Daily Requirements Forecasting And Transportation Optimization For Military Petroleum Products

By

Michael B. Wilson

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Signed: Michael B. Wilson
Michael B. Wilson

Approved: James W. Crafton
Dr. James W. Crafton
Thesis Advisor

Golden, Colorado

Date: April 9, 1990

Craig W. Van Kirk
Dr. Craig W. Van Kirk
Professor and Head,
Petroleum Engineering Department

ABSTRACT

In this current era of diminishing physical and fiscal resources it is imperative that the U. S. military conduct its operations in an efficient manner. History has proven that victory is most often achieved by the force which can best manage strategy, tactics, and logistics.

Wars have been won or lost because of logistics. For many centuries, feeding the soldier was the primary logistical demand. More recently, the Industrial Revolution caused ammunition to become the principal supply concern. Modern military forces consume large amounts of petroleum products in support of combat operations and training. One U. S. Army division with 16,000 personnel may require over 700,000 gallons of petroleum products each day.

The subject of this thesis research is military liquid logistics. Liquid logistics support involves forecasting, procurement, distribution, and storage of petroleum, oils, and lubricants (POL) as well as potable water. Army POL includes motor gasoline, diesel fuel, and jet propellants. The focus is on forecasting the POL requirements of U. S. Army units operating in different tactical environments and optimizing the transportation, distribution, and storage of bulk POL supply.

Tactical and logistical data is published by various Army agencies. Unit logisticians prepare fuel forecasts based exclusively on limited historical records and imprecise approximation methods. The reason is that the available published data is not coherent.

This research reveals that a relationship exists between Equipment Category Codes and Line Item Numbers. The discovery of this relationship affords both structure and coherence to large volumes of tactical and logistical data. A computer program is presented which uses this data to develop POL demand forecasts.

This thesis also provides the means to evaluate the constrained fuel resource problem once POL demands are available. The method presented can be used as a decision making tool to reduce costs and conserve valuable resources. It demonstrates that the optimal solutions to a myriad of POL transportation, distribution, and storage problems can be readily determined by very practical methods.

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Chapter 1
INTRODUCTION

The mission of the United States Department of Energy (DOE) is to ensure an adequate supply of domestic energy at acceptable costs and environmental impacts. In 1986, the DOE Secretary asked the Energy Research Advisory Board (ERAB) to identify and report the nation's geoscience research needs relative to the DOE mission. The ERAB report highlighted the rapidly declining rate of domestic oil production and the depletion of known reserves. The report also stated:

> The major energy problem facing the United States is a shortage of domestic liquid hydrocarbons, which threatens the nation's long-term energy security and international competitiveness.[1]

The shortage of domestic liquid hydrocarbons could also have a direct impact on the ability of the United States Army to conduct its mission of national defense. Modern ground and air forces are very mobile, therefore fuel intensive. Their fuel demands can only be satisfied by liquid hydrocarbon energy sources.

A single Army division with 16,000 assigned personnel may have daily liquid hydrocarbon fuel demands in excess of 700,000 gallons. The Army currently has 764,000 active soldiers and 18 divisions. In addition, 776,000 soldiers and 10 divisions constitute the Army Reserves.[2] In the event of conflict, the domestic ability to produce liquid hydrocarbon fuels may be critical for military success.

In this age of diminishing physical and fiscal domestic resources, it is imperative that the U. S. Army conduct its operations in an efficient manner. History has shown that victory is most often achieved by the force which can best manage strategy, tactics, and logistics.

The subject of this thesis research is military liquid logistics. Liquid logistics support involves forecasting, procurement, distribution, and storage of petroleum, oils, and lubricants (POL) as well as potable water. Army POL includes motor gasoline, diesel fuel, and jet propellants. The thesis focus is on forecasting the POL requirements of U. S. Army units operating in different environments and optimizing the transportation, distribution, and storage of bulk POL supply.

The word logistics stems from the Greek "logistikos" which means "skilled in calculating".[2] Logisticians have been calculating answers to the same questions throughout history. What do we need? When do we need it? Where can we get it? How should we transport, distribute, and store it? Most logisticians learn from experience that the answers to these questions are not easily determined or necessarily obvious. They also realize that finding the near optimal answers is the key to victory.

The thesis objective is to develop a method which logisticians could use to calculate the optimal solutions for POL transportation, distribution, and storage problems. The initial research effort therefore focused on the study of operations research and linear programming techniques.

Dr. E. D. Woolsey is a proponent of a "quick and dirty" method for transportation problems which uses matrices and a relatively simple iterative solution technique.[4] The method's procedure is outlined in Appendix B. This very practical technique is used in this thesis for POL resource optimization.

If one can identify costs, supply, and demand, then an optimal solution for the associated transportation problem can be found. Logisticians are often able to express POL costs by variables such as time, distance, or volume. The bulk supply of POL is based on demand forecasts developed by the consuming unit's logistician. The entire POL logistics system is dependent on the quality of these forecasts.

The consuming unit's logistician must prepare fuel forecasts based exclusively on limited historical data and imprecise approximation methods. Army FM 100-5, the guide for Army tactical doctrine, directs the logistician to develop fuel forecasts based on "experience and planning data".[5] The planning data referenced appears in FM 100-10-1 and consists of several generic approximation methods.[6] The logistician is encouraged by FM 100-5 to "consider special factors"[5], which include terrain and weather, but is not provided definitive guidance.

The consuming unit is, by definition, the battalion or company level. This unit's logistician is also at the entry level of professional logistics. He (or she) has a small staff and few technical resources at his disposal. He must daily satisfy a myriad of supply demands. The units which depend on him for their POL support expect and often require instant supply gratification. Commanders are of necessity very unforgiving of any logistical shortfalls. The dynamic nature of the battlefield does not often afford time to conduct extensive research or detailed calculations.

The thesis objective is achieved in two steps. The first step is to provide a tool which logisticians may use to forecast fuel demands more accurately. This step involves providing coherence to the large volume of data contained in FM 100-10-1, FM 100-5, and SB 710-2.[7] Unit organizational structures, equipment authorizations, fuel consumption rates, tactical operating conditions, and geographical data are compiled into a data base. A menu driven computer program enables the user to access the data and compute fuel demands for Army units under a wide variety of battlefield conditions.

The second step is to address the problem of bulk POL resource optimization. This thesis demonstrates that many apparently complex POL transportation, distribution, and storage problems are tractable. Optimal solutions can be determined by very practical methods.

It must be understood that in the context of this thesis an "optimal" solution is the mathematical solution of the problem matrix which minimizes the total cost. This solution will always be the most economical but may not always be the most useful or desirable. The logistician may need to incorporate the principles of Utility Theory[12], as postulated by von Neumann and Morgenstern.

Chapter 2

HISTORICAL PERSPECTIVE

Military historians and theorists have been obsessed with the study of strategy and tactics. The importance of logistics has not often been considered. Few would likely admit that many wars have been won or lost because of logistics. George C. Thorpe provided a very illuminating analogy:

> Strategy is to war what the plot is to a play. Tactics is represented by the role of the players. Logistics furnishes stage management, accessories, and maintenance. The audience, thrilled by the action of the play and the art of the performers, overlooks all of the cleverly hidden details of stage management.[4]

The history of military logistics can be divided into three distinct periods. The demands for food, ammunition, and fuel have successively dominated logistical planning. Analysis of each period provides useful insights regarding the importance of modern liquid logistics.

Food and the Foot Soldier

The first period spans from the beginning of recorded history through the Napoleonic Wars which ended in 1815. During this time small armies relied on the overburdened foot soldier and pack animals for supply support. Food was the primary logistical necessity.

Alexander the Great was the first military commander to skillfully organize logistical support. His exploits began in 340 B.C.. He trained soldiers to march long distances under heavy weights. Only pack animals were allowed to follow the line of march. He allowed no wagons because the poor terrain and lack of roads made them a burden. Local merchants were conscripted to purchase and requisition supplies. He precisely coordinated land marches with the movement of maritime cargoes. Alexander's appreciation of logistics enabled him to maneuver a well trained and well fed army over great distances.[8]

The Roman legions followed Alexander's example. They loaded as much as possible on the backs of their marching infantry. In addition, they constructed roads which served as principal supply routes over which wagons and pack animals could more easily travel.[9]

Through the centuries that followed the collapse of the Roman empire logistical considerations changed very little. The development of weapons such as the musket only meant that cartridge pouches were added to the weight which soldiers bore. The soldier carried his weapon, food, and all of the ammunition he was likely to use in the course of battle.

Napoleon improved logistical doctrine. He was able to increase the size of his armies by allowing his soldiers to "live off the land".[8] He reduced the foot soldier's load by organizing foraging parties which systematically plundered occupied lands. Temporary depots were often established to store looted food and supplies.

Napoleon was very successful in Italy and Germany which were relatively rich and well cultivated. The limitations of his logistical methods caused setbacks for his forces in Spain from 1807 until 1812. The ultimate defeat came in Russia where more men died from starvation and exposure than from enemy fire.

The Napoleonic Wars marked the end of the logistical period dominated by the foot soldier and his need for food. The weight of military logistics support was beginning to shift from the soldier's back and would soon burden entire national economies.

Steam and Ammunition

The second period of logistical history lasted only from the American Civil War until the end of World War I. The technology introduced by the Industrial Revolution transformed warfare. Factories produced large quantities of supplies and equipment. Steam transportation, by rail and water, made it possible to maneuver and supply much larger armies over greater distances.[3]

The Civil War was marked by the development of muzzle loaded rifled weapons produced in large quantities. A soldier could no longer carry all of the ammunition he was likely to use in the course of a day's battle. Ammunition became the most critical supply concern.

Weapon technology continued to improve during the subsequent Franco-Prussian War, 1871, and Russo-Japanese War, 1905. Muzzle loaded weapons were replaced by breech loaded weapons. At the start of World War I, 1914, the machine gun had become standard equipment in all armies. The demands for ammunition and manpower continued to increase very rapidly during this period.

Despite the technological advances, armies were still dependent on pack animals and wagons to move their supplies from railheads to the battlefield.[9] These huge armies still moved tactically at the pace of the foot soldier. However, logisticians could not forage for ammunition and weapons. Armies were much too large to be fed only from food found locally. The entire economies of industrialized nations had to be organized to support any war effort.[3]

Internal Combustion Engine and Fuel

The final period of logistics began in the closing years of World War I and extends to the present. The most revolutionary changes in logistics during this period began with the appearance of the internal combustion engine.[3] This type of engine brought with it the tank, truck, and airplane. Very large armies gained increased mobility. Continuous resupply of fuel became the principle logistical concern.

During World War II the availability of POL was the limiting factor for maneuvering armies. The German military commander General Heinz Guderian called logistics the "ball and chain of armored warfare".[10] General George Patton's armored drive across Europe in 1945 was halted prematurely because the famous Red Ball Express was unable to provide vital POL to his mechanized units. He exclaimed to General Dwight D. Eisenhower, "My men can eat their belts, but my tanks gotta have gas!".[11] Over 60 per cent of all the supply tonnage shipped by the United States overseas during this time was in the form of a single petroleum product, gasoline.[3]

The huge resupply quantities of World War II are dwarfed by today's requirements. For comparison, the fuel demands of a modern division are the same as those of a corps, a unit three to four times its size, during World War II. Today, fuel hungry, highly mobile, ground and air forces as well as mobile electric power and steam generation plants have fuel demands which can only be satisfied by providing large quantities of liquid hydrocarbon resources.

Chapter 3

COHERENCE AND STRUCTURE

Many volumes of tactical and logistical data have been published by various Army agencies. Despite an abundance of information, unit logisticians prepare fuel forecasts based exclusively on limited historical records and imprecise approximation methods. The reason is that the different Army agencies do not use common terms, each effectively speaks its own language, and provide data to logisticians which is not coherent.

The Training and Doctrine Command (TRADOC) is the proponent agency for Army tactical doctrine. TRADOC publishes FM 100-5 which defines not only tactics but also provides logistical equipment operating parameters for "types" of equipment.

The Army Logistics Center (LOGC) is responsible for publishing general logistics policy and guidance. No documents published by LOGC address the "types" of equipment used in TRADOC literature. LOGC issues SB 710-2 which provides data based on Equipment Category Codes (E/C).

The Department of the Army publishes FM 100-10-1 which provides organizational structures and identifies authorized equipment. FM 100-10-1 does not use "types" of equipment or E/C. It relies on the equipment Line Item Number (LIN).

This thesis research discovered a single thread which provides coherence to the volumes of data. The discovery of a relationship between the Equipment

Category Code (E/C) and the Line Item Number (LIN) was essential. Each E/C has a unique set of associated LIN's.

FM 101-10-1 identifies Army organizational structure and lists each authorized piece of equipment with its unique LIN. SB 710-2 provides fuel consumption data by E/C. FM 100-5 defines operating parameters for "types" of equipment as a function of geographical locations and levels of combat intensity. The "types" of equipment correspond directly to E/C. This set of relationships is the structure which makes the fuel demand forecasting problem tractable.

The POL requirements forecasting program exploits the discovered structure and coherence of the data from the three principal sources. The program is menu driven and oriented toward the inexperienced computer user. The user need only identify the unit type, geographical location, and the anticipated level of combat intensity.

The program provides the daily requirements for all petroleum fuels necessary to support Army unit personnel and equipment. The program description and loading instructions are presented in Appendix D. This forecasting program can be used for any units described in the standard Army Tables of Organization and Equipment (TO&E). It considers the principal locations to which Army units are most likely to be deployed. Official unclassified Army logistics reference data and fuel consumption information have been incorporated into the program data base.

The FM 101-10-1 provides compiled TO&E which include the authorized personnel, weapons, vehicles, and equipment for every unit from division to company level.[6] The program data base includes the organizational structure, authorized personnel, and fuel consuming equipment for all infantry, armor, artillery, and combat aviation units. Many generic combat support and combat service units are also included. The user can also combine units or change the authorized equipment to customize unique organizations.

Anticipated POL consumption rates are calculated as a function of the unit organization, fuel consuming equipment density, geographical location, and expected level of combat intensity. SB 710-2 is the primary source document for fuel usage rates.[6] FM 100-5 provides the strategic and tactical doctrine considerations necessary to account for geography and variable levels of combat intensity.[5]

Chapter 4
OPTIMIZATION

An optimal solution to fuel transportation problems can be found when demands, supply, and costs can be identified. The requirements forecasting program provides the user with anticipated fuel demands. POL supply is a direct function of forecasted demands.

The supply of bulk fuel is based on forecasts of POL requirements developed at the consuming unit level. These POL forecasts are reviewed, consolidated, and forwarded up the chain of command. To ensure adequate reaction time each forecast covers the 72 hour period beyond the next day. For example, a forecast developed on the third day should project requirements for the fifth, sixth, and seventh days. The consuming unit's logistician is routinely informed in advance of the fuel quantities which will be provided during the next delivery period. Appendix C provides a brief description of the logistics support system for POL on the battlefield.

The consuming unit's logistician must also develop a cost function. The POL costs are most often expressed as time, volume, and/or distance variables. A typical cost function is gallons per day per transported mile which can be abbreviated as gallon-miles. The unit mission, tactical situation, and standard operating procedures are used to identify the coefficients for the variable elements of the cost function.

The "quick and dirty" transportation method is used to find an optimal solution for the problem matrix which minimizes the cost function. This optimal solution may not be the most desirable or useful solution. Utility theory[12] can be employed to determine an optimal and most desirable solution.

The fundamental proposition of utility theory is that it is possible to obtain a numerical expression for any single individual's preferences. The basic assumption is that this individual behaves consistently in accordance with his or her own tastes. The unit's logistician can express the unit commander's POL desires or preferences by modifying the coefficients of the cost function.

Validation

A primary assertion of this thesis is that optimal solutions can be easily determined for a myriad of liquid logistics problems. This contention is validated by considering a hypothetical problem.

Appendix A presents a hypothetical military situation based on the deployment of an armor battalion into a hostile area. Two different solution techniques are demonstrated and analyzed. The first technique depicts the traditional solution approach which depends on limited historical data, imprecise approximation methods, and intuition. The second technique utilizes the thesis forecasting program and the "quick and dirty" transportation method.

During the five day scenario a fictitious battalion supply officer is confronted by several challenging fuel problems. He must initially forecast fuel demands and then anticipate potential shortages. Using the traditional approach, the supply officer estimates that the battalion's diesel fuel demands will be 20,900 gallons per day. The thesis forecasting program confirms that this estimate is valid only for operations in the United States. The program reveals that 22,020 gallons per day are required for combat in the Middle East.

The battalion arrives at its destination without two of its original companies and is augmented with one M1A1 tank company and a rifle company. The mission is to defend a given area for three days. POL is available based on the traditional forecast of 20,900 gallons per day.

Using the traditional solution methods, the supply officer predicts that the augmented battalion will require more POL than the original forecast. He estimates that the unit will experience a daily diesel shortfall of 1,850 gallons. The forecasting program indicates that the unit will actually have a shortfall of 3,815 gallons per day.

The supply officer is tasked to develop an efficient plan to transport, distribute, and store fuel. His plan must be modified each day in response to dynamic battlefield conditions. The battalion commander wants the headquarters unit to receive fuel supply priority. The "quick and dirty" transportation method provides an optimal solution which costs 221,198 gallon-miles. The traditional method would cost over 370,000 gallon-miles.

The M1A1 company suffers equipment losses. The supply officer would intuitively assume that any losses will increase the amount of available POL. The thesis methods indicate that the M1A1 company could lose more than 50% of its tanks without changing the optimum solution.

Chapter 6
RECOMMENDATIONS

1. The program data base should be expanded to include all Army, Air Force, and Marine Corps units and equipment.
2. The program structure should be modified to calculate ammunition, food, and water demands.
3. The program should be used as an exception reporting device at all levels of command. Consuming unit fuel requests could be verified by comparison to the program results. Many unit problems caused by otherwise unknown conditions, such as poor equipment maintenance or fuel waste, may be detected.
4. The program should be modified for use as a real time data base for reporting unit supply and repair parts status.
5. The optimization techniques should be employed at all operational levels to evaluate the constrained resource problems. The methods can be used to verify or redefine periodic procurement, maintenance, allocation, and strategic fuel reserve requirements.

Chapter 7
CONCLUSIONS

This thesis identifies the resource allocation problems associated with providing petroleum fuels to Army units. It demonstrates that the optimal solutions to a myriad of POL transportation, distribution, and storage problems can be readily determined by very practical methods.

This research reveals that a simple relationship exists between Equipment Category Codes and Line Item Numbers. The discovery of this relationship affords both structure and coherence to large volumes of tactical and logistical data. A computer program is presented which uses this data to develop POL demand forecasts.

This thesis also provides the means to evaluate the constrained fuel resource problem once POL demands are available. The method presented can be used as a decision making tool to reduce costs and conserve valuable resources.

Comparing the solution results presented in Appendix A reveals that this thesis POL forecasting program combined with the "quick and dirty" method provides the following advantages over the traditional solution methods.

1. The unit commander's ability to make strategic and tactical decisions is enhanced.

2. POL transportation, storage, and distribution problems are made tractable and optimal solutions can be found using a practical iterative method.
3. Fuel costs can be significantly reduced and lives may be saved. The optimum solution minimizes the total transportation requirements, resulting in reduced exposure of vulnerable fuel supplies.
4. The unit fuel demand forecasts are consistent and verifiable.

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Appendix A

HYPOTHETICAL PROBLEM

Problem Statement

The 1st Tank Battalion is ordered to prepare for immediate deployment from its base in Kentucky to protect our national interests in the Middle East. The battalion is equipped with the M60A3 main battle tank. The supply officer is directed to prepare a fuel request for the initial 72 hours of deployment.

He quickly reviews the actual POL usage report files for the last two years of combat training. He discovers that the largest daily amount of fuel consumed during training was 19,000 gallons of diesel and 600 gallons of motor gasoline (MOGAS). He decides to use 110 percent of these amounts as the basis for his forecast. A request is therefore prepared for 62,700 gallons of diesel fuel and 1,980 gallons of MOGAS.

The battalion arrives at its destination one day later minus the personnel and equipment of two tank companies. The unit is augmented with an M1A1 tank company and an infantry rifle company equipped with the Bradley Fighting Vehicle (BFV).

The mission is to defend a given area. The level of combat intensity is expected to be moderate. The requested fuel is stored in equal amounts at two separate locations. No additional fuel will be supplied for the next three days. The distances between the company areas of operation and storage sites are presented in Table A-1.

TABLE A-1

Distances

	Site 1	Site 2
Headquarters Company	5	9
Company A (M60A3)	18	10
Company B (M60A3)	20	12
Company C (M1A1)	15	24
Company D (BFV)	21	17

<u>Issues</u>

1. Is sufficient diesel fuel available to perform the three day mission? If not, what is the likely shortfall?
2. On the first day the commander wants headquarters company to have supply priority. How should the diesel fuel be allocated? Which companies should absorb any shortfall?
3. The M1A1 tank company loses 20 per cent of its main battle tanks on the first day. How should the diesel fuel be allocated for the second and third days?
4. The commander directs that remaining diesel fuel should be consolidated and issued from a single site. Which site should be selected? Will consolidation be beneficial?

Traditional Solution

Issue 1

The supply officer would not have historical fuel usage data for the rifle and M1 tank companies and he would have to estimate their fuel requirements. An M1 tank generally requires twice as much fuel as an M60A3 but since two M60A3 tank companies did not deploy with the battalion the supply officer would deduce there is sufficient fuel for all tanks. He would predict a shortfall due to the rifle company BFV fuel demands only.

The BFV replaces the older M113 and generally requires 50 per cent more fuel. The rifle company has thirteen BFVs and one M113. The 1st Battalion also has an M113 assigned. The logistician might review his unit historical records and discover that the M113 requires an average of 90 gallons per day. He would estimate the shortfall at 1,850 gallons per day.

Issue 2

Fuel site 1 is closest to the headquarters company area of operation. The supply officer would likely direct that its fuel demands be satisfied exclusively from site 1. He would also impose supply constraints on all other companies, such as restricting vehicle use to only mission essential activities. He would closely monitor consumption by the four line companies. They would equally share the burden of any shortfall.

Issue 3

The supply officer would not be able to immediately determine the impact of losing three M1A1 tanks but would assume that this loss will increase the amount of available POL.

Issue 4

Site 1 is closest to both the M1 and headquarters companies. These two units have the largest fuel demands. The fuel distribution elements are part of the headquarters company. The supply officer might intuitively decide to consolidate all fuel at site 1.

Forecasting Program with Quick and Dirty Method

Issue 1

The forecasting program confirms that the original fuel estimate of 19,000 gallons per day is reasonable for battalion operations in Kentucky. The original fuel request was for 20,900 gallons per day. However, the program also reveals that 22,020 gallons per day is required for moderate intensity combat in the Middle East. If the battalion had deployed with all of its original companies, it would have experienced an initial shortfall of 1120 gallons per day.

The program calculates the augmented battalion daily fuel requirement as 24,715 gallons. The total shortfall will be approximately 3,815 gallons per day.

Issue 2

The Quick & Dirty Transportation Method used to address this issue is presented in Appendix B. The unit fuel demands are calculated by the forecasting program. The cost function is assumed to be the distance between the unit areas of operation and the fuel sites multiplied by the gallons of fuel transported.

The optimal solution includes satisfying all of the headquarters company's fuel demands. The M1A1 company absorbs the entire shortfall. Total cost is 221,198 gallon- miles. Table A-2 shows an initial solution by the Northwest corner method. The first iteration is provided in Table A-3. The optimal solution was determined after six iterations and is presented in Table A-4.

The unit commander may want to distribute the shortfall equally among the other companies. The unit logistician could modify the cost function to

TABLE A-2

Northwest Corner

	Co. A	Co. B	M1A1	BFV	HQ Co	SUPPLY	
	3,551	3,551	3,348	0	0	10,450	Site 1
	0	0	4,348	2,078	3,498	10,450	Site 2
	0	0	0	0	3,815	3,815	Shortfall
DEMAND	3,551	3,551	8,222	2,078	7,313		

TOTAL COST = 368,942 gallon-miles

TABLE A-3

1st Iteration

	Co. A	Co. B	M1A1	BFV	HQ Co	SUPPLY	
	3,551	0	6,899	0	0	10,450	Site 1
	0	0	1,323	2,078	7,049	10,450	Site 2
	0	3,551	0	0	264	3,815	Shortfall
DEMAND	3,551	3,551	8,222	2,078	7,313		

TOTAL COST = 297,922 gallon-miles

TABLE A-4

Optimal Solution

	Co. A	Co. B	M1A1	BFV	HQ Co	SUPPLY	
	0	0	4,407	0	6,043	10,450	Site 1
	3,551	3,551	0	2,078	1,270	10,450	Site 2
	0	0	3,815	0	0	3,815	Shortfall
DEMAND	3,551	3,551	8,222	2,078	7,313		

TOTAL COST = 221,198 gallon-miles

accommodate this desire. He might use coefficients to make the distances equal for all of the companies required to share the shortfall. He could then iterate a new solution which would be both optimal and desirable.

The optimal solution is the most economical and the most secure method of distribution. Cost is directly proportional to liability because the assumed cost function represents the miles which each gallon of fuel must be transported. Increasing the miles that POL is transported also increases the risk of accident or destruction by hostile forces.

Issue 3

The POL forecasting program indicates that the M1A1 company fuel demands will reduce by 1,757 gallons per day. This reduction does not change the optimal solution because it is less than the shortfall of 3,815 gallons per day. The optimal solution remains the same except the shortfall is now 2,058 gallons and the M1A1 fuel demand is reduced.

The logistician does not need to determine a new optimal solution until the change in fuel demand exceeds the shortfall. The POL forecasting program indicates that the M1A1 company could lose more than 50% of its tanks without changing this optimum solution.

Issue 4

The optimal solution matrices for fuel consolidation at sites 1 and 2 are presented in Tables 5 and 6. If fuel consolidation must occur and cost is the only evaluation factor, then site 1 should be selected because its total cost of 268,898 gallon-miles is less than consolidation at site 2.

TABLE A-5

Site 1

	Co. A	Co.B	M1A1	BFV	HQ Co	SUPPLY	
	3,551	3,551	6,465	20	7,313	0,900	Site 1
	0	0	0	2,058	0	2,058	Shortfall
DEMAND	3,551	3,551	6,465	2,078	7,313		

TOTAL COST = 268,898 gallon-miles

TABLE A-6

Site 2

	Co. A	Co. B	M1A1	BFV	HQ Co	SUPPLY	
	3,551	3,551	4,407	2,078	7,313	20,900	Site 2
	0	0	2,058	0	3,815	2,058	Shortfall
DEMAND	3,551	3,551	6,465	2,078	7,313		

TOTAL COST = 285,033 gallon-miles

If site 1 is selected, the rifle company would receive only 20 gallons of fuel per day. This alternative may be tactically acceptable because the rifle company might be able to perform its mission as dismounted infantry.

If consolidation is not required, the most economical choice is to maintain both fuel sites which, as shown in Table A-4, costs only 221,198 gallon-miles.

Appendix B

QUICK & DIRTY TRANSPORTATION METHOD

<u>Procedure</u>

M supply points supply N demand points with a certain product. Supply point i produces a_j units and demand point j requires b_j units. Suppose that the cost of shipping one unit from supply point i to demand point j is c_{ij}. Let x_{ij} be the amount sent from supply point i to demand point j. We now wish to find the shipping pattern that minimizes total cost.

Destinations

Sources	1	. . .	N	Supply	
1	c_{11} x_{11}		c_{1n} x_{1m}	a_1	u_1
. .	. .		. .	. .	
M	c_{m1} x_{m1}		c_{mn} x_{mn}	a_m	u_m
Demand	b_1		b_n	$a_i=b_j$	
	v_1	. . .	v_n		

1. Find a solution by the Northwest corner method.
2. Find that row or column with the largest number of non- zero x_{ij}'s and set the corresponding u_i or $v_j = 0$.
3. Compute the other u_i's or v_j's so that for each position $c_{ij} = u_i + v_j$.
4. Compute the $r_{ij} = c_{ij} - (u_i + v_j)$ for all positions where $x_{ij} = 0$.
5. Find the most negative r_{ij}. If all r_{ij} are positive or zero, then GOTO step 8.

6. For the position with the most negative r_{ij}, determine the closed circuit that will maintain a supply and demand balance.
7. For those positions in the closed circuit that must be decreased find the smallest x_{ij}. Subtract this amount from every place on the closed circuit that must be decreased and add this amount to every place on the closed circuit that must be increased. GOTO step 2.
8. The present set of x_{ij}'s is optimum. Compute the total minimum cost which is the summation of $c_{ij} * x_{ij}$.

Example

Given two supply points and three demand points. Each supply point has 75 units and each demand point requires 50 units. The costs of shipping from the first supply point to each of the demand points in ascending order are 2, 3, and 6 dollars per unit. The comparable costs from the second supply point are 1, 4, and 5 dollars per unit. Find the optimum shipping pattern.

1. To find a solution by the Northwest corner method the problem data must be placed in a matrix. Starting in the Northwest corner of the matrix, compare demand to available supply.
   a. If demand > supply, then satisfy the demand, subtract this amount from the available supply, and move one column to the right.
   b. If demand < or = supply, then place the available supply in this square, subtract this amount from the demand, and move down one row.
   c. Repeat steps 1. a and b until all demands have been satisfied.

The solution matrix by the Northwest corner method is:

	1	2	3	Supply
1	[2] 50	[3] 25	[6] 0	75
2	[1] 0	[4] 25	[5] 50	75
Demand	50	50	50	150

2. Set u_1 equal to zero.

3. Compute the other ui's and vj's:

   $v_1 = c_{11} - u_1 = 2 - 0 = 2$

   $v_2 = c_{12} - u_1 = 3 - 0 = 3$

   $u_2 = c_{22} - v_2 = 4 - 3 = 1$

   $v_3 = c_{23} - u_2 = 5 - 1 = 4$

4. Compute $r_{ij} = c_{ij} - (u_i + v_j)$ where $x_{ij} = 0$:

   $r_{21} = c_{21} - (u_2 + v_1) = 1 - (1 + 2) = -2$

   $r_{13} = c_{13} - (u_1 + v_3) = 6 - (0 + 4) = +2$

5. The most negative r_{ij} is r_{21}.

6. The closed circuit is:

	1	2	3	Supply
1	[2] 50 -	[3] 25 +	[6] 0	75
2	[1] 0 +	[4] 25 -	[5] 50	75
Demand	50	50	50	150

7. The smallest x_{ij} is 25. The resulting matrix is:

	1	2	3	Supply
1	[2] 25	[3] 50	[6] 0	75
2	[1] 25	[4] 0	[5] 50	75
Demand	50	50	50	150

GOTO step 2.

2. Set u_1 equal to zero.

3. Compute the other u_i's and v_j's:

$v_1 = c_{11} - u_1 = 2 - 0 = 2$

$v_2 = c_{12} - u_1 = 3 - 0 = 3$

$u_2 = c_{12} - v_1 = 1 - 2 = -1$

$v_3 = c_{23} - u_2 = 5 + 1 = 6$

4. Compute $r_{ij} = c_{ij} - (u_i + v_j)$ where $x_{ij} = 0$:

$r_{22} = c_{22} - (u_2 + v_2) = 4 - (-1 + 3) = +2$

$r_{13} = c_{13} - (u_1 + v_3) = 6 - (0 + 4) = +2$

5. There is no negative r_{ij}. GOTO step 8.

8. This set of x_{ij}'s is optimum.

Compute the total minimum cost = 50 + 25 + 150 + 250 = 475 dollars.

Appendix C

LOGISTICS SUPPORT

Logistics Support System Operations

The following discussion addresses operations of the logistics system at division level and below. The interface with the corps system, the next higher echelon, is described only to show how it supports division logistic operations.

The support areas which group personnel, vehicles and equipment assembled to provide logistic support to a unit are called "trains". Normally, the term is not used above brigade level. At company level, trains include a small stock of POL necessary to support very short term operations. Company trains can be employed in one of two ways: either as one entity, in which case they are termed "unit trains"; or in echelon, with the more urgently needed elements well forward, "combat trains", and the not so urgently needed elements located farther in the rear, "field trains". The actual position(s) selected for trains is dependent on tactical considerations.

The battalion trains are the connecting link between the company trains and the units in the brigade support area. The battalion trains provide POL support to the companies. This is the lowest level at which the program can be used for distribution planning. It is assumed that POL requirements generated by the program will be provided by the battalion to its parent brigade or division. Like the company trains, the battalion trains can operate from one or two locations.

The brigade provides POL support with units located in its "trains" area, which is more commonly called the brigade support area. Divisional brigades have no organic combat support structure. The units in the brigade support area providing POL support are those elements of the division which are tasked to support the brigade. The thesis program allows the user to allocate units from division assets to support each brigade using the equipment/vehicle data base and to obtain optimal solutions for resulting transportation problems. The user may also use the program at brigade level when the unit is an independent brigade which has an organic combat support structure.

The division support area is located in the division rear and will be positioned near both airlanding facilities and along the main supply route from corps. The corps provides POL support to the divisions and its is assumed that POL requirements identified by the program will be provided from the corps to the division.

Appendix D

PROGRAM DESCRIPTION

Loading Instructions

The user must load LOTUS 1-2-3 according to the instruction in the LOTUS user's manual. The file directory must be the same as the disk drive in which the program diskette has been inserted. The user must load the file named "POL.WK2".

Initiating the Forecasting Program

Loading the POL.WK2 file initiates the program. The user will view a series of screens. Each screen contains a menu and prompting instructions.

The first screen will provide the user with the option to view or get a printout of the information produced by the program. The user selects an output option by typing either 1 or 2 and pressing ENTER.

The second screen prompts the user to identify the units by type and quantity. The Standard Requirement Codes (SRCs) for all units in the program data base are listed in Appendix E. The user identifies units by typing the appropriate SRCs.

The third screen allows the user to select a geographic profile by entering the number corresponding to the desired geographical location. A geographic profile consists of operating conditions for each equipment category. At this point, the user has entered all of the required data and the program begins to compute fuel requirements.

The program calculates the 24 hour fuel requirements for each equipment line item number by multiplying the equipment density, operating conditions profile, and fuel consumption rate. It then summarizes the forecasted POL consumption by fuel type for each SRC and the total force.

Appendix E

UNITS IN THE PROGRAM DATA BASE

Units in Database Files

SRC	Unit Type
77000L000	LT INF DIV
87000J450	ARMOR DIV, 6 M60, 4 M113
87000J460	MX DIV, 5 M60/wM113
57000L000	ABN DIV (AOE)
67000L100	AIR ASLT DIV
87000J480	MX DIV, 5-M1/BFVS
01385J410	ATK HEL BN, AH1
05147J400	ENG CO, ENG BN, HVY DIV
06365J410	FA BN, 155 SP, HVY DIV
07245J410	MECH INF BN, BFVS
07245J420	MECH INF BN, M113
07246J410	HHC, MECH INF BN, BFVS
07246J420	HHC, MECH INF BN, M113
07247J410	RFL CO, MECH INF BN, BFVS
07247J420	RFL CO, MECH INF BN, M113
07248J400	ANTI-ARMOR CO, INF BN
17235J410	TANK BN, M60
11038J500	FWD COMM CO
17235J420	TANK BN, M1
17236J410	HHC, TANK BN, M60
17236J420	HHC, TANK BN, M1
17237J410	TANK CO, M60
17237J420	TANK CO, M1
19217J400	MP CO, HVY DIV
63005J410	FWD SPT BN, HVY DIV
87042J410	HHC, BDE, ARMOR DIV
87042J420	BDE HHC, INF MX DIV
06300J410	DIVARTY, ARMD DIV
44167L000	ADA BTRY, GUN SP, STINGER
05157L000	ENG CO, ENG BN, LT INF DIV
06705L000	FA BN, 105MM TOW, AIR ASLT
07055L000	INF BN, AIR ASLT
08437L000	MED CO, HVY SEP BDE (HSB)
17187L000	CAV TRP, LT INF DIV
34144L000	MI CO (CEWI), HVY SEP BDE
42084L000	S&T CO, SPT BN, SEP HVY BDE
43079L000	ORD CO (MAINT), HVY SPT BN
63086L000	HHC, SPT BN, HVY SEP BDE
87102L100	HHC, HVY SEP BDE, ARMOR
06367J410	FA BTRY, 155SP, HVY DIV
07000D600	MTZ DIV
06365J420	FA BN, 155 SP, HVY DIV
06365J430	FA BN, 155 SP, HVY DIV
06398J200	FA BTRY, MLRS

SRC	Unit Type
06398J400	FA BTRY, MLRS
06445J420	FA BN, 8" SP (3X8), AOE
06455H300	FA BN, 155 SP
03117D500	CHEM CO, INF DIV (INT)
01285D600	CS AVN BN, INF DIV (INTERIM)
05255D600	ENG BN, INF DIV (INTERIM)
06100D600	DIVARTY, INF DIV (INTERIM)
07004D600	HHC, INF DIV (INTERIM)
07042D600	HHC, MTZ BDE, INF DIV (INT)
07065D600	INF BN, LT ATK (I-FAV), INF DIV
07065D610	INF BN, LT ATK (HMMWV), INF DIV
07095D610	CA BN, HVY, INF DIV (INTERIM)
07095D620	CA BN LT, INF DIV (INTERIM)
11035D600	SIG BN, INF DIV (INTERIM)
17201D600	CBT BDE AIR ASLT, INF DIV (INTERIM)
17385D600	ATK HEL BN, INF DIV (INT)
19417D600	MP CO, MTZ DIV
34295D600	MI BN, INF DIV (INTERIM)
44155D600	AD BN (SHORAD), INF DIV (INT)
63011D600	DIV SPT CMD, INF DIV (INT)
87000J430	ARMD DIV, 6-M1, 4-BFVS, 2-AHB
87000L200	MECH DIV, 5-M60, 5-M113, 2-AHB
44166L000	HHB, ADA BN, HVY DIV
44165L000	ADA BN, HVY DIV
01400L500	CBT AVN BDE, CORPS
06100L000	DIVARTY, LT INF DIV
06525J300	FA BN, MLRS
17485L200	ARMD CAV SQDN, ACR (1X8)
87000J440	MX DIV, 5-M1, 5-BFV'S, 2-AHB
06300J420	DIVARTY, HVY DIV
17201J420	CAV BDE, AIR ATK (AH-64)
63001J420	SPT CMD, HVY DIV
01257J420	CBT SPT AVN CO, CBT BDE AIR ASLT
01287J400	GEN SPT AVN CO, CBT BDE AIR ASLT
01385J420	ATK HEL BN, AH-64, CBT BDE AIR ASLT
03387J400	CHEMICAL CO, HVY DIV
05145J410	ENG BN, HVY DIV (RIB)
06302J400	HHB, DIVARTY, HVY DIV
06307J400	TGT ACQ BTRY, DIVARTY, HVY DIV
11035J500	SIGNAL BN, HVY DIV
17202J400	HHT, CBT BDE AIR ASLT
17205J410	CAV SQDN, AH-1, CBT BDE AIR ASLT
34285J400	MI BN (CEWI)
55427J410	AVN MAINT CO (AVIM), HVY DIV
63002J400	HHC/wMMC, SPT CMD, HVY DIV
63005J420	FSB, 2X2, HVY DIV
63005J430	FSB, 1X2, HVY DIV
63135J400	MAIN SPT BN, HVY DIV
87004J420	HHC, MECH INF DIV

SRC	Unit Type
05074J200	ENG CO, MDM GIRDER BRIDGE
11067L000	AREA SIG CO, MSE
05148J410	BRIDGE CO, RIBBON
06425L200	FA BN, 155 TOWED (3X8)
44347J400	ADA BTRY, CHAPARRAL SP
44445L100	ADA BN, CHAPARRAL, CORPS
05058H400	ENG CBT SPT EQUIP CO
87004L200	HHC, MECH INF DIV
19333L000	MP CO, HVY DIV
11035L000	SIGNAL BN, HVY DIV
11036L000	HHC, SIGNAL BN, HVY DIV
11037L000	CMD OPS CO
11038L000	FWD COMM CO
11039L000	AREA SIG CO
05146L000	HHC, ENG BN, HVY DIV
05147L000	ENG CO, HVY DIV
05148L000	RIBBON BRIDGE CO
34285L000	MI BN (CEWI)
34286L000	HQ, HQ & SVC CO, MI BN
87000J470	ARMOR DIV, 6-M1, 4-BFVs, 1-AHB
34288L000	INTEL & SURVL CO
34289L000	EW CO
87042L100	HHC, BDE, ARMOR
87042L200	HHC, BDE, MECH INF
17375L000	TANK BN, M60
17376L000	HHC, TANK BN, M60
17377L000	TANK CO, TANK BN, M60
07245L000	MECH INF BN, M113
07246L000	HHC, MECH INF BN, M113
07247L000	RFL CO, MECH BN, M113
07248L000	ANTI-ARMOR CO, ITV
06300L200	DIVARTY, HVY DIV
06302L000	HHB BTRY, DIVARTY, HVY DIV
06303L000	TGT ACQ BTRY, HVY DIV
06398L000	FA BTRY, MLRS, HVY DIV
06365L100	FA BN, 155 SP (3X8), HVY DIV
06365L200	FA BN, 155 SP (3X8), HVY DIV
06365L300	FA BN, 155 SP (3X8), HVY DIV
01300L100	CBT AVN BDE, 2 AHB, AH-1
01302L000	HHC, CBT AVN BDE
01303L100	CBT AVN CO, UH-1
01304L000	CMD AVN CO
01385L100	ATK HEL BN, AH-1
17385L100	CAV SQDN, M113
63000L200	SPT CMD, HVY DIV
63002L000	HHC/wMMC, SPT CMD, HVY DIV
01933L100	AVN MAINT CO (AVIM), 2 AHB, AH-1, HVY DIV
63005L100	FWD SPT BN, 2X1, HVY DIV
63005L200	FWD SPT BN, 2X2, HVY DIV

SRC	Unit Type
63005L300	FWD SPT BN, 1X2, HVY DIV
63135L000	MAIN SPT BN, HVY DIV
87004J410	HHC, ARMD DIV
17201J430	CAV BDE, AIR ATK, AH-1 (AOE)
01257J410	CBT SPT AVN CO
63001J430	SPT CMD, 6X4X1, HVY DIV
17201J440	CAV BDE, AIR ATK (CBAA)
63001J440	SPT CMD, 6X4X1, HVY DIV
55427J430	AVN MAINT CO, SPT CMD, HVY DIV
57004L000	HHC, ABN DIV (AOE)
19313L000	MP CO, ABN DIV
11215L000	SIG BN, ABN DIV
11216L000	HHC, SIG BN, ABN DIV
11217L000	CMD COMM CO, SIG BN, ABN DIV
11218L000	FWD COMM CO, SIG BN, ABN DIV
44136L000	HHB, ADA BN, ABN DIV
44137L000	ADA BTRY, VULCAN/STINGER, ABN DIV
05025L000	ENG BN, ABN DIV
05026L000	HHC, ENG BN, ABN DIV
05027L000	ENG CO, ENG BN, ABN DIV
03057L000	CHEM CO, ABN/AIR ASLT DIV
34265L000	MI BN (CEWI), ABN DIV
34266L000	HQ, HQ & OP CO, MI BN, ABN DIV
34267L000	C&J CO, MI BN, ABN DIV
34268L000	INTEL & SURVL CO, MI BN
34269L000	SVC SPT CO, MI BN, ABN DIV
57042L000	HHC, BDE, ABN DIV
07035L000	INF BN, ABN DIV
07036L000	HHC, INF BN, ABN DIV
07037L000	RFL CO, INF BN, ABN DIV
07038L000	ANTI-ARMOR CO, INF BN, ABN DIV
06200L000	DIVARTY, ABN DIV
06202L000	HHB, DIVARTY, ABN DIV
06205L000	FA BN, 105 TOWED, ABN DIV
01070L200	CBT AVN BDE, ABN DIV
01072L200	HHC, AVN BDE, ABN DIV
01375L200	ATK HEL BN, AH-64
01277L000	ASLT HEL CO, UH-60
01075L000	AIR CAV SQDN, AH-1
63051L000	DISCOM, ABN DIV
63052L000	HHC/wMMC, SPT CMD, ABN DIV
08065L000	MED BN, SPT CMD, ABN DIV
42055L000	S&T BN, SPT CMD, ABN DIV
43055L000	MAINT BN, SPT CMD, ABN DIV
01973L200	AVN MAINT CO (AVIM), ABN DIV
67004L000	HHC, AIR ASLT DIV
19343L000	MP CO, AIR ASLT DIV
11205L000	SIGNAL BN, AIR ASLT DIV
11206L000	HHC, SIG BN, AIR ASLT DIV

SRC	Unit Type
11207L000	CMD COMM CO, AIR ASLT DIV
11208L000	SIG SPT CO, AIR ASLT DIV
44145L000	ADA BN, AIR ASSLT DIV
44146L000	HHB, ADA BN, AIR ASLT DIV
44147L000	ADA BTRY, AIR ASLT DIV
05215L000	ENG BN, AIR ASLT DIV
05216L000	HHC, ENG BN, AIR ASLT DIV
34275L000	MI BN, AIR ASLT DIV
34277L000	C&J CO, MI BN, AIR ASLT DIV
34278L000	INTEL & SURVL CO, MI BN
34279L000	SVC SPT CO, MI BN
67042L000	HHC, BDE, AIR ASLT DIV
06702L000	HHB, DIVARTY, AIR ASLT DIV
01200L000	CBT AVN BDE, AIR ASLT DIV
01202L000	HHC, CBT AVN BDE,
01205L000	CBT AVN BN, UH-60
01245L100	CBT AVN BN, CH-47
01215L000	CMD AVN BN, AIR ASLT DIV
01265L100	AIR RCON SQDN, AIR ASLT DIV
01266L100	HHT, AIR CAV SQDN
01267L100	AIR CAV TRP, AH-1
63041L000	DISCOM, AIR ASLT DIV
77004L000	HHC, LT INF DIV
19323L000	MP CO, LT INF DIV
11045L000	SIGNAL BATTALION
11046L000	HHC, SIG BN, LT INF DIV
11047L000	CMD COMM CO
11048L000	SIG SPT CO
44115L000	AIR DEFENSE BN
44116L000	HHB, ADA BN, LT INF DIV
44117L000	ADA BTRY, VULCAN/STINGER, LT INF DIV
05155L000	ENG BATTALION
05156L000	HHC, ENG BN, LT INF DIV
77042L000	HHC, BDE, LT INF DIV
07016L000	HHC, INF BN, LT INF DIV
07017L000	RFL CO, INF BN, LT INF DIV
01100L000	CBT AVN BDE, LT INF DIV
01102L000	HHC, CBT AVN BDE, LT INF DIV
17185L000	RECON SQDN, LT INF DIV
63021L000	DISCOM, LT INF DIV
63022L000	HHC, SPT CMD, LT INF DIV
08045L000	MED BN, LT INF DIV
42025L000	S&T BN, LT INF DIV
43045L000	MAINT BN, LT INF DIV
01977L000	AVN MAINT CO (AVIM), LT INF DIV
44325H000	ADA BN, AIM DIVISION
01385L200	ATK HEL BN (AH-64)
34285J500	MI BN, HVY DIV
55427J440	TAMC SPT CMD, HVY DIV

Appendix F

PROGRAM DISKETTE