Manual Handling		☐	☐

(10-2)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Quick Transfer Speed at ASP and ATP	☐	☐	☐
Provide HazMat Contingency Equipment		☐	☐

(10-4)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Quick Transfer Speed at ASP and ATP		☐	☐
	☐		
Design Flat Racks for Multipurpose Use		☐	☐

(9-6)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Capable of Automated and Manual Handling		☐	☐
	☐		
Use Current Handling/ Transport Equipment		☐	☐

(8-1)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible with Allied Equipment		☐	☐
	☐		
Provide HazMat Containment Training		☐	☐

(5-3)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
High Reliability and Maintainability		☐	☐
	☐		
No Increase in Manpower		☐	☐

(2-7)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Contingency Equipment		☐	☐
	☐		
Compatible between Modes of Transport		☐	☐

(10-1)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Quick Transfer Speed at ASP and ATP		☐	☐
	☐		
Provide HazMat Containment Training		☐	☐

(1-6)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Containment Training		☐	☐
	☐		
Use Current Handling/ Transport Equipment		☐	☐

(6-7)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Use Current Handling/ Transport Equipment		☐	☐
	☐		
Compatible between Modes of Transport		☐	☐

(5-9)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
High Reliability and Maintainability			
Capable of Automated and Manual Handling			

(8-7)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible with Allied Equipment			
Compatible between Modes of Transport			

(3-4)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
No Increase in Manpower			
Design Flat Racks for Multipurpose Use			

(6-2)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Use Current Handling/ Transport Equipment			
Provide HazMat Contingency Equipment			

(10-9)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Quick Transfer Speed at ASP and ATP	☐	☐	☐
Capable of Automated and Manual Handling		☐	☐

(5-6)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
High Reliability and Maintainability	☐	☐	☐
Use Current Handling/ Transport Equipment		☐	☐

(7-5)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible between Modes of Transport	☐	☐	☐
High Reliability and Maintainability		☐	☐

(5-9)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
High Reliability and Maintainability	☐	☐	☐
Compatable with Allied Equipment		☐	☐

(6-8)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Use Current Handling/ Transport Equipment	☐	☐	☐
Compatible with Allied Equipment		☐	☐

(1-3)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Containment Training	☐	☐	☐
No Increase in Manpower		☐	☐

(2-5)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Contingency Equipment	☐	☐	☐
High Reliability and Maintainability		☐	☐

(8-10)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible with Allied Equipment	☐	☐	☐
Quick Transfer Speed at ASP and ATP		☐	☐

(1-5)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Containment Training	☐	☐	☐
High Reliability and Maintainability		☐	☐

(4-7)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Design Flat Racks for Multipurpose Use	☐	☐	☐
Compatible between Modes of Transport		☐	☐

(8-4)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible with Allied Equipment	☐	☐	☐
Design Flat Racks for Multipurpose Use		☐	☐

(4-9)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Design Flat Racks for Multipurpose Use	☐	☐	☐
Capable of Automated and Manual Handling		☐	☐

(7-1)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible between Modes Modes of Transport	☐	☐	☐
Provide HazMat Containment Training		☐	☐

(4-2)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Design Flat Racks for Multipurpose Use	☐	☐	☐
Provide HazMat Contingency Equipment		☐	☐

(10-7)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Quick Transfer Speed at ASP and ATP	☐	☐	☐
Compatible between Mod of Transport		☐	☐

(9-1)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Capable of Automated and Manual Handling	☐	☐	☐
Provide HazMat Containment Training		☐	☐

(6-4)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Use Current Handling/ Transport Equipment			
Design Flat Racks for Multipurpose Use			

(3-8)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
No Increase in Manpower			
Compatible with Allied Equipment			

(9-3)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Capable of Automated and Manual Handling			
No Increase in Manpower			

(3-10)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
No Increase in Manpower			
Quick Transfer Speed at ASP and ATP			

(2-3)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Provide HazMat Contingency Equipment			
No Increase in Manpower			

(6-10)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Use Current Handling/ Transport Equipment			
Quick Transfer Speed at ASP and ATP			

(9-8)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Capable of Automated and Manual Handling			
Compatible with Allied Equipment			

(4-5)	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Design Flat Racks for Multipurpose Use			
High Reliability and Maintainability			

(7-3)

	Equally Important Preferred	Significantly More Important/ Preferred	Extremely More Important/ Preferred
Compatible between Modes of Transport		☐	☐
	☐		
No Increase in Manpower		☐	☐

Appendix C: Logistics Concepts Assessment

Briefing Paper

Good morning, and thank you for taking valuable time out of your busy work schedule to participate in this survey. My name is Captain John S. Lenart, Jr., and I am an Army Transportation Corps officer. I am a graduate student pursuing a Masters of Science degree in Transportation Management at the Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio. My masters thesis is an analysis of logistics fielding concepts for liquid propellant in Field Artillery applications.

This survey is being administered to a select group of senior logistics "experts;" therefore, your response is extremely important. You were selected to participate in this research effort because your experience and knowledge qualify you as a senior logistics transportation "expert". Your ratings will be combined with those of other experts to assess the proposed liquid propellant logistics concepts.

Please complete the following steps:

1. Read the brief narrative of the three liquid propellant logistics concepts (Attachment 1).

2. Read the brief background summary of current developments in liquid propellant technology and hazard characterization (Attachment 2).

3. Read the brief glossary of qualitative surface transportation system design attributes for development of a logistics concept. These criteria will be used to rank the three liquid propellant logistics concepts (Attachment 3).

4. Please enclose your biography and written comments concerning the three logistics concepts.

5. FAX your biography and written comments to:

CPT Lenart
AFIT/LSM/Class 91S
FAX: AV 785-8458, COMM (513)255-8458

Thank you for your time and effort.

Liquid Propellant Logistics Concepts

Three liquid propellant logistics concepts are currently be studied as potential candidates for liquid propellant technology. Each concept was designed to be compatible with development of both the Maneuver Oriented Ammunition Distribution System (MOADS) and the Palletized Loading System. These three concepts are:

(1) Discrete. Liquid propellant (LP) is loaded at the load, assembly and pack (LAP) facility and transferred through the entire logistics chain to the user's battalion reload/rearm point (BARP) in palletized 30-50 gallon sealed plastic containers. At the BARP, the LP is pumped from the rearm vehicle directly into the self-propelled howitzer's (SPH) LP reservoirs. This concept continues to use existing logistics chain (solid propellant) transportation and transfer equipment, except for the inclusion of a winch or lifting equipment to upload containers into the rearm vehicles. Containers are palletized on existing standard size pallets and shipped in break-bulk containers. At the Ammunition Transfer Point (ATP), container pallets are broken-down and individual containers are loaded onto user rearm vehicles. The LP is pumped from the resupply rearm vehicle directly into the SPH reservoir tanks. The 30 and 50 gallon containers are not manhandleable but are easily palletized on existing pallets and could be handled and stored in the resupply vehicle in an efficient manner.

(2) Bulk. LP is loaded at the LAP facility into 1,800 gallon stainless steel tanks which are either trailer-mounted or are on integrated skids/pallets for vehicle transfer. The LP, in tanks, is transferred to the forward ATP and pumped into the storage containers on the rearm vehicle. The LP is then pumped from the rearm vehicle directly into the SPH's LP reservoirs at the BARP. The transporting and transfer of the 1800 gallon tanks is handled in a manner similar to POL products. The total weight for one 1,800 tank is 10-11 tons. Four of these size containers will supply one day's battalion requirement at 300 rounds per day per gun.

(3) Combination. LP is loaded at the LAP facility into bulk 1,800 gallon stainless tanks, which are trailer-or skid mounted and transferred as far forward as possible. The propellant is then down-loaded at this location by pumping into discrete containers (30-50 gallons or 150 gallons). The discrete containers are then uploaded into the rearm vehicle at the BARP, and finally pumped from the discrete containers into the SPH's reservoirs. This logistics concept uses bulk POL type transfer from the wholesale to the retail supply location (CSA, ASP, or ATP).

Attachment 1

Background Summary of Current Developments in Liquid Propellant Technology and Hazard Characterization

The components of the LP logistics system can be grouped into two broad categories: 1) containers, included palletization of discrete containers (less than 150 gallons) and containerization for larger containers; and, 2) transfer systems used to transfer LP between storage tanks, containers, and the howitzer.

The three logistics concepts do not require new vehicular material handling equipment (MHE); however, modifications may be necessary to supply power to the transfer components. Suitable containers and transfer components are commercially available. Satisfactory compatibility of the products is achievable by using various combinations of stainless steels and plastics. Final selection of each is dependant upon final identification of the physical properties and hazard classification of the propellant.

Safety is a high-priority concern, including both explosive hazard and toxicity. The numerous preliminary and ongoing hazard classification tests have placed LP in DOT Class B, with Class C a possibility after appropriate full scale testing is concluded.

Testing has shown that unconfined propellant is relatively insensitive. The drop weight sensitivity test results were 29 inches for LP 1845 and 31 inches for LP 1846. Most solid propellants have an average sensitivity range of 10 inches. LP will not burn at atmospheric pressure and can be safely stored under low pressure. While the exact threshold pressure that will sustain combustion has not been determined, bonfire tests indicate that LP decomposes and gives off large amounts of toxic brown fumes of mixed nitrogen oxides. The card gap test also records detonation sensitivity - both LP 1845 and LP 1846 tested at zero cards.

Propellant vulnerability tests also have shown relative insensitivity of the propellant. Hot spall tests (steel balls heated to various temperatures and dropped into containers of propellant) reveal that red hot steel balls dropped into small containers fizz and give off yellow fumes. Dropped into large containers of propellant, the heat capacity of the LP was sufficient to stop the reaction. Next, a rifle bullet failed to cause a reaction when shot into a gallon container of LP. A 5-inch shaped charge shot into a polyethylene container did result in a violent explosion; however, this reaction was suppressed by using small (38mm) hollow plastic balls as baffles (consuming only 8% of the container volume). Subsequent testing showed that as the 5-inch shaped charge jet penetrated the LP container

Attachment 2

and ignited the aluminum plate behind the container, the LP stream following the jet quenched the white not burning aluminum.

Toxicity of liquid propellant is relatively low. When handling LP, goggles should be worn and water resistant protective clothing is recommended. Absorbed through the skin, LP will cause a typical nitrate poisoning reaction by attacking the red blood cells. If washed off immediately, test have shown it to be an irritant with reversible effects. Splashed in the eyes, tests have also shown it to be an irritant. In tests with laboratory animals, washing out within 20 seconds did little damage to the eyes; however, if left in the eyes for one minute, the animals took a week or more to recover. There is no vapor hazard from LP (the vapor above the liquid is water); however, an aerosol stream from a broken pumping line would pose an inhalation hazard.

The major environmental impacts are in the manufacture, transportation, and disposal of LP. In the logistics chain, there is always the possibility of a spill. Small spills can be washed away with water. The resulting effect on the environment would be the same as an overdose of fertilizer. A large spill would, however, require remediation. A protocol for handling large spills has not been developed. If a large amount of LP entered either surface or ground water, serious contamination would occur. Nitrate ion concentrations (below 2 ppm concentration requirement) in water can lead to methoglobinemia in infants (blue babies).

Glossary of Qualitative Surface Transportation System Design Attributes

1. High Reliability and Maintainability. Reliability is defined as the probability that an item will perform its intended function for a specified interval under stated conditions. In the simplest sense, reliability means how long an item will perform its intended function without a breakdown. Maintainability is defined as the ability of an item to be retained in, or restored to, specified condition when maintenance is performed be people having specified skill levels, using prescribed procedures and resources. In the simplest sense, maintainability means when it does break down, how difficult is it to troubleshoot and repair?

2. Compatible between Modes of Transport. Package configuration should be compatible with the physical characteristics of MHE, lighterage (watercraft), rail, and truck modes of transportation. The package must contain and protect the contents against the dynamic fluid conditions inherent with each mode.

3. Provide HazMat Containment Training. Provide LP containment training for safe, immediate response in the event of spills. Training should include immediate first aid treatment methods for exposure to liquid propellant (LP).

4. Quick Transfer Speed at ASP and ATP. These are the transfer nodes located in the Combat Zone (CZ). Transfer time needs to be reduced as much as possible. Anticipated higher munitions expenditure rates and greater mobility requirements on the future battle field necessitate a logistics system that is both responsive and efficient.

5. Use Current Handling/Transport Equipment. The LP logistics system should be compatible with current handling and transport equipment. The system should incorporate only current and emerging equipment. Any new equipment requirements should be satisfied with off-the-shelf purchases.

6. Provide HazMat Contingency Equipment. Provide supplies and equipment for the handling, containment, and/or limited demilitarization of LP spills to render non-functional as a propellant or explosive in an emergency situation. Equipment should include first aid supplies for personal exposure to LP.

Attachment 3

7. Capable of Automated and Manual Handling. Packaging designs that enable manhandling in order to sustain logistics chain support in the event of material handling equipment (MHE) unavailability due to malfunction, threat action, etc.

8. Compatible with Allied Equipment. France, Germany, and Great Britain are currently studying LP technology. LP logistics system must include capability to supply and be supplied by allied logistics equipment in a multinational force structure.

9. No Increase in Manpower. No increase in manpower required to transport LP. An important guideline for the study of LP technology is the capability to reduce manpower in the logistics pipeline.

10. Design Flat Racks for Multipurpose Use. Design flat racks for the transport of multiple/alternative products and classes of supplies. Includes adaptability for use in retrograde operations.

Appendix D: Transportation Corps Paired Comparison Data

Criteria Paired Comparison

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	5	5	5	1	1	5	1	5	.2	.2	1	5
2	(5-1)	1	.2	1	.2	.2	10	1	1	5	5	1	10
3	(6-5)	1	5	.1	1	5	5	.2	1	5	1	.1	5
4	(4-2)	10	5	5	10	1	10	5	5	5	10	10	10
5	(3-4)	1	5	.2	1	1	10	.2	1	10	10	.1	10
6	(1-4)	.2	1	1	1	5	.1	1	1	1	.2	1	.1
7	(6-2)	5	1	5	5	1	.1	.	5	1	1	1	.1
8	(3-6)	10	5	5	5	5	10	1	1	5	5	5	10
9	(4-6)	1	5	1	5	.2	10	5	1	1	5	10	10
10	(2-3)	.1	.1	5	.1	.2	.1	1	1	.2	1	.1	.1
11	(1-3)	1	1	1	.2	.2	.1	5	5	.2	1	5	.1
12	(6-1)	.2	1	5	1	5	.1	.2	.2	1	5	.2	.1
13	(2-5)	.2	.2	.2	.2	5	.1	.2	1	.2	1	.1	.1
14	(5-3)	1	.2	5	1	.2	.1	5	1	.2	1	5	.1
15	(4-5)	1	5	.2	1	1	10	1	.2	5	5	.2	10

Attribute Paired Comparison

Increase Personnel and Environmental Safety.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	1	1	1	10	1	1	1	5	1	1	1	1
2	(10-5)	1	.2	.2	.2	.1	1	1	.2	1	.2	1	1
3	(7-9)	1	5	1	5	1	1	1	5	.2	5	.2	1
4	(1-4)	5	5	5	5	10	.2	1	5	1	.2	.2	1
5	(3-6)	5	5	.2	.2	.2	1	.1	.2	5	.1	1	.1
6	(8-2)	5	.2	.2	.2	.2	.2	.2	.2	1	5	1	.2
7	(2-9)	1	1	1	.2	5	1	5	5	1	.2	.2	5
8	(10-2)	5	1	.2	5	5	1	.1	.2	1	.1	5	.1
9	(10-4)	5	1	5	5	5	1	.2	.2	5	.2	5	.2
10	(9-6)	1	5	5	.2	10	.2	1	.2	1	5	.2	1
11	(8-1)	1	.2	5	.2	1	.2	1	.2	1	5	.2	1
12	(5-3)	.2	5	5	5	10	1	10	5	5	5	1	10
13	(2-7)	.2	5	5	.2	.1	1	5	5	1	.2	.2	5
14	(10-1)	.2	5	.2	1	1	1	.2	.2	5	.2	1	.2
15	(1-6)	.2	1	1	10	10	1	10	5	5	.2	.2	10
16	(6-7)	.2	5	1	.1	.1	.2	1	5	.2	.2	1	1
17	(5-9)	5	.2	1	10	1	1	1	5	5	1	.2	1
18	(8-7)	1	.2	1	1	1	1	1	.2	1	1	1	1
19	(3-4)	5	1	5	5	1	1	1	1	10	.2	5	1
20	(6-2)	5	.2	1	5	.1	.2	.1	.2	.2	.2	5	.1
21	(10-9)	1	.2	.2	.2	1	1	.2	1	5	1	1	.2
22	(5-6)	.2	.2	1	5	10	1	10	5	10	.2	1	10
23	(7-5)	1	5	.2	.2	1	1	.2	.2	5	5	1	.2
24	(5-8)	.2	5	5	5	1	1	5	1	1	1	1	5
25	(6-8)	1	5	1	1	.2	1	1	5	.2	1	1	1

26	(1-3)	1	5	5	5	10	1	10	5	1	5	.2	10
27	(2-5)	5	1	1	.2	10	5	5	5	5	1	.2	5
28	(8-10)	1	.2	5	5	1	1	1	1	1	1	1	1
29	(1-5)	5	1	1	1	1	5	10	5	5	5	.2	10
30	(4-7)	.2	1	.2	.2	.1	1	1	1	1	1	1	1
31	(8-4)	5	.2	5	5	5	1	1	1	1	1	1	1
32	(4-9)	.2	1	.2	5	.1	1	.2	1	5	1	1	.2
33	(4-2)	.2	.2	.2	5	.1	.2	.2	.2	1	5	5	.2
34	(7-1)	1	1	1	1	1	.2	.1	.2	1	.2	5	.1
35	(10-7)	1	1	.2	.2	1	1	1	.2	5	.2	1	1
36	(9-1)	1	.2	1	.2	1	.2	.1	.2	1	.2	5	.1
37	(6-4)	5	5	5	5	1	1	1	5	.2	1	1	1
38	(3-8)	1	5	1	.2	.1	1	.2	1	1	.2	5	.2
39	(9-3)	1	1	1	5	10	1	5	1	.2	10	.2	5
40	(3-10)	1	1	5	.2	.2	1	1	1	1	.1	5	1
41	(2-3)	1	1	1	5	5	5	5	5	1	10	.2	5
42	(6-10)	1	1	5	5	.2	1	5	5	.2	1	.2	5
43	(9-8)	1	5	1	5	1	1	1	1	.2	.2	.2	1
44	(4-5)	.2	1	.2	.2	.1	1	.2	.2	1	5	.2	.2
45	(7-3)	.2	5	1	5	10	1	1	5	1	5	.2	1

<u>Increase Operation Capability of Logistics</u>.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	1	1	1	1	1	1	5	1	1	1	1	1
2	(10-5)	5	5	5	.2	5	5	.2	1	1	5	.2	5
3	(7-9)	1	1	5	1	5	1	.2	5	1	5	1	1
4	(1-4)	1	.1	5	.2	.2	.2	5	5	10	.2	1	.1
5	(3-6)	1	1	5	.2	5	1	.2	1	.2	1	.2	1
6	(8-2)	5	5	.2	5	5	5	5	.2	1	5	5	5
7	(2-9)	.2	5	5	.2	.2	.2	1	1	1	1	.2	5
8	(10-2)	5	5	.2	.2	5	5	1	.2	1	1	5	5
9	(10-4)	1	1	1	.2	.2	1	5	5	10	1	5	1
10	(9-6)	1	1	.2	5	.2	1	5	5	1	.2	.2	1
11	(8-1)	5	5	1	1	.2	1	5	1	1	1	.2	5
12	(5-3)	1	1	5	5	.2	5	5	5	10	1	5	1
13	(2-7)	.2	.1	5	.2	.2	.2	1	1	1	.2	.2	.1
14	(10-1)	5	1	.2	10	.2	5	5	5	1	1	.2	1
15	(1-6)	.1	.2	5	.2	.2	.2	1	5	1	.2	.2	.2
16	(6-7)	1	1	1	5	1	1	1	1	1	1	1	1
17	(5-9)	1	1	1	1	1	1	1	5	1	5	1	1
18	(8-7)	1	1	.2	1	1	1	1	.2	1	1	1	1
19	(3-4)	5	1	.2	.2	5	.2	5	1	1	1	.2	1
20	(6-3)	5	5	.2	5	5	5	1	1	.1	1	5	5
21	(10-9)	1	1	1	.2	1	1	1	1	1	5	1	1
22	(5-6)	1	1	.2	1	1	1	1	5	1	1	5	1
23	(7-5)	1	1	1	.2	1	1	1	1	1	1	1	1
24	(5-8)	5	5	.2	5	.2	1	5	5	1	.2	.2	5
25	(6-8)	1	.2	1	.2	1	1	1	5	1	.2	5	.2
26	(1-3)	5	1	5	5	.2	.2	5	5	10	1	1	1
27	(2-5)	5	.2	5	.2	.2	.2	.2	1	1	.2	.2	.2
28	(8-10)	5	1	1	5	1	1	1	.2	1	1	.2	1

29	(1-5)	5	.2	5	.2	.2	.2	1	1	1	.2	.2	.2
30	(4-7)	1	1	1	.2	1	1	.2	.2	.2	1	.2	1
31	(8-4)	1	1	1	1	1	1	5	.2	5	1	5	1
32	(4-9)	1	1	.2	1	1	1	.2	1	.2	1	.2	1
33	(4-2)	1	5	.2	5	5	5	.2	.2	.2	5	5	5
34	(7-1)	5	5	.2	5	5	5	1	1	1	5	5	5
35	(10-7)	1	1	1	.2	1	1	1	.2	1	1	5	1
36	(9-1)	5	1	.2	.2	5	1	1	1	1	1	5	1
37	(6-4)	5	1	5	1	1	1	5	.2	5	1	5	1
38	(3-8)	1	.1	.2	.2	5	1	1	5	.2	1	.2	.1
39	(9-3)	5	1	1	5	.2	1	1	5	10	1	5	1
40	(3-10)	.2	1	.2	5	5	1	1	.2	.2	1	.2	1
41	(2-3)	5	1	5	5	.2	.2	5	5	5	5	1	1
42	(6-10)	1	1	1	5	.2	1	.2	1	1	.2	.2	1
43	(9-8)	1	1	.2	1	1	1	1	[illegible]	1	.2	5	1
44	(4-5)	5	1	5	.1	1	1	.2	.2	.1	1	.2	1
45	(7-3)	5	1	5	10	.2	1	1	5	10	5	5	1

<u>Increase Tactical Capability of Users</u>.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	1	1	1	.2	1	1	1	1	1	1	5	.2
2	(10-5)	.2	1	5	10	5	1	.2	1	1	1	.2	10
3	(7-9)	1	1	5	10	.2	5	.2	1	1	1	.2	10
4	(1-4)	5	.2	.2	.2	.2	5	5	10	5	5	5	.2
5	(3-6)	1	1	5	.2	.2	1	5	1	.2	1	1	.2
6	(8-2)	5	5	5	10	5	.2	1	1	5	5	5	10
7	(2-9)	5	.2	1	5	.2	1	.2	1	.2	1	.2	5
8	(10-2)	.2	5	5	10	5	1	.2	1	5	1	5	10
9	(10-4)	.2	5	10	1	5	5	5	10	5	5	.2	1
10	(9-6)	.2	.2	1	.2	.2	5	5	1	5	5	1	.2
11	(8-1)	.2	.2	1	1	.2	.2	5	1	5	5	1	1
12	(5-3)	1	5	1	5	5	5	5	10	.2	5	1	5
13	(2-7)	5	.2	.2	.2	.2	1	5	1	5	1	.2	.2
14	(10-1)	.2	5	10	1	.2	5	.2	1	5	1	5	1
15	(1-6)	5	.2	.2	.2	.2	5	5	10	5	.2	1	.2
16	(6-7)	5	1	.1	.1	.2	.2	1	.1	1	1	.2	.1
17	(5-9)	1	1	1	10	.2	5	1	1	1	5	.2	10
18	(8-7)	1	1	1	1	.2	.2	5	1	1	5	1	1
19	(3-4)	5	.2	5	1	5	1	5	1	5	5	5	1
20	(6-2)	.2	5	1	5	5	.2	.2	.1	1	5	5	5
21	(10-9)	1	5	5	10	5	1	.2	.1	1	1	1	10
22	(5-6)	5	1	1	1	.2	5	5	1	.2	5	5	1
23	(7-5)	.2	1	1	1	5	1	.2	1	5	.2	1	1
24	(5-8)	.2	.2	1	1	.2	5	5	1	1	5	1	1
25	(6-8)	5	.2	.2	1	5	5	.2	1	1	1	1	1
26	(1-3)	5	.2	.2	1	.2	1	.2	10	1	.2	1	1
27	(2-5)	5	.2	1	.2	.2	1	.2	1	1	.2	.2	.2
28	(8-10)	5	.2	1	1	.2	.2	5	1	1	5	1	1
29	(1-5)	5	.2	.2	.2	.2	1	1	1	1	.2	.2	.2
30	(4-7)	1	.2	.2	1	.2	.2	1	.1	.2	.2	5	1
31	(8-4)	.2	5	1	1	.2	.2	5	5	5	5	5	1

32	(4-9)	1	.2	1	5	.2	1	.2	.2	.2	.2	.2	5
33	(4-2)	.2	5	5	5	5	.2	.2	.2	.2	1	5	5
34	(7-1)	.2	5	5	5	5	1	.2	1	1	1	5	5
35	(10-7)	5	5	1	1	5	1	1	1	1	1	.2	1
36	(9-1)	.2	5	1	1	5	.2	5	1	1	1	5	1
37	(6-4)	1	5	1	1	5	1	1	5	5	5	1	1
38	(3-8)	.2	1	1	.2	5	1	1	.2	1	1	1	.2
39	(9-3)	1	1	1	1	.2	1	.2	5	1	.2	1	1
40	(3-10)	1	.2	.2	1	.2	1	5	.2	1	1	5	1
41	(2-3)	5	.2	1	5	.2	1	1	5	1	1	.2	5
42	(6-10)	5	.2	.2	1	.2	.2	5	.2	1	1	5	1
43	(9-8)	.2	5	.2	1	5	5	1	5	1	1	1	1
44	(4-5)	5	.2	1	1	5	.2	.2	.1	.2	.2	5	1
45	(7-3)	5	5	.2	5	.2	1	.2	10	1	.2	.2	5

Reduce Logistics Burden.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	1	1	5	5	1	1	.2	1	1	1	1	1
2	(10-5)	1	.2	5	5	1	5	5	5	10	.2	1	10
3	(7-9)	1	1	1	1	1	1	5	5	1	5	1	1
4	(1-4)	5	.2	10	5	.2	5	.1	5	1	.1	.2	.1
5	(3-6)	1	.2	.1	5	1	.2	1	5	.2	.2	5	1
6	(8-2)	.2	5	1	1	5	.2	10	.2	5	5	5	10
7	(2-9)	5	.2	1	1	1	5	1	5	.2	.2	.2	1
8	(10-2)	.2	5	1	1	5	.2	5	.2	5	.2	5	5
9	(10-4)	1	1	5	1	10	5	1	5	1	1	1	1
10	(9-6)	.2	1	1	1	1	.2	5	5	1	1	.2	5
11	(8-1)	.2	1	.2	.2	1	1	1	5	1	.2	1	1
12	(5-3)	.2	5	.2	1	10	.2	5	.2	5	1	5	5
13	(2-7)	.2	5	1	.2	1	1	.2	5	.2	1	.2	.2
14	(10-1)	.2	.2	.2	5	1	1	1	.2	1	5	.2	1
15	(1-6)	.2	1	1	.2	10	1	1	5	.2	1	.2	.2
16	(6-7)	1	.2	1	1	1	1	.2	.2	1	.2	1	1
17	(5-9)	1	1	5	.2	1	.2	1	1	1	1	1	1
18	(8-7)	1	1	1	1	1	1	1	1	1	.2	1	1
19	(3-4)	5	.2	5	.2	5	5	1	.2	1	1	.2	1
20	(6-2)	5	5	1	5	.1	1	5	.1	5	1	5	5
21	(10-9)	1	.2	5	1	1	1	10	.2	1	1	1	1
22	(5-6)	1	.2	10	.2	1	.2	1	5	5	1	1	1
23	(7-5)	1	5	1	5	10	5	1	1	1	1	1	1
24	(5-8)	.2	.2	1	.2	1	.2	5	5	.2	1	.2	5
25	(6-8)	5	1	1	1	.2	1	1	5	.2	1	1	1
26	(1-3)	1	1	10	1	.2	.2	1	1	1	5	.2	1
27	(2-5)	.2	.2	.2	1	1	5	.2	5	.2	1	.2	.2
28	(8-10)	1	5	.2	5	1	1	1	1	1	.2	1	1
29	(1-5)	.2	.2	.2	1	1	5	.2	1	.2	1	.2	.2
30	(4-7)	.2	.2	.2	1	1	.2	1	1	1	.2	1	1
31	(8-4)	5	.2	1	1	10	5	1	1	1	.2	1	1
32	(4-9)	.2	.2	.2	1	.1	.2	1	5	1	1	1	1
33	(4-2)	5	.2	.2	5	.1	.2	5	.2	1	.2	5	1
34	(7-1)	5	1	1	1	10	.2	5	1	5	1	5	5

35	(10-7)	5	.2	1	1	1	1	5	1	1	1	1	1
36	(9-1)	5	.2	5	5	1	1	10	.2	5	1	5	5
37	(6-4)	5	5	5	5	10	5	.2	1	1	1	.2	1
38	(3-8)	5	5	.2	1	.1	5	1	5	.2	.2	5	1
39	(9-3)	5	5	5	5	1	1	5	1	5	5	.2	5
40	(3-10)	.2	.2	.2	.2	.1	.2	1	1	.2	.2	5	1
41	(2-3)	.2	5	.2	5	10	5	.2	5	1	1	1	1
42	(6-10)	.2	5	.2	1	1	1	.2	1	1	1	.2	1
43	(9-8)	5	1	1	1	.2	1	1	5	1	5	1	1
44	(4-5)	1	.2	.2	5	.1	.2	5	1	1	.2	1	1
45	(7-3)	.2	5	5	5	5	5	10	5	1	1	5	1

Appendix E: Ordnance Corps Paired Comparison Data

Criteria Paired Comparison

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	5	1	.1	.1	10	5	5	5	5	.2	1	5
2	(5-1)	.2	1	10	10	1	5	10	1	1	5	5	.2
3	(6-5)	.1	1	.1	.1	.2	.1	.1	1	1	.2	.2	5
4	(4-2)	5	5	5	5	10	5	5	5	5	10	5	10
5	(3-4)	10	1	10	10	.2	.2	.2	5	1	1	1	.2
6	(1-4)	5	5	.1	.1	.2	.1	.1	1	5	1	1	.2
7	(6-2)	5	1	.1	.1	5	5	1	1	5	1	5	5
8	(3-6)	10	5	10	10	5	5	10	1	1	5	5	5
9	(4-6)	1	1	10	10	5	10	5	5	1	5	5	5
10	(2-3)	.1	.2	.1	.1	.2	.1	.2	.2	.2	.2	.2	.2
11	(1-3)	.1	1	.1	.1	5	.2	5	1	1	1	1	5
12	(6-1)	5	5	1	1	.2	.2	1	1	1	.2	.2	.2
13	(2-5)	.2	5	1	1	.2	.1	.1	.2	.2	1	.1	.2
14	(5-3)	.1	.2	1	1	5	5	10	1	1	1	5	.2
15	(4-5)	10	1	.1	.1	5	.2	.2	1	5	1	.2	5

Attribute Paired Comparison

Increase Personnel and Environmental Safety.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	1	5	1	1	5	5	.2	1	5	1	1	.2
2	(10-5)	.2	1	1	.2	.2	.1	.2	.2	1	1	.2	.2
3	(7-9)	.2	5	1	1	1	.2	1	1	1	1	1	.2
4	(1-4)	10	5	10	5	5	10	5	5	5	5	1	5
5	(3-6)	1	1	1	1	1	.2	.2	.2	1	1	.2	1
6	(8-2)	.1	1	.1	.1	.2	.1	.2	.2	5	.2	5	.2
7	(2-9)	10	5	10	10	5	10	5	5	1	1	.2	.2
8	(10-2)	.1	1	.1	.2	.2	.1	.2	.2	5	1	1	.2
9	(10-4)	5	1	1	1	1	1	5	1	1	5	1	1
10	(9-6)	5	1	5	1	1	5	5	5	.2	1	1	1
11	(8-1)	5	1	5	1	1	5	.2	5	1	.2	5	1
12	(5-3)	10	1	10	5	5	10	5	5	.2	1	5	5
13	(2-7)	10	.2	10	5	5	10	1	5	1	1	1	5
14	(10-1)	5	1	10	1	1	1	1	5	1	1	1	1
15	(1-6)	10	5	10	5	5	10	5	5	1	1	.2	5
16	(6-7)	.2	1	1	1	1	5	1	1	1	1	1	1
17	(5-9)	5	1	1	1	1	10	5	5	1	1	.2	5
18	(8-7)	1	1	.2	1	1	1	.2	1	1	1	1	5
19	(3-4)	5	5	.2	.2	1	.2	5	1	1	1	1	.2
20	(6-2)	.1	5	.1	.2	.2	.2	.2	.2	5	1	5	.2
21	(10-9)	1	5	1	1	1	.2	1	1	5	1	1	.2
22	(5-6)	5	1	5	1	1	5	5	5	.2	1	1	5
23	(7-5)	.2	1	.2	1	1	.1	.2	.2	5	1	1	.2
24	(5-8)	10	1	10	5	1	10	5	5	.2	5	5	5
25	(6-8)	1	.2	5	1	1	5	5	1	5	5	1	.2

26	(1-3)	10	.2	10	10	5	10	5	5	1	5	5	5
27	(2-5)	5	1	10	10	5	5	.2	1	5	1	.2	5
28	(8-10)	1	5	.2	1	1	5	.2	1	.2	1	.2	5
29	(1-5)	10	1	10	10	5	5	.2	1	5	1	.2	.2
30	(4-7)	1	1	1	1	1	.2	.2	1	1	.2	1	1
31	(8-4)	1	1	.2	1	1	5	1	1	.2	1	1	5
32	(4-9)	1	5	1	5	1	.2	.2	1	10	.2	1	.2
33	(4-2)	.1	5	.1	.1	.2	.1	.2	.2	5	.2	5	.2
34	(7-1)	.1	5	.1	.1	.2	.1	.2	.2	1	1	5	.2
35	(10-7)	5	5	1	1	1	.2	1	1	5	1	1	1
36	(9-1)	.1	5	.1	.1	.2	.1	5	1	.1	1	5	.2
37	(6-4)	1	1	1	1	1	5	5	.2	1	5	1	1
38	(3-8)	.2	5	5	.2	1	.2	1	.2	5	1	.2	.2
39	(9-3)	5	1	5	5	1	5	5	5	.2	1	5	5
40	(3-10)	.1	1	.2	1	1	.2	.2	.2	1	1	.2	1
41	(2-3)	10	1	10	10	5	10	5	5	.2	1	5	5
42	(6-10)	.2	1	1	1	1	5	.2	1	1	1	1	1
43	(9-8)	1	1	5	1	1	5	5	1	.2	5	1	5
44	(4-5)	.2	1	.2	.2	1	.1	.1	.2	5	.2	.2	.2
45	(7-3)	5	1	5	1	1	5	5	5	.2	1	5	1

<u>Increase Tactical Capability of Users</u>.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	10	1	1	1	.2	5	.2	1	5	1	.2	1
2	(10-5)	5	.2	.2	.2	5	10	.2	.2	5	1	.2	5
3	(7-9)	5	5	.2	5	.2	.2	1	1	.2	1	.2	.2
4	(1-4)	5	5	10	5	.2	5	1	1	1	5	.2	.2
5	(3-6)	.1	1	.2	10	1	.2	1	.2	5	1	.2	1
6	(8-2)	1	5	.2	.1	5	5	.2	5	5	1	5	5
7	(2-9)	5	5	5	10	.2	.2	.2	1	.2	1	.2	.2
8	(10-2)	5	5	.2	.2	5	10	5	1	1	1	5	5
9	(10-4)	.1	1	1	5	5	10	5	1	1	5	5	.2
10	(9-6)	5	1	5	10	5	10	5	1	.2	1	1	5
11	(8-1)	5	5	5	.1	5	10	1	1	.2	1	5	.2
12	(5-3)	10	5	10	5	5	10	10	5	.2	1	5	5
13	(2-7)	1	.2	1	5	.2	.2	.2	5	1	1	.2	5
14	(10-1)	5	5	5	.2	5	10	5	1	1	1	5	5
15	(1-6)	10	1	1	5	1	.2	1	5	5	1	.2	.2
16	(6-7)	.2	1	1	.2	1	1	.2	1	.2	1	1	5
17	(5-9)	.1	5	10	5	1	1	5	1	.2	1	5	.2
18	(8-7)	.1	1	.2	.2	5	1	.2	1	.2	1	1	5
19	(3-4)	.1	.2	.2	5	.2	.2	1	.2	1	5	.2	.2
20	(6-2)	1	5	1	.2	1	.2	5	.2	5	1	5	5
21	(10-9)	10	5	5	5	1	10	1	.2	1	1	1	.2
22	(5-6)	5	1	10	5	1	10	5	10	.2	1	5	5
23	(7-5)	5	1	.1	.2	1	.1	.2	.1	5	1	.2	.2
24	(5-8)	1	1	10	5	.2	10	10	5	.2	5	5	5
25	(6-8)	1	1	5	5	.2	.2	5	.2	1	1	1	5
26	(1-3)	5	.2	10	.2	1	10	5	5	1	1	.2	5
27	(2-5)	1	.2	.2	5	.2	.2	.1	1	1	1	.2	.2
28	(8-10)	.2	.2	.2	.2	1	.1	.2	1	.2	1	.2	5

29	(1-5)	10	.2	1	5	1	.2	.2	.2	5	1	.2	.2
30	(4-7)	1	1	1	.2	.2	1	.2	1	1	.2	1	5
31	(8-4)	1	1	.2	.2	5	5	1	1	.2	5	1	.2
32	(4-9)	1	5	1	5	.2	.2	.2	1	5	.2	1	.2
33	(4-2)	.2	5	.2	.2	5	.2	.2	1	5	.2	5	5
34	(7-1)	5	5	.2	.2	1	.2	5	.2	.2	1	5	.2
35	(10-7)	1	1	1	5	5	10	1	1	1	1	1	5
36	(9-1)	.1	.2	.2	.2	5	1	5	1	.2	1	5	5
37	(6-4)	.2	5	1	5	1	1	5	1	1	5	1	.2
38	(3-8)	1	5	5	5	.2	.1	1	.2	5	1	5	.2
39	(9-3)	5	1	1	5	5	10	5	5	1	1	1	5
40	(3-10)	.1	.2	.2	5	.2	.1	5	.2	.2	1	.2	.2
41	(2-3)	5	5	5	5	5	10	5	5	1	1	.2	5
42	(6-10)	.2	1	.2	.2	.2	.1	.2	1	.2	1	1	5
43	(9-8)	5	.2	1	.2	1	1	5	1	1	1	1	5
44	(4-5)	5	5	.1	.2	1	.1	.1	.2	5	.2	.2	.2
45	(7-3)	5	5	1	5	5	5	5	1	1	1	1	5

Increase Operational Capability of Logistics.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	1	1	1	1	1	1	.2	.2	1	1	.2	.2
2	(10-5)	10	5	1	5	1	5	.2	1	5	1	1	.2
3	(7-9)	1	5	1	5	1	5	5	1	5	1	1	.2
4	(1-4)	.2	5	.2	.2	.2	.2	5	1	1	1	.2	.2
5	(3-6)	.2	5	.2	1	5	.1	5	.2	1	1	1	1
6	(8-2)	5	5	1	5	5	5	.2	1	5	1	.2	1
7	(2-9)	.2	.2	.2	.2	1	.2	.2	1	1	1	.2	.2
8	(10-2)	10	5	5	5	5	10	1	1	5	1	5	.2
9	(10-4)	1	.2	1	.2	1	10	5	1	1	1	1	.2
10	(9-6)	5	1	1	1	5	5	1	1	.2	1	1	5
11	(8-1)	5	.2	.2	1	5	5	.2	1	.2	1	1	5
12	(5-3)	10	5	10	5	5	10	5	5	.2	1	1	5
13	(2-7)	.2	.2	.2	.2	.2	.2	1	1	.2	1	.2	5
14	(10-1)	10	5	.2	1	5	10	1	1	1	1	5	5
15	(1-6)	.2	5	.2	.2	1	1	5	1	5	1	.2	5
16	(6-7)	1	1	1	.2	1	.2	.2	1	1	1	1	5
17	(5-9)	.2	5	1	.2	1	5	1	.2	1	1	1	5
18	(8-7)	.2	1	.2	.2	5	.2	.2	1	1	1	1	5
19	(3-4)	.1	1	.2	.2	.2	.2	5	.2	1	1	.2	.2
20	(6-2)	5	5	5	.2	1	1	1	1	5	1	5	.2
21	(10-9)	1	5	1	1	1	10	1	1	10	1	1	.2
22	(5-6)	5	1	1	5	5	10	1	1	.1	1	.2	5
23	(7-5)	5	1	1	5	.2	.2	.2	1	10	1	1	.2
24	(5-8)	1	1	5	.2	5	5	5	1	.1	1	1	5
25	(6-8)	1	1	5	.2	.2	.2	5	1	1	1	1	5
26	(1-3)	1	.2	5	1	5	5	5	1	1	1	.2	5
27	(2-5)	.2	1	.1	.2	.2	.1	.2	1	1	1	5	.2
28	(8-10)	.2	1	.1	.2	1	.1	.2	1	.2	1	.2	1
29	(1-5)	.2	5	.1	.2	.2	.1	.2	.2	10	1	.2	.2
30	(4-7)	1	1	1	5	1	.2	.2	1	1	1	1	5
31	(8-4)	.2	1	.1	.2	1	5	1	1	.2	1	.2	.2

32	(4-9)	1	5	1	.2	1	1	.2	1	5	1	1	.2
33	(4-2)	5	1	5	1	5	1	.2	1	5	1	5	5
34	(7-1)	5	5	5	5	5	5	.2	1	1	1	5	.2
35	(10-7)	5	1	1	5	1	10	1	1	5	1	1	5
36	(9-1)	5	.2	5	5	5	5	.2	5	.1	1	5	5
37	(6-4)	1	1	1	.2	.2	5	1	1	1	1	1	.2
38	(3-8)	.2	.2	.2	.2	.2	.1	1	.2	5	1	5	1
39	(9-3)	5	.2	10	5	5	5	5	5	.2	1	1	5
40	(3-10)	.1	.2	.1	.2	.2	.1	.2	.2	1	1	.2	1
41	(2-3)	.2	.2	5	5	5	5	5	5	.2	1	.2	5
42	(6-10)	.2	5	1	.2	.2	.1	.2	1	.2	1	.2	1
43	(9-8)	1	1	5	1	1	.1	5	1	1	1	5	5
44	(4-5)	5	1	1	1	.2	.1	.2	1	5	1	1	5
45	(7-3)	5	5	10	5	5	10	5	5	1	1	1	1

Reduce Logistics Burden.

N	PAIR	1	2	3	4	5	6	7	8	9	10	11	12
1	(1-2)	10	1	1	1	1	.1	.2	1	5	1	.2	1
2	(10-5)	10	1	1	.2	1	.1	1	.2	5	1	5	.2
3	(7-9)	1	5	5	10	.2	10	1	1	5	1	1	1
4	(1-4)	.2	1	.2	.2	.2	.1	.2	.2	1	5	.2	.2
5	(3-6)	10	.2	.1	.2	5	.2	.2	.2	1	1	1	.2
6	(8-2)	10	5	10	1	5	.2	.2	5	5	.2	.2	5
7	(2-9)	.2	.2	.1	5	.2	.2	.2	.2	1	1	.2	.2
8	(10-2)	10	5	.2	5	5	5	5	5	5	1	5	5
9	(10-4)	1	1	1	.2	.2	.2	5	1	1	5	1	.2
10	(9-6)	1	.2	.1	1	5	.1	1	.1	.2	1	1	1
11	(8-1)	1	.2	.1	.2	5	.1	.2	.2	1	.2	5	1
12	(5-3)	5	5	10	1	5	10	5	10	.2	1	.2	5
13	(2-7)	.2	.2	.2	.2	5	.2	.2	.2	1	5	.2	.2
14	(10-1)	1	5	1	.2	5	.1	1	1	1	1	5	1
15	(1-6)	.2	.2	1	.2	5	.1	.2	1	1	1	.2	.2
16	(6-7)	1	1	1	.2	5	10	1	1	1	1	1	1
17	(5-9)	1	5	1	10	5	10	1	5	.2	1	.2	5
18	(8-7)	1	1	1	.1	5	.2	.2	1	1	.2	.2	5
19	(3-4)	.2	.2	.2	1	.2	.2	.2	.2	1	5	1	.2
20	(6-2)	5	5	5	.2	5	10	5	1	5	1	5	1
21	(10-9)	1	5	5	5	1	5	1	1	5	1	1	.2
22	(5-6)	1	1	5	5	1	5	5	5	.2	1	.2	5
23	(7-5)	1	1	.2	5	.2	.1	.2	.2	5	1	5	.2
24	(5-8)	5	1	5	5	5	10	5	1	.2	5	.2	5
25	(6-8)	5	1	10	5	5	10	5	.2	1	5	1	5
26	(1-3)	1	.2	1	5	1	5	1	.2	1	1	.2	5
27	(2-5)	.2	.2	.2	10	.2	.1	.2	.2	5	1	5	.2
28	(8-10)	.2	5	.2	.2	.2	5	.2	1	1	.2	1	5
29	(1-5)	.2	.2	.2	5	.2	.1	.1	.2	10	1	.2	.2
30	(4-7)	1	1	1	.2	5	1	.2	1	1	.2	1	5
31	(8-4)	1	1	1	.2	.2	.2	1	5	.2	1	1	.2
32	(4-9)	1	1	1	5	.2	5	.2	1	5	.2	1	5
33	(4-2)	10	5	1	.2	5	5	1	5	5	.2	5	5
34	(7-1)	5	5	1	.2	1	5	5	5	1	1	5	5

35	(10-7)	1	1	1	.2	5	.2	1	1	1	1	1	5
36	(9-1)	5	5	1	.2	5	5	5	5	.2	1	5	5
37	(6-4)	1	1	1	.2	.2	10	1	1	.2	5	1	.2
38	(3-8)	.2	1	1	5	1	.2	1	.2	1	5	5	.2
39	(9-3)	5	1	5	.2	5	5	5	5	.2	1	1	5
40	(3-10)	.1	1	.2	5	.2	.2	.2	.2	1	1	1	.2
41	(2-3)	1	.2	1	5	5	5	1	1	1	1	.2	5
42	(6-10)	1	1	1	.2	.2	10	.2	1	1	1	1	5
43	(9-8)	1	5	5	5	1	1	5	1	.2	5	1	5
44	(4-5)	1	1	1	.2	.2	.1	.1	.2	5	.2	5	.2
45	(7-3)	5	1	1	5	5	10	5	1	1	1	5	5

<u>Appendix F: Paired Comparison and Scoring Matrices Spread Sheet</u>

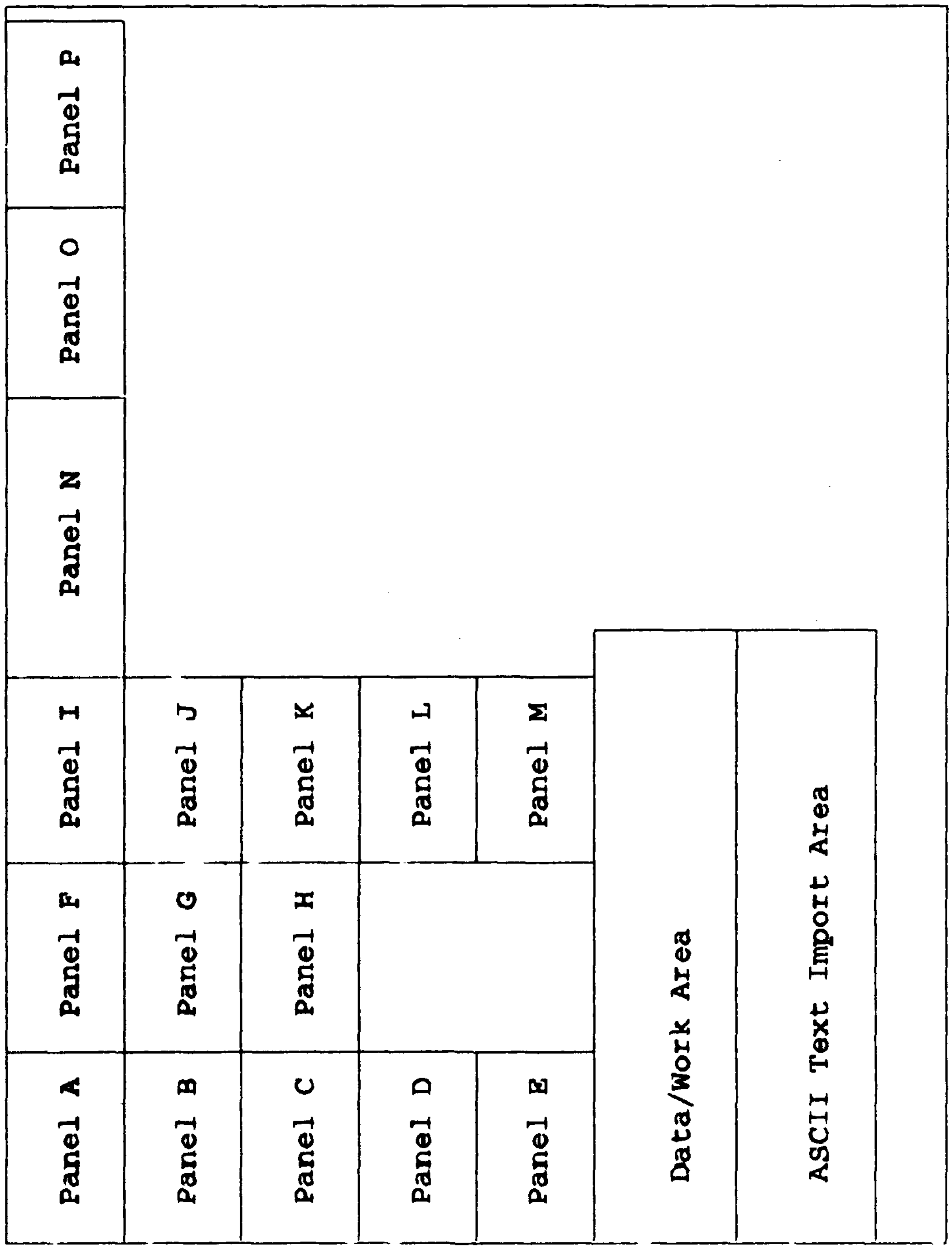

Figure 26. Spreadsheet Map

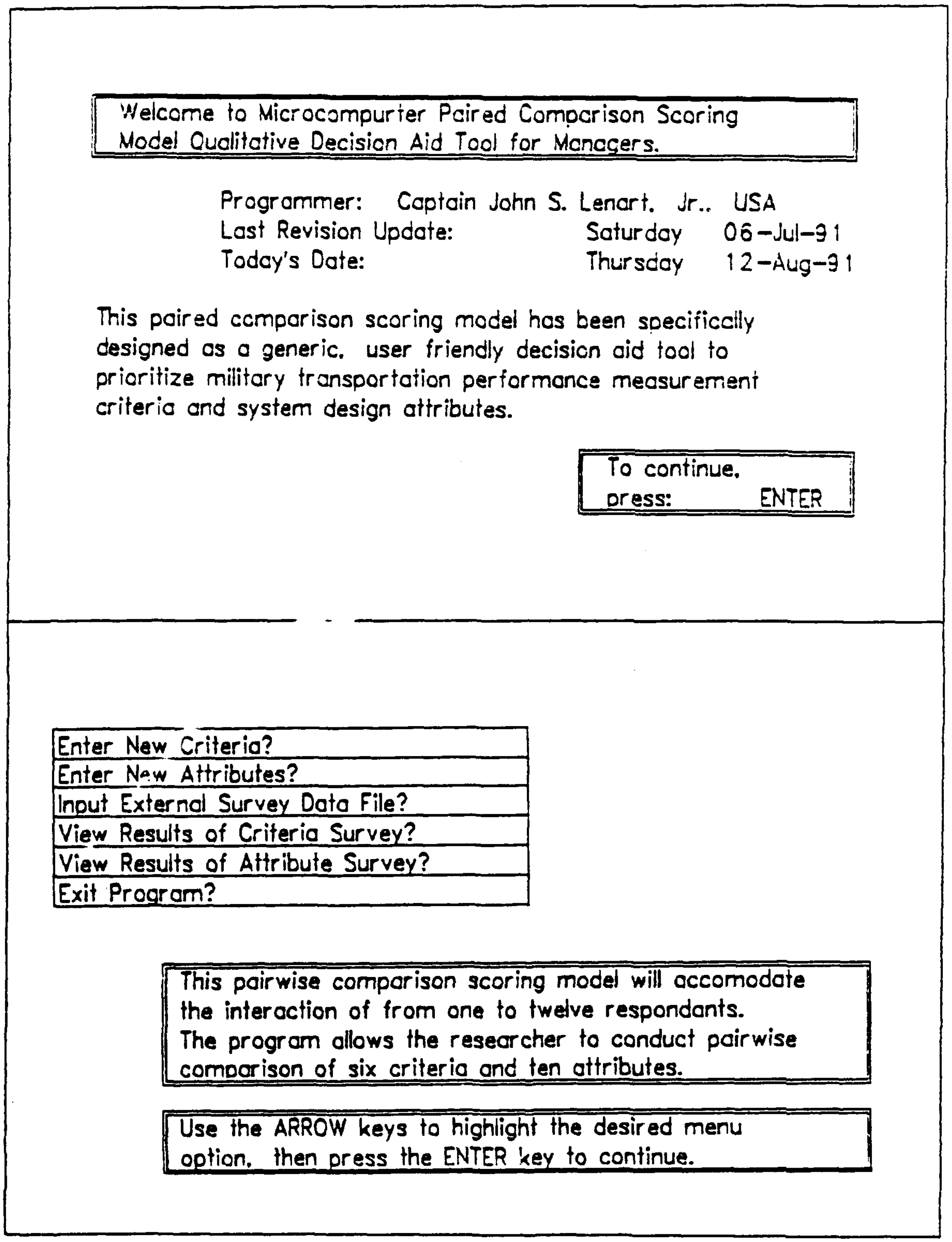

Figure 27. Spreadsheet Panel A (Welcome Screen) and B (Main Menu)

Select Criteria?
Print Criteria Ranking Table?
Return to Main Menu?

The criteria have been rank ordered by the paired comparison technique. This ranking has been determined by selected experts in the field.

3	Increase Personnel and Environmental Safety	0.2793
4	Increase Operational Capability of Logistics	0.2510
5	Increase Tactical Capability of Users	0.1739
1	Reduce Logistics Burden	0.1361
6	Low Cost to Implement	0.0910
2	No Customized Technology	0.0687

Criteria to be used in the paired comparison survey:

Criteria #1	0.2793
#2	0.2510
#3	0.1739
#4	0.1361

Print Attribute Ranking Table?
Return to Main Menu?

The attributes have been weighted by all criteria and then ranked on a scale of 0 to 100. This table presents the ranking as determined by selected experts in the field.

1	High Reliability and Maintainability	100
2	Compatable between Modes of Transport	85
3	Provide HazMat Containment Training	69
4	Quick Transfer Speed at ASP and ATP	62
5	Provide HazMat Contingency Equipment	56
6	Use Current Handling and Transport Equipment	54
7	Capable of Automated and Manual Handling	45
8	Compatible with Allied Equipment	45
9	Design Flat Racks for Multipurpose Use	2
10	No Increase in Manpower	0

Figure 28. Spreadsheet Panel C (Criteria Ranking) and D (Attribute Ranking)

0	1	2	3	4	5	6
Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday

Enter your new criteria. Use the ARROW keys to move within the blocks, and then the F2 key to enter or edit a line. Each line is limited to 24 characters. Press the ENTER key ONLY when finished entering all six criteria (12 blocks) to return to the main menu screen.

1	Reduce Logistics Burden
2	No Customized Technology
3	Increase Personnel and Environmental Safety

4	Increase Operational Capability of Logistics
5	Increase Tactical Capability of Users
6	Low Cost to Implement

Figure 29. Spreadsheet Panel E (Date Lookup) and F (Criteria Entry)

Please enter your new attributes. Use the ARROW keys to move within the blocks, and the F2 key to enter or edit a line. Each line is limited to 24 characters. Press the ENTER key to continue.

1	Provide HazMat Containment Training	6	Use Current Handling and Transport Equipment
2	Provide HazMat Contingency Equipment	7	Compatable between Modes of Transport
3	No Increase in Manpower	8	Compatible with Allied Equipment
4	Design Flat Racks for Multipurpose Use	9	Capable of Automated and Manual Handling
5	High Reliability and Maintainability	10	Quick Transfer Speed at ASP and ATP

Enter your data disk path and file name in the block. Use the F2 key to enter or edit the name. Press the ENTER key to continue.

A:\ATDATA.PRN

To return to the main menu and view the results of the paired comparison matrices, press: ENTER

Figure 30. Spreadsheet Panel G (Attribute Entry) and H (ASCII Data File Entry)

	Criteria	1	2	3	4	5	6	Row Totals	
1	Reduce Logistics Burden		34.4	19.8	12.6	20.6	43.6	131.0	0.1361
2	No Customized Technology	15.2		9.0	2.6	8.5	30.8	66.1	0.0687
3	Increase Personnel and Environmental Safety	39.6	73.2		49.5	39.6	67.0	268.9	0.2793
4	Increase Operational Capability of Logistics	37.2	86.0	24.6		39.6	54.2	241.6	0.2510
5	Increase Tactical Capability of Users	35.6	62.2	19.8	19.8		30.0	167.4	0.1739
6	Low Cost to Implement	19.0	25.4	3.7	10.1	29.4		87.6	0.0910
	Column Totals	146.6	281.2	76.9	94.6	137.7	225.6	Grand Total 962.6	1.0000

Figure 31. Spreadsheet Panel I (Criteria Matrix)

	Increase Personnel and Environmental Safety	First Attribute Survey 1	2	3	4	5	6	7	8	9	10	Row Totals	
1	Provide HazMat Containment Training		25.0	58.2	38.6	49.2	53.6	41.2	30.4	49.2	34.4	379.8	0.1611
2	Provide HazMat Contingency Equipment	10.3		44.2	46.6	43.4	56.6	27.9	42.4	25.6	43.8	340.8	0.1446
3	No Increase in Manpower	9.3	10.3		36.2	8.5	18.1	15.9	15.9	15.8	17.5	147.5	0.0626
4	Design Flat Racks for Multipurpose Use	19.1	17.5	11.9		9.5	12.0	8.7	12.8	15.9	23.2	130.6	0.0554
5	High Reliability and Maintainability	10.2	14.3	62.2	48.2		53.6	29.6	31.2	31.4	41.0	321.7	0.1365
6	Use Current Handling and Transport Equipment	18.8	17.3	52.6	31.2	18.8		15.0	18.4	24.7	29.6	226.4	0.0961
7	Compatable between Modes of Transport	11.8	33.0	35.4	33.0	20.0	44.4		20.0	26.4	27.2	251.2	0.1066
8	Compatible with Allied Equipment	16.0	13.6	35.4	27.2	12.0	18.4	10.4		22.4	19.2	174.6	0.0741
9	Capable of Automated and Manual Handling	10.2	20.8	40.4	35.4	16.7	29.8	16.8	17.6		31.2	218.9	0.0929
10	Quick Transfer Speed at ASP and ATP	15.2	23.7	27.4	32.8	7.1	20.0	12.8	14.4	12.0		165.4	0.0702
	Column Totals	120.9	175.5	367.7	329.2	185.2	306.5	178.3	203.1	223.4	267.1	Grand Total 2356.9	1.0000

Figure 32. Spreadsheet Panel J (First Attribute Matrix)

	Increase Operational Capability of Logistics	Second Attribute Survey 1	2	3	4	5	6	7	8	9	10	Row Totals	
1	Provide HazMat Containment Training		16.0	39.4	28.0	14.4	13.5	9.6	16.8	17.6	19.9	175.2	0.0837
2	Provide HazMat Contingency Equipment	11.2		38.4	22.4	13.6	19.4	9.4	12.8	20.0	19.2	166.4	0.0795
3	No Increase in Manpower	15.1	14.4		20.8	10.3	16.8	10.2	15.0	11.9	16.0	130.5	0.0624
4	Design Flat Racks for Multipurpose Use	42.7	36.8	25.6		15.8	12.0	8.0	13.6	8.8	16.7	180.0	0.0860
5	High Reliability and Maintainability	38.4	42.4	44.2	40.4		19.2	16.0	32.8	20.0	18.4	271.8	0.1299
6	Use Current Handling and Transport Equipment	47.4	38.3	26.4	31.2	14.4		16.0	16.8	25.6	12.8	228.9	0.1094
7	Compatable between Modes of Transport	43.2	53.2	49.2	32.0	11.2	11.2		20.0	27.2	19.2	266.4	0.1273
8	Compatible with Allied Equipment	26.4	46.4	44.4	23.2	23.2	26.4	10.4		18.4	18.4	237.2	0.1133
9	Capable of Automated and Manual Handling	22.4	29.6	36.2	28.0	10.4	20.8	12.8	18.4		15.2	193.8	0.0926
10	Quick Transfer Speed at ASP and ATP	34.6	33.6	30.4	31.4	37.6	27.2	14.4	18.4	15.2		242.8	0.1160
	Column Totals	281.4	310.7	334.2	257.4	150.9	166.5	106.8	164.6	164.7	155.8	Grand Total 2093.0	1.0000

Figure 33. Spreadsheet Panel K (Second Attribute Matrix)

	Increase Tactical Capability of Users	Third Attribute Survey 1	2	3	4	5	6	7	8	9	10	Row Totals	
1	Provide HazMat Containment Training		14.4	21.0	41.0	10.4	32.2	15.2	25.6	16.8	19.9	198.5	0.0857
2	Provide HazMat Contingency Equipment	19.2		25.6	27.2	10.4	28.2	19.2	8.6	20.0	14.2	172.6	0.0753
3	No Increase in Manpower	30.3	20.8		30.2	9.5	16.8	27.9	12.8	23.2	16.8	197.3	0.0861
4	Design Flat Racks for Multipurpose Use	28.3	32.0	10.4		19.1	8.0	10.3	19.2	14.4	13.4	153.1	0.0668
5	High Reliability and Maintainability	39.2	30.2	40.2	38.6		30.4	22.4	21.8	36.4	20.6	296.6	0.1294
6	Use Current Handling and Transport Equipment	31.9	32.7	26.4	32.0	16.0		10.0	21.6	28.8	20.0	219.4	0.0957
7	Compatable between Modes of Transport	34.4	33.6	33.0	44.2	17.6	59.2		18.4	35.6	13.6	289.6	0.1263
8	Compatible with Allied Equipment	20.8	57.2	27.2	33.6	21.6	21.6	18.4		16.8	21.6	238.8	0.1042
9	Capable of Automated and Manual Handling	26.4	29.6	13.6	38.4	16.6	24.0	20.8	26.4		20.8	216.4	0.0944
10	Quick Transfer Speed at ASP and ATP	34.6	40.4	26.4	52.4	35.6	29.6	23.2	21.6	40.3		312.1	0.1361
	Column Totals	283.1	307.9	231.8	346.6	158.8	250.0	167.2	175.8	232.3	160.9	Grand Total 2292.4	1.0000

Figure 34. Spreadsheet Panel L (Third Attribute Matrix)

	Reduce Logistics Burden	Fourth Attribute Survey 1	2	3	4	5	6	7	8	9	10	Row Totals	
1	Provide HazMat Containment Training		19.2	22.6	31.0	10.4	21.0	11.1	27.2	14.3	30.4	188.1	0.0863
2	Provide HazMat Contingency Equipment	14.4		34.6	37.8	14.4	24.4	15.2	18.2	20.8	23.2	203.0	0.0932
3	No Increase in Manpower	22.3	19.9		24.8	23.1	19.9	9.5	28.7	9.6	9.5	167.3	0.0768
4	Design Flat Racks for Multipurpose Use	46.9	23.1	24.8		15.0	15.1	8.0	17.5	11.0	8.7	171.9	0.0789
5	High Reliability and Maintainability	39.2	38.4	37.8	35.4		26.6	8.7	19.2	14.4	14.2	233.9	0.1073
6	Use Current Handling and Transport Equipment	30.3	38.2	34.6	39.4	21.5		8.8	18.4	21.8	12.8	225.6	0.1035
7	Compatable between Modes of Transport	40.2	34.4	48.2	32.0	33.0	28.0		16.0	24.0	14.4	270.2	0.1240
8	Compatible with Allied Equipment	12.8	47.6	29.0	27.4	33.6	18.4	11.2		13.6	18.4	212.0	0.0973
9	Capable of Automated and Manual Handling	43.4	25.6	43.2	36.2	19.2	21.6	9.6	23.2		18.3	240.3	0.1103
10	Quick Transfer Speed at ASP and ATP	16.0	32.8	48.2	33.0	48.4	27.2	19.2	18.4	23.4		266.6	0.1224
	Column Totals	285.5	270.2	323.0	207.9	219.5	202.2	101.3	186.8	153.6	140.0	Grand Total 2178.0	1.0000

Figure 35. Spreadsheet Panel M (Fourth Attribute Matrix)

	Criteria / Attributes	Increase Personnel and Environmental Safety	Increase Operational Capability of Logistics	Increase Tactical Capability of Users	Reduce Logistics Burden	Total Across Rows	As a % of Grand Total	Scale of 0 to 100
1	Provide HazMat Containment Training	0.1611 • 0.2793 = 0.0450	0.0837 • 0.2510 = 0.0210	0.0857 • 0.1739 = 0.0149	0.0863 • 0.1361 = 0.0117	0.0927	0.1103	69
2	Provide HazMat Contingency Equipment	0.1446 • 0.2793 = 0.0404	0.0795 • 0.2510 = 0.0200	0.0753 • 0.1739 = 0.0131	0.0932 • 0.1361 = 0.0127	0.0861	0.1025	56
3	No Increase in Manpower	0.0626 • 0.2793 = 0.0175	0.0624 • 0.2510 = 0.0157	0.0861 • 0.1739 = 0.0150	0.0768 • 0.1361 = 0.0105	0.0586	0.0697	0
4	Design Flat Racks for Multipurpose Use	0.0554 • 0.2793 = 0.0155	0.0860 • 0.2510 = 0.0216	0.0668 • 0.1739 = 0.0116	0.0789 • 0.1361 = 0.0107	0.0594	0.0707	2
5	High Reliability and Maintainability	0.1365 • 0.2793 = 0.0381	0.1299 • 0.2510 = 0.0326	0.1294 • 0.1739 = 0.0225	0.1073 • 0.1361 = 0.0146	0.1078	0.1283	100
6	Use Current Handling and Transport Equipment	0.0961 • 0.2793 = 0.0268	0.1094 • 0.2510 = 0.0275	0.0957 • 0.1739 = 0.0166	0.1035 • 0.1361 = 0.0141	0.0850	0.1012	54
7	Compatable between Modes of Transport	0.1066 • 0.2793 = 0.0298	0.1273 • 0.2510 = 0.0320	0.1263 • 0.1739 = 0.0220	0.1210 • 0.1361 = 0.0169	0.1006	0.1197	85
8	Compatible with Allied Equipment	0.0741 • 0.2793 = 0.0207	0.1133 • 0.2510 = 0.0284	0.1042 • 0.1739 = 0.0181	0.0973 • 0.1361 = 0.0132	0.0805	0.0958	45
9	Capable of Automated and Manual Handling	0.0929 • 0.2793 = 0.0259	0.0926 • 0.2510 = 0.0232	0.0944 • 0.1739 = 0.0164	0.1103 • 0.1361 = 0.0150	0.0806	0.0950	45
10	Quick Transfer Speed at ASP and ATP	0.0702 • 0.2793 = 0.0196	0.1160 • 0.2510 = 0.0291	0.1361 • 0.1739 = 0.0237	0.1224 • 0.1361 = 0.0167	0.0890	0.1060	82
	Column Totals	0.2793	0.2510	0.1739	0.1361	Grand Total 0.8104	1.0000	

Figure 36. Spreadsheet Panel N (Scoring Model)

```
\0   {Home}~{GOTO}G15~{?}~{GOTO}A17~              Startup "Welcome" screen
     /xmmenu1~

\a   {/ Block;Erase}C536..N730~                    Import ASCII data file
     {/ Block;Copy}N34~BH7~{GOTO}A536~
     {/ File;ImportText}{CLEAR}
     A:\ATDATA.PRN
     ~
     {GOTO}A536~/tpr~cLA536..A731~o~
     {d}~g~{GOTO}A536~{u}/edr~
     /eeA731..N732~/sarA536..N730~
     /ecA536..N730~A300..N494~                     Copy imported ASCII data
     /sarA300..N494~{GOTO}I29~{GOTO}M39~             file to work area
     {?}~{GOTO}A17~/xmmenu1~                       Return to main menu

\b   {LET B38, (@S(K8)&" "&@S(K9))}~               Writes criteria ranking table
     {LET H38, 23}~
     {LET B39, (@S(K10)&" "&@S(K11))}~
     {LET H39, Z5}~
     {LET B40, (@S(K12)&" "&@S(K13))}~
     {LET H40, Z7}~
     {LET B41, (@S(N8)&" "&@S(N9))}~
     {LET H41, Z9}~
     {LET B42, (@S(N10)&" "&@S(N11))}~
     {LET H42, Z11}~
     {LET B43, (@S(N12)&" "&@S(N13))}~
     {LET H43, Z13}~
     {LET A38, J8}~{LET A39, J10}~
     {LET A40, J12}~{LET A41, M8}~
     {LET A42, M10}~{LET A43, M12}~
     {GOTO}H44~{/ Block;Erase}{DOWN 3}~
     {GOTO}A33~{GOTO}H44~/xmmenu2~

\c   {LET B57, (@S(AH3)&" "&@S(AH4))}~             Writes attribute ranking
     {LET H57, BE4}~                                 table
     {LET B58, (@S(AH5)&" "&@S(AH6))}~
     {LET H58, BE6}~
     {LET B59, (@S(AH7)&" "&@S(AH8))}~
     {LET H59, BE8}~
     {LET B60, (@S(AH9)&" "&@S(AH10))}~
     {LET H60, BE10}~
     {LET B61, (@S(AH11)&" "&@S(AH12))}~
     {LET H61, BE12}~
     {LET B62, (@S(AH13)&" "&@S(AH14))}~
     {LET H62, BE14}~
     {LET B63, (@S(AH15)&" "&@S(AH16))}~
     {LET H63, BE16}~
     {LET B64, (@S(AH17)&" "&@S(AH18))}~
     {LET H64, BE18}~
     {LET B65, (@S(AH19)&" "&@S(AH20))}~
     {LET H65, BE20}~
     {LET B66, (@S(AH21)&" "&@S(AH22))}~
     {LET H66, BE22}~
     {/ Sort;Block}B57..H66~                       Sorts attribute ranking
     {/ Sort;Key1}H57..H66~~{/ Sort;Go}              table
     {GOTO}A50~/xmmenu3~

\d   {/ Sort;Block}A38..H43~                       Sorts criteria ranking table
     {/ Sort;Key1}H38..H43~~{/ Sort;Go}
     {/ Block;Copy}{ESC}{UP 6}{DOWN 3}~~           Writes criteria list for use
     /xmmenu2~                                       in the survey

\e   {GOTO}A1~{GOTO}F6~                            Updates revision day
     @VLOOKUP(@MOD(@NOW, 7),$A$93..$G$94, 1)~
     /ev~~
     {GOTO}G6~@today~/ev~~                         Updates revision date
     /fa{?}~r~/fc~                                 Exit the program

\pa  {/ Print;Block}{ESC}{HOME}{PGDN 3}.           Prints attribute ranking
     {DOWN 17}{RIGHT 7}~{/ Print;Go}                 table
     /xmmenu3~

\pc  {/ Print;Block}{ESC}{HOME}{PGDN 2}.           Prints criteria ranking
     {DOWN 16}{RIGHT 7}~{/ Print;Go}                 table
     /xmmenu2~
```

Figure 37. Spreadsheet Panel O (Spreadsheet Macros)

\z	{GOTO}A17~/xmmenu1~					
menu1	Enter New Criteri	Enter New Attribu	Input External Sur	View Results of C	View Results of A	Exit Program?
	To begin new sur	To begin new sur	Enter external da	View paired com	Ranking by all cri	Save program, update revision date, then close worksheet
	{GOTO}I1~{GOTO}K	{GOTO}I15~{GOTO}	{GOTO}I29~{GOTO}	{GOTO}A33~	{GOTO}A50~	{branch \e}~
	/xmmenu1~	/xmmenu1~	{branch \a}~	{branch \b}~	{branch \c}~	
menu2	Select Criteria?	Print Criteria Ran	Return to Main Menu?			
	Program selects	Prints results of	Return to main menu			
	{branch \d}~	{branch \pc}~	{GOTO}A17~			
			/xmmenu1~			
menu3	Print Attribute Ra	Return to Main Menu?				
	Prints results of	Return to main menu				
	{branch \pa}~	{GOTO}A17~				
		/xmmenu1~				

Figure 38. Spreadsheet Panel P (Spreadsheet Menus)

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Vita

Captain John S. Lenart, Jr. was born on 22 October 1952 in Ashtabula, Ohio. He graduated from high school in Jefferson, Ohio, in 1970. He enlisted in the Army in 1972, serving for almost ten years before receiving an Army OCS commission in November 1982. Reporting to the 233rd Transportation Company (Heavy Truck) at Fort Bliss, Texas, in March 1983, he was assigned as a truck platoon leader. His major additional duties included company operations, training, maintenance, and mobility officer. From July 1986 to August 1987, he was assigned to the Fully Funded Degree Completion Program. He attended Christopher Newport College, from which he received a degree of Bachelor of Science in Accounting, Summa Cum Laude, in August, 1987. From August 1987 to August 1988, Captain Lenart was the S-4 logistics officer of the 10th Transportation Battalion (Terminal), Fort Eustis, Virginia. He then assumed command of the 558th Transportation Company (Floating Craft General Support Maintenance and Supply Support Activity). In March 1989, Captain Lenart was assigned to the Office of the Chief of Transportation, Fort Eustis, Virginia. In May 1989, he entered the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. Captain Lenart is a graduate of the U.S. Army Transportation Officer Basic and Advance Courses.

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This study applied a screening technique methodology to systematically obtain organizational consensus in the establishment and ranking of Army surface transportation performance measurement criteria and system design attributes. This performance evaluation model was then used to assess the feasibility of three potential liquid propellant logistics concepts. Two sample groups of subject matter experts from the Army's Transportation and Ordnance (Munitions) Corps participated in the research. The methodology consisted of nominal-interacting group processes, repeated use of the paired comparison instrument, and use of a scoring model to rank-order the ten attributes. Research findings supported the Army's qualitative commitment to ensuring environmental and personnel safety, to simultaneously improve the operational capability of logistics with the tactical capability of combat forces, and to reducing the logistics burden in support of highly mobile forces. Visual and statistical examination of the rankings revealed sufficient evidence that the two sampled populations have identical probability distributions and a high degree of positive correlation. Discrete distribution was selected as the most feasible logistics concept.

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