EVALUATION OF AMMUNITION AND FUEL SUPPLY SYSTEMS OF A TURKISH ARMORED BATTALION DURING MOBILIZATION AND DEPLOYMENT USING SIMULATION

A THESIS
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By
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July, 2002

I certify that I have read this thesis and in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

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In current wars, supply systems have become vital factors to reach military success. With improvements in technology, the capabilities and means of military units have also improved and as a result, the supply materials which military units require have also increased greatly. The timely delivery of supply materials to the combatant units is the key to success. The delivery of supply materials to combatant units at the right time and as needed can only be possible with the efficient planning of supply systems by staff officers. The insufficient evaluation of supply systems will cause interruptions in delivery of supply materials to combatant units and consequently prevent the combatant units from accomplishing their tasks.

In this study, the existing ammunition and fuel supply systems of an armored battalion before alarm order is evaluated via simulation. By using the simulation models which were coded for existing systems, commanders will have the capability to detect potential problems and take precautions. The main objectives of this study are: (1) To evaluate existing systems via simulation because of difficulties in executing real world systems due to impediments in creating real world conditions and also economic reasons. (2) To detect the factors which have significant effects on the existing system. (3) To foresee the probable problems of the existing system by studying the simulation model outputs using statistical methods. (4) To select the most critical region of Turkey according to performance measures of interest. The codes of models are created by using ARENA 3.0 simulation program and SIMAN programming language.

Key Words: Military Simulation, Ammunition Supply, Fuel Supply, Logistics

ÖZET

ALARM FAALİYETLERİ ESNASINDA BİR TÜRK TANK TABURUNUN MÜHİMMAT VE YAKIT İKMAL SİSTEMLERİNİN SİMÜLASYONLA ANALİZ EDİLMESİ

Aydın Özçevik
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Günümüz muharebelerinde ikmal sistemleri askeri başarının elde edilmesinde önemli faktörler haline gelmiştir. Gelişen teknoloji ile birlikte askeri birliklerin imkan ve kabiliyetleri de gelişmiş ve bunun sonucunda ihtiyaç duydukları ikmal maddelerinde de büyük bir artış olmuştur. İkmal maddelerinin muharip birliklere zamanında dağıtımı ordunun başarısı için çok önemlidir. İkmal maddelerinin zamanında ve tam olarak muharip birliklere dağıtılabilmesi ancak ikmal sistemlerinin karargah subayları tarafından iyi planlanması ile mümkün olabilir. İkmal sistemlerinin iyi analiz edilmemesi ikmal maddelerinin muharip birliklere ulaştırılmasında aksaklıklara sebep olacak ve neticede muharip birliklerin vazifelerini başarmalarını engelleyecektir.

Bu çalışmada, bir tank taburunun alarm emri öncesi kullandığı mevcut mühimmat ve yakıt ikmal sistemleri simülasyon vasıtasıyla analiz edilmektedir. Komutanlar henüz barış zamanında iken mevcut sistemler için kurulan simülasyon modellerini kullanarak, mevcut sistemlerin icrasında karşılaşabilecekleri muhtemel problemleri önceden görme ve bunlara karşı tedbir alma imkanına sahip olacaklardır. Bu çalışmanın ana hedefleri: (1) Gerek gerçek koşulların oluşturulmasındaki güçlük ve gerekse maddi nedenler dolayısıyla tatbiki zor olan mevcut mühimmat ve yakıt ikmal sistemlerini simülasyon vasıtasıyla analiz etmek. (2) Sistemler üzerine etkili olan faktörleri tespit etmek. (3) Simülasyon modellerinin çıktılarını istatiksel metodlarla inceleyerek sistemlerdeki muhtemel problemleri önceden görmek. (4) Performans kriterlerine göre en kritik bölgeyi seçmektir. Modellerin kodları ARENA 3.0 simülasyon programı kullanılarak ve SIMAN dilinde yazılmıştır.

Anahtar Sözcükler: Askeri Simülasyon, Mühimmat İkmali, Yakıt İkmali, Lojistik

To my family

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Aydın Özçevik

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GLOSSARY

Alert Dispersion Area: Area where the troops spread to minimize the casualties during enemy attack.

Ammunition: Military stores, especially of explosives (shells, bombs, etc.) to be used against the enemy.

Armored Vehicle: A vehicle covered with metal sheeting for protection and equipped with special guns.

Battalion: An army unit made of several companies and forming part of a brigade.

Company: Subdivision of a battalion, commanded by a captain.

Convoy: To travel, especially said of motor vehicles, in a procession for safety and convenience.

Field Manual: Military publication for use by military personnel explaining tactics and techniques of any military activity.

Logistics: The science of planning and carrying out the movement and maintenance of forces.

Maintenance: Maintenance is the function of sustaining material (weapon systems, components, spares, support equipment) and facilities in an operational status; restoring them to a serviceable condition; or upgrading their functional utility through modification.

Mobilization: A situation in which the power, sources and mainly the military forces of the country are prepared, gathered, arranged and used for the needs of a war and in which the rights and liberties are limited partially or wholly.

CHAPTER 1

INTRODUCTION

The purpose of the supply systems is to provide the supply materials to the military units on time and in order. Any delay or disorder in distribution of supply materials to military units because of improper functioning of supply systems can prevent military units from carrying out their missions. The timely delivery of supply materials to forces in the field is the key to success of military units' missions. In the Turkish military, there are five classes of supply materials (Kara Kuvvetleri Lojistik Faktörler Yönergesi, 1994) and these supply materials are as follows:

Class-I : This class includes subsistence items and health and welfare items.

Class-II : This class includes items of equipment, other than principal items, that are prescribed in authorization and allowance tables. Individual tools and tool sets, individual equipment and clothing items, batteries and housekeeping supplies are in this class of supply.

Class-III : This class comprises all types of petroleum products. All types of motorin, benzin jet fuel, lubricants, greases, hydraulic fluids, antifreeze materials and firewoods are considered as class-III supply materials.

Class-IV : This class comprises materials that are used for special duties.

Class-V : This class comprises all ammunition items (small arms, artillery and tank rounds, mines and demolotions, fuzes, missiles and bombs).

In our study we only focus on two classes of supply materials. These are Class-III and Class-V supply materials. Class-III supply materials provide mobility of military units and Class-V supply materials provide the fire power. Our systems are subsystems of the Army Logistics System which aims to support the soldier in the field on time and with the required amount of supply materials. The Army Logistics System connects all logistics activities and establishes a framework of fundamental logistics principles which helps the army to accomplish its mission. The models of our systems are examples of combat simulation because they include combat activities like enemy air and artillery attack.

In this study, we model the ammunition and fuel supply systems of one of the armored battalions in the Turkish Army during mobilization and deployment using simulation. We study the following two systems which are used in the Turkish military:

- Ammunition and fuel supply of an armored battalion at supply points (System-1).
- Ammunition and fuel supply of an armored battalion by ammunition trucks and fuel tankers at alert dispersion areas (System-2).

We develop simulation models of these systems because of their importance in achieving military objectives. Improper functioning of systems would cause delays in carrying out military objectives and also increase personnel casualties and number of destroyed vehicles if the battalion is under enemy threat. In our study, the armored battalion under consideration is positioned close to a regional border and under enemy threat.

In this study, we aim to reach our following objectives: (1) To examine the behaviors of these two existing systems. (2) To detect the factors which have significant effects on existing systems. (3) To find time standards of existing systems. (4) To rank the regions of Turkey from most to least critical according to performance measures of interest.

As a member of the North Atlantic Treaty Organization (NATO), the Turkish military uses NATO standards and unit structures. In a Turkish armored battalion there are four companies. The main firepower of the battalion is provided by three identical armored companies and these companies are supported by Headquarters Company. The structure of an armored battalion is presented in Appendix-H. In our models, the distance between company alert dispersion areas and garages is 400 meters. The distance between garages and the ammunition depot is 8 km. The distance between the ammunition depot and fuel supply points is 1 km.

Military units have two main activities when tension between two countries increases and a would-be conflict is imminent. The first one is to disperse vehicles at alert dispersion areas as soon as possible so as not to be a mass target in case of a sudden enemy attack. The second one is to complete supply material needs of personnel and vehicles as soon as possible. At peace times, armored vehicles are unloaded of ammunition because of safety reasons. In our models, the ammunition of armored vehicles is preserved in the ammunition depot of the battalion and the ammunition of small arms (i.e. rifles) is preserved in ammunition trucks. When military tension between two countries increases, companies distribute the ammunition of small arms to company personnel as soon as possible. In our study, we only deal with ammunition loading of armored vehicles. We assume that armored and wheeled vehicles are half fueled because we can not be sure about the level of fuel in each vehicle. The level of fuel in a vehicle tank would change according to its daily consumption. In real life, ammunition depots and fuel supply points are highly protected against enemy attacks. In our study, we assume that there is a strong air defense system against enemy planes around the ammunition depot and fuel supply points.

System-1, ammunition and fuel supply of armored battalion at supply points, starts with the order of battalion commander. In this existing system, armored and wheeled vehicles travel to supply points for ammuniton and fuel supply. After the order of the battalion commander, companies of the battalion start preparations. Ammunition of small arms is distributed and vehicle crews start to prepare their vehicles to travel to supply points. When preparations are done, each company's armored vehicles convoy to the ammunition depot via preplanned company pathes. The armored vehicles of Headquarters Company convoy with the armored vehicles of armored companies to the ammunition depot. Wheeled vehicles also convoy to company fuel supply points in company formation. Armored vehicles queue close to the ammunition depot which has two loading points according to the priority of their companies' tasks in battalion plans. In our study, the queue order of companies for ammunition supply is 1st Company, 2nd Company and 3rd Company. At the ammunition depot, the loaded armored vehicle immediately travels to its company fuel supply point and queues with other wheeled or armored vehicles. At fuel supply points company wheeled vehicles wait for the completion of the rest of company wheeled vehicles' fuel supply and when all are fueled, wheeled vehicles convoy to the company alert dispersion area. Armored vehicles also convoy after fueling to company alert dispersion area. The system ends when all undestroyed armored and wheeled vehicles of the battalion arrive to alert dispersion areas. During convoys, some stochastic events like breakdowns, enemy air attacks and enemy artillery attacks can occur. These events can damage or destroy vehicles during convoy and delay the supply activity, hence the mission success of the armored battalion. When a vehicle is destroyed by enemy attack or breakdown it is taken off the road, not to create traffic congestion. If it is damaged by enemy attack or breakdown, a vehicle crew tries to repair the vehicle. If it can not be repaired, then a maintenance team is called. The ammunition and fuel supply flow in System-1 can be seen in Figure 1.1.

System-2, ammunition and fuel supply of armored battalion by ammunition trucks and fuel tankers, also starts with the order of the battalion commander. The main difference of this system from System-1 is the distribution of supply materials to armored and wheeled vehicles. Only supply vehicles from Headquarters Company convoy to supply points and then transport supply materials to alert dispersion areas. After the order of the battalion commander, the ammunition trucks and fuel tankers from Headquarters Company complete their preparations to convoy to supply points. At the same time, the rest of the armored and wheeled vehicles of the battalion travel to company alert dispersion areas so as not to be a mass target at garages. All of the ammunition trucks responsible for transportation of ammunition to any company of the battalion convoy to the ammunition depot and all of the fuel tankers responsible for fuel supply of any company of battalion convoy to the company fuel supply point. At the ammunition depot, ammunition trucks are loaded according to the priority of each companies' tasks. After ammunition trucks are loaded, they convoy to company alert dispersion areas. They unload their ammunition at the company alert dispersion areas then proceed to Headquarters Company alert dispersion area. Armored vehicles' crews start to load their vehicles and then wait for the fuel supply process. Fuel tankers first fuel wheeled vehicles of companies at alert dispersion areas and then fuel armored vehicles. Fuel tankers also travel to the Headquarters Company alert dispersion area when all fuel supply activity is completed. During travel, some stochastic events like breakdowns, air and artillery attacks can occur. These events can damage or destroy supply vehicles during convoys. If an ammunition truck or fuel tanker is destroyed and

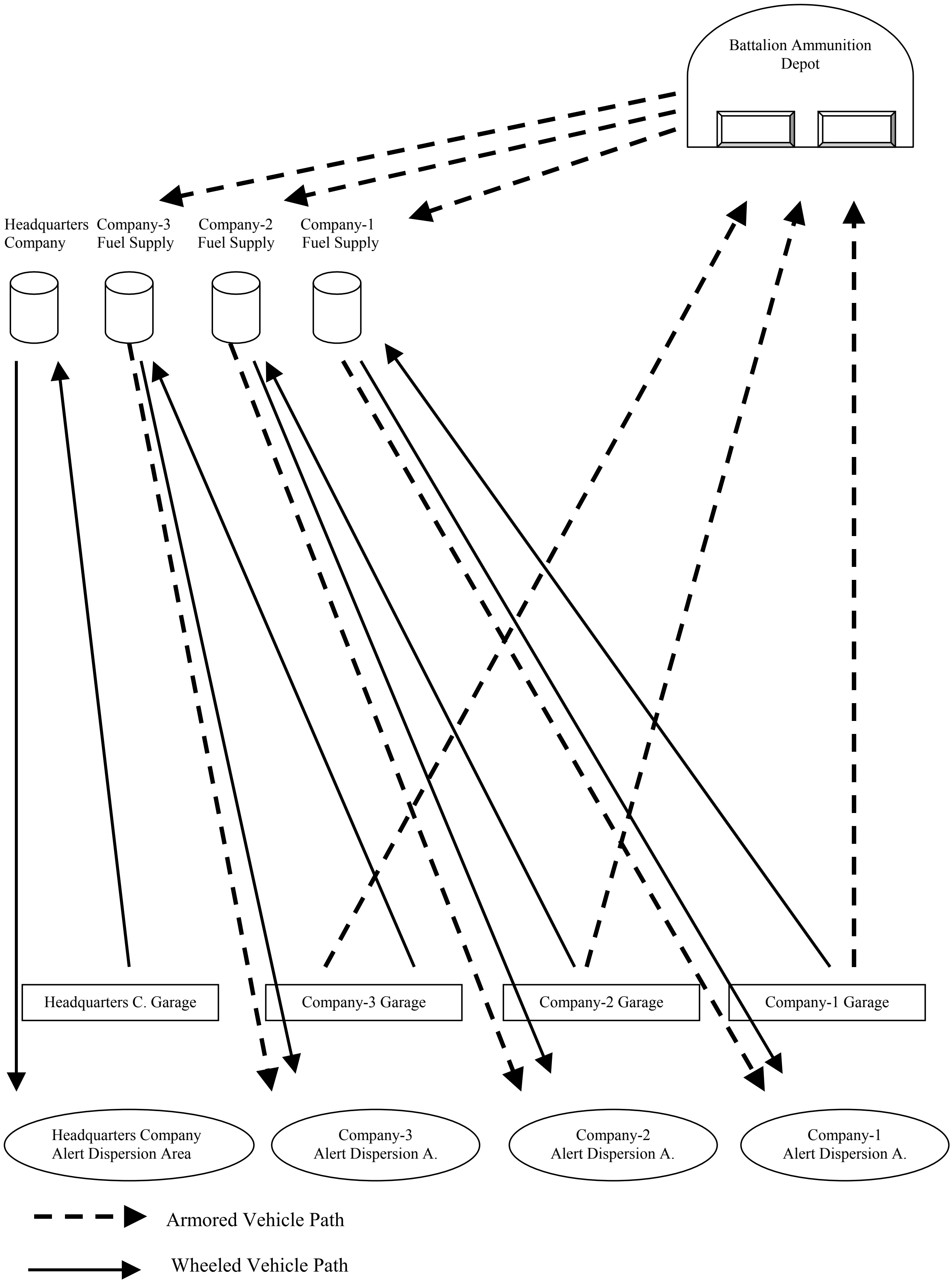


Figure 1.1. Ammunition and Fuel Supply Flow in System-1

can be safely moved, then it is taken off the road. If it is not safe to move because of fire or explosion, then necessary safety measures are taken and other supply vehicles are directed to alternate safe paths. The supply materials are distributed accordingly at alert dispersion areas despite the loss of ammunition or fuel because of enemy attacks. If the supply vehicles are destroyed on the way to supply points, then spare supply vehicles are sent to supply points. When an ammunition truck or fuel tanker is damaged, the vehicle driver first tries to repair the vehicle and if he can not repair the damage, then a maintenance crew is called. These events can delay the supply activity, hence the mission success of the armored battalion. The armored and wheeled vehicles at alert dispersion areas are also under enemy threat. They can be destroyed or damaged by enemy attacks but these events do not cause important delays in the system since these vehicles had already been at alert dispersion areas before enemy attacks occured. The system ends when all undestroyed vehicles are supplied at alert dispersion areas. The ammunition and fuel supply flow in System-2 can be seen in Figure 1.2.

We study the systems via simulation because of the difficulties in creating real world war conditions such as air and artillery attacks. Simulation also enables us to include stochastic events such as vehicle maintenance and breakdown. Finally, simulation is far more economical than exercising the systems in the field. We use Arena 3.0 simulation program in our study because it is a powerful and flexible tool with animation capabilities.

The rest of the thesis is organized as follows: In Chapter 2 we present the relevant literature with the simulation software and methods; general supply system applications in the field of military logistics similar to our systems; the requirements of military simulation modeling; combat modeling applications. In Chapter 3, we describe existing

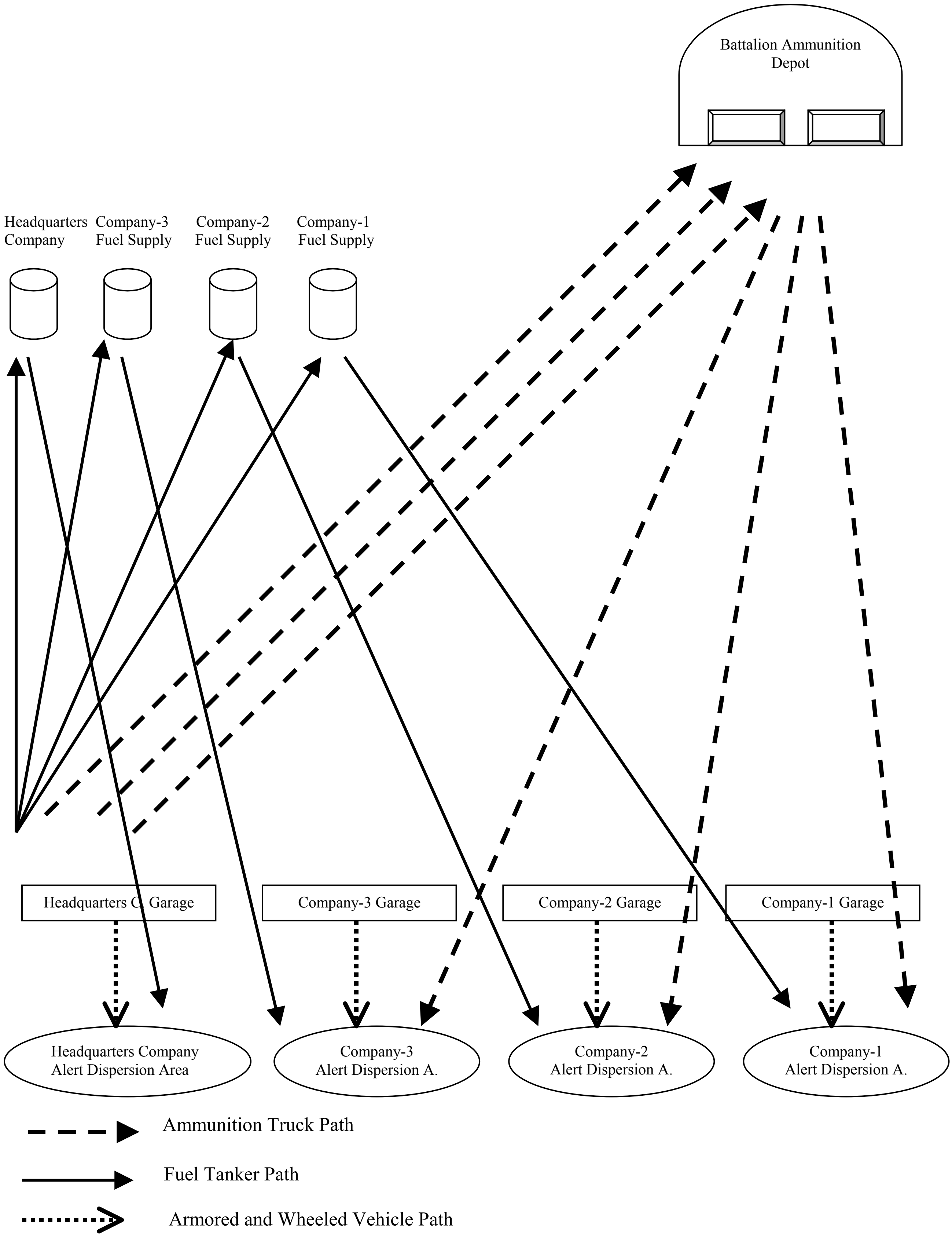


Figure 1.2. Ammunition and Fuel Supply Flow in System-2

systems. The conceptual models of existing systems, verification and validation of models are explained in this chapter. In Chapter 4, we give the design and analysis of experiments. The results of the statistical analyses are also presented in this chapter. In Chapter 5, we rank the regions of Turkey from most to least critical according to performance measures of interest. The results of simulation study and future research suggestions are given in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

In the literature review we could not find a study which considers all aspects of ammunition and fuel supply systems of an armored battalion. Our systems are military logistics systems which operate under enemy threat. In this chapter, we review some studies about combat modeling because our models include combat activities such as enemy air and artillery attacks. We also review some of the studies related military logistics because our models include distribution activities of supply materials. We organize this chapter as follows:

- Simulation software and methodology
- Military simulation
- Combat modeling
- Military logistics

2.1. Simulation Software and Methodology

While building the simulation models and performing some of the analyses of the outputs, we used ARENA 3.0 and its output Analyzer, which is a product of Systems Modeling Corporation. Takus and Profozich (1997) explain the ARENA software and its capabilities in their tutorial.

Jennifer Chew and Cindy Sullivan (2000) explain the activities and tasks during the early stages of model development and address each of Verification, Validation and Accreditation (VV&A) efforts separately, along with its associated activities. They outline the specific VV&A activities and products that are appropriate to each phase of model development.

Law and Kelton (1991) explain the timing and relationships of validation, verification and establishing credibility, and discuss guidelines for determining the level of model detail and some techniques for verification and validation.

Don Coughlin (2000) explains an integrated approach to VV&A from a system perspective and identifies the relationships between the M&S resources in an integrated VV&A program.

Balci Osman (1998) explains how to create sufficiently valid models and principles of verification and validation.

Sargent (1998) explains various verification and validation techniques and discusses conceptual model validity, model verification and data validity.

Alexopoulos and Seila (1998) explain techniques and procedures dealing with output data analysis.

Law and Kelton (1991) explain some comparison techniques and describe ranking and selection procedures.

2.2. Military Simulation

In this section, we present the papers related with military modeling and simulation. These papers provide insights regarding military simulation theory and the underlying limitations assocatiated with them. We use guidance from them to define our models and better understand the problems we could encounter before creating the models.

Metz Micheal (2000) focuses on Joint Warfare System (JWARS) verification and validation processes. JWARS users include the United States Joint Staff, regional military commanders, the office of secretary of defense, and military Joint Task of Forces.

Grabau M. and Payne M. (2000) provide planners to assess critical factors such as transportation network constraints, equipment reliability and maintainability, varying task times and the effects of air interdiction.

Raymond R.Hill, J.Miller and Gregory A. (2001) discuss the uses of military simulation and the issues associated with military simulation to include categorizations of various types of military simulation.

Garrabrants (1998) proposes an expansion of simulation systems' roles to support all levels of command and control functioning. He explains how Marine Tactical Warfare Simulation is used to model all aspects of combat.

Hartley (1997) stresses on the difficulties, methods and cost of the military simulation studies and presents the comparison of military simulation studies with others in terms of verification, validation and accreditation.

Robinson Stewart (1997) provides an understanding of how simulation models can be verified and validated. He aims to show where Verification and Validation (V&V) fit within the overall modelling process and to describe various methods of V&V.

Sisti (1996) deals with a wide variety of research issues in simulation science being presented by government, academia, industry and their application to the military domain.

Smith (1998) provides a brief historical introduction and goes on with essential methods necessary for modern military training simulations in his study. He stresses on the importance of modeling the right problem while mentioning the fundamental principles of military modeling.

Kang and Roland (1998) stress on the differences of military simulation and classify the military simulation models in their study. They provide some explanations about simulation as a training tool and also mention a war-gaming model of joint theater-level simulation.

Pace (1993) discusses naval modeling and simulation verification, validation and accreditation. He reviews VV&A processes developed as interim policy guidance for navy managed models and simulations.

2.3. Combat Modeling

In this section, we review studies of combat modeling because our models include combat activities such as enemy air and artillery attacks. Few declassified papers are available in the field of combat modeling due to the highly sensitive nature of the information. The combat activities in our models, air and artıllery attacks, are highly anticipated in a typical war. These papers help us integrate these anticipated combat activities into our models.

Müslüm and Sabuncuoğlu (2002) develop a simulation model of mobilization and deployment activities of one of the armored battalions in the Turkish Army that includes loading of vehicles, marching to alert dispersion area, and marching to the assembly area under enemy attack. The authors measure the combat readiness of an armored battalion. Specifically, they present a decision support tool for armored battalion commanders to observe the troop behavior in a computer-simulated environment before the war. Of all the studies from the literature review, this paper provided the most applicable combat modeling information for our study. Similarities include stochastic events such as air and artillery attacks, the same armored battalion structure and analysis of critical regions in Turkey. Their study does not include logistics activities such as ammunition loading and fuel supply. Our study attempts to capture this feature of mobilization and deployment planning for a Turkish Armored Battalion using the same ARENA 3.0 simulation software.

Parker (1995) explains a unique approach developed for analyzing force structures of the armed forces of United States of America. With this approach, combat readiness is measured to ensure armed forces remain ready to fight despite military drawdown.

Childs and Lubaczewski (1987) propose a simulation model used for training Brigade and Battalion commanders and their staff to improve their decision-making skills.

Henry (1994) describes the Corps Battle Simulation as a standard tool for training commanders and their staff. He also stated the hardware and evaluation of the Corps Battle Simulation.

Youngren, Parry, Gaver and Jacobs (1994) describe research conducted at the Naval Postgraduate School into new methodologies for joint theater-level combat simulation modeling.

Blais (1994) gives the description of a computer assisted, two-sided warfare gaming system designed to support training of U.S. Marine Corps commanders and their staffs.

Mostaglio, Johnson and Peterson (1993) give an overview of a distributed interactive simulation training system used in the army called the close combat tactical trainer. They discuss how protocol standards within its program architecture will ensure its long term training success.

Oswalt Ivar (1995) presents the technologies critical to military simulation. He proposes technologies that are likely to be applied in future military simulations, and concludes with a review of two current simulation architectures-SIMOBJECT and J-MASS.

Kathman (1995) explains the processes and techniques of data collection in field combat simulation with particular attention to data requirements, operational environment, and instrumentation. He describes four basic types of instrumentation that have been developed to assist data collection in field combat simulation.

2.4. Military Logistics

In this section, we review some studies about military logistics because our models include distribution activities of supply materials. These papers show specific applications for fuel and ammunition supply systems even though they are in separate military branches. We expand our search of supply systems beyond ammunition and fuel. These papers highlight the areas of ammunition and fuel supply systems and help us create valid models for our existing systems.

Parsons and Krause (1999) introduce the Tactical Logistics and Distribution Systems (TLOADS) simulation model that is a tool to study the delivery of logistics material to U.S. Marine Expeditionary Forces. This tool tries to provide inexpensive, flexible and frequent evaluations of new logistics delivery tactics and logistics material transport vehicles.

Parker and Williams (1997) introduce a model to develop alternative approaches to Air Force logistics support strategies. The model makes it possible to evaluate the steady state flow of fuel and ammunition.

Parker (1990) developes a simulation model capable of analyzing the deployment strategies of combat, combat support and service support units. The model is developed on the deployment of the field artillery ammunition carrying vehicles to an ammunition supply.

All these studies in the literature are summarized in Table 2.1.

Table 2.1. Summary Table of Related Literature

CLASSIFICATION	PUBLICATION	SUBJECT
Simulation Software and Methodology	Takus and Profozich (1997)	ARENA software tutorial
	Don Coughlin (2000)	An integrated approach to VV&A of models and simulations
	Jennifer and Cindy (2000)	VV&A in the life cycle of models
	Sargent (1998)	V&V of simulation models
	Kelton (1997)	Statistical analysis of simulation output
Military Simulation	Grabau and Payne (2000)	Predicting enemy force closure with simulation
	Metz Micheal (2000)	Joint warfare system verification and validation lessons learned
	Raymond Hill, Miller and Gregory (2001)	Applications of discrete event simulation modeling to military problems
	Garrabrants (1998)	Simulation as a mission planning and rehearsal tool
	Hartley (1997)	V&V in military simulations
	Oswalt Ivar (1995)	Technology trends in military simulation
	Sisti (1996)	Modeling and simulation technologies for military applications
	Smith (1998)	Essential techniques for military modeling and simulation
	Kang and Roland (1998)	Military simulation
	Pace (1993)	Naval modeling and simulation VV&A
Combat Modeling	Parker (1995)	Military force structure and realignment through dynamic simulation
	Childs and Lubaczewski (1987)	A battalion/brigade training simulation
	Henry (1994)	The Corps battle simulation
	Blais (1995)	Scalability issues in enhancement of the MAGTF tactical warfare simulation
	Kathman (1985)	Data collection in field combat
	Youngren and Parry (1993)	The future theater-level combat
	Mostaglio,Johnson and Peterson (1993)	The close combat tactical training program
	Müslüm and Sabuncuoğlu (2002)	Evaluation of Mobilization and Deployment Plan of an Armored Battalion
Military Logistics	Parker (1990)	Ammunition upload and deployment
	Parker and Williams (1997)	Integrating logistics support operations
	Parsons and Krause (1999)	Tactical logistics and distribution systems simulation

CHAPTER 3

THE SIMULATION MODEL

3.1. Formulation of the Problem and Planning the Study

We develop the models of ammunition and fuel supply systems of an armored battalion during mobilization and deployment using simulation to enable commanders to examine the behaviors of existing systems before conducting real exercises. The systems we analyze in this study are:

- Ammunition and fuel supply of an armored battalion at supply points (System-1)
- Ammunition and fuel supply of an armored battalion by ammunition trucks and fuel tankers at alert dispersion areas (System-2)

In this study we have the following objectives: (1) To examine the behaviors of the existing systems by constructing valid models of systems. (2) To detect the factors which have significant effects on existing systems. (3) To find time standards of existing systems. (4) To rank the regions of Turkey from most to least critical according to performance measures of interest.

We have two main performance measures in our study for both models. These performance measures are maximum time-in-system and number of destroyed vehicles. Maximum time-in-system is the time the last battalion vehicle arrives at the alert dispersion area after supply activity. Both performance measures have vital importance in the military since they affect the course of war. By using our simulation models, we try to answer the following questions:

- Do the systems operate efficiently?
- What can be the time standards of the systems?

- How do vehicle breakdowns, enemy air attacks and enemy artillery attacks affect the system performances?
- What are the significant factors on performance measures?
- Which region of Turkey is the most critical region against enemy air and artillery attacks?
- What is the ranking of regions of Turkey according to maximum time-in-system performance measure?

We study the systems under war conditions and we need the following data in our simulation models.

For Model-1,

- Velocity of armored vehicles.
- Velocity of wheeled vehicles.
- Ammunition loading time of an armored vehicle.
- Fuel supply time of an armored vehicle.
- Fuel supply time of a wheeled vehicle.
- Maintenance times for vehicles due to vehicle breakdowns, air attacks and artillery attacks.

For Model-2,

- Velocity of ammunition trucks.
- Velocity of fuel tankers.
- Ammunition loading and unloading times of ammunition trucks.
- Fuel supply time of a fuel tanker.

- Maintenance times for vehicles due to vehicle breakdowns, air attacks and artillery attacks.
- Ammunition loading time of an armored vehicle.
- Fuel supply times of armored and wheeled vehicles.

By using the models, the military planners can examine the physical behaviors of systems with the help of animation. The models can be adapted to model other supply systems of the army using the flexibility of Arena software. The end users of this study are the armored battalion commanders.

3.2. Why Simulation?

We model the existing systems and analyze them by using simulation for the following reasons:

- The systems under study have many stochastic features such as vehicle breakdowns, enemy air attacks and maintenance times for damages due to enemy attacks.
- Because of economic reasons and difficulties creating real world conditions, it is almost impossible to exercise the systems in the field.
- Simulation enables us to analyze different policies and system alternatives in our study.
- Simulation enables us to animate our models. Animations of our models greatly assist in the models' validation and also help present our models to other people.
- By using simulation we compare different scenarios of existing systems in the study.

- Simulation enables us to train military personnel in a safe environment.

3.3. Model Development

The first step in model building consists of observing the real system and the interactions among its various components and collecting data on its behavior. The second step in model building is the construction of a conceptual model (a collection of assumptions on the components and the structure of the system, plus hypotheses on the values of model input parameters). The third step is the translation of the operational model into the computerized model. (Banks, Carson, and Nelson, 1999)

We form the conceptual models of our real systems by data gathered from the experts of supply systems and also from users of the systems. The warfare related data are taken primarily from army publications. We interviewed personnel responsible for ammunition depot and fuel supply points to obtain information about ammunition loading and fuel supply processes. We also interviewed maintenance personnel to gather maintenance times for possible damages and squadran leaders for insights about difficulties during supply activities. After we gathered enough data about real systems, we developed the logical model (flowchart) of the systems to show relationships among the elements of the models. We then wrote the code of simulation models by using the Arena 3.0 simulation program.

3.3.1. Conceptual Model

"The construction of a model is probably as much art as science. The art of modeling is enhanced by an ability to abstract the essential features of the problem, to select and modify basic assumptions that characterize the system, and then to enrich and elaborate the model until a useful approximation results" (Banks, Carson, Nelson, 1999).

A conceptual model is not intended to be a design for a system to simulate the real world. Rather, it provides an organised way for an analyst to document the workings of the system of interest and a framework for the modeller to document the system. Only objects necessary for understanding of the system need to be documented.

To examine the essential components and structures of the real world systems under consideration, we devise conceptual models of these real world systems. In our study the real world systems of interest are:

- Ammunition and fuel supply of an armored battalion at supply points (System-1).
- Ammunition and fuel supply of an armored battalion by ammunition trucks and fuel tankers at alert dispersion areas (System-2).

We present the basic elements of our simulation models in the following:

Events

Common Events for Model-1 and Model-2

- Breakdown of vehicles.
- Maintenance of broken vehicles.
- Artillery attack of enemy.
- Loading of ammunition to armored vehicles.
- Air attack of enemy.
- Damage of vehicles because of enemy attacks.
- Completion of maintenance of damaged and broken vehicles.

Unique Model-1 Events

- Departure of armored and wheeled vehicles to supply points.
- Arrival of armored vehicles to ammunition depot.
- Arrival of wheeled vehicles to fuel supply points.
- Fuel supply to armored and wheeled vehicles.
- Departure of vehicles to alert dispersion areas from supply points.
- Arrival of vehicles to alert dispersion areas.

Unique Model-2 Events

- Departure of ammunition trucks and fuel tankers to supply points.
- Departure of armored and wheeled vehicles to company alert dispersion areas.
- Arrival of armored and wheeled vehicles to company alert dispersion areas.
- Arrival of ammunition trucks to ammunition depot.
- Arrival of fuel tankers to fuel supply points.
- Loading of ammunition to ammunition trucks.
- Fuel supply to fuel tankers.
- Departure of ammunition trucks and fuel tankers to alert dispersion areas from supply points.
- Arrival of ammunition trucks and fuel tankers to alert dispersion areas.
- Unloading of ammunition from ammunition trucks.
- Fuel supply to armored and wheeled vehicles by fuel tankers.
- Completion of ammunition loading to armored vehicles.
- Completion of fuel supply to armored and wheeled vehicles.
- Departure of ammunition trucks and fuel tankers to Headquarters Company alert dispersion area.

- Arrival of ammunition trucks and fuel tankers to Headquarters Company alert dispersion area.

Entities

Common Entities for Model-1 and Model-2

- Armored vehicles.
- Wheeled vehicles.

Unique Model-2 Entities

- Fuel tankers.
- Ammunition Trucks.

Activities

Common Activities for Model-1 and Model-2

- Ammunition loading to armored vehicles.
- Fuel supply to armored and wheeled vehicles.
- Convoy of vehicles.
- Breakdowns of vehicles.
- Enemy attacks.
- Maintenance.

Unique Model-2 Activities

- Ammunition loading to ammunition trucks.
- Fuel supply to fuel tankers.
- Unloading of ammunition from ammunition trucks.

Attributes

Common Attributes for Model-1 and Model-2

- Company identification numbers.
- Convoy identification numbers.
- Fuel level of vehicles.
- The beginning time of supply activity.

Exogenous Variables (Input Variables)

a) Decision Variables (Controllable Variables)

Common Decision Variables for Model-1 and Model-2

- Number of loading points at ammunition depot.
- Number of fuel supply points per company.

Unique Model-1 Decision Variables

- Velocity of wheeled and armored vehicles.
- The vehicle convoy formation (in company or squadran formation).

Unique Model-2 Decision Variables

- Velocity of ammunition trucks and fuel tankers.
- Capacity of ammunition trucks and fuel tankers.

b) Parameters (Uncontrollable Variables)

Common Parameters for Model-1 and Model-2

- Ammunition loading time of an armored vehicle.
- Fuel supply time of an armored vehicle.
- Fuel supply time of a wheeled vehicle.

- Maintenance times for vehicle damages due to enemy air attack and artillery attack.
- Distances between supply points, garages and alert dispersion areas.

Unique Model-1 Parameters

- Number of armored and wheeled vehicles.

Unique Model-2 Parameters

- Ammunition loading time of an ammunition truck.
- Fuel supply time of a fuel tanker.
- Number of ammunition trucks and fuel tankers.
- Ammunition unloading time of an ammunition truck.

Endogenous Variables (Output Variables)

a) State variables

Common State Variables for Model-1 and Model-2

- State of ammunition loading units.
- State of fuel supply units.

Unique Common State Variables for Model-1

- Number of armored vehicles in ammunition queue.
- Number of vehicles in fuel supply queues.

Unique Common State Variables for Model-2

- Number of ammunition trucks in ammunition queue.
- Number of fuel tankers in fuel supply queues.
- Number of armored vehicles in ammunition queues at alert dispersion areas.
- Number of vehicles in fuel supply queues at alert dispersion areas.

b) Performance measures

Common Performance Measures for Model-1 and Model-2

- Maximum time-in-system (the time the last battalion vehicle occupied its position at the alert dispersion area after supply activities).
- Number of destroyed vehicles.
- Number of broken vehicles because of vehicle breakdowns.
- Number of damaged vehicles because of enemy attacks.
- Utilization of the ammunition loading units.
- Utilization of fuel supply units.

Unique Model-1Performance Measures

- Average time-in-system of an armored vehicle.
- Average time-in-system of a wheeled vehicle.
- Average waiting time of an armored vehicle in ammunition queue.
- Average waiting time of a vehicle (armored and wheeled) in fuel supply queue.
- Average number of armored vehicles at ammunition depot.
- Average number of vehicles (armored and wheeled) at fuel supply point.

Unique Model-2 Performance Measures

- Average time-in-system of an ammunition truck.
- Average time-in-system of a fuel tanker.
- Average waiting time of an ammunition truck in ammunition queue.
- Average waiting time of an armored vehicle in ammunition queue at alert dispersion area.
- Average waiting time of a vehicle in fuel supply queue at alert dispersion area.

Assumptions

Common Assumptions for Model-1 and Model-2

- Basic unit is company.
- Armored Battalion is an independent mission battalion.
- In the beginning all armored vehicles are unloaded of ammunition.
- The personnel in charge at supply points are well trained and there is no accident because of personnel mistakes.
- There is a strong air defense system at supply points against enemy air attacks.

Unique Model-1 Assumptions

- The ammunition loading will be carried out by the sequence of 1st, 2nd and 3rd armored companies at the ammunition depot.
- In the beginning all wheeled and armored vehicles are half fueled.
- Velocity of armored vehicles is 25km/hour.
- Velocity of wheeled vehicles is 40km/hour.

Unique Model-2 Assumptions

- In the beginning all wheeled and armored vehicles are half fueled.
- The weight of an ammunition box (two shells in one box) is 70 kg.
- Velocity of ammunition trucks is 30 km/hour.
- Velocity of fuel tankers is 30 km/hour.

3.3.2. Logical Model

In this section, we explain the logic of Model-1 and Model-2. In Model-1, our entities are armored and wheeled vehicles. After it starts, entities resembling wheeled vehicles convoy to fuel supply station and entities resembling armored vehicles convoy to the ammunition supply station. During convoy some entities go through breakdown or artillery attacks according to probabilities given in the model. Those entities which experience the breakdown or artillery attacks are delayed by the time depending on minor, medium or severe damage status or disposed from the system when completely destroyed. At the end, armored vehicle entities arrive at the ammunition supply station while wheeled vehicle entities arrive at the fuel supply station. Armored vehicle entities are delayed at ammunition supply station before convoying to the fuel supply station and queing behind the wheeled vehicle entities. Meanwhile, wheeled vehicle entities are delayed at the fuel supply station before convoying to alert dispersion area station. Armored vehicle entities are delayed after completion of wheeled vehicle entities fueling. Armored vehicle entities convoy to alert dispersion area station after the delay. Some armored and wheeled vehicle entities go through breakdown or air attack stations during convoy to the alert dispersion area station. Those entities which experience the breakdown or air attacks are delayed by the time depending on minor, medium, or severe damage status or disposed from the system when completely destroyed. The last entity to reach the alert dispersion area station completes the model. We present the simplified flowchart of Model-1 in Figure 3.1 and detailed flowchart of Model-1 in Appendix-A.

In Model-2, our entities are armored vehicles, wheeled vehicles, ammunition trucks and fuel tankers. After the model starts, entities resembling wheeled and armored vehicles convoy to alert dispersion area station and do not visit any stations during the

Ammunition and Fuel Supply of an Armored Battalion at Supply Points

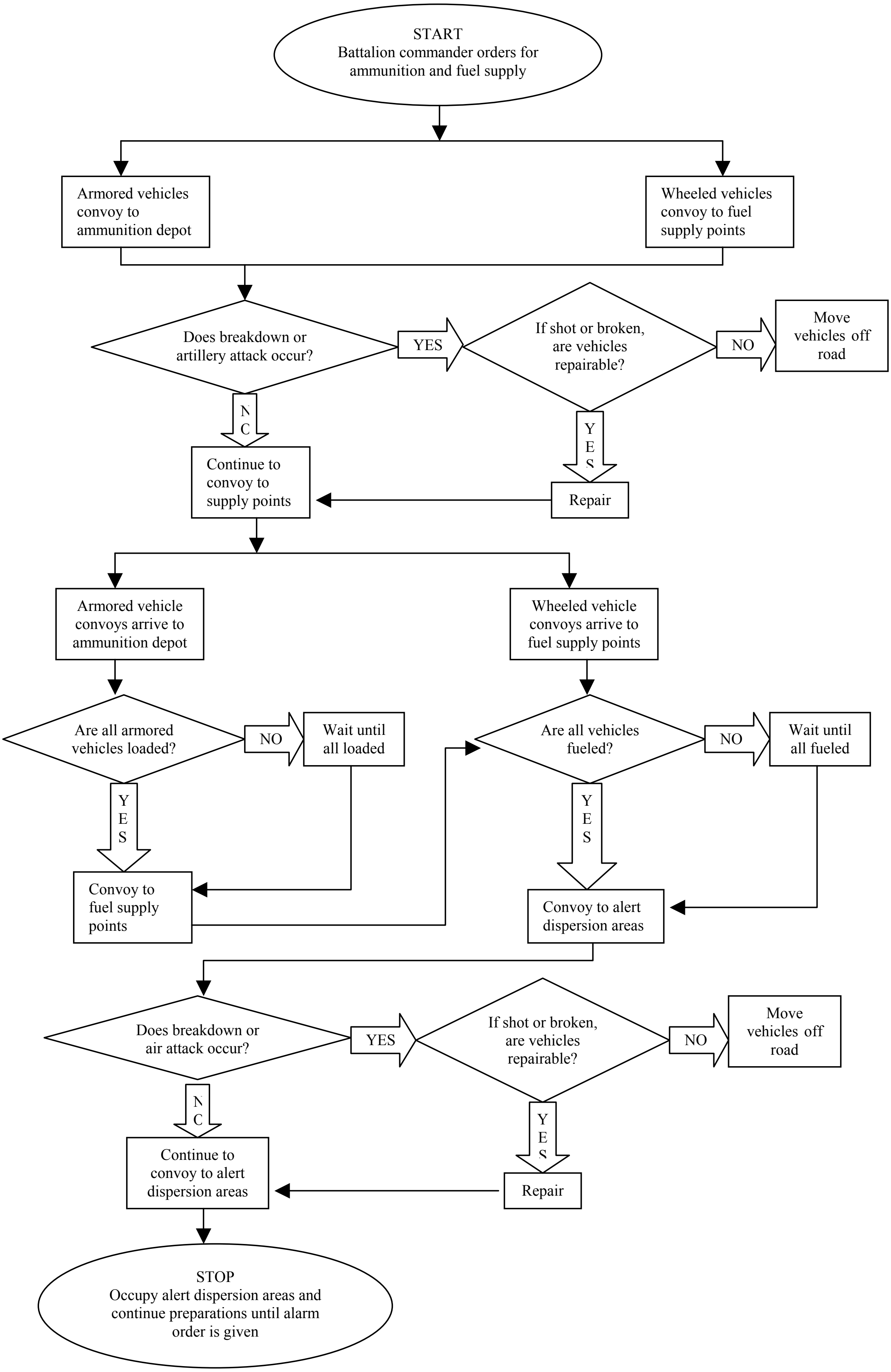


Figure 3.1. Simplified Flowchart of System-1

convoy. They wait at the alert dispersion area station until ammunition truck and fuel tanker entities arrive. Meanwhile, ammunition truck entities convoy to the ammunition supply station and fuel tanker entities convoy to the fuel supply station. During convoy some ammunition truck and fuel tanker entities go through breakdown or artillery attack stations according to probabilities given in the model. Those entities which experience the breakdown or artillery attacks are delayed by the time depending on minor, medium, or severe damage status or disposed from the system when completely destroyed. At the end, ammunition truck and fuel tanker entities arrive at the supply stations. Ammunition truck entities are delayed at the ammunition supply station while fuel tanker entities are delayed at the fuel supply station. After supply activity delays, entities convoy to the alert dispersion area station to supply armored and wheeled vehicle entities. Some ammunition truck and fuel tanker entities go through breakdown or air attack stations during convoy to the alert dispersion area station. Those entities which experience the breakdown or air attacks are delayed by the time depending on minor, medium, or severe damage status or disposed from the system when completely destroyed. Ammunition truck and fuel tanker entities are delayed to unload their supply material before travelling to alert dispersion area station. The last entity to arrive to the alert dispersion area station completes the model. We present the simplified flowchart of Model-2 in Figure 3.2 and detailed flowchart of Model-2 in Appendix-A.

Ammunition and Fuel Supply of an Armored Battalion by Ammunition Trucks and Fuel Tankers

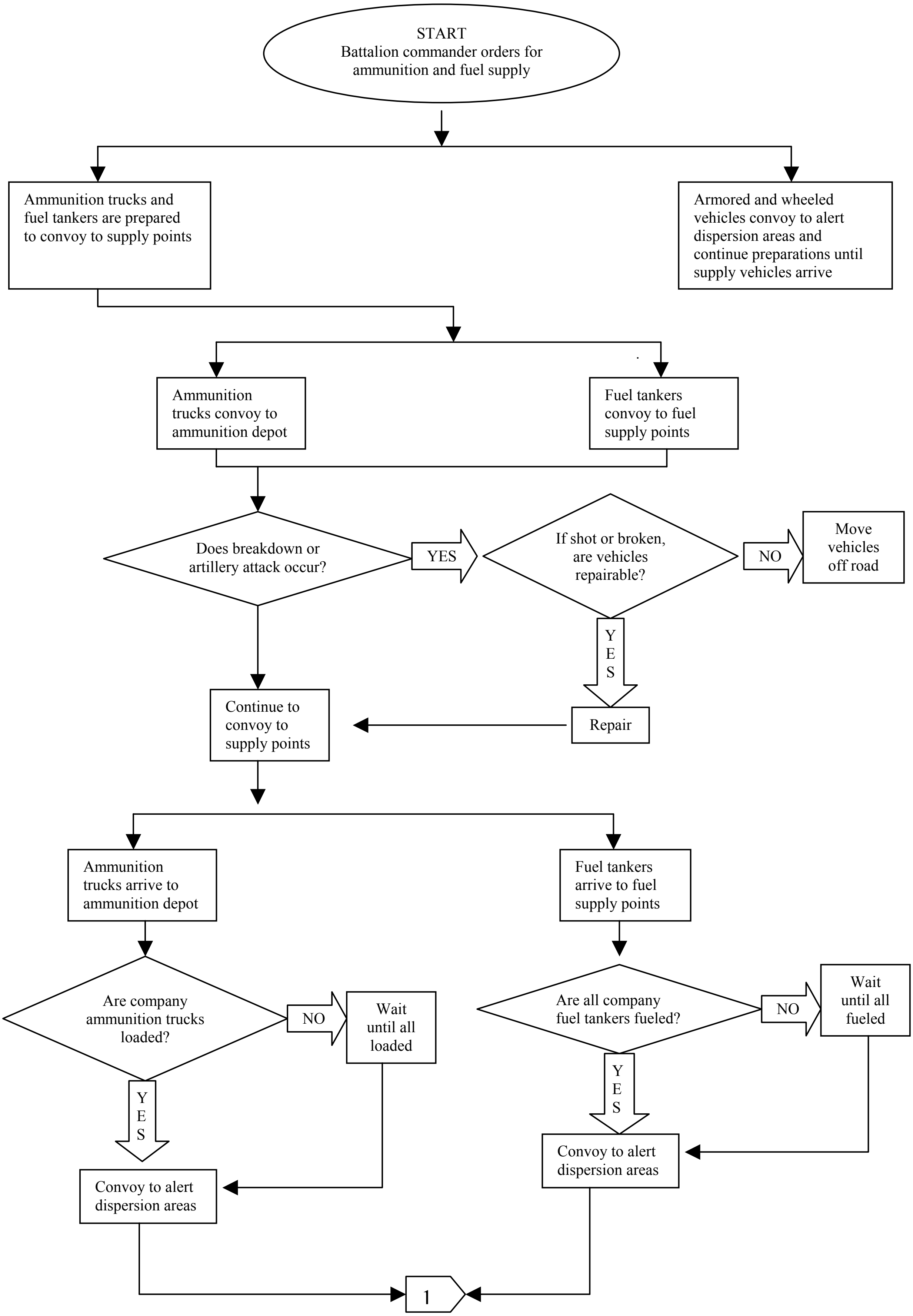


Figure 3.2. Simplified Flowchart of System-2

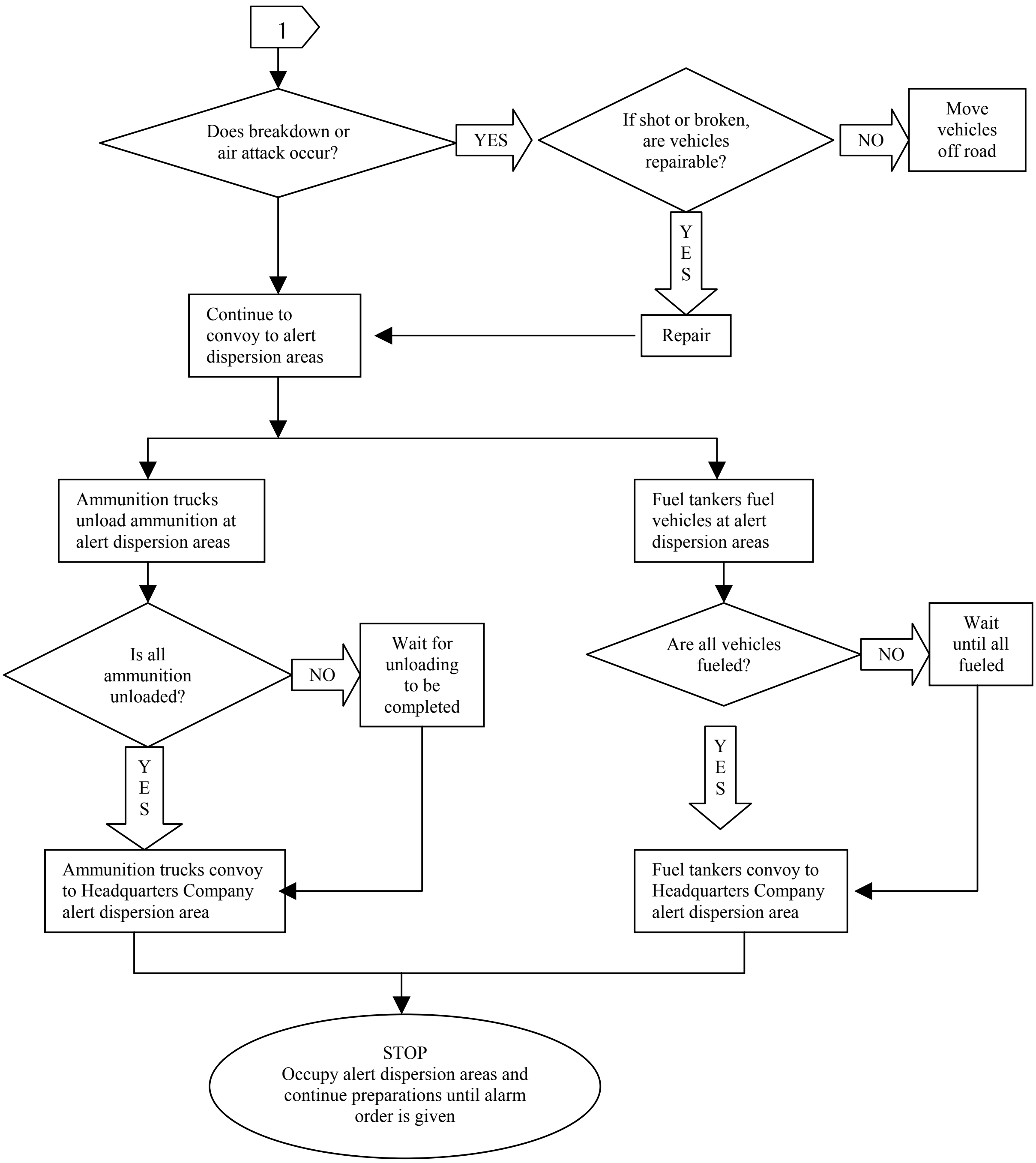


Figure 3.2. Simplified Flowchart of System-2 (cont'd)

3.3.3. Simulation Model (Computer Code)

In our study we use ARENA 3.0 software for the simulation codes of existing systems. Arena software has the capability of creating animated models and is a flexible tool. We have two models in our study. The model of ammunition and fuel supply of an armored battalion at supply points, Model-1, and the model of ammunition and fuel supply of an armored battalion by ammunition trucks and fuel tankers at alert dispersion areas, Model-2. Some details are as follows:

- Technical information about Model-1

Size of model : 3.64 MB

Total number of lines : 460 Siman lines

- Technical information about Model-2

Size of model : 4.21 MB

Total number of lines : 633 Siman lines

We present some parts of the computer codes of Model-1 and Model-2 in Appendix-G.

3.4. Input Data Analysis

There are three probability distributions which are often used in absence of data or limited data. These distributions are the uniform, triangular and beta distributions. The uniform distribution can be used when an interarrival or service time is known to be random, but no information is immediately available about the distribution. The triangular distribution can be used when we have some information about the minimum, maximum and modal values of the random variable. The beta distribution provides a variety of distributional forms on the unit interval which with appropriate modification can be shifted to any desired interval (Pegden, Shannon and Sadowski, 1995).

In our case, since we do not have actual data for war conditions, we use triangular distributions. The parameters of the distribution functions are obtained from army field manuals and defense ministry publications. For data concerning ammunition and fuel supply activities in war conditions, we use Kara Kuvvetleri Lojistik Faktörler Yönergesi (Turkish Army Logistics Procedures) which is mainly used for logistics calculations for the Turkish Army. We interviewed expert personnel from ammunition and fuel supply activities in the army. We also interviewed maintenance personnel for technical information and staff officers for tactical information.

We present the parameters of triangular distribution for maintenance times of wheeled vehicles in Table 3.1 and maintenance times of armored vehicles in Table 3.2.

Table 3.1. Maintenance Times of Wheeled Vehicles

	Damage Type		
	Minor Damage	Medium Damage	Severe Damage
Vehicle Breakdown	Tria (10,15,20)	Tria (25,30,35)	Tria (40,45,50)
Air Attack	Tria (30,35,40)	Tria (35,40,45)	Tria (50,55,60)
Artillery Attack	Tria (20,25,30)	Tria (35,40,45)	Tria (50,55,60)

Table 3.2. Maintenance Times of Armored Vehicles

	Damage Type		
	Minor Damage	Medium Damage	Severe Damage
Vehicle Breakdown	Tria (15,20,25)	Tria (30,35,40)	Tria (45,50,55)
Air Attack	Tria (35,40,45)	Tria (40,45,50)	Tria (55,60,65)
Artillery Attack	Tria (25,30,35)	Tria (40,45,50)	Tria (55,60,65)

The parameters of distribution functions of ammunition loading times and fuel supply times are obtained by interviewing expert personnel at supply activities and studying Kara Kuvvetleri Lojistik Faktörler Yönergesi (Turkish Army Logistics Procedures, 1994). We present ammunition loading times in Table 3.3 and fuel supply times in Table 3.4.

Table 3.3. Ammunition Loading Times

Vehicle	Loading Time
Armored Vehicle	Tria (20,25,30)
Ammunition Truck	Tria (65,75,85)

Table 3.4. Fuel Supply Times

Vehicle	Fuel Supply Time
Wheeled Vehicle	Tria (1,3,6)
Armored Vehicle	Tria (4,7,10)

We take destruction probabilities of enemy air and artillery weapons from the JANUS database (http://www-leav.army.mil/nsc/famsim/janus/index.htm) software, the war simulation package which is used to model combat field activities. In our study, we use the ARENA software because JANUS is only used for combat activities. JANUS is effective for battle-focused training from platoon to brigade level and for command and battle staff training. We not only deal with combat activies in our study but also logistics activities. ARENA allows us to model logistics activities and also combat activities. Logistics activities include the storage, movement, distribution, maintenance, evacuation, and disposition of material; evacuation and hospitalization of personnel; construction, maintenance, operation, and disposition of facilities. We present destruction probabilities of enemy weapons in Table 3.5.

Table 3.5. Destruction Probabilities of Enemy Weapons

	Wheeled Vehicles	Armored Vehicles
Enemy War Plane Cannon (30 mm)	0.65	0.55
Enemy Artillery Cannon (155 mm)	0.5	0.35

3.5. Verification and Validation of the Models

In this section, we discuss whether our simulation models operate correctly and whether they simulate their real-world counterparts. Verification and validation of the model is one of the challenging tasks for the model developer.

3.5.1. Verification of the Models

Verification is the process of determining whether a model operates as intended. The purpose of model verification is to ensure that the conceptual model is reflected accurately in the computerized representation. In this section, the computer programs representing existing systems are verified by techniques recommended by (Banks, Carson and Nelson, 1999) and by techniques stated in Department of the Army Pamphlet 5-11 (1999).

- **Debugging :** We used Arena debugger so as not to make logical mistakes when building our models. By applying the debugging process, we test our models to reveal the existence of errors. Then we make necessary model changes to correct the detected errors in models and retest to ensure successful modification. This iterative process continues until no errors are identified in our models.

- **Design Walkthroughs :** The walkthrough procedure involves gathering a small group for an informal review of the model's logic. We applied this procedure by gathering the personnel responsible for ammunition and fuel supply activities in the battalion, maintenance personnel and also the armored squadran leaders. We incorporated their comments into the models.

- **Using Animation as a Verification Aid :** Animation presents a dynamically moving picture of many interactions taking place within the simulation. Such interactions are often the source of errors. By animating our models we followed the complex interactions occuring in our models and corrected some minor mistakes.

- **Checking :** The codes of our models were checked by Gokhan Celik, Ozan Pembe and Burhan Urek who are all military officers and have expertise in military simulation modelling and analysis. First, we explained the systems under consideration and then allowed them to check the codes of our models.

3.5.2. Validation of the Models

Validation is the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model (Department of the Army Pamphlet 5-11, 1999). Validation is concerned with building the right model. In our study we validate our models by using the techniques recommended by (Banks, Carson and Nelson, 1999) and by the techniques stated in Department of the Army Pamphlet 5-11 (1999).

- **Sensitivity Analysis :** Sensitivity analysis is performed by systematically changing model input variables and parameters over some range of interest and observing the effect upon model behavior. Unexpected effects reveal invalidity. We applied sensitivity analysis by changing input variables of our models. The details are as follows:

Sensitivity analysis for Model-1

We change the parameters of triangular distribution for ammunition loading time and fuel supply time to armored vehicles in our model. Our aim is to observe effects of changes in our model. We expect an increase in maximum time-in-system statistics when we increase the parameters of triangular distributions of these random variables.

Firstly, we increase the parameters of triangular distribution for ammunition loading time to an armored vehicle in our model. The parameters of triangular distribution for ammunition loading time and maximum time-in-system statistics are given below. The sample size of Model-1 is 15 (The determination of sample sizes for models are explained in Chapter 4. Section 4.1.1).

Existing System : Tria (20,25,30) $\overline{X}$ (15) = 533.45 min.

Changed System : Tria (80,85,90) $\overline{X}$ (15) = 1813.95 min.

As seen above, when we increase the parameters of triangular distribution for ammunition loading time to armored vehicles, the maximum time-in-system statistics increase from 533.45 min. to 1813.95 min.

Secondly, we increase the parameters of triangular distribution for fuel supply time to armored vehicles:

Existing System : Tria (4,7,10) $\overline{X}$ (15) = 533.45 min.

Changed System : Tria (40,45,50) $\overline{X}$ (15) = 1898.04 min.

Again, as expected, we observe an increase in the maximum time-in-system statistics after increasing the parameters of triangular distribution for fuel supply time.

Sensitivity analysis for Model-2

In Model-2, we increase the parameters of triangular distribution for ammunition loading time to ammuniton truck and then decrease the velocity of ammunition trucks. We expect an increase in maximum time-in-system statistics after we make changes. Firstly, we increase the parameters of triangular distribution for ammunition loading time to an ammunition truck in our model. The parameters of triangular distribution for ammunition loading time to ammuniton truck and the maximum time-in-system statistics of existing and changed models are below. The sample size of Model-2 is 10.

Existing System : Tria (65,75,85) $\overline{X}$ (10) = 469.85 min.

Changed System : Tria (190,200,210) $\overline{X}$ (10) = 1362.71 min.

As expected, we observe an increase in maximum time-in-system statistics after increasing the parameters of triangular distribution for ammunition loading time to ammunition truck. Secondly, we decrease the velocity of ammunition trucks:

Existing System : 30 km/hour $\overline{X}$ (10) = 469.85 min.

Changed System : 15 km/hour $\overline{X}$ (10) = 574.38 min.

As expected, we observe an increase in maximum time-in-system statistics after decreasing the velocity of ammunition trucks.

- **Face Validation :** The project team members, potential users of the model, and the subject matter experts (SMEs) review simulation outputs (eg. numerical results, animations, etc.) for reasonableness. They use their estimates and intution to compare model and system behaviors subjectively under identical input conditions and judge whether the model and its results are reasonable (Hermann, 1967). In our study, we include the users of the models and the people who are knowledgeable about systems from the beginning of the study. Armored squadran leaders, two maintenance personnel from the Armored Branch School, one staff officer from the Land Force Headquarters and two expert supply system personnel from the Army Logistics Department were included in the model development process. The model outputs were examined by these personnel and found reasonable by them.

- **Cause-Effect Graphing :** Cause-effect graphing addresses the question of what causes what in the model representation. Causes and effects are first identified in the system being modeled and then their representations examined in the model specification.

In Model-1, we increase the number of wheeled vehicles of Headquarters Company to evaluate the effect on fuel supply point utilization. There are seventy-five wheeled vehicles in Headquarters Company utilizing the supply point at %59.28. We increase the number of wheeled vehicles to one hundred and observe the fuel supply point utilization increases to %72.58.

In Model-2, we observe the effect of increasing the number of ammunition trucks. In Model-2, there are 12 ammunition trucks with an ammunition loading unit utilization of %64.36. We increase the number of ammunition trucks to 18 and observe an increase of the ammunition loading unit utilization to %79.53. Secondly, we observe the effect of the increase in number of fuel tankers on utilization of the Headquarters Company fuel supply point. In Model-2, there are 3 fuel tankers for Headquarters Company and the utilization of the company fuel supply point is %26.35. We increase the number of fuel tankers to 6 and observe that utilization of the fuel supply point increases to %39.84.

- **Review :** Detailed examination of input data, key parameters and resulting output data are discussed with the personnel who are knowledgeable about modeling the functional areas represented in our models.

- **Visualization and Animation :** Animation is an effective method for model validation. Displaying graphical images of internal and external dynamic behaviors of the models during execution helped us uncover errors. In Figure 3.3 we present a view from animation of Model-1. In Figure 3.4 we present statistics collected for Model-1. In Figure 3.5 we present a view from animation of Model-2. Finally, in Figure 3.6 we present statistics collected for Model-2.

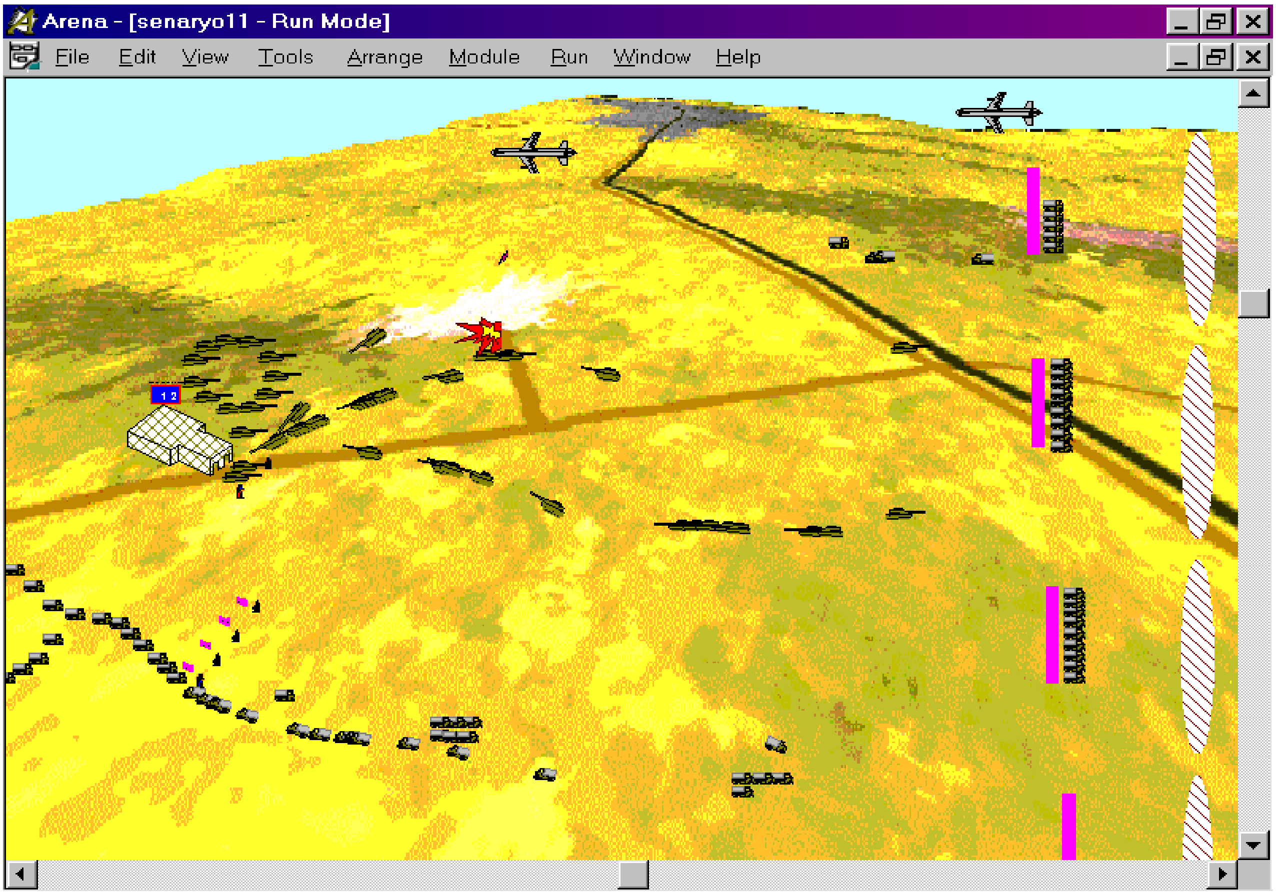


Figure 3.3. View from Animation of Model-1

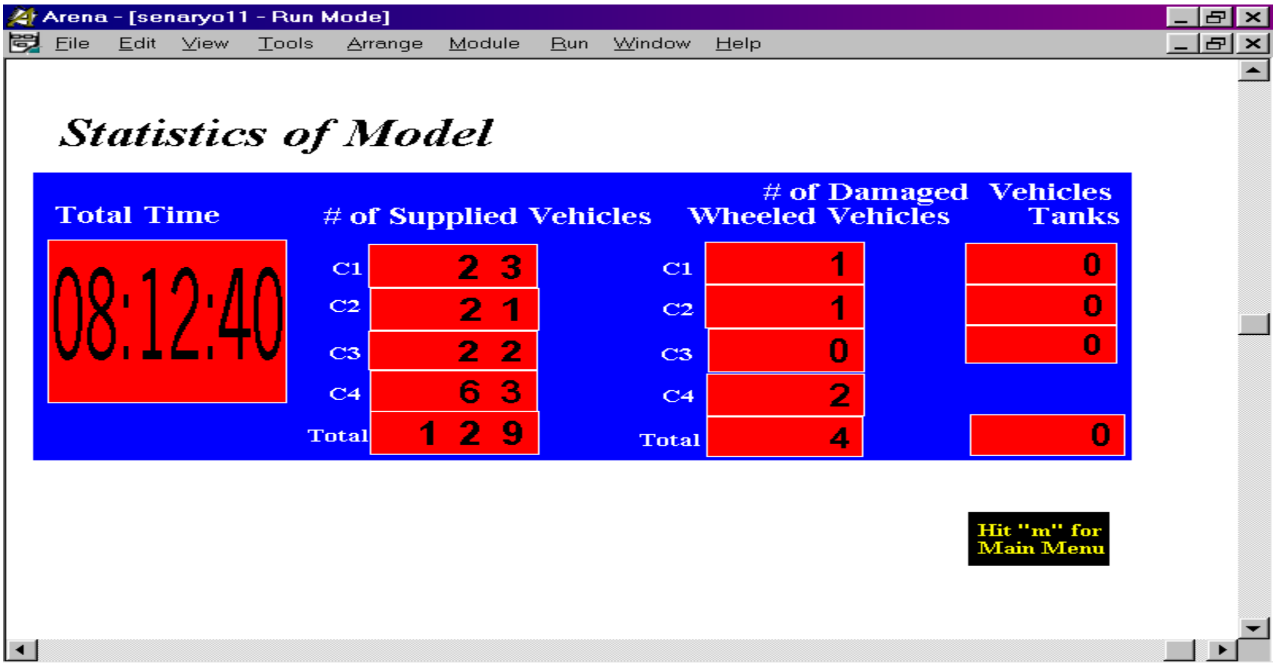


Figure 3.4. Statistics Collected for Model-1

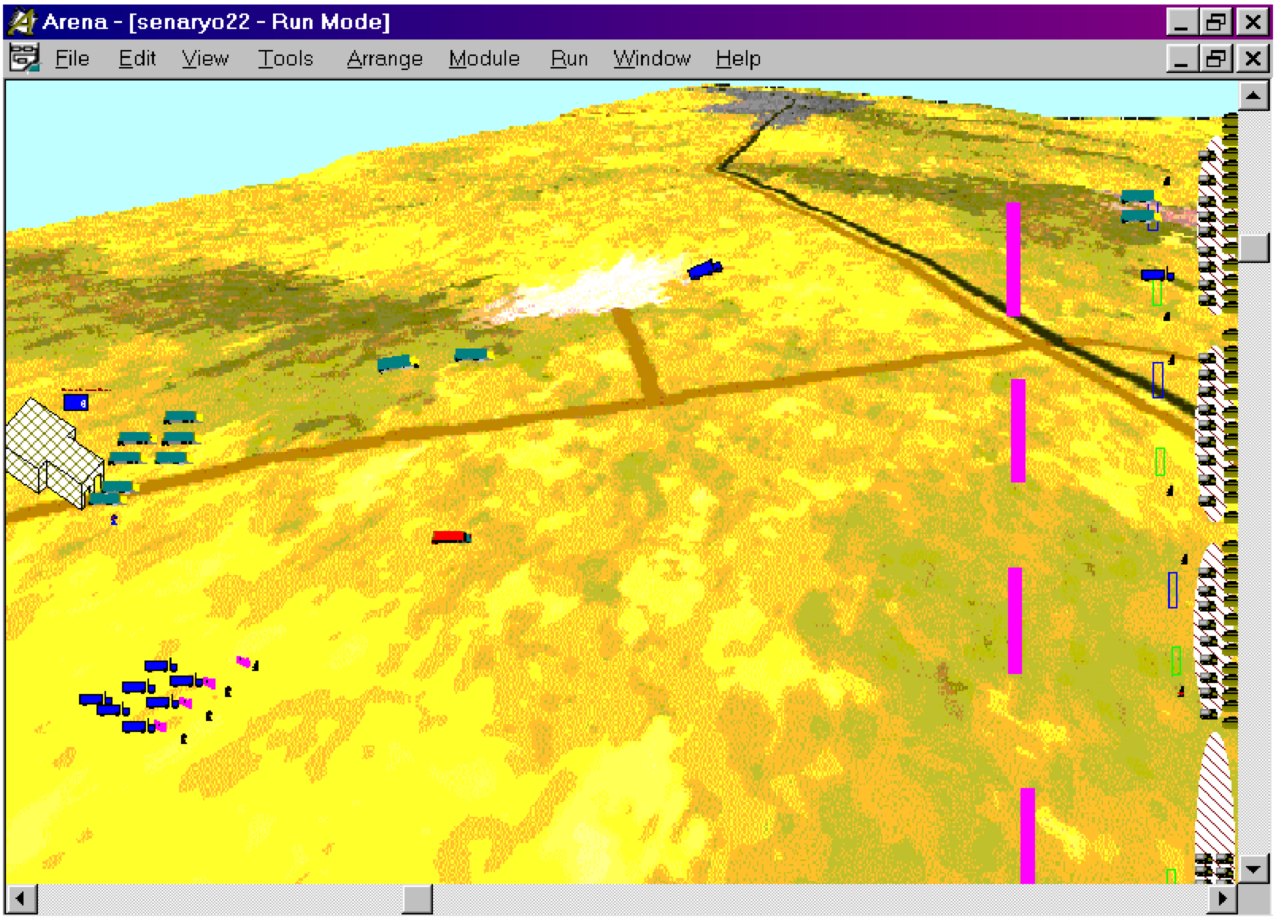


Figure 3.5. View from Animation of Model-2

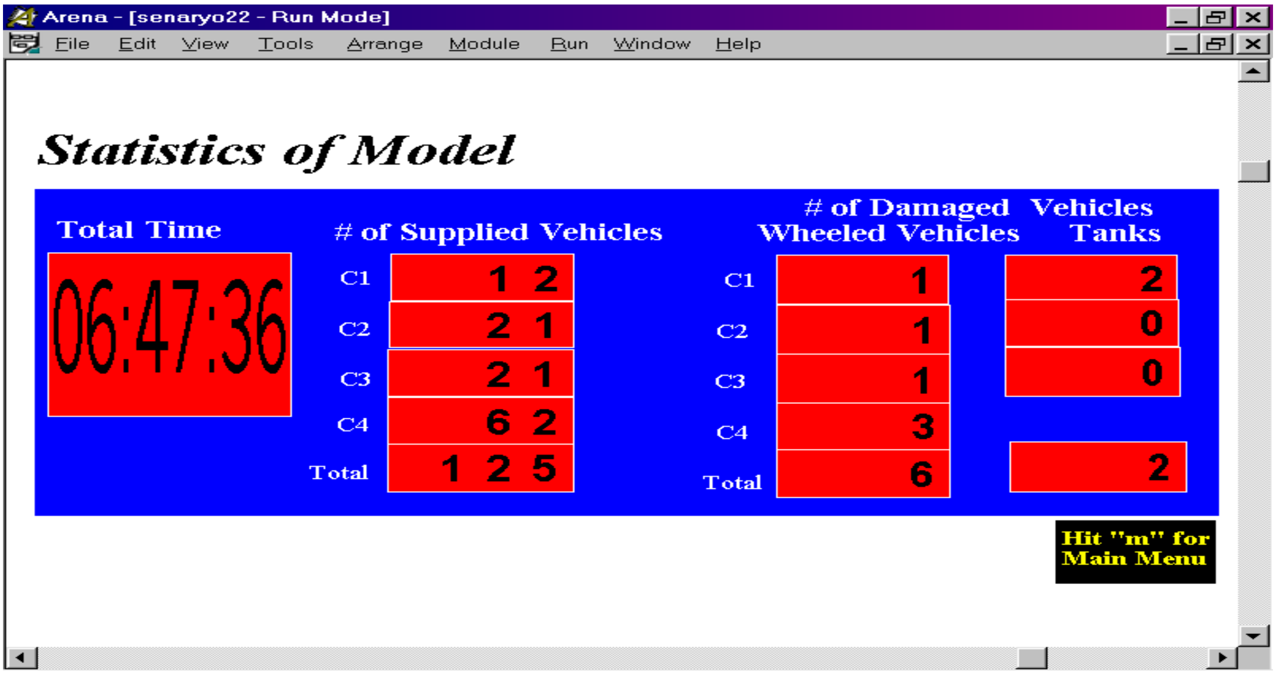


Figure 3.6. Statistics Collected for Model-2

CHAPTER 4

DESIGN AND ANALYSIS OF EXPERIMENTS

4.1. Factorial Designs and Analysis of Experiments

One of our aims in this study is to determine the effects of the factors on system performances. We know that factorial designs are very efficient and widely used to determine the effects of factors on system performances. In our study, we model two systems: System-1 (ammunition and fuel supply of an armored battalion at supply points) and System-2 (ammunition and fuel supply of an armored battalion by ammunition trucks and fuel tankers). We implement 2^k factorial design for both models to discover the effects and possible interactions of factors on system performance according to performance measures. Our performance measures in this study are maximum time-in-system and number of destroyed vehicles. Both performance measures have vital importance for the military since they affect the course of war. In this chapter, we also try to determine which factors and interactions have significant effect on system performance. We implement analysis of variance (ANOVA) to find out which factors and interactions have significant effects on system performance. In our study, there are five factors under consideration. We present these factors and their levels in Table 4.1.

Table 4.1. Factors and Their Levels

	Factor Name	**Low Level**	**High Level**
1	Breakdown	0.02	0.2
2	Air Attack	0.1	0.8
3	Artillery Attack	0.1	0.8
4	Number of Ammunition Depot Loading Points	2	4
5	Number of Company Fuel Supply Points	1	3

Among them breakdown, air attack and artillery attack are uncontrollable factors. Number of ammunition depot loading points and number of company fuel supply points are controllable factors. In existing systems, there is one ammunition depot for all companies' ammunition supply. On the other hand, each company has its own fuel supply point. The factor levels are determined by asking military experts and by studying field manuals related with our study. We implement factorial designs for five factors in our study, hence there are 32 design points. We present 32 design points of five factors in Appendix-B (Table B.1). In our design points, "1" implies the high factor level and "0" implies the low factor level. For example, "10000" means that the first factor is at high level and other factors are at low levels.

In factorial design, we make the following assumptions: (1) the usual normality assumptions are satisfied (2) homogeneity of variances is satisfied and (3) the designs are completely randomized. We replicate each of the 32 design points with different seeds and use the required sample size for each model to randomize design points completely. We determine the sample sizes of models in Section 4.1.1, check the assumption of homogeneity of variances in Section 4.1.2 and check the normality of data by examining residual plots of performance measures in Section 4.1.3 (Diagnostic Checking).

4.1.1. Determination of Sample Sizes

In this section, we determine the number of replications required to obtain the point estimates of performance measures with a specified absolute precision and confidence level. We use sequential procedure for obtaining sample sizes of our models. The sequential procedure is given below (Law and Kelton, 1991).

Let $\delta(n,\alpha) = t_{n-1,1-\alpha/2}\sqrt{\frac{s^2(n)}{n}}$, be the usual confidence-interval half-length,

Choose $n_o \geq 2$,

1. Make n_o replications of the simulation and set $n = n_o$
2. Compute $\overline{X}(n)$ and $\delta(n,\alpha)$ from $X_1, X_2, \ldots, X_n$
3. If $\delta(n,\alpha) < \beta$, use $\overline{X}(n)$ as the point estimate for μ
4. Else $n = n+1$ and go to step 2

In our study, we would like to obtain a point estimate of maximum time-in-system with an absolute error $\beta = 45$ minutes and a confidence level of 95 percent. We would like to obtain a point estimate of the number of destroyed vehicles with an absolute error $\beta = 2$ vehicles and a confidence level of 95 percent. We obtain the desired precision and confidence levels from the experts of the systems. The results of the procedure suggest that the number of replications required to obtain the point estimate of maximum time-in-system in Model-1 is 15 and the number of replications required to obtain the point estimate of number of destroyed vehicles in Model-1 is 6. Hence, we set the sample size to 15 for Model-1. Similarly, the number of replications required to obtain the point estimate of maximum time-in-system in Model-2 is 7 and the number of replications required to obtain the point estimate of number of destroyed vehicles in Model-2 is 10. Hence, we set the sample size to 10 for Model-2.

4.1.2. Testing the Assumptions of Analysis of Variances

We check the assumption of homogeneity of variances by drawing scatter plots of variances of performance measures and also by implementing the Bartlett Test. By drawing scatter plots of variances of performance measures, we try to determine whether there is correlation of variances or not. We present the scatter plots of variances of maximum time-in-system performance measure and number of destroyed vehicles performance measure for both models in Appendix-F (Figure F.1 - Figure F.4). It is seen in scatter plots that there is no correlation of variances.

We also implement the Bartlett Test to check the homogeneity of variances. The Bartlett Test is a widely used procedure to diagnose the inequality of variances. The results of the Bartlett Test according to maximum time-in-system performance measure for both models are presented in Table 4.2. The results of the Bartlett Test for the number of destroyed vehicles performance measure are presented in Table 4.3. We note that the assumption of homogeneity of variances is satisfied in both cases.

Table 4.2. Bartlett Test Results for Maximum Time-in-System Statistics

	Model-1	**Model-2**
S_p^2	4390.944	1902.48
q	10.081	6.01
c	1.025	1.038
X_0^2	22.668	13.332
$X_{0.05,31}$	44.97	44.97
Results	**Pass**	**Pass**

Table 4.3. Bartlett Test Results for Number of Destroyed Vehicles Statistics

	Model-1	**Model-2**
S_p^2	4.313	4.037
q	18.241	9.412
c	1.025	1.038
X_0^2	40.98	20.878
$X_{0.05,31}$	44.97	44.97
Results	**Pass**	**Pass**

4.1.3. Diagnostic Checking

In this section, we examine residual plots of performance measures to check normality assumption. If the model is correct and if the assumptions are satisfied, the residuals should be structureless (Montgomery, 1984). The plot of residuals should not reveal any obvious pattern. We present residual analysis for performance measures in Appendix-D (Table D.1 - Table D.4) and scatter plots of the residuals in Appendix-D (Figure D.1 - Figure D.4). As seen in scatter plots, residuals are structureless for both models.

4.2. 2^5 Factorial Design for Maximum Time-in-System Performance Measure

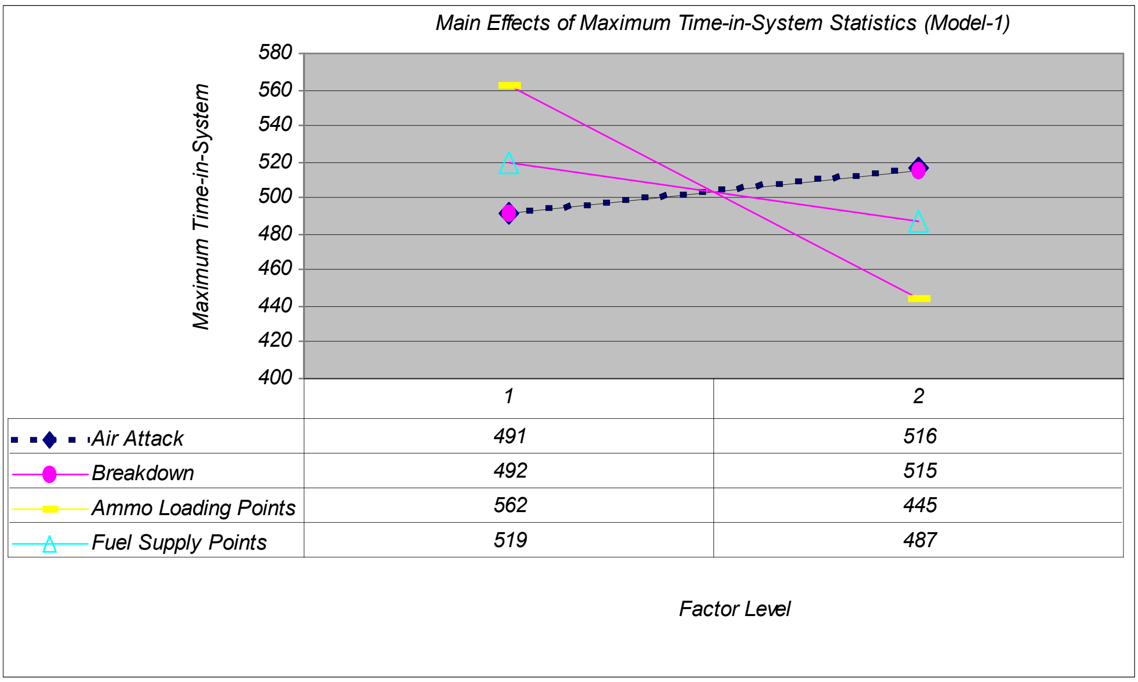
One of our main performance measures is maximum time-in-system. Maximum time-in-system performance measure defines the time of the last battalion vehicle which completes its supply process and occupies its position at the alert dispersion area. In this section, we try to determine significant factors and their interactions. As we have two models in our study, we implement ANOVA for both models to determine the significant factors and interactions on the performance measure.

We implement 2^5 factorial design for these five factors according to maximum time-in-system performance measure. We replicate each of the 32 design points 15 times for Model-1 and 10 times for Model-2 with different seeds (based on pilot runs which determine sample sizes). We present averages and variances of 32 design points of Model-1 for maximum time-in-system performance measure in Appendix-B (Table B.2.1 - Table B.2.4) and averages and variances of 32 design points of Model-2 for maximum time-in-system performance measure in Appendix-B (Table B.3.1 - Table B.3.4). In

Section 4.2.1, we analyze the results of ANOVA and interpret main effects and interactions according to maximum time-in-system performance measure for Model-1. In Section 4.2.2, we analyze the results of ANOVA and interpret main effects and interactions according to maximum time-in-system performance measure for Model-2.

4.2.1. ANOVA Results and Interpretation of Main Effects and Interactions of Maximum Time-in-System Measure for Model-1

In our study, we use SPSS software package to implement ANOVA and we present the SPSS output of maximum time-in-system statistics for Model-1 in Appendix-C (Table C.5). We also present the effects of factors and ANOVA results of maximum time-in-system statistics for Model-1 in Appendix-C (Table C.1). As seen in Table C.1, there are four significant factors. The significant factors are breakdown, air attack, number of ammunition depot loading points and number of company fuel supply points. Breakdown has a positive effect (24.619) on maximum time-in-system performance measure. Air attack has a positive effect (22.308) on performance measure. The number of ammunition depot loading points has a negative effect (-116.11). The number of company fuel supply points has a negative effect (-32.059). As seen from results, the number of ammunition depot loading points has the greatest effect on performance measure. The only factor that does not have a significant effect on performance measure is artillery attack. There are two reasons for the insignificance of artillery attack. Firstly, the number of vehicles destroyed by artillery attack is higher than that of other factors. When the number of destroyed vehicles increases in model, maximum time-in-system decreases because the number of vehicles in queues will decrease and less vehicles will be supplied. The increase on maximum time-in-system because of maintenance times of damages caused by artillery attack will not be significant when artillery attack probability is at a high level due to the increased number of destroyed vehicles. Secondly, artillery attack does not cause delays at time of attack. When an enemy air attack occurs the vehicles wait for the end of the attack in a covered place if possible. During artillery attack the vehicles continue to march since the enemy can not see our movements and there is no need to cover ourself from enemy sight. In our models there is a delay block for vehicles whenever air attack occurs and maximum time-in-system increases due to this delay. There is no such delay for vehicles during artillery attack. There are two significant interactions on performance measure. These are breakdown-air attack (-13.411) and breakdown-artillery attack (-12.616).



1: Low level of factors 2 : High level of factors

Figure 4.1. Main Effect Diagram of Significant Factors for Maximum Time-in-System (Model-1)

We explain effects of significant factors via Figure 4.1. As seen in Figure 4.1, the number of ammunition loading points and the number of fuel supply points have negative effects on performance measure. When the factor level of the number of ammunition depot loading points or the number of company fuel supply points is at its high level, this causes a decrease in maximum time-in-system statistics. There will be fewer vehicles waiting in queues when the number of supply points increases. Although an increase in the number of supply points causes a decrease on maximum time-in-system statistics, it also increases the requirement for more loading units. As seen in Figure 4.1, the slope of the line of number of ammunition loading points is greater than that of the number of company fuel supply points. An improvement at ammunition depot loading points will have a more significant effect on performance measure than an improvement at fuel supply points. This is because ammunition loading time is longer than fuel supply time and the number of ammunition depot loading points is less than the number of fuel supply points for the battalion. The air attack line slope is very close to the breakdown line slope. They both have positive effects on performance measure. When the factor level of air attack or breakdown is at its high level, this causes an increase in maximum time-in-system statistics. The number of damaged vehicles increases when we increase the factor level of air attack or breakdown. The increase in the number of damaged vehicles causes more maintenance activities and more maintenance activities increases maximum time-in-system statistics.

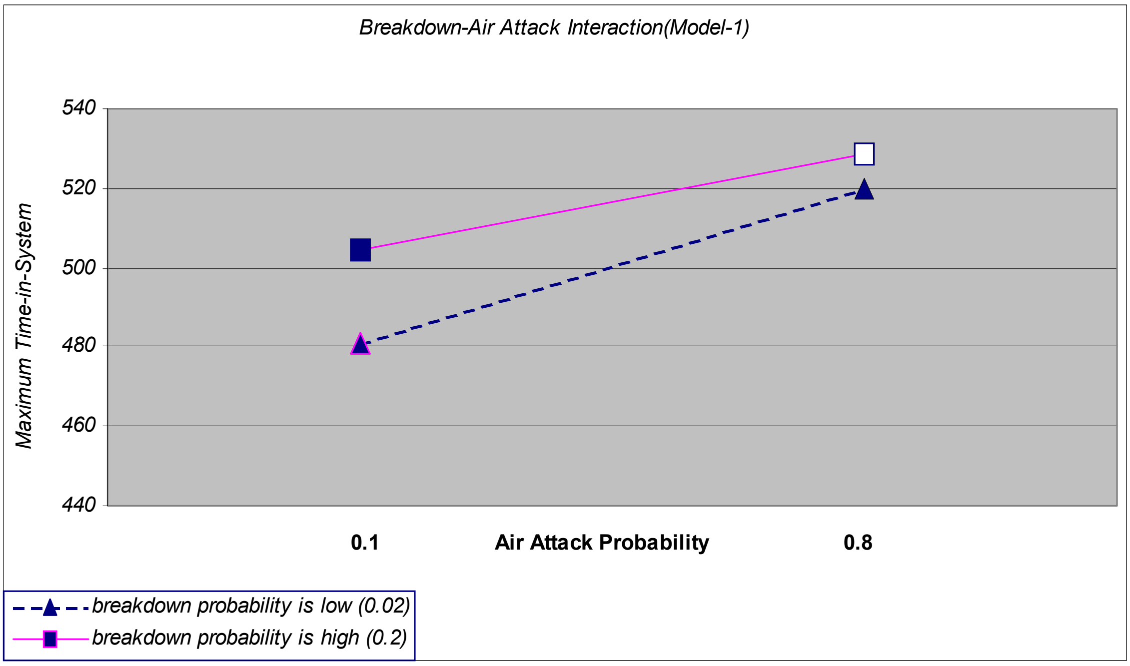


Figure 4.2. Interaction Diagram of Breakdown-Air Attack for Maximum Time-in-System (Model-1)

We explain the interaction between breakdown and air attack via Figure 4.2. The continuous line in the diagram describes the change in maximum time-in-system when the breakdown factor level is at its high value (0.2) and the air attack factor level is changing from its low value (0.1) to its high value (0.8). The dotted line describes the change in maximum time-in-system when the breakdown factor level is at its low value (0.02) and air attack factor level is changing from its low value to its high value. There is interaction between air attack and breakdown since the effect of air attack on performance measure depends on the level chosen for breakdown and the effect of breakdown on performance measure depends on the level chosen for air attack. Firstly, we analyze the effect of air attack on performance measure according to the levels of breakdown. In our model air attacks are carried out on vehicle convoys to cause more effect. When the breakdown probability is high, then there will be fewer vehicles in convoy because the broken ones are being repaired in places that are not in enemy field of view. This means fewer vehicles will be affected by air attacks and the effect of air attack on maximum time-in-system will be less. When breakdown probability is low, then more vehicles will be in convoy and that means more vehicles will be affected by air attack. Secondly, we analyze the effect of breakdown on performance measure according to the levels of air attack. When air attack probability is high then there will be more vehicles to be repaired. This means vehicle breakdowns will increase and this will cause an increase in maximum time-in-system statistics. The effect of breakdown on performance measure will be more when air attack probability is high. When air attack probability is low then there will be fewer vehicles to be repaired and that means the effect of breakdown on performance measure will be less. Then we can say that in Model-1, the effect of air attack on maximum time-in-system performance measure depends on the level chosen for breakdown and the effect of breakdown on maximum time-in-system performance measure depends on the level chosen for air attack.

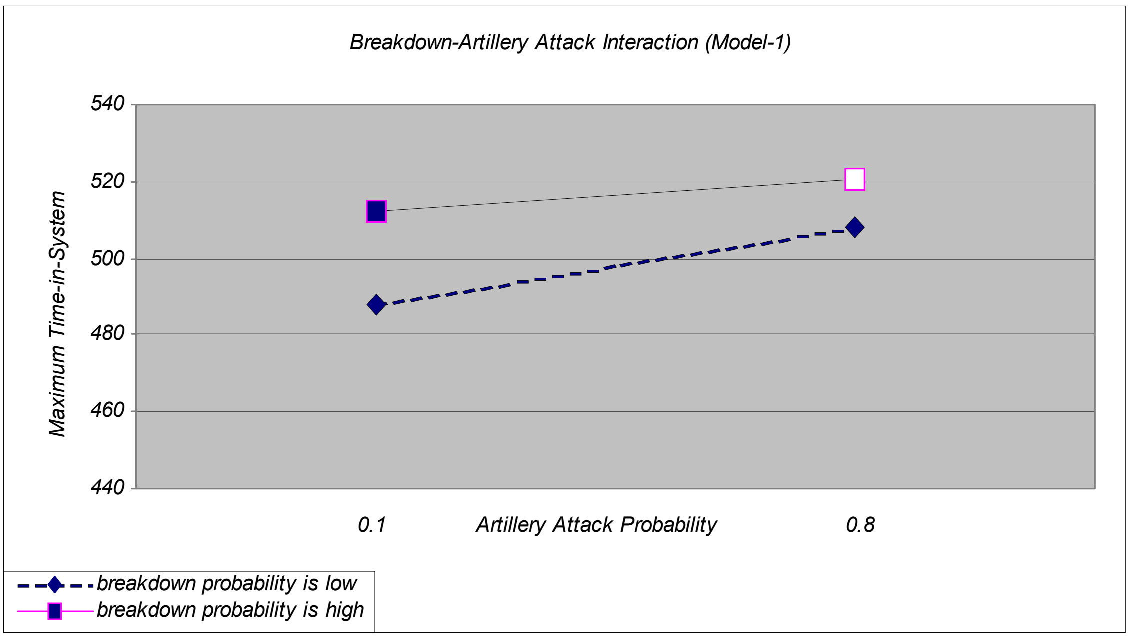


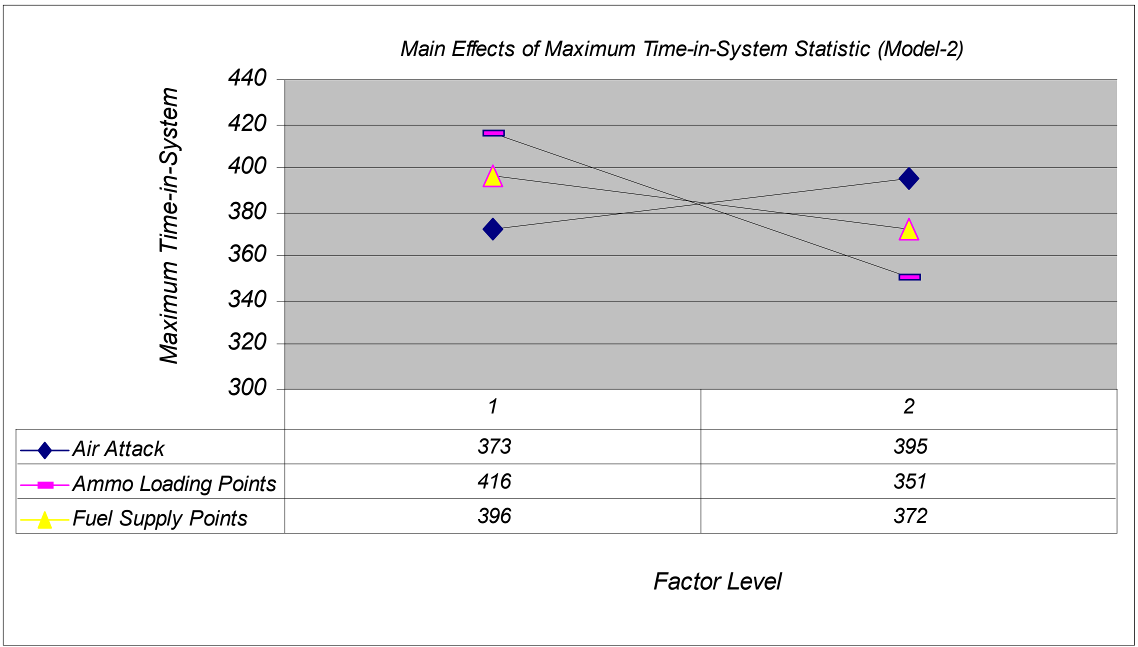
Figure 4.3. Interaction Diagram of Breakdown-Artillery Attack for Maximum Time-in System (Model-1)

We explain the interaction between breakdown and artillery attack via Figure 4.3. The continuous line in the above diagram describes the change on maximum time-in-system when the breakdown factor level is at its high value (0.2) and artillery attack factor level is changing from its low value (0.1) to its high value (0.8). The dotted line describes the change in maximum time-in-system when breakdown factor level is at its low value (0.02) and artillery attack factor level is changing from its low value to its high value. The effect of artillery attack on performance measure depends on the level chosen for breakdown because when breakdown probability is low, then the number of vehicles in convoys will increase and thus increase the number of damaged vehicles due to artillery attack. When breakdown factor level is high, then the number of vehicles in convoys will decrease, meaning fewer damaged vehicles because of artillery attack. The effect of breakdown on maximum time-in-system depends on the level chosen for artillery attack because when artillery attack probability is high, then the number of broken vehicles will increase. When artillery attack probability is low then the number of broken vehicles will decrease.

We validate ANOVA results of the maximum time-in-system statistics for Model-1 by analyzing normal probability effects of performance measure. Analysis of normal probability plot effects of maximum time-in-system statistics is presented in Appendix-E (Table E.1). Normal probability plot of maximum time-in-system statistics for Model-1 is presented in Appendix-E (Figure E.1). The effects of significant factors are farther to the other effects in normal probability plot. In Figure E.1, it is seen that there are two significant factors which have negative effects on maximum time-in-system and there are two significant factors which have positive effects on maximum time-in-system.

4.2.2. ANOVA Results and Interpretation of Main Effects and Interactions of Maximum Time-in-System Measure for Model-2

We present SPSS output of maximum time-in-system statistics for Model-2 in Appendix-C (Table C.6). We also present the effects of factors and the ANOVA results of maximum time-in-system statistics for Model-2 in Appendix-C (Table C.2). There are three significant factors. The significant factors are air attack, number of ammunition depot loading points and number of company fuel supply points. Air attack has a positive effect (22.079) on performance measure. The number of ammunition depot loading points has a negative effect on performance measure (-64.817) and the number of company fuel supply points also has a negative effect (-23.958). In Model-2, breakdown and artillery attack do not have significant effects on performance measure. Contrary to Model-1, breakdown is not a significant factor in maximum time-in-system performance measure. In Model-2, most of the vehicles of battalion only march to company alert dispersion areas which are close to company garages. In real life, even if there is a broken vehicle on the way to an alert dispersion area, it is towed by another vehicle to its position at the alert dispersion area and does not cause any delay to the system. In Model-2, the probability of breakdown for vehicles which convoy to alert dispersion areas from garages is very low. In Model-2, ammunition and fuel supply vehicles convoy to supply points and after they are supplied, they convoy to alert dispersion areas. Breakdowns do not affect maximum time-in-system significantly in Model-2 contrary to Model-1 because the number of supply vehicles is only 21. Artillery attack is also not a significant factor in Model-2 because artillery attack causes less vehicle damage due to fewer vehicles in convoys and there is no delay during time of artillery attack. There is one significant interaction on performance measure. The significant interaction is between breakdown and air attack.



1 : Low level of factors   2 : High level of factors

Figure 4.4. Main Effect Diagram of Significant Factors for Maximum Time-in-System (Model-2)

We explain effects of significant factors via Figure 4.4. As seen in Figure 4.4, the number of ammunition loading points and the number of company fuel supply points have negative effects on performance measure. The increase in the number of supply points decreases the number of supply vehicles waiting in queues. As seen in Figure 4.4, the slope of the line of number of ammunition loading points is greater than that of the number of fuel supply points. It shows that the effect of the number of ammunition depot loading points is greater than the effect of the number of company fuel supply points. This is because in Model-2, the number of ammunition trucks is more than the number of fuel tankers and also the ammunition loading time of an ammunition truck is longer than the fuel supply time of a fuel tanker. The enemy air attack has a positive effect on performance measure. The number of damaged vehicles increases when we increase the factor level of air attack. The increase in the number of damaged vehicles causes more maintenance activities and more maintenance activities increase maximum time-in-system statistics.

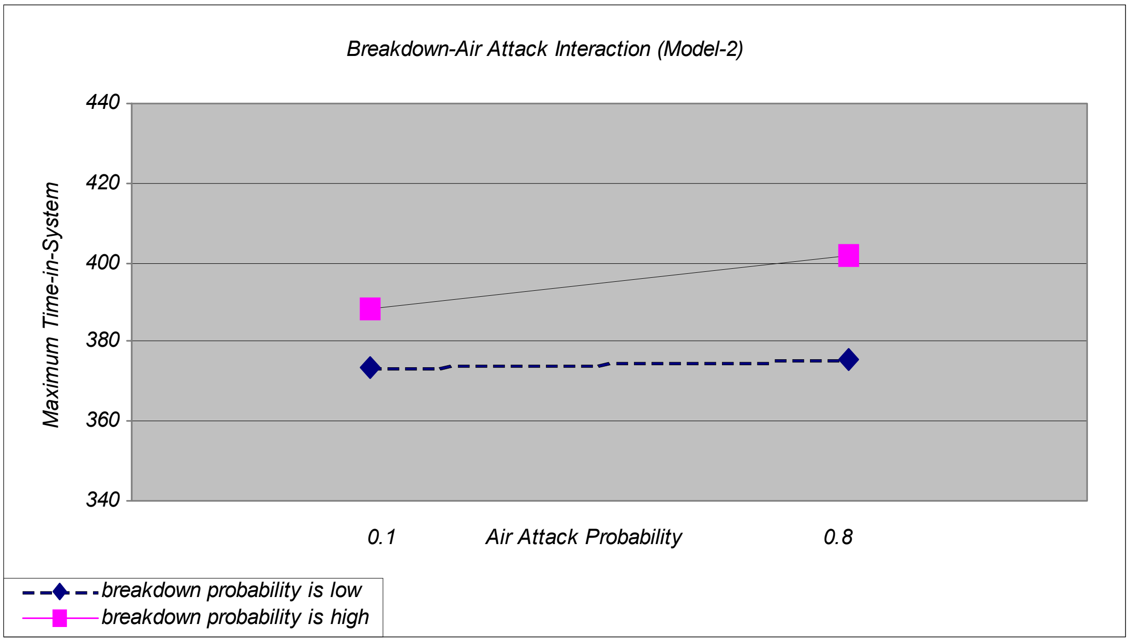


Figure 4.5. Interaction Diagram of Breakdown-Air Attack for Maximum Time-in-System (Model-2)

The explanations about breakdown-air attack interaction on maximum time-in-system performance measure for Model-1 is also valid for Model-2 (see Figure 4.5).

Analysis of normal probability plot effects of maximum time-in-system statistics is presented in Appendix-E (Table E.2). Normal probability plot of maximum time-in-system statistics for Model-2 is presented in Appendix-E (Figure E.2).

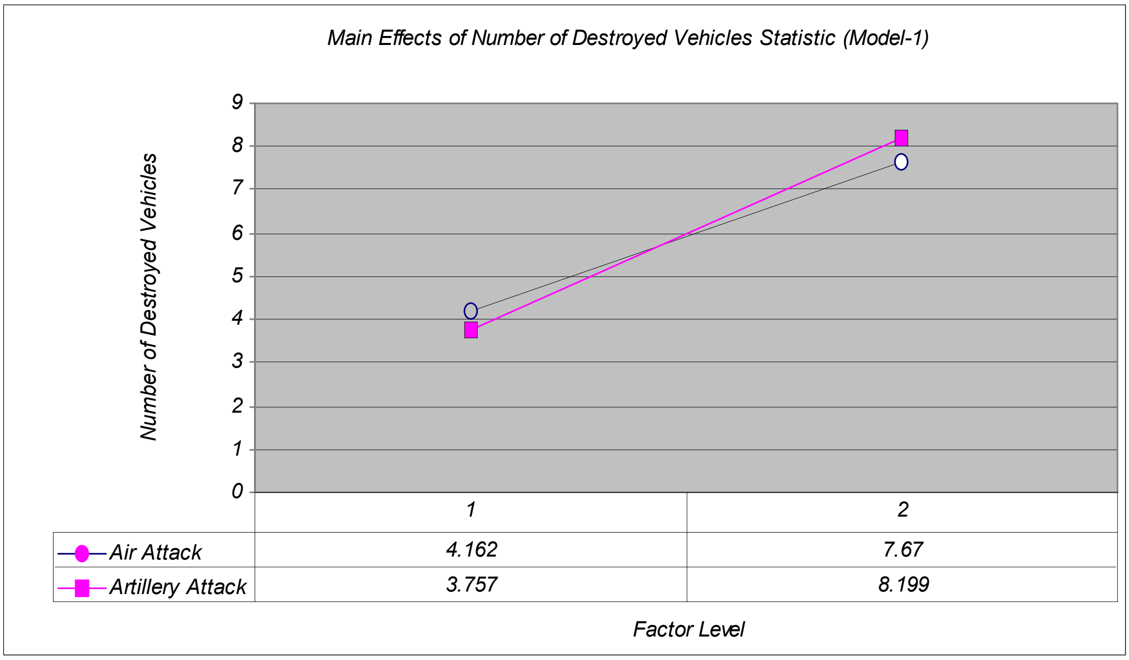
4.3. 2^5 Factorial Design for Number of Destroyed Vehicles Performance Measure

The number of destroyed vehicles performance measure is an important statistic for the battalion commander since it shows how many vehicles were lost and whether a battalion would carry out its mission. If the number of destroyed vehicles were high, then the battalion would be unable to carry out its task and this would affect overall success of military operations.

We implement 2^5 factorial design for five factors given in Table 4.1 for the number of destroyed vehicles performance measure. We replicate each of the 32 design points 15 times for Model-1 and 10 times for Model-2 with different seeds. We present averages and variances of 32 design points of Model-1 in Appendix-B (Table B.4.1 - Table B.4.4) and averages and variances of 32 design points of Model-2 in Appendix-B (Table B.5.1 - Table B.5.4). In Section 4.3.1 we analyze the results of ANOVA and interpret main effects and interactions for the number of destroyed vehicles performance measure for Model-1. In Section 4.3.2, we analyze the results of ANOVA and interpret main effects and interactions according to the number of destroyed vehicles performance measure for Model-2.

4.3.1. ANOVA Results and Interpretation of Main Effects and Interactions of Number of Destroyed Vehicles Measure for Model-1

We present SPSS output of number of destroyed vehicles statistics for Model-1 in Appendix-C (Table C.7). We also present the effects of factors and ANOVA results of number of destroyed vehicles statistics for Model-1 in Appendix-C (Table C.3). There are two significant factors. These significant factors are air and artillery attack. Both significant factors have positive effects on the number of destroyed vehicles performance measure. As seen in Table C.3, the effect of artillery attack is greater than the effect of air attack on performance measure. Breakdown, number of ammunition depot loading points and number of company fuel supply points do not have significant effects on performance measure. Breakdown does not have a significant effect on the number of destroyed vehicles measure because the probability of vehicle destruction due to breakdown is very low in Model-1. Vehicle destruction due to breakdown is a very rare event in real life. Ammunition and fuel supply points are highly protected against enemy attacks given their importance in real life. They are well constructed so as to withstand enemy attacks and their locations are chosen carefully to avoid enemy detection. There is also a strong air defense system against enemy planes around supply points. Thus in our model, the probability of vehicle destruction at ammunition depot loading points and company fuel supply points is very low. There is no significant interaction on performance measure.



1 : Low level of factors 2 : High level of factors

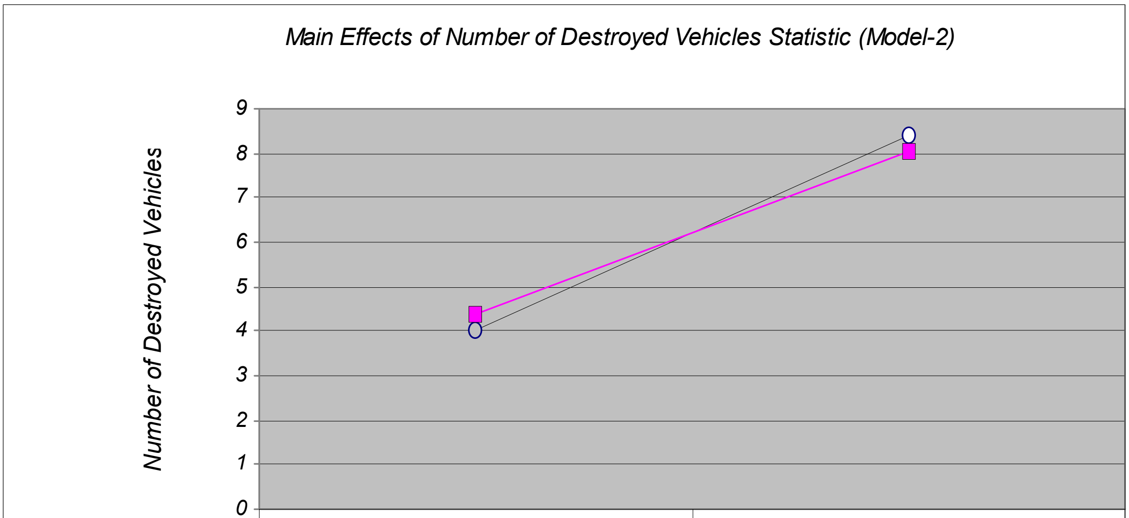
Figure 4.6. Main Effect Diagram of Significant Factors for Number of Destroyed Vehicles (Model-1)

As seen in Figure 4.6, both significant factors have positive effects on the number of destroyed vehicles performance measure. When the factor level of air or artillery attack is at its high level, this causes an increase in the number of destroyed vehicles statistic. As seen in Figure 4.6, the effect of artillery attack on performance measure is greater than the effect of air attack.

We validate ANOVA results of the number of destroyed vehicles statistics for Model-1 by analyzing normal probability effects of performance measure. Analysis of the normal probability plot effects of number of destroyed vehicles statistics is presented in Appendix-E (Table E.3). Normal probability plot of number of destroyed vehicles statistics for Model-1 is presented in Appendix-E (Figure E.3). In Figure E.3, it is seen that there are two significant factors which have positive effects on number of destroyed vehicles performance measure.

4.3.2. ANOVA Results and Interpretation of Main Effects and Interactions of Number of Destroyed Vehicles for Model-2

We present SPSS output for the number of destroyed vehicles statistics of Model-2 in Appendix-C (Table C.8). We also present the effects of factors and the ANOVA results for Model-2 in Appendix-C (Table C.4). There are two significant factors (in Table C.4). As in Model-1, air and artillery attacks are again significant factors in Model-2 and both factors have positive effects on performance measure. Contrary to Model-1, the effect of air attack in Model-2 is greater than the effect of artillery attack as seen in Table C.4. The effect of artillery attack in Model-2 is less than the effect of artillery attack in Model-1 since in Model-2, there are fewer vehicles in convoys and most of the vehicles remain at alert dispersion areas. It is more difficult for artillery weapons to destroy when vehicles are dispersed since artillery attacks are long range attacks. On the other hand, airplanes cause more destruction than artillery attack in Model-2. Breakdown, number of ammunition depot loading points and number of company fuel supply points do not have significant effects on number of destroyed vehicles performance measure in Model-2 due to reasons explained in Section 4.3.1 for Model-1. There is no significant interaction on performance measure.



	1	2
Air Attack	4.012	8.393
Artillery Attack	4.375	8.031

Figure 4.7. Main Effect Diagram of Significant Factors for Number of Destroyed Vehicles (Model-2)

As seen in Figure 4.7, when the factor level of air attack or artillery attack is at its high level, this causes an increase in the number of destroyed vehicles. They both have positive effects on number of destroyed vehicles performance measure. It is also seen that in Model-2, the effect of air attack is greater than the effect of artillery attack on performance measure.

Analysis of normal probability plot effects of number of destroyed vehicles statistics is presented in Appendix-E (Table E.4). Normal probability plot of number of destroyed vehicles statistics for Model-2 is presented in Appendix-E (Figure E.4). In Figure E.4, it is seen that there are two significant factors which have positive effects on the number of destroyed vehicles performance measure.

4.4. Determination of Time Standards of Existing Systems

Finally, one of our objectives is to find time standards of the existing systems. In our study, we have two systems and we evaluate their performances under enemy threat. In military field manuals, there are no time standards of maximum time-in-system measure for the existing systems when we consider war conditions. Maximum time-in-system measure is vital information for a commander since it shows when the military activity is over and lets a commander make his plans more reasonable. We think our findings in this study will be helpful for commanders in their military planning. As obtained in Section 4.1.1, the sample size of Model-1 is 15 and the sample size of Model-2 is 10. We run Model-1 fifteen times and collect the maximum-time-in-system statistics and then we run Model-2 ten times and collect the maximum time-in-system statistics. We then construct confidence intervals by using the SPSS software package to find time standards of existing systems under enemy threat. We present confidence interval of maximum time-in-system statistics for Model-1 in Table 4.4 and we present confidence interval of maximum time-in-system statistics for Model-2 in Table 4.5.

Table 4.4. Confidence Interval of Maximum Time-in-System Statistics for Model-1

	Test Value = 0					
	t	**df**		**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	**Upper**
A	35.217	14		521.6	489.833	553.366

According to our findings, when we exercise System-1 in real life under enemy threat, ammunition and fuel supply activity of an armored battalion will finish within a 489-553 minute time interval.

Table 4.5. Confidence Interval of Maximum Time-in-System Statistics for Model-2

	Test Value = 0					
	t	df		Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
A	27.612	9		473.4	434.616	512.183

According to our findings, when we exercise System-2 in real life under enemy threat, ammunition and fuel supply activity of an armored battalion will finish within a 434-512 minute time interval. We consulted with Turkish military experts about our time standards for both Model-1 and Model-2. Their assessments about the findings revealed that the outputs are reasonable. They also indicated that our findings could be considered relevant in today's military logistics planning under the current threat environment.

4.5. Conclusion

We present the significant factors and interactions on maximum time-in-system and number of destroyed vehicles performance measures for Model-1 and Model-2 in Table 4.6.

Table 4.6. Significant Factors and Interactions

	MODEL-1		MODEL-2	
Performance Measure / **Factors**	Maximum Time-in-System	Number of Destroyed Vehicles	Maximum Time-in-System	Number of Destroyed Vehicles
Breakdown	***Significant***	Insignificant	Insignificant	Insignificant
Air Attack	***Significant***	***Significant***	***Significant***	***Significant***
Artillery Attack	Insignificant	***Significant***	Insignificant	***Significant***
Number of Ammunition Loading Points	***Significant***	Insignificant	***Significant***	Insignificant
Number of Company Fuel Supply Points	***Significant***	Insignificant	***Significant***	Insignificant
Breakdown-Air Attack Interaction	***Significant***	Insignificant	***Significant***	Insignificant
Breakdown-Artillery Attack Interaction	***Significant***	Insignificant	Insignificant	Insignificant

- In Model-1, breakdown, air attack, number of ammunition depot loading points and number of company fuel supply points are significant factors on maximum time-in-system performance measure. Air attack and breakdown have positive effects on performance measure. Number of ammunition depot loading points and number of company fuel supply points have negative effects. Number of ammunition depot loading points has the greatest effect on maximum time-in-system performance measure. There are two significant interactions. These are breakdown-air attack and breakdown-artillery attack.
- In Model-2, air attack, number of ammunition depot loading points and number of company fuel supply points are significant factors on maximum time-in-system performance measure. Air attack has a positive effect and other

significant factors have negative effects on performance measure. Number of ammunition depot loading points has the greatest effect on maximum time-in-system performance measure. There is one significant interaction and that is between breakdown and air attack.

- In Model-1, artillery attack and air attack are significant factors on number of destroyed vehicles performance measure. Both significant factors have positive effects on performance measure. The effect of artillery attack is greater than the effect of air attack. There is no significant interaction.
- In Model-2, air attack and artillery attack are again significant factors on number of destroyed vehicles performance measure. Air attack has a greater effect than artillery attack and both significant factors have positive effects on performance measure.
- When we consider number of destroyed vehicles performance measure, we see that significant factors are the same in Model-1 and Model-2. The only difference is that in Model-1, the effect of artillery attack is greater than the effect of air attack and in Model-2, air attack has a greater effect. In light of this information, we can conclude that commanders must increase their measures against artillery attacks whenever they exercise System-1 and they must increase their air defense capabilities whenever they exercise System-2.
- When we consider maximum time-in-system performance measure, we see that the only difference between Model-1 and Model-2 according to significant factors is breakdown. In Model-1, breakdown is a significant factor but in Model-2, it is not. We can conclude that commanders must take necessary measures to decrease the number of broken vehicles and to increase the

maintenance activity whenever they exercise System-1. Other significant factors are the same for both models. Commanders must increase their battalion air defense capabilities to avoid significant effects from enemy air attacks. Changes at fuel and ammunition supply points are also necessary to decrease maximum time-in-system for both models.

- In our study, we also determine time standards of existing systems which are exercised under enemy threat by constructing confidence intervals of maximum time-in-system statistics of our simulation models. According to our findings, when we exercise System-1 in real life, ammunition and fuel supply activity of an armored battalion will finish within a 489-553 minute time interval. When we exercise System-2 in real life, ammunition and fuel supply activity of an armored battalion will finish within a 434-512 minute time interval. Our findings for Model-1 and Model-2 were considered reasonable by military experts.

CHAPTER 5

IMPLEMENTATION OF RANKING PROCEDURES FOR THE REGIONS OF TURKEY

5.1. Introduction

In this chapter, we rank the regions of Turkey from most to least critical according to performance measures of interest. We only deal with regions which have borders with other countries by land or by sea. We do not deal with regions which have no borders with neighboring countries since the enemy attack probability is very low for these regions. The regions under consideration in our study are:

(1) Greek border

(2) Bulgarian border

(3) Syrian border

(4) Iranian border

(5) Iraqi border

(6) Eastern Black Sea

(7) Aegean

(8) Mediterranean

Countries deploy their military units according to the relations with their neighbor countries. They deploy more troops and better equipment to the critical regions. The relations between countries would change from time to time according to the interests of neighboring countries thereby affecting critical regions within Turkey.

Turkey is situated in a sensitive part of the world and has sensitive relations with some of its neighbors due to its strategic location. When we evaluate the last decade of Turkish history, we see that east and southeast regions of Turkey have been the most critical regions. We also see that interior regions of Turkey have been the least critical regions because of their distance to borders. In our study, we do not include the interior regions of Turkey due to low probability of enemy attack in interior regions.

In our study, we have different parameters of vehicle breakdown and enemy attack probabilities for each region. We determine vehicle breakdown probabilities according to terrain conditions of regions and the conditions of vehicles in each region of interest. Terrain conditions show big differences along the borders of Turkey. For example, the terrain conditions in eastern and southeastern regions of Turkey are tougher than that of other regions. Other important factor to determine vehicle breakdown probability in each region is the condition of vehicles. Newer vehicles are deployed along the critical borders. We examine the terrain conditions of regions and the conditions of vehicles in each region by consulting military experts and then determine vehicle breakdown probability for each region. In our models, the enemy air attack probability in each region is determined according to air attack capabilities of neighboring countries and also the distance between Turkey and its neighboring countries. Air attack probability of Greek war planes are higher than that of other neighboring countries since Greece has the most advanced air force among neighboring countries. On the other hand, the effect of enemy air attack decreases when the distance between a neighboring country and Turkey increases. For example, Russia has a strong air force but the effect of its air attack decreases due to its distance. Finally, enemy artillery attack probability in each region is also determined according to the enemy artillery attack capabilities and the distance. The effect of artillery attack decreases when the distance between Turkey and its neighboring country increases. Among the neighboring countries Iran has the biggest artillery attack capability.

The performance measures of interest are maximum time-in-system and number of destroyed vehicles in our study. We aim to rank the regions under consideration according to performance measures of interest for both models. This study will help commanders determine the most critical regions of Turkey according to performance measures of interest and take necessary measures for the critical regions.

5.2. Ranking of Regions by Rinott Procedure

In this section, we implement the Rinott Procedure (1978) to rank the regions of Turkey from the most to least critical according to performance measures of interest. In the first stage for each region, we run 15 independent replications and then calculate averages and variances of these replications. We then find N_i (required number of replications) for each region by the following formula: $N_i = \max \{n_o, (h^*S_i / d)^2 \}$. In the second stage, we take additional replications ($N_i - n_o$) and calculate the average of N_i replications for each region. We then select the region with the highest average as the most critical region. In our study, we choose $n_o = 15$ as $n_o > 10$ is recommended. Our desired probability of correct selection (p^*) is 0.95 for our performance measures. The constant *h* equals 3.839. In our study, indifference amount value (d) for maximum time-in-system statistics is 10 minutes and indifference amount value (d) for number of destroyed vehicles statistics is 1 vehicle. We decide indifference amount values (d) by the help of users of systems.

5.2.1. Ranking of Regions by Rinott Procedure According to Maximum Time-in-System Performance Measure (Model-1)

In this section of study, we present the results of the Rinott Procedure according to maximum time-in-system statistics for each region under consideration in Model-1. We aim to rank regions from most to least critical according to maximum time-in-system statistics. We implement the Rinott Procedure as it was explained in Section 5.2. The averages and variances of 15 replications according to maximum time-in-system statistics for each region are presented in Appendix-J (Table J.1). After we obtain the results of 15 replications for each region, we determine the total sample size (N_i) required for each region by using the formula in Section 5.2 and then calculate the average of N_i replications for each region. We present the total sample sizes (N_i) required for each region and averages of N_i replications for each region in Appendix-J (Table J.2). We rank the regions from most to least critical in Table 5.1 according to the Rinott Procedure results.

Table 5.1. Ranking of Regions According to Maximum Time-in-System Statistics (Model-1)

	Regions	**Averages of N_i Replications**
1	Greek border	592.097
2	Aegean	565.403
3	Iranian border	551.042
4	Iraqi border	540.043
5	Syrian border	532.187
6	Bulgarian border	515.393
7	Eastern Black Sea	500.271
8	Mediterranean	485.351

The most critical region according to maximum time-in-system performance measure in Model-1 is the Greek border. This is because the damage probabilities of enemy air and artillery weapons along the Greek border are greater than that of other regions in Model-1. It is primarily because of the military structure of Greek forces along the border. They can intervene in our military activities by their air force and artillery weapons from time to time during a possible conflict. Their air force is more advanced than that of other neighbors of Turkey and cause more delays in our military activities. They can also be effective through the use of their artillery weapons along the border because of the short distance between military units. The damages increase maintenance activities and maintenance activities increase the maximum time-in-system statistics. Terrain conditions along the Greek border also delay our military activities more than terrain conditions of other neighbors because of limited movement capabilities along the Greek border. The Mediterranean region is the least critical region according to maximum time-in-system performance measure because of the low damage probabilities of enemy air attacks and artillery attacks in Model-1. It is not possible for any neighboring country to have air superiority during a possible conflict over the Mediterranean region and it is also difficult for neighboring countries to be effective through the use of their artillery weapons due to long distances. Our military activities in the Mediterranean region can not be easily disrupted during a possible conflict due to reasons above.

5.2.2. Ranking of Regions by Rinott Procedure According to Number of Destroyed Vehicles Performance Measure (Model-1)

In this section, we rank the regions of interest in Model-1 from most to least critical according to number of destroyed vehicles statistics. We implement the Rinott Procedure as it was explained in Section 5.2. The averages and variances of 15 replications according to number of destroyed vehicles statistics for each region in Model-1 are presented in Appendix-J (Table J.3). We present the total sample sizes (N_i) required for each region and averages of N_i replications for each region in Appendix-J (Table J.4). We rank the regions from most to least critical in Table 5.2 according to the Rinott Procedure results.

Table 5.2. Ranking of Regions According to Number of Destroyed Vehicles Statistics (Model-1)

	Regions	**Averages of N_i Replications**
1	Iranian border	5.866
2	Greek border	5.667
3	Syrian border	5.133
4	Iraqi border	4.933
5	Bulgarian border	4.6
6	Aegean	4.267
7	Eastern Black Sea	3.4
8	Mediterranean	2.067

As seen in Table 5.2, the most critical region is the Iranian border according to number of destroyed vehicles performance measure in Model-1. The Greek border follows the Iranian border. The destruction probability of artillery weapons along the Iranian border is greater than that of other regions in Model-1 because in real life, the number of artillery units in Iran is more than those of other countries under consideration. The Iranian Army is bigger than the armies of other neighbors of Turkey and they have more military equipment. The Iranian border is not the most critical region according to maximum time-in-system performance measure because the number of destroyed vehicles is higher along that border than that of other regions and when the number of destroyed vehicles statistics increase maximum time-in-system statistics decrease in our model. The least critical region according to number of destroyed vehicles statistics in Model-1 is the Mediterranean since the destruction probabilities of enemy air attacks and artillery attacks are very low. As explained in Section 5.2.1, it is difficult for neighboring countries to be disruptive to our military activities in that region. Fewer vehicles are affected by enemy air and artillery attacks in the Mediterranean region due to long distances between this region and neighboring countries.

5.2.3. Ranking of Regions by Rinott Procedure According to Maximum Time-in-System Performance Measure (Model-2)

In this section we implement the Rinott Procedure to rank the regions of interest in Model-2 from most to least critical according to maximum time-in-system statistics. The averages and variances of 15 replications according to maximum time-in-system statistics for each region in Model-2 are presented in Appendix-J (Table J.5). We present the total sample sizes (N_i) required for each region and the averages of N_i replications for each region in Appendix-J (Table J.6). We rank the regions from most to least critical in Table 5.3 according to Rinott Procedure results.

Table 5.3. Ranking of Regions According to Maximum Time-in-System Statistics (Model-2)

	Regions	Averages of N_i Replications
1	Greek border	512.125
2	Iranian border	501.742
3	Aegean	486.033
4	Iraqi border	475.893
5	Bulgarian border	460.619
6	Syrian border	439.938
7	Eastern Black Sea	418.153
8	Mediterranean	405.639

The Greek border is again the most critical region according to maximum time-in-system performance measure. As explained in Section 5.2.1, the Greek Air Force is more advanced than that of other neighboring countries. The damage probability of their air weapons is higher than that of others in Model-2. They also have advanced artillery weapons, although fewer than the Iranians. Thus, the number of damaged vehicles due to air attacks is greater along the Greek border. An increase in the number of damaged vehicles results in an increase in maximum time-in-system statistics. The Mediterranean is the least critical region according to maximum time-in-system in Model-2 for reasons explained in Section 5.2.1 for Model-1. The most and least critical regions according to maximum time-in-system performance measure for both models are the same. The Greek border is the most critical region for both models and the Mediterranean is the least critical region according to maximum time-in-system statistics.

5.2.4. Ranking of Regions by Rinott Procedure According to Number of Destroyed Vehicles Performance Measure (Model-2)

In this section, we present the results of the Rinott Procedure according to the number of destroyed vehicles statistics for regions in Model-2. We present the averages and variances of 15 replications according to the number of destroyed vehicle statistics for each region in Model-2 in Appendix-J (Table J.7). We present the total sample sizes (N_i) required for each region and averages of N_i replications for each region in Appendix-J (Table J.8). We rank the regions from most to least critical in Table 5.4 according to the Rinott Procedure results.

Table 5.4. Ranking of Regions According to Number of Destroyed Vehicles Statistics (Model-2)

	Regions	**Averages of N_i Replications**
1	Iranian border	6.066
2	Greek border	5.867
3	Iraqi border	5.533
4	Syrian border	5.266
5	Aegean	4.867
6	Bulgarian border	4.667
7	Eastern Black Sea	3.533
8	Mediterranean	1.867

As seen in Table 5.4, the most and least critical regions in Model-2 according to the number of destroyed vehicles performance measure are the same as in Model-1. The Iranian border is the most critical region while the Mediterranean is the least critical due to reasons explained in Section 5.2.2.

5.2.5. Summary of Rinott Procedure Results

In this section of study, we summarize the Rinott Procedure results we obtained in previous sections of this chapter. The results of the Rinott Procedure for Model-1 are presented in Table 5.5 and the results for Model-2 in Table 5.6.

Table 5.5. Rinott Procedure Results for Model-1

	Maximum Time-in-System	**Number of Destroyed Vehicles**
1	Greek border	Iranian border
2	Aegean	Greek border
3	Iranian border	Syrian border
4	Iraqi border	Iraqi border
5	Syrian border	Bulgarian border
6	Bulgarian border	Aegean
7	Eastern Black Sea	Eastern Black Sea
8	Mediterranean	Mediterranean

As seen in Table 5.5, the rankings are not consistent according to each performance measure. We can not identify a single most critical region from the table. We can only make conclusions about the rankings of the Mediterranean and Eastern Black Sea regions as they both have the same rankings for each performance measure. Therefore, we will implement the Analytic Hierarchy Process in Section 5.3.1 to identify a single ranking of regions for Model-1.

We present the rankings of regions for Model-2 according to performance measures of interest in Table 5.6.

Table 5.6. Rinott Procedure Results for Model-2

	Maximum Time-in-System	**Number of Destroyed Vehicles**
1	Greek border	Iranian border
2	Iranian border	Greek border
3	Aegean	Iraqi border
4	Iraqi border	Syrian border
5	Bulgarian border	Aegean
6	Syrian border	Bulgarian border
7	Eastern Black Sea	Eastern Black Sea
8	Mediterranean	Mediterranean

As seen in Table 5.6, we can again only make conclusions about the rankings of the Mediterranean and Eastern Black Sea regions since these regions are the least critical regions according to both performance measures in Model-2. We can not make conclusions about the rankings of other regions when we consider both performance measures. Therefore, we will implement the Analytic Hierarchy Process in Section 5.3.2 to identify a single ranking of regions for Model-2.

5.3. Solution of Multiple Objective Problem

In the previous sections we have implemented the Rinott Procedure to rank the regions for Model-1 and Model-2 for each performance measure. The ranking of regions are different according to performance measures as seen in Table 5.5 and in Table 5.6. In this section, we implement Analytic Hierarchy Process (AHP) to rank regions for both models involving both performance measures. Analytic Hierarchy Process is a technique for converting subjective assessments of relative importance into a set of weights. Using AHP we first determine the weight of each criterion. The criteria in our study are:

Criterion-1 (C1) : Maximum time-in-system

Criterion-2 (C2) : Number of destroyed vehicles

In order to obtain the weight of each criterion, first we determine a pairwise comparison matrix by consulting military experts. A pairwise comparison matrix indicates relative importance of criterion (i) to criterion (j). We present the pairwise comparison matrix of criteria below.

$$\begin{array}{cc} & \begin{array}{cc} C1 & C2 \end{array} \\ \begin{array}{c} C1 \\ C2 \end{array} & \begin{bmatrix} 1 & 6/5 \\ 5/6 & 1 \end{bmatrix} \end{array}$$

Next we calculate the relative weight of each criterion. First, we obtain a new matrix which is called the normalized matrix by dividing each entry in column (i) of the pairwise comparison matrix by the sum of the entries in column (i). We present the normalized matrix of criteria below.

$$\begin{array}{cc} & \begin{array}{cc} C1 & C2 \end{array} \\ \begin{array}{c} C1 \\ C2 \end{array} & \begin{bmatrix} 0.545 & 0.545 \\ 0.454 & 0.454 \end{bmatrix} \end{array}$$

We then determine relative weights for each criterion by taking the average of entries in each row of the normalized matrix. We present relative weights of each criterion in Table 5.7.

Table 5.7. Relative Weights of Criteria

Criterion	**Weight**
C1	0.545
C2	0.454

As seen in the normalized matrix, each of the ratio pairwise comparisons given by decision-makers is consistent, as each of the normalized columns yields identical values. Next we obtain pairwise comparison matrices of regions for each criterion by using the Rinott Procedure results we obtained in previous sections. In Section 5.3.1, we rank the regions using the AHP technique for Model-1 and in Section 5.3.2, we rank the regions using the AHP technique for Model-2.

5.3.1. Ranking of Regions by AHP Technique (Model-1)

We obtained the relative weights of criteria in Section 5.3. The pairwise comparison matrices and normalized matrices of pairwise matrices for each criterion in Model-1 are given in Appendix-I. Next, we obtain a utility matrix according to the procedure given in Saaty's book (Saaty, 1988). We present the utility matrix for Model-1 below.

$$
\begin{array}{l}
 \\
\text{Greek border} \\
\text{Aegean border} \\
\text{Iranian border} \\
\text{Iraqi border} \\
\text{Syrian border} \\
\text{Bulgarian border} \\
\text{Eastern Black Sea} \\
\text{Meditteranean}
\end{array}
\begin{array}{c}
\begin{array}{cc} C1 & C2 \end{array} \\
\begin{bmatrix}
0.418 & 0.228 \\
0.201 & 0.071 \\
0.137 & 0.265 \\
0.101 & 0.123 \\
0.077 & 0.146 \\
0.052 & 0.095 \\
0.031 & 0.035 \\
0.023 & 0.016
\end{bmatrix}
\end{array}
$$

We finally obtain the relative value of each region using the AHP. We present the relative values and rankings of regions from most to least critical in Table 5.8. The results indicate that the Greek border is the most critical region of Turkey in Model-1 according to the AHP result.

Table 5.8. Ranking of Regions by AHP (Model-1)

	Regions	**Relative value**
1	Greek border	0.331
2	Iranian border	0.195
3	Aegean	0.141
4	Iraqi border	0.111
5	Syrian border	0.108
6	Bulgarian border	0.071
7	Eastern Black Sea	0.032
8	Mediterranean	0.019

5.3.2. Ranking of Regions by AHP Technique (Model-2)

We present pairwise comparison matrices and normalized matrices of pairwise matrices for each criterion in Model-2 in Appendix-I. We present the utility matrix for Model-2 below.

$$\begin{array}{lc} & \begin{array}{cc} C1 & C2 \end{array} \\ \begin{array}{l} \text{Greek border} \\ \text{Aegean border} \\ \text{Iranian border} \\ \text{Iraqi border} \\ \text{Syrian border} \\ \text{Bulgarian border} \\ \text{Eastern Black Sea} \\ \text{Meditteranean} \end{array} & \begin{bmatrix} 0.303 & 0.203 \\ 0.156 & 0.102 \\ 0.243 & 0.236 \\ 0.118 & 0.171 \\ 0.042 & 0.136 \\ 0.078 & 0.087 \\ 0.025 & 0.036 \\ 0.020 & 0.018 \end{bmatrix} \end{array}$$

We obtain the relative value of each region using the AHP. We present the relative values and rankings of regions from the most to least critical in Table 5.9.

Table 5.9. Ranking of Regions by AHP (Model-2)

	Regions	**Relative value**
1	Greek border	0.257
2	Iranian border	0.239
3	Iraqi border	0.142
4	Aegean	0.131
5	Syrian border	0.085
6	Bulgarian border	0.082
7	Eastern Black Sea	0.029
8	Mediterranean	0.019

As it in Table 5.9, the Greek border is the most critical region of Turkey in Model-2 according to the AHP result.

5.3.3. Summary of AHP Results

In this section of study, we summarize AHP results obtained in previous sections. We present the AHP results of Model-1 and Model-2 in Table 5.10.

Table 5.10. AHP Results of Model-1 and Model-2

	Model-1	**Model-2**
1	Greek border	Greek border
2	Iranian border	Iranian border
3	Aegean	Iraqi border
4	Iraqi border	Aegean
5	Syrian border	Syrian border
6	Bulgarian border	Bulgarian border
7	Eastern Black Sea	Eastern Black Sea
8	Mediterranean	Mediterranean

In general, the Greek border is the most critical region of Turkey according to both models in our study and the Iranian border the second most critical region. The Mediterranean region is the least critical according to both models. The ranking of regions according to Model-1 and Model-2 is almost the same. Defense measures along critical regions must be well planned and necessary precautions taken at peace time. This would include modernization of air defense systems especially along the Greek border and more advanced intelligence gathering systems in general. Troop training curriculums must create realistic conditions to improve survivability and response times. The findings in this study would enhance future military deployment plans by giving commanders insights about the critical regions of Turkey. Resources would be more effectively deployed to high risk regions according to our findings.

The ranking of regions in Turkey was also performed in another study (Evaluation of Mobilization and Deployment Plan of a Turkish Armored Battalion via Simulation, Müslüm and Sabuncuoğlu, 2002). This study was mentioned in the literature review as being the most related study for our purposes. In this study, Müslüm and Sabuncuoğlu (2002) develop a simulation model of mobilization and deployment activities of one of the armored battalions in the Turkish Army that includes loading of vehicles and convoying to assembly area under enemy attack. The authors measure the combat readiness of an armored battalion. Specifically, they present a decision tool for armored battalion commanders to observe the troop behavior before war. Our study has some similarities with their study. These similarities include stochastic events such as air and artillery attacks, the same armored battalion structure and analysis of critical regions in Turkey. In their study, they also implement Analytic Hierarchy Process to select the most critical region in Turkey. The main difference between two studies is that their study does not include logistics activities such as ammunition loading and fuel supply. Our study attempts to capture this feature of mobilization and deployment planning for a Turkish armored battalion. In our study, we not only consider combat modeling activities but also military logistics activities. We also have different stochastic events. In their study, they include stochastic events such as enemy ambush and minefield. In our study, we include stochastic events such as ammunition loading to ammunition trucks, transfer of ammunition to armored vehicles and fueling of armored and wheeled vehicles.

Their results about the ranking of regions in Turkey provide solid comparisons with our study results. While they consider ten regions in total (we only consider eight), their findings have similarities with our findings in that the Greek and Iranian borders pose the highest threats. In other regions, the results are less consistent but still similar. For example, the Eastern Black Sea and Mediterranean regions ranked very low. The reason for these differences may be attributed to the fact that their study evaluates a different timeframe within the military planning stages, they include no logistics events, and the stochastic events for both studies are somewhat different.

Given the strong similarities between the two studies however, we can say that the rankings of each study according to the AHP technique validate each other. It is reasonable that our findings about the ranking of regions in Turkey are similar to their findings. This is because we simulate the ammunition and fuel supply activities of an armored battalion during mobilization and deployment while they simulate the convoy activities of an armored battalion to assembly area during mobilization and deployment. Mobilization and deployment activities of an armored battalion include the activities in our study and also the activities in their study. Our study mostly includes logistics features of mobilization and deployment while their study includes combat features of mobilization and deployment.

CHAPTER 6

CONCLUSION

6.1. General

In this study, we analyzed the behaviors of existing ammunition and fuel supply systems of an armored battalion before alarm order via simulation. We defined all the necessary components of the systems and their interactions which are needed to develop the simulation models. The models can easily be modified to represent other types of ammunition and fuel supply systems. The objectives of this study were: (1) To examine the behaviors of the existing systems by constructing valid models of systems (2) To detect the factors which have significant effects on performance measures (3) To find time standards of existing systems, and (4) To rank the regions of Turkey from the most to least critical according to performance measures of interest.

In our study we have two existing systems. These are :

- Ammunition and fuel supply of an armored battalion at supply points (System-1)
- Ammunition and fuel supply of an armored battalion by ammunition trucks and fuel tankers at alert dispersion areas (System-2)

In this study, the performance measures of interest are maximum time-in-system and number of destroyed vehicles. These two performance measures have vital importance for commanders since they affect the course of war. We examined the existing systems by using these performance measures. We determined the effects of factors on performance measures of interest and we ranked the regions of Turkey from most to least critical according to performance measures of interest.

6.2. Significant Factors and Interactions on Performance Measures

In Chapter 4, we implemented 2^k factorial design for both models to understand the effects of factors and interactions on performance measures of interest. We also implemented analysis of variance (ANOVA) to determine which factors and interactions have significant effects on performance measures. We present the significant factors and interactions on performance measures for Model-1 in Table 6.1. We present the significant factors and interactions on performance measures for Model-2 in Table 6.2.

Table 6.1. Significant Factors and Interactions on Performance Measures (Model-1)

Performance Measures	**Significant Factors and Interactions**
Maximum Time-in-System	Breakdown Air Attack Number of Ammunition Depot Loading Points Number of Company Fuel Supply Points Breakdown-Air Attack Breakdown-Artillery Attack
Number of Destroyed Vehicles	Air Attack Artillery Attack

As seen in Table 6.1, significant factors on maximum time-in-system performance measure in Model-1 are breakdown, air attack, number of ammunition depot loading points and number of company fuel supply points. Air attack and breakdown have positive effects on performance measure. Number of ammunition depot loading points and number of company fuel supply points have negative effects. Number of ammunition depot loading points has the biggest effect on maximum time-in-system performance measure. There are two significant interactions on maximum time-in-system performance measure. These are breakdown-air attack and breakdown-artillery attack.

Significant factors on number of destroyed vehicles performance measure in Model-1 are artillery and air attack. Both significant factors have positive effects on performance measure. The effect of artillery attack is greater than the effect of air attack. There is no significant interaction.

Table 6.2. Significant Factors and Interactions on Performance Measures (Model-2)

Performance Measures	**Significant Factors and Interactions**
Maximum Time-in-System	Air Attack Number of Ammunition Depot Loading Points Number of Company Fuel Supply Points Breakdown-Air Attack
Number of Destroyed Vehicles	Air Attack Artillery Attack

As seen in Table 6.2, significant factors on maximum time-in-system performance measure in Model-2 are air attack, number of ammunition depot loading points and number of company fuel supply points. Air attack has a positive effect and other significant factors have negative effects on performance measure. The number of ammunition depot loading points has the greatest effect on maximum time-in-system performance measure. The only significant interaction is between breakdown and air attack.

The significant factors on number of destroyed vehicles performance measure in Model-2 are air and artillery attack. Air attack has a greater effect than artillery attack and both significant factors have positive effects on performance measure. There is no significant interaction.

When we consider number of destroyed vehicles performance measure we see that significant factors are the same in Model-1 and Model-2. The only difference is that in Model-1, the effect of artillery attack is greater than the effect of air attack, whereas in Model-2, air attack has a greater effect. In light of this information, we conclude that commanders must increase their measures against artillery attacks when exercising System-1, and increase air defense capabilities when exercising System-2. When we consider maximum time-in-system performance measure, we see that the only difference between Model-1 and Model-2 according to significant factors is breakdown. In Model-1, breakdown is a significant factor but in Model-2 it is not. We conclude that commanders must take necessary measures to decrease the number of broken vehicles and to increase the maintenance activity when exercising System-1.

6.3. Time Standards of Existing Systems

One of our objectives in this study is to determine time standards of existing systems. Maximum time-in-system measure is vital information for a commander since it improves pre-planning and indicates completion of a military activity. We think our findings in this study will be helpful to commanders for these reasons.

In our study, we determine time standards of existing systems which are exercised under enemy threat by constructing confidence intervals of maximum time-in-system statistics of our simulation models. According to our findings, when we exercise System-1 in real life, ammunition and fuel supply activity of an armored battalion will finish within a 489-553 minute time interval. When we exercise System-2 in real life, ammunition and fuel supply activity of an armored battalion will finish within a 434-512 minute time interval.

6.4. Ranking of Regions of Turkey

We implemented the Rinott Procedure to rank the regions of Turkey from most to least critical according to each performance measure of interest. The regions under consideration have land or sea borders with other countries. We present the rankings of regions for Model-1 and Model-2 according to the Rinott Procedure results in Table 6.3.

Table 6.3. Summary Table of Ranking of Regions According to Rinott Procedure Results

	MODEL-1		**MODEL-2**	
	Maximum Time-in-System	**Number of Destroyed Vehicles**	**Maximum Time-in-System**	**Number of Destroyed Vehicles**
1	Greek border	Iranian border	Greek border	Iranian border
2	Aegean	Greek border	Iranian border	Greek border
3	Iranian border	Syrian border	Aegean	Iraqi border
4	Iraqi border	Iraqi border	Iraqi border	Syrian border
5	Syrian border	Bulgarian border	Bulgarian border	Aegean
6	Bulgarian border	Aegean	Syrian border	Bulgarian border
7	Eastern Black Sea	Eastern Black Sea	Eastern Black Sea	Eastern Black Sea
8	Mediterranean	Mediterranean	Mediterranean	Mediterranean

We reach the following conclusions by analyzing Table 6.3.

- The Greek border is the most critical region according to maximum time-in-system performance measure for Model-1 and Model-2.

- The Iranian border is the most critical region according to the number of destroyed vehicles performance measure for Model-1 and Model-2.
- The Eastern Black Sea and Mediterranean regions are the least critical regions according to performance measures of interest for Model-1 and Model-2.

As seen in Table 6.3, we obtained different ranking of regions for each performance measure in both models by using the Rinott Procedure. We then implemented Analytic Hierarchy Process (AHP) to singularly rank regions according to both performance measures. We present the ranking of regions for Model-1 and Model-2 according to AHP in Table 6.4.

Table 6.4. Summary Table of Ranking of Regions According to AHP Results

	Model-1	**Model-2**
1	Greek border	Greek border
2	Iranian border	Iranian border
3	Aegean	Iraqi border
4	Iraqi border	Aegean
5	Syrian border	Syrian border
6	Bulgarian border	Bulgarian border
7	Eastern Black Sea	Eastern Black Sea
8	Mediterranean	Mediterranean

We reach following conclusions by analyzing Table 6.4.

- The Greek border is the most critical region of Turkey in both models according to AHP. The Iranian border is the second most critical.

- The Mediterranean region is the least critical region of Turkey in both models according to AHP.
- Measures against possible air and artillery attacks along the Iranian and Greek borders must be increased to decrease maximum time-in-system and number of destroyed vehicles statistics. Air defense systems especially along the Greek border must be modernized.
- Troop training curriculums must create realistic conditions to improve survivability and response times.
- The findings in this study would enhance future military deployment plans by giving commanders insights about the critical regions of Turkey.

6.5. Comparison of System-1 and System-2

According to our findings, when we consider number of destroyed vehicles performance measure, the only difference between Model-1 and Model-2 is that in Model-1, the effect of artillery attack is greater than the effect of air attack and in Model-2, air attack has a greater effect. In light of this information, we can conclude that commanders must exercise System-2 whenever they know enemy has a strong artillery attack capability and they must exercise System-1 whenever they know enemy has a strong air attack capability.

When we consider maximum time-in-system performance measure, we see that the only difference between Model-1 and Model-2 according to significant factors is breakdown. In Model-1, breakdown is a significant factor but in Model-2 it is not. We can conclude that commanders must exercise System-2 whenever they know vehicle breakdown probability is high due to terrain conditions and the conditions of vehicles.

In our study, we determined time standards for each system. According to our findings, when we exercise System-1 in real life, ammunition and fuel supply activity of an armored battalion will finish within a 489-553 minute time interval. When we exercise System-2 in real life, ammunition and fuel supply of an armored battalion will finish within a 434-512 minute time interval. System-2 is favorable to System-1 in terms of time standards but System-2 is not applicable in all situations. System-2 can not be exercised when there is severe weather condition such as heavy rain or snow since supply vehicles can have maintenance problems during their travels in such severe weather conditions. System-2 is also not applicable for each armored battalion due to differences in the structure of armored battalions. Not all armored battalions have enough supply vehicles to transport their supply materials. A battalion commander will use either technique depending on resources at hand and weather conditions.

6.6. Future Research Topics

In our study, we evaluate the ammunition and fuel supply systems of one of the armored battalions in the Turkish Army before alarm order. Ammunition and fuel supply systems of an armored brigade can be studied as a future research topic. Ammunition and fuel supply systems of an infantry battalion or an infantry brigade can also be studied as a future research topic.

Military equipment and vehicles are complex and very expensive systems. With the improvements in technology, the cost of military equipment and vehicles are increasing rapidly. In the future research studies, cost criterion should be included.

In this study, we only consider two classes of supply materials, ammunition and fuel. Future studies could consider other classes of supply materials.

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APPENDICES

APPENDIX-A

DETAILED FLOWCHARTS FOR MODEL-1 AND MODEL-2

Ammunition and Fuel Supply of an Armored Battalion at Supply Points

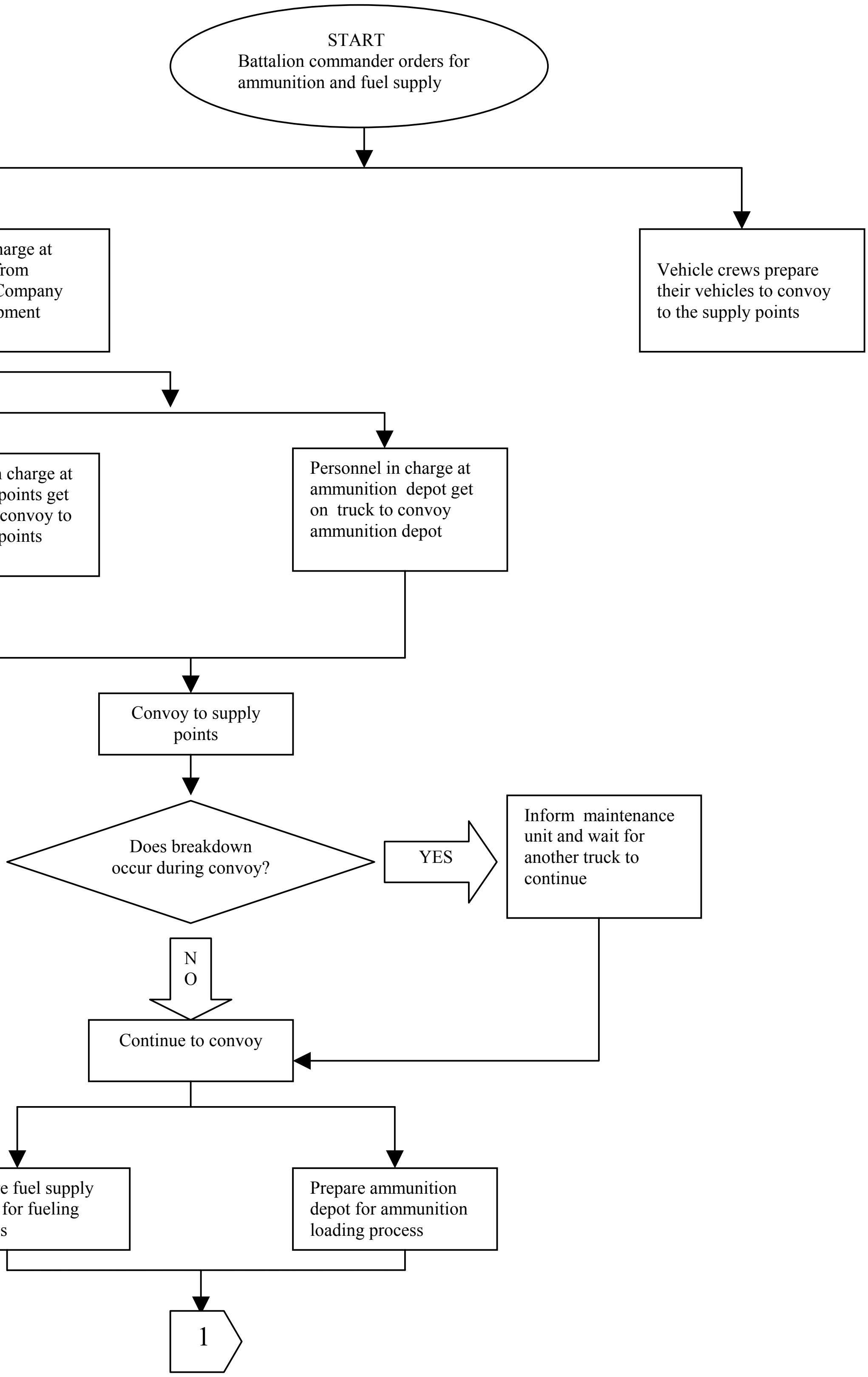


Figure A.1. Detailed Flowchart of System-1

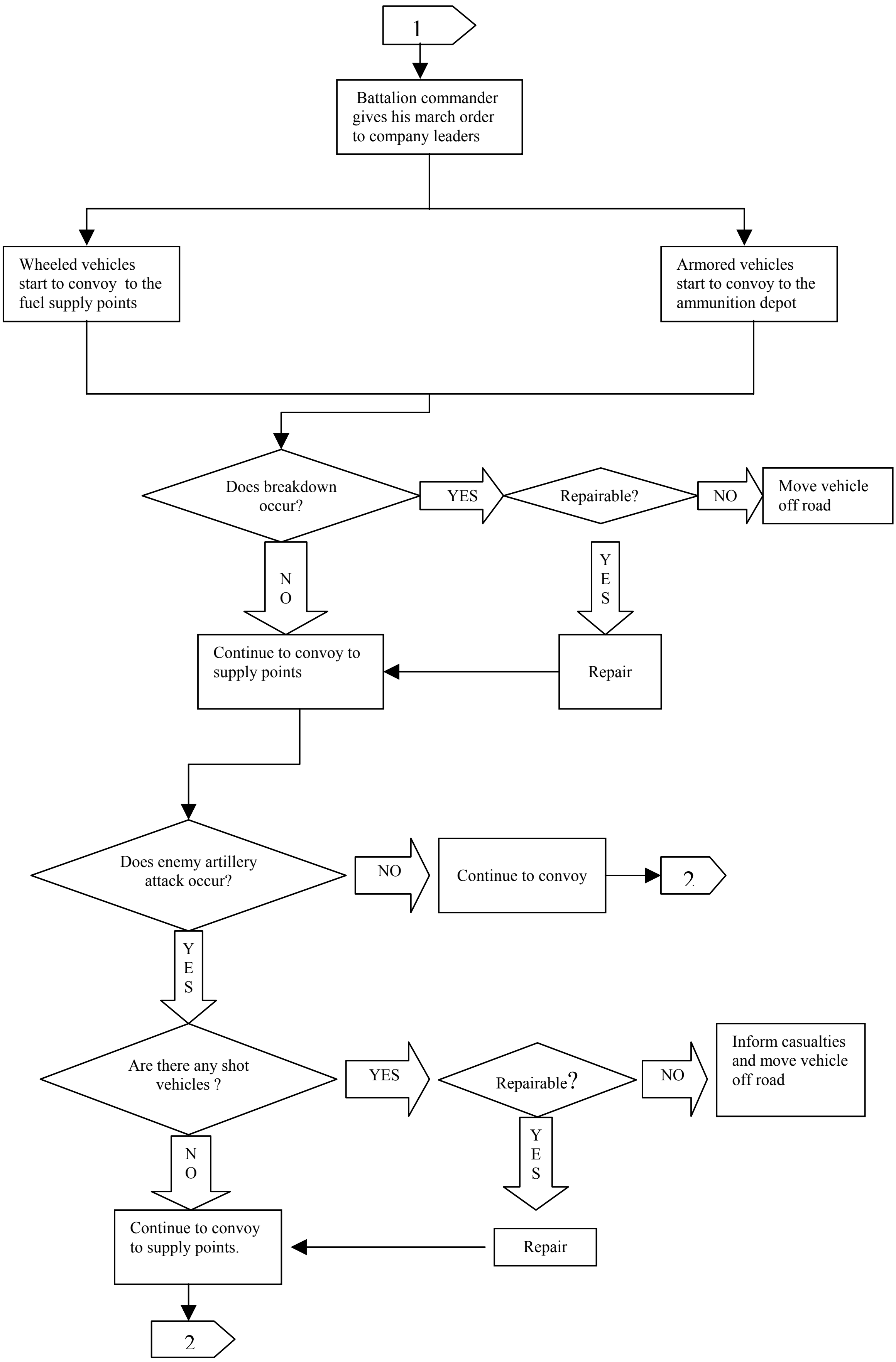


Figure A.1. Detailed Flowchart of System-1

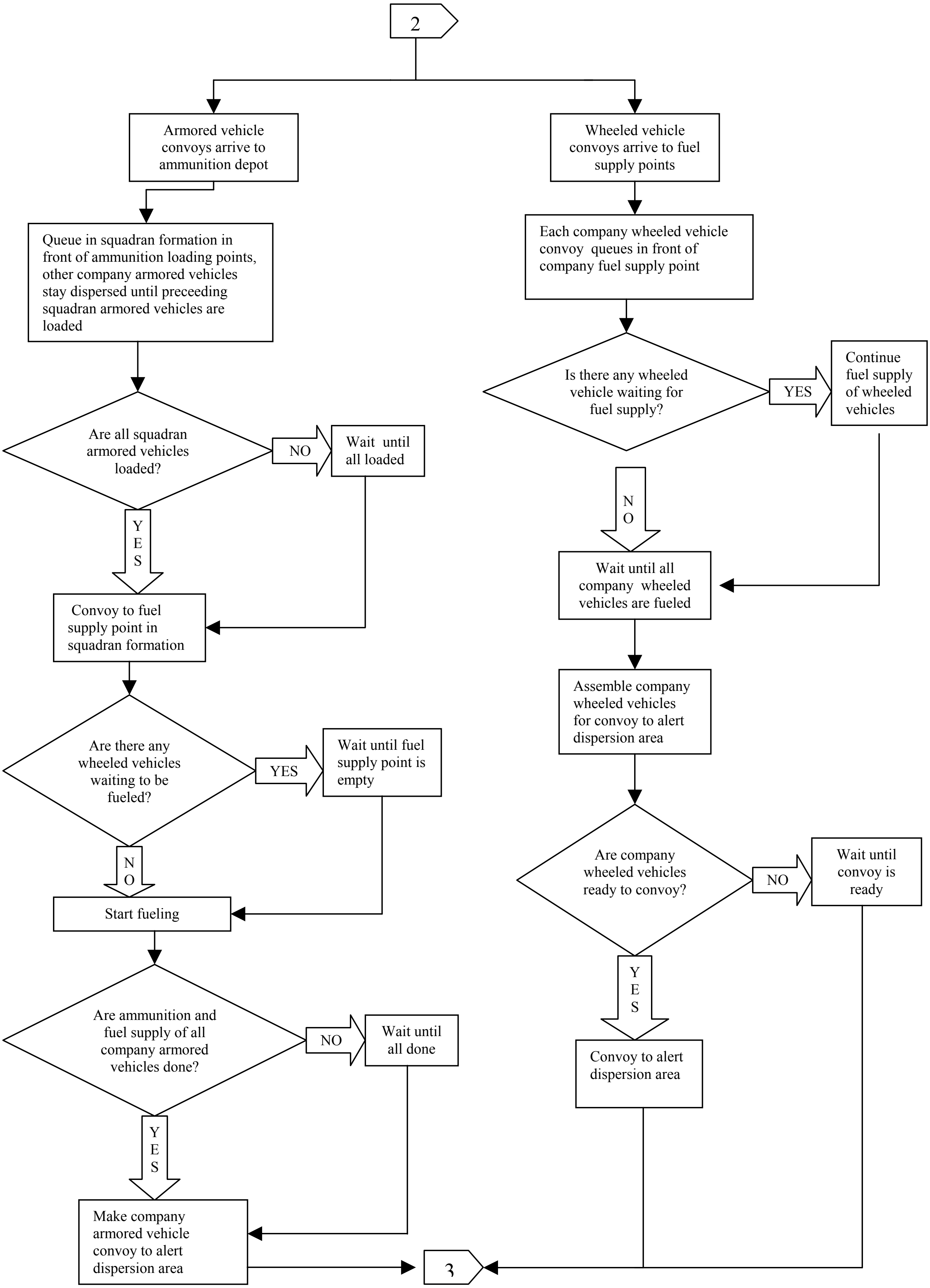


Figure A.1. Detailed Flowchart of System-1

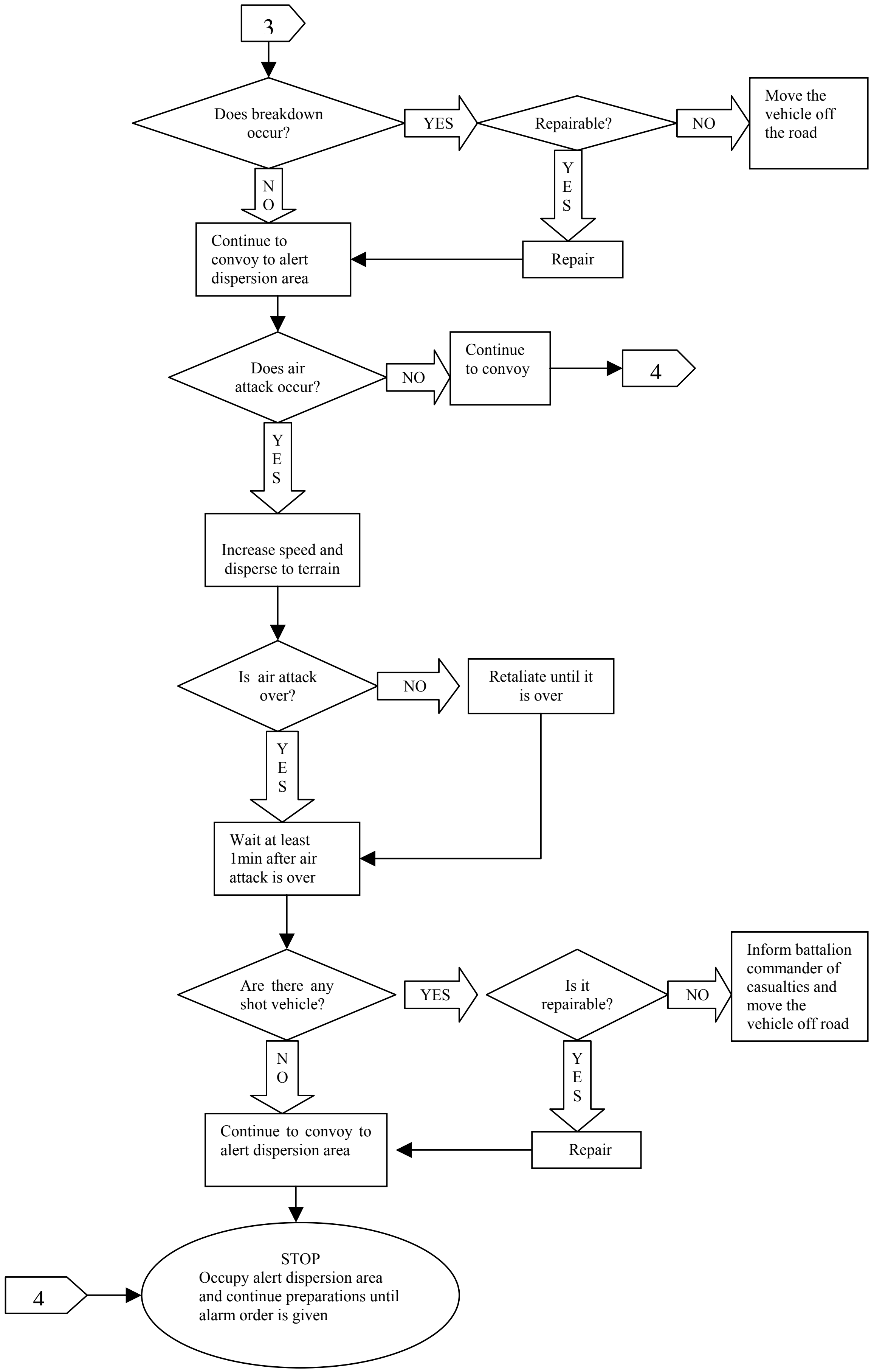


Figure A.1. Detailed Flowchart of System-1

Ammunition and Fuel Supply of an Armored Battalion by Ammunition Trucks and Fuel Tankers

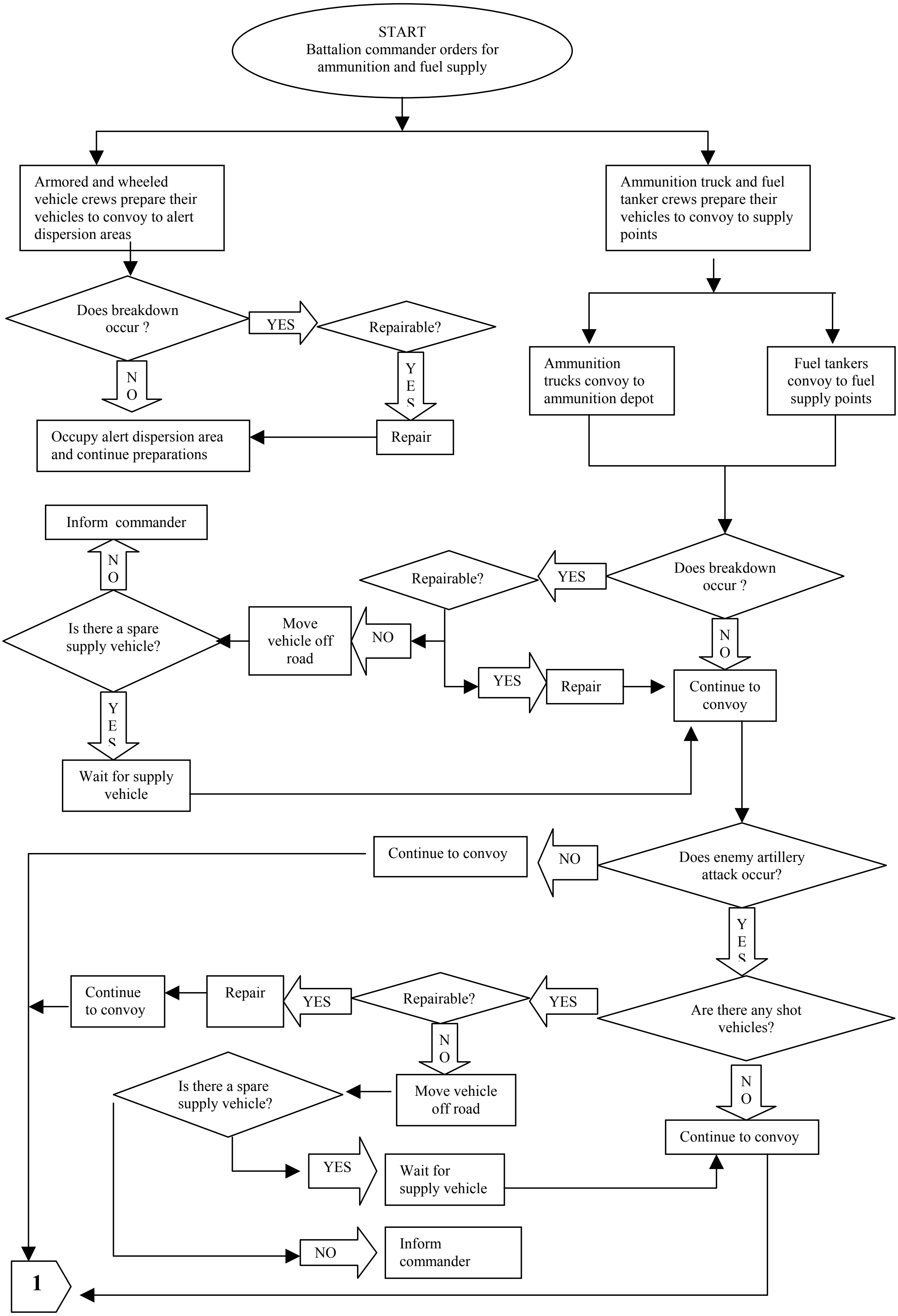


Figure A.2. Detailed Flowchart of System-2

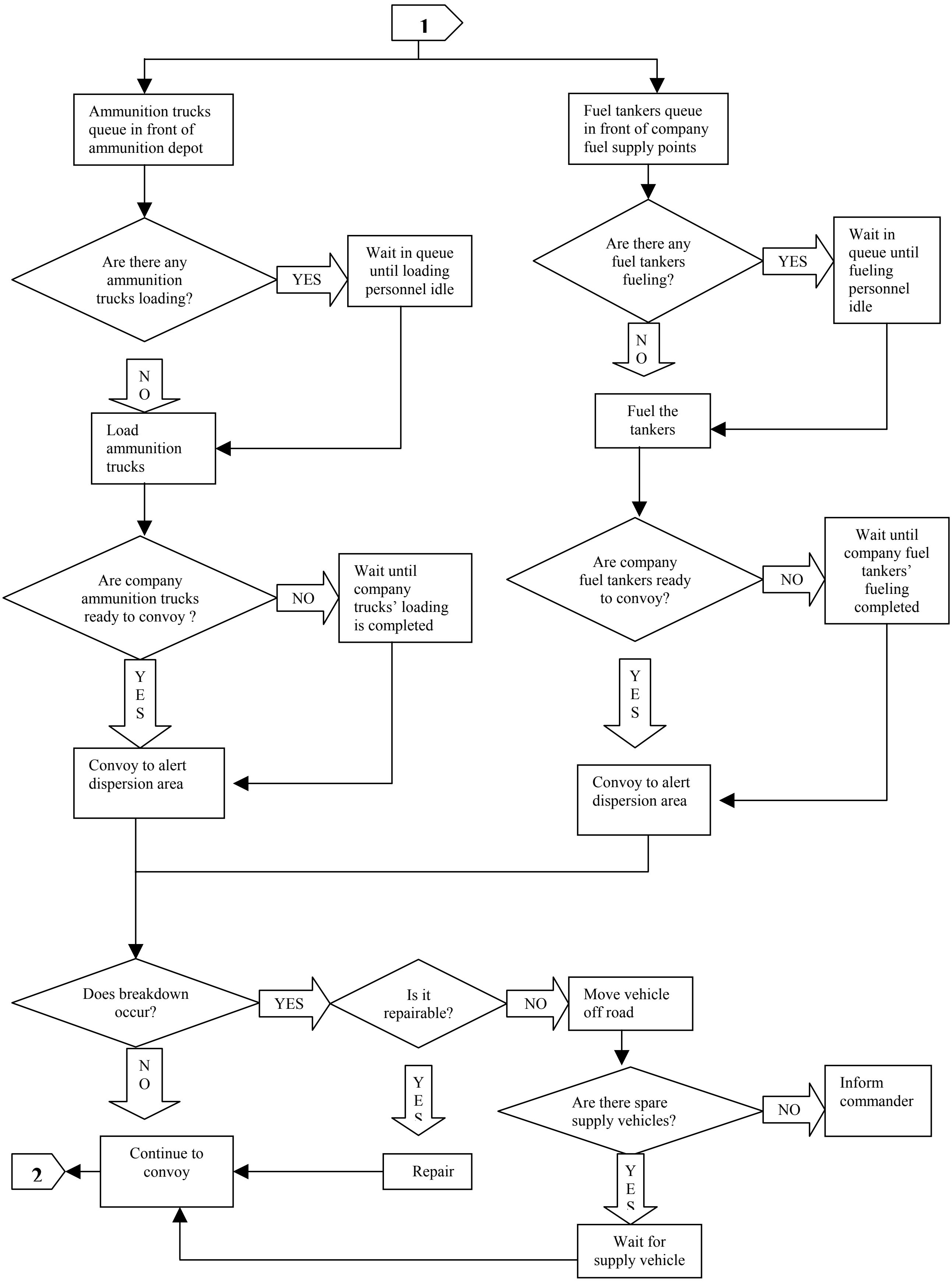


Figure A.2. Detailed Flowchart of System-2

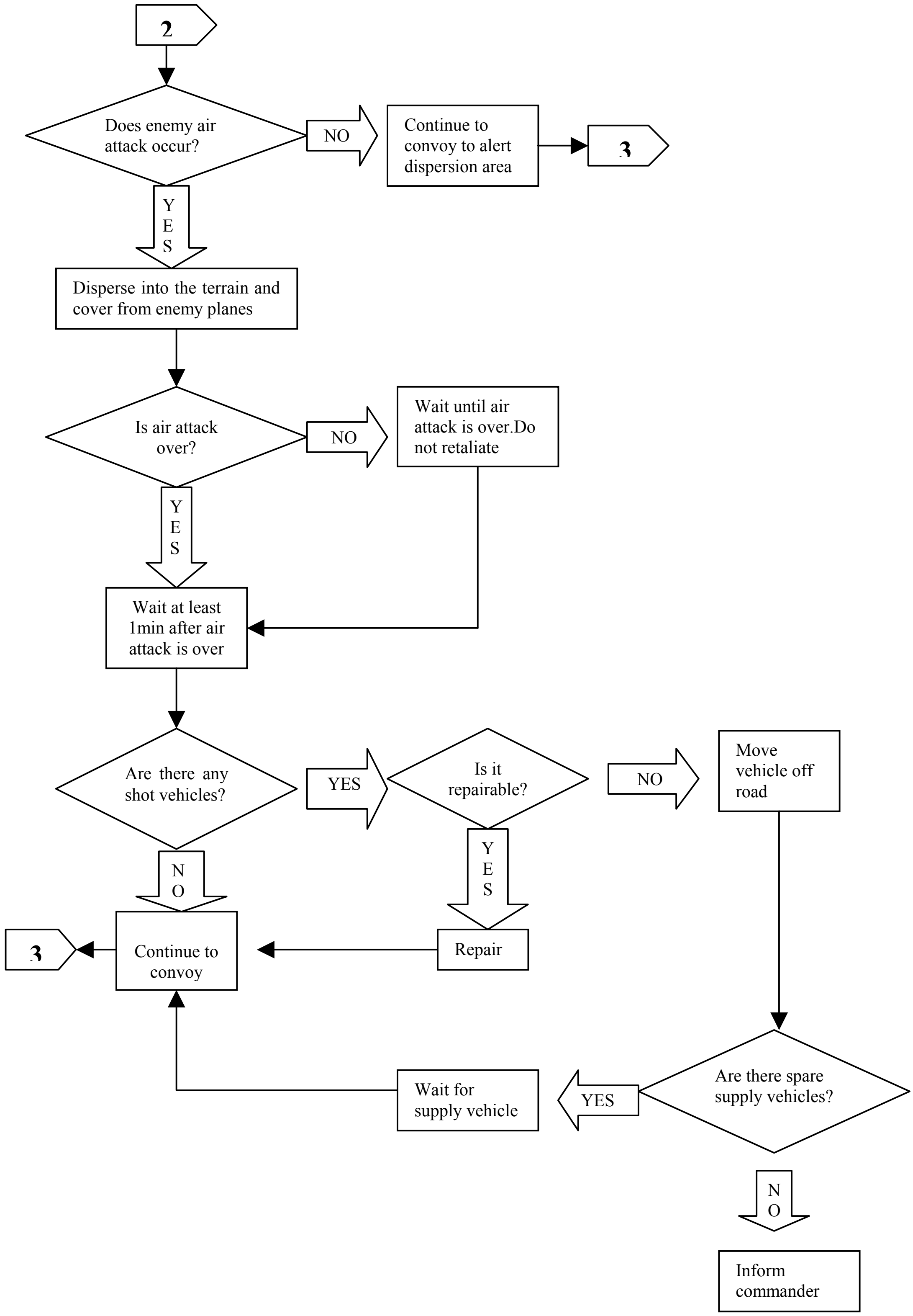


Figure A.2. Detailed Flowchart of System-2

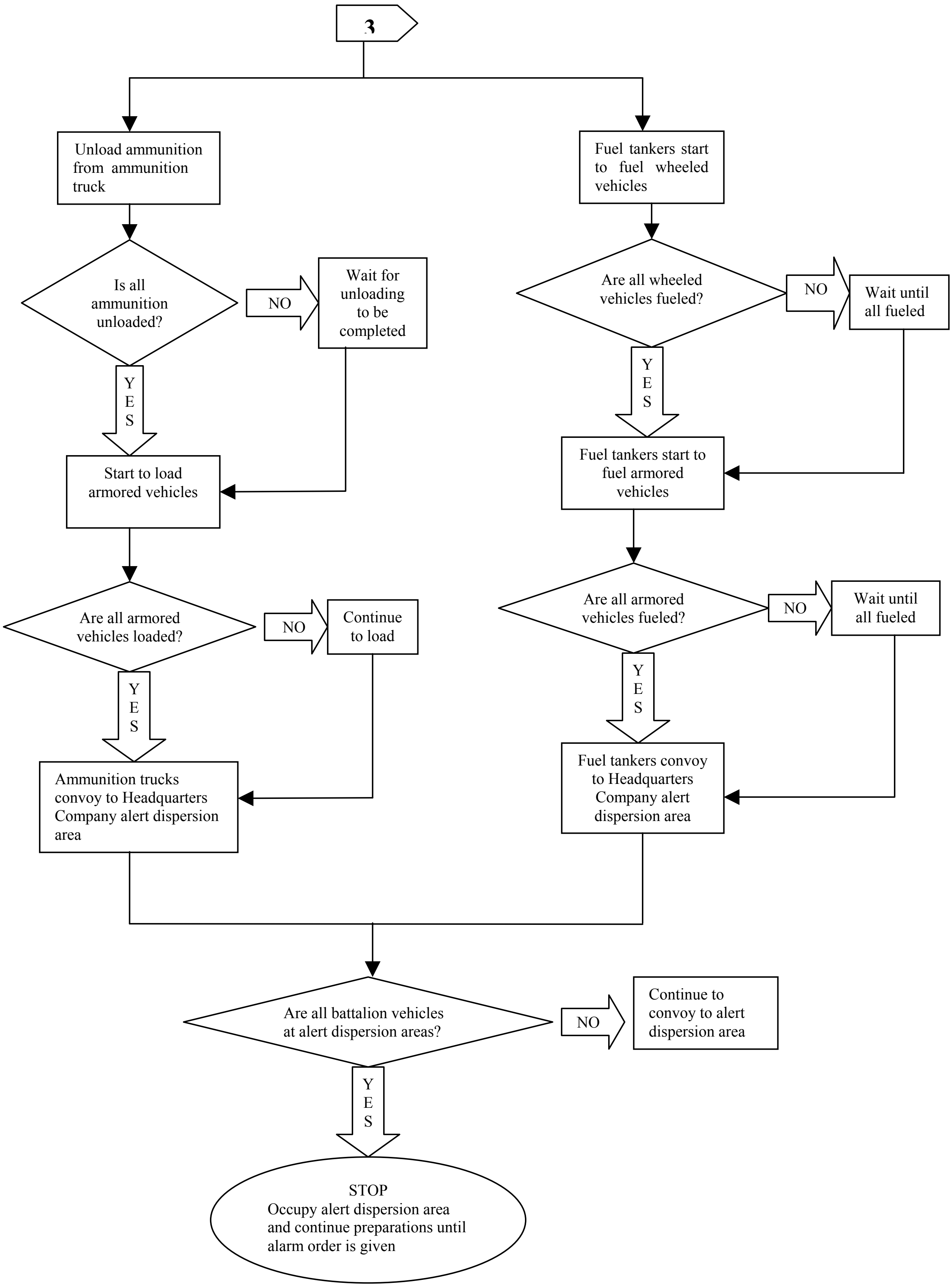


Figure A.2. Detailed Flowchart of System-2

APPENDIX-B

DESIGN POINTS AND RESULTS OF REPLICATIONS FOR EXPERIMENTAL DESIGN

Table B.1. Factor Names and Design Points for Performance Measures

	Breakdown (0.02-0.2)	Air Attack (0.1-0.8)	Artillery Attack (0.1-0.8)	Number of Ammunition Loading Points(2-4)	Number of Company Fuel Supply Points (1-3)	Design Points
1	-	-	-	-	-	00000
2	+	-	-	-	-	10000
3	-	+	-	-	-	01000
4	-	-	+	-	-	00100
5	-	-	-	+	-	00010
6	-	-	-	-	+	00001
7	+	+	-	-	-	11000
8	+	-	+	-	-	10100
9	+	-	-	+	-	10010
10	+	-	-	-	+	10001
11	-	+	+	-	-	01100
12	-	+	-	+	-	01010
13	-	+	-	-	+	01001
14	-	-	+	+	-	00110
15	-	-	+	-	+	00101
16	-	-	-	+	+	00011
17	+	+	+	-	-	11100
18	+	+	-	+	-	11010
19	+	+	-	-	+	11001
20	+	-	+	+	-	10110
21	+	-	+	-	+	10101
22	+	-	-	+	+	10011
23	-	+	+	+	-	01110
24	-	+	+	-	+	01101
25	-	+	-	+	+	01011
26	-	-	+	+	+	00111
27	+	+	+	+	-	11110
28	+	+	+	-	+	11101
29	+	+	-	+	+	11011
30	+	-	+	+	+	10111
31	-	+	+	+	+	01111
32	+	+	+	+	+	11111

	00000	10000	01000	00100	00010	00001	11000	10100
1	576.38	601.23	585.37	477.82	360.21	478.52	612.56	455.34
2	499.68	556.27	498.24	623.56	468.66	499.54	645.23	712.34
3	481.21	433.89	537.23	522.13	505.03	623.56	572.34	633.24
4	480.04	655.87	642.75	602.45	424.03	544.52	633.56	533.25
5	665.37	525.18	574.23	555.62	344.33	427.87	489.56	577.34
6	526.61	547.77	600.43	611.55	493.67	542.76	456.53	625.76
7	585.36	680.43	546.83	489.13	470.89	477.73	647.24	595.23
8	580.04	623.15	652.78	478.23	476.22	442.32	588.35	580.13
9	489.55	505.14	538.87	569.23	459.49	534.78	613.27	499.15
10	694.88	598.47	644.56	647.37	343.9	414.54	659.47	513.75
11	512.92	612.45	626.63	615.33	456.03	503.27	666.97	572.34
12	574.33	584.98	433.23	549.23	484.57	466.76	701.76	649.34
13	515.93	602.12	672.23	453.87	498.63	546.34	548.76	686.65
14	600.04	646.87	555.16	674.47	343.95	545.78	673.66	623.45
15	520.02	683.16	673.43	600.46	367.52	533.91	624.56	644.56
Average	*553.491*	*590.465*	*585.465*	*564.697*	*433.142*	*505.48*	*608.921*	*593.458*
Variance	*4275.473*	*4649.523*	*4736.308*	*4641.732*	*3931.467*	*3081.149*	*4661.168*	*5065.209*

Table B.2.1. Averages and Variances of 15 Replications for Maximum Time-in-System (Model-1)

Table B.2.2. Averages and Variances of 15 Replications for Maximum Time-in-System (Model-1)

	10010	10001	01100	01010	01001	00110	00101	00011
1	477.23	515.45	449.23	593.54	550.21	444.87	389.67	345.54
2	456.15	466.23	572.43	423.56	402.76	508.56	542.74	366.77
3	600.67	543.23	393.52	388.73	399.23	543.22	548.02	501.22
4	534.27	482.34	523.34	423.13	632.17	601.87	608.03	520.36
5	488.45	634.26	572.43	534.23	599.77	388.98	499.34	430.43
6	563.63	443.78	592.56	437.34	478.87	456.76	395.66	383.72
7	388.34	532.45	499.34	376.23	601.11	399.94	533.76	353.66
8	431.35	467.23	549.29	455.91	467.34	432.75	549.72	352.76
9	399.65	644.24	560.23	524.76	505.96	376.45	641.74	401.22
10	412.34	578.34	383.22	522.45	577.33	412.09	526.55	372.34
11	478.25	456.34	589.34	412.97	523.96	378.67	562.43	387.34
12	399.34	449.67	399.23	435.31	599.87	478.65	599.33	376.23
13	434.15	552.12	577.34	477.23	589.65	477.67	489.01	436.23
14	456.76	456.23	589.76	512.98	623.05	455.19	455.76	367.23
15	488.75	505.23	600.27	404.44	639.98	450.03	613.49	398.98
Average	*467.289*	*515.143*	*523.435*	*461.521*	*546.084*	*453.713*	*530.35*	*399.602*
Variance	*3839.646*	*4248.209*	*6228.963*	*3980.613*	*6340.782*	*3937.433*	*5583.935*	*2732.084*

Table B.2.3. Averages and Variances of 15 Replications for Maximum Time-in-System (Model-1)

	11100	11010	11001	10110	10101	10011	01110	01101
1	499.34	477.23	590.46	566.54	650.34	409.34	500.73	552.18
2	723.58	486.29	403.23	476.29	567.23	485.17	484.27	682.28
3	576.34	588.42	499.43	460.23	535.01	356.01	602.91	477.14
4	401.04	378.87	670.45	509.23	599.18	484.28	625.39	601.15
5	536.76	480.16	599.24	369.45	467.26	401.93	491.14	553.26
6	567.87	521.45	655.08	346.45	563.56	388.29	519.08	542.83
7	623.45	490.84	601.43	582.12	665.24	451.62	476.38	532.13
8	515.73	501.54	554.33	444.23	453.23	374.28	411.72	541.28
9	559.34	399.64	623.12	399.84	505.39	353.49	532.83	646.93
10	484.34	428.93	595.23	488.72	601.51	452.97	401.29	484.28
11	601.73	501.77	609.86	459.93	627.34	499.17	388.27	688.61
12	532.59	489.43	622.34	490.72	433.83	383.41	366.39	690.11
13	619.82	389.09	669.35	437.85	606.83	376.49	432.95	471.27
14	603.56	515.53	589.45	473.73	616.39	399.15	401.64	501.54
15	654.65	469.02	590.23	514.23	588.26	343.16	501.28	499.26
Average	*566.676*	*474.547*	*591.549*	*467.971*	*565.373*	*410.584*	*475.751*	*564.283*
Variance	*6038.905*	*3082.81*	*4579.11*	*4167.823*	*5168.509*	*2644.945*	*5847.404*	*6178.877*

Table B.2.4. Averages and Variances of 15 Replications for Maximum Time-in-System (Model-1)

	01011	00111	11110	11101	11011	10111	01111	11111
1	367.26	458.02	543.92	590.43	376.18	421.28	359.29	430.29
2	449.91	363.26	379.31	642.16	459.26	376.18	466.29	359.71
3	502.18	439.31	495.38	570.22	477.28	366.71	437.28	502.69
4	539.29	491.27	355.87	408.23	389.36	437.83	504.29	533.48
5	420.15	373.28	517.32	536.28	465.38	430.71	428.39	376.38
6	363.29	381.26	533.98	640.12	452.36	501.27	440.29	466.39
7	421.46	436.72	500.12	443.47	364.73	433.27	451.27	399.29
8	412.26	389.29	462.02	688.24	419.49	401.21	382.38	568.21
9	374.73	355.82	499.87	563.76	442.27	398.42	452.38	463.38
10	449.16	462.87	483.28	589.26	395.16	498.29	388.26	571.34
11	472.16	432.71	563.72	621.28	382.38	462.88	401.29	382.17
12	388.17	445.25	604.25	573.28	485.29	361.28	398.38	402.47
13	391.24	348.38	612.71	593.27	492.49	388.29	377.39	482.39
14	395.25	368.29	533.28	692.36	482.61	404.14	532.29	581.42
15	353.28	399.26	401.24	655.23	488.19	482.09	573.38	372.19
Average	*419.986*	*409.666*	*499.085*	*587.173*	*438.162*	*424.257*	*439.523*	*459.453*
Variance	*2890.186*	*2029.363*	*5639.065*	*6374.487*	*2107.91*	*2075.031*	*3658.077*	*6094.017*

Table B.3.1. Averages and Variances of 10 Replications for Maximum Time-in-System (Model-2)

	00000	10000	01000	00100	00010	00001	11000	10100
1	407.75	430.91	422.47	403.76	298.44	430.69	442.62	425.78
2	429.16	411.53	430.41	409.23	343.06	406.36	402.72	433.27
3	389.32	389.95	458.55	435.49	385.57	406.88	462.92	352.65
4	426.6	375.54	435.78	366.43	339.55	403.84	369.31	418.92
5	403.22	347.88	500.19	432.41	360.61	418.74	428.63	500.11
6	383.98	415.54	393.71	372.72	334.81	320.36	517.37	432.35
7	514.43	430.67	428.21	427.48	320.79	346.51	512.84	412.94
8	404.11	445.34	341.81	352.11	362.71	331.83	433.56	385.52
9	380.61	477.75	420.91	467.91	366.94	423.71	429.19	428.14
10	363.51	402.06	511.15	431.37	399.31	408.16	481.72	377.63
Average	*410.269*	*412.717*	*434.319*	*409.891*	*351.179*	*389.708*	*448.088*	*416.731*
Variance	*1751.454*	*1352.678*	*2379.008*	*1327.395*	*904.8489*	*1646.217*	*2176.095*	*1590.017*

	10010	10001	01100	01010	01001	00110	00101	00011
1	382.71	442.29	423.92	360.46	428.82	369.82	425.72	306.01
2	363.27	321.07	485.11	302.47	389.72	442.53	349.73	279.76
3	396.83	389.78	404.02	412.36	409.42	320.17	406.37	367.24
4	336.63	465.76	412.19	440.66	372.11	342.18	408.09	325.94
5	386.52	389.43	386.98	395.49	408.78	368.74	332.82	360.61
6	312.49	409.29	407.17	362.83	507.72	361.64	403.28	280.52
7	389.74	411.23	427.43	381.03	414.62	351.28	366.32	292.43
8	353.21	409.83	516.62	388.42	347.18	319.43	411.53	350.37
9	327.45	427.19	502.73	337.63	452.17	338.07	358.63	345.82
10	301.29	398.64	409.13	300.61	442.29	362.21	421.54	310.53
Average	*355.014*	*406.451*	*437.531*	*368.196*	*417.283*	*357.607*	*388.403*	*321.923*
Variance	*1175.321*	*1465.886*	*2122.888*	*2047.874*	*2001.153*	*1226.8*	*1101.817*	*1076.837*

Table B.3.2. Averages and Variances of 10 Replications for Maximum Time-in-System (Model-2)

Table B.3.3. Averages and Variances of 10 Replications for Maximum Time-in-System (Model-2)

	11100	11010	11001	10110	10101	10011	01110	01101
1	**492.72**	**317.72**	**365.29**	**358.92**	**322.42**	**299.42**	**375.12**	**382.15**
2	**362.72**	**414.26**	**482.73**	**444.34**	**426.87**	**354.81**	**446.04**	**355.18**
3	**511.82**	**386.63**	**418.72**	**355.71**	**358.29**	**384.15**	**432.72**	**426.98**
4	**508.38**	**372.52**	**398.36**	**441.73**	**428.97**	**343.29**	**389.79**	**381.03**
5	**442.31**	**400.42**	**419.02**	**365.83**	**415.82**	**289.01**	**442.16**	**418.28**
6	**421.27**	**363.61**	**462.72**	**347.02**	**389.13**	**348.32**	**326.76**	**424.63**
7	**379.29**	**309.73**	**347.26**	**353.86**	**335.77**	**388.82**	**303.02**	**358.28**
8	**412.82**	**362.09**	**400.62**	**326.56**	**400.92**	**313.64**	**342.42**	**385.29**
9	**412.84**	**411.82**	**458.38**	**300.19**	**409.09**	**284.03**	**376.27**	**417.01**
10	**501.76**	**380.01**	**439.11**	**332.98**	**443.63**	**290.18**	**324.07**	**527.27**
Average	***444.593***	***371.881***	***419.221***	***362.714***	***393.091***	***329.567***	***375.837***	***407.61***
Variance	***3078.572***	***1272.226***	***1858.107***	***2156.073***	***1702.585***	***1566.641***	***2696.183***	***2468.983***

	01011	00111	11110	11101	11011	10111	01111	11111
1	**376.19**	**341.71**	**362.83**	**389.21**	**362.08**	**413.28**	**348.28**	**372.72**
2	**289.53**	**331.23**	**372.19**	**408.93**	**316.74**	**358.92**	**418.09**	**269.12**
3	**326.76**	**287.45**	**445.29**	**497.03**	**382.19**	**344.54**	**283.38**	**377.21**
4	**339.04**	**317.46**	**302.15**	**513.27**	**293.02**	**302.79**	**327.08**	**456.03**
5	**319.61**	**439.29**	**328.39**	**439.29**	**288.42**	**283.47**	**326.28**	**362.23**
6	**273.93**	**352.18**	**401.33**	**404.21**	**345.81**	**263.98**	**397.81**	**361.79**
7	**398.18**	**278.38**	**364.03**	**376.82**	**396.18**	**279.18**	**301.03**	**298.76**
8	**302.17**	**365.08**	**386.72**	**405.26**	**388.92**	**338.81**	**437.21**	**336.36**
9	**287.16**	**327.19**	**422.02**	**501.42**	**376.02**	**347.92**	**352.02**	**417.23**
10	**402.18**	**310.37**	**432.78**	**512.61**	**303.87**	**364.54**	**313.28**	**352.79**
Average	***331.475***	***335.034***	***381.773***	***444.805***	***345.325***	***329.743***	***350.446***	***360.424***
Variance	***2173.537***	***2064.189***	***2068.661***	***3051.071***	***1730.949***	***2157.908***	***2645.032***	***2842.416***

Table B.3.4. Averages and Variances of 10 Replications for Maximum Time-in-System (Model-2)

	00000	10000	01000	00100	00010	00001	11000	10100
1	2	4	5	7	3	4	9	7
2	1	3	8	8	2	2	5	10
3	3	0	3	4	3	1	6	5
4	4	1	3	8	5	3	6	3
5	1	0	5	5	2	2	4	11
6	0	1	4	8	5	1	8	7
7	1	1	3	5	1	3	6	6
8	1	2	10	3	0	0	4	9
9	3	3	4	9	4	1	3	8
10	1	0	4	6	3	2	5	8
11	3	5	4	6	1	1	4	4
12	1	0	9	8	0	2	8	7
13	0	4	9	4	2	1	6	8
14	2	2	4	10	3	1	5	3
15	3	3	9	3	1	4	7	8
Average	*1.733*	*1.933*	*5.6*	*6.266*	*2.333*	*1.866*	*5.733*	*6.933*
Variance	*1.495*	*2.780*	*6.685*	*4.923*	*2.523*	*1.409*	*2.923*	*5.638*

Table B.4.1. Averages and Variances of 15 Replications for Number of Destroyed Vehicles(Model-1)

Table B.4.2 Averages and Variances of 15 Replications for Number of Destroyed Vehicles(Model-1)

	10010	10001	01100	01010	01001	00110	00101	00011
1	3	3	11	5	5	4	8	2
2	1	5	14	7	8	10	6	4
3	2	1	7	3	3	5	5	0
4	4	2	11	6	2	7	6	1
5	3	0	9	4	4	6	3	3
6	5	1	8	8	5	6	8	2
7	1	1	8	5	7	7	9	3
8	2	2	11	6	5	3	6	0
9	3	3	10	7	4	9	7	1
10	2	1	7	9	5	8	4	2
11	1	0	15	3	3	4	7	2
12	1	2	10	1	7	9	8	0
13	2	4	11	6	9	5	5	2
14	1	1	9	6	8	8	9	1
15	0	3	8	9	8	4	5	2
Average	*2.066*	*1.933*	*9.933*	*5.666*	*5.533*	*6.333*	*6.4*	*1.666*
Variance	*1.780*	*2.066*	*5.495*	*5.095*	*4.695*	*4.666*	*3.257*	*1.380*

Table B.4.3. Averages and Variances of 15 Replications for Number of Destroyed Vehicles(Model-1)

	11100	11010	11001	10110	10101	10011	01110	01101
1	9	8	7	9	6	3	10	9
2	14	2	5	7	9	5	13	14
3	8	7	5	5	5	1	7	8
4	9	6	6	7	7	0	10	11
5	12	4	2	8	8	0	8	7
6	8	6	9	8	9	1	9	9
7	7	6	4	5	4	0	10	8
8	12	4	5	3	2	2	11	11
9	10	2	3	8	6	3	9	10
10	7	5	5	5	5	1	7	7
11	14	4	4	6	6	5	14	13
12	12	7	7	8	8	1	12	12
13	14	6	6	4	4	5	11	10
14	10	9	5	9	10	2	8	9
15	8	7	7	3	4	1	7	8
Average	*10.266*	*5.533*	*5.333*	*6.333*	*6.2*	*2*	*9.733*	*9.733*
Variance	*6.495*	*4.123*	*3.095*	*4.238*	*5.171*	*3.285*	*4.780*	*4.495*

Table B.4.4 Averages and Variances of 15 Replications for Number of Destroyed Vehicles(Model-1)

	01011	00111	11110	11101	11011	10111	01111	11111
1	5	5	9	9	6	6	10	9
2	6	6	15	15	7	9	12	11
3	3	5	8	8	2	5	8	13
4	2	8	10	10	3	7	11	10
5	5	5	9	9	5	5	9	9
6	4	7	10	8	4	10	5	13
7	3	5	8	7	3	5	8	8
8	9	3	11	12	9	3	9	7
9	4	8	9	10	4	8	13	12
10	5	6	7	8	6	6	9	11
11	4	10	14	13	7	7	13	13
12	9	8	9	13	7	8	10	14
13	10	4	12	11	8	4	11	14
14	4	9	9	7	5	9	9	10
15	9	3	7	12	10	5	8	9
Average	*5.467*	*6.133*	*9.8*	*10.133*	*5.733*	*6.467*	*9.667*	*10.867*
Variance	*6.552*	*4.552*	*5.457*	*5.980*	*5.352*	*4.123*	*4.523*	*4.980*

Table B.5.1. Averages and Variances of 10 Replications for Number of Destroyed Vehicles(Model-2)

	00000	10000	01000	00100	00010	00001	11000	10100
1	3	2	9	4	2	1	8	5
2	2	1	5	3	0	0	5	7
3	1	2	4	7	2	2	4	6
4	3	3	6	6	2	4	6	7
5	3	4	10	7	4	1	9	2
6	4	3	7	9	1	4	8	5
7	2	3	4	8	2	3	5	8
8	0	0	6	4	4	2	4	4
9	1	2	8	6	4	3	11	5
10	2	3	7	5	1	0	7	9
Average	*2.1*	*2.3*	*6.6*	*5.9*	*2.2*	*2*	*6.7*	*5.8*
Variance	*1.433*	*1.344*	*4.044*	*3.655*	*1.955*	*2.222*	*5.344*	*4.177*

Table B.5.2. Averages and Variances of 10 Replications for Number of Destroyed Vehicles(Model-2)

	10010	10001	01100	01010	01001	00110	00101	00011
1	3	1	7	8	5	2	3	3
2	0	2	10	3	3	6	5	0
3	2	4	12	7	8	5	6	2
4	3	2	13	4	5	7	8	2
5	3	5	8	5	4	7	7	1
6	2	2	14	9	5	5	4	5
7	4	2	8	7	9	10	9	4
8	0	0	11	6	8	4	3	1
9	1	2	10	8	10	6	6	4
10	4	3	8	6	5	5	7	0
Average	*2.2*	*2.3*	*10.1*	*6.3*	*6.2*	*5.7*	*5.8*	*2.2*
Variance	*2.177*	*2.011*	*5.655*	*3.566*	*5.511*	*4.455*	*4.177*	*3.066*

Table B.5.3. Averages and Variances of 10 Replications for Number of Destroyed Vehicles(Model-2)

	11100	11010	11001	10110	10101	10011	01110	01101
1	7	7	6	3	5	3	8	8
2	10	5	7	5	3	0	9	9
3	12	4	5	8	6	1	14	14
4	11	7	8	6	6	2	7	12
5	8	5	8	7	8	1	8	8
6	13	7	6	5	9	4	12	7
7	9	8	5	9	7	1	9	10
8	9	4	2	3	3	6	13	13
9	12	10	9	8	7	4	10	10
10	13	8	8	5	5	1	8	9
Average	*10.4*	*6.5*	*6.4*	*5.9*	*5.9*	*2.3*	*9.8*	*10*
Variance	*4.488*	*3.833*	*4.266*	*4.322*	*3.877*	*3.566*	*5.733*	*5.333*

Table B.5.4. Averages and Variances of 10 Replications for Number of Destroyed Vehicles(Model-2)

	01011	00111	11110	11101	11011	10111	01111	11111
1	2	4	8	7	8	4	10	8
2	6	4	9	11	5	4	9	11
3	5	5	12	14	4	5	8	15
4	9	7	9	12	8	6	14	12
5	7	5	8	8	9	8	8	9
6	5	5	15	14	10	7	14	13
7	8	9	8	9	7	6	8	10
8	3	4	13	10	5	3	11	9
9	9	6	9	12	8	8	13	12
10	7	5	8	8	6	5	10	14
Average	*6.1*	*5.4*	*9.9*	*10.5*	*7*	*5.6*	*10.5*	*11.3*
Variance	*5.655*	*2.488*	*6.322*	*6.277*	*3.777*	*2.933*	*5.833*	*5.344*

APPENDIX-C

ANOVA TABLES OF THE PERFORMANCE MEASURES

Table C.1. Effects and ANOVA Results for Maximum Time-in-System Statistics (Model-1)

Source of Variation	Effect	SSx	df	MSx	Fo	
10000	24.619	72735.851	1	72735.851	16.565	Significant
01000	22.308	59719.855	1	59719.855	13.601	Significant
00100	7.714	7141.930	1	7141.930	1.627	Insignificant
00010	-116.111	1617837.263	1	1617837.263	368.449	Significant
00001	-32.059	123340.591	1	123340.591	28.09	Significant
11000	-13.411	21583.932	1	21583.932	4.916	Significant
10100	-12.616	17107.118	1	17107.118	3.896	Significant
10010	-6.064	4413.258	1	4413.258	1.005	Insignificant
10001	-2.529	768.057	1	768.057	0.175	Insignificant
01100	-9.071	9875.053	1	9875.053	2.249	Insignificant
01010	2.917	1021.242	1	1021.242	0.233	Insignificant
01001	1.269	181.751	1	181.751	0.041	Insignificant
00110	0.785	33.096	1	33.096	0.008	Insignificant
00101	10.471	11398.437	1	11398.437	2.596	Insignificant
00011	-9.413	10633.113	1	10633.113	2.422	Insignificant
11100	7.916	7411.036	1	7411.036	1.688	Insignificant
11010	-1.508	273.159	1	273.159	0.062	Insignificant
11001	2.955	1048.020	1	1048.020	0.239	Insignificant
10110	-1.16	161.751	1	161.751	0.037	Insignificant
10101	0.384	17.787	1	17.787	0.004	Insignificant
10011	-1.105	1.342	1	1.342	0.01	Insignificant
01110	11.097	12752.625	1	12752.625	2.905	Insignificant
01101	3.548	1510.88	1	1510.88	0.344	Insignificant
01011	-11.383	12937.01	1	12937.01	2.946	Insignificant
00111	-11.903	14266.357	1	14266.357	3.249	Insignificant
11110	3.017	1092.637	1	1092.637	0.249	Insignificant
11101	-6.749	5465.88	1	5465.88	1.245	Insignificant
11011	0.116	1.640	1	1.640	0.001	Insignificant
10111	1.483	263.974	1	263.974	0.06	Insignificant
01111	-3.601	1556.208	1	1556.208	0.354	Insignificant
11111	2.742	902.666	1	902.666	0.206	Insignificant
Error		1967142.944	448	4390.944		
Total		3980830.512	479			

Table C.2. Effects and ANOVA Results for Maximum Time-in-System Statistics (Model-2)

Source of Variation	Effect	SSx	df	MSx	Fo	
10000	9.433	6741.519	1	6741.519	3.576	Insignificant
01000	22.079	38998.579	1	38998.579	20.687	Significant
00100	6.194	3069.994	1	3069.994	1.628	Insignificant
00010	-64.817	336099.479	1	336099.479	178.282	Significant
00001	-23.958	45919.340	1	45919.340	24.358	Significant
11000	-10.047	7533.628	1	7533.628	3.994	Significant
10100	-6.387	3235.483	1	3235.483	1.716	Insignificant
10010	-3.84	1179.648	1	1179.648	0.626	Insignificant
10001	3.347	896.527	1	896.527	0.476	Insignificant
01100	4.146	1375.477	1	1375.477	0.73	Insignificant
01010	-4.257	1449.764	1	1449.764	0.769	Insignificant
01001	-1.182	111.935	1	111.935	0.059	Insignificant
00110	3.682	1084.864	1	1084.864	0.575	Insignificant
00101	1.818	264.446	1	264.446	0.14	Insignificant
00011	-3.574	1022.379	1	1022.379	0.542	Insignificant
11100	5.225	2294.604	1	2294.604	1.217	Insignificant
11010	-1.412	159.5	1	159.5	0.085	Insignificant
11001	2.653	563.232	1	563.232	0.299	Insignificant
10110	-1.167	108.951	1	108.951	0.058	Insignificant
10101	-0.644	33.243	1	33.243	0.018	Insignificant
10011	-2.395	459.026	1	459.026	0.243	Insignificant
01110	-1.123	100.89	1	100.89	0.054	Insignificant
01101	4.21	1418.517	1	1418.517	0.752	Insignificant
01011	1.211	117.443	1	117.443	0.062	Insignificant
00111	0.143	1.656	1	1.656	0.01	Insignificant
11110	-0.667	35.591	1	35.591	0.019	Insignificant
11101	3.187	812.621	1	812.621	0.431	Insignificant
11011	-0.053	0.232	1	0.232	0.001	Insignificant
10111	-1.896	287.775	1	287.775	0.153	Insignificant
01111	-2.038	332.479	1	332.479	0.176	Insignificant
11111	-2.176	379.016	1	379.016	0.201	Insignificant
Error		542941.281	288	1885.213		
Total		988056.122	319			

Table C.3. Effects and ANOVA Results for Number of Destroyed Vehicles Statistics (Model-1)

Source of Variation	Effect	SSx	df	MSx	Fo	
10000	0.2	4.800	1	4.800	1.113	Insignificant
01000	3.633	1584.133	1	1584.133	367.259	Significant
00100	4.441	2367.408	1	2367.408	548.851	Significant
00010	0.016	3.333E-02	1	3.333E-02	0.008	Insignificant
00001	-0.066	.533	1	.533	0.124	Insignificant
11000	0.058	.408	1	.408	0.095	Insignificant
10100	0.15	2.700	1	2.700	0.626	Insignificant
10010	0.025	7.50E-02	1	7.50E-02	0.017	Insignificant
10001	0.075	0.675	1	0.675	0.156	Insignificant
01100	0.001	0.833	1	0.833	0.193	Insignificant
01010	0.008	8.33E-03	1	8.33E-03	0.002	Insignificant
01001	0.091	1.008	1	1.008	0.234	Insignificant
00110	-0.083	0.833	1	0.833	0.193	Insignificant
00101	0.066	0.533	1	0.533	0.124	Insignificant
00011	0.091	1.008	1	1.008	0.234	Insignificant
11100	0.091	1.008	1	1.008	0.234	Insignificant
11010	0.066	0.533	1	0.533	0.124	Insignificant
11001	0.083	0.833	1	0.833	0.193	Insignificant
10110	0.025	7.50E-02	1	7.50E-02	0.017	Insignificant
10101	0.008	8.33E-03	1	8.33E-03	0.002	Insignificant
10011	0.233	6.533	1	6.533	1.515	Insignificant
01110	0.058	0.408	1	0.408	0.095	Insignificant
01101	0.075	0.675	1	0.675	0.156	Insignificant
01011	0.133	2.133	1	2.133	0.495	Insignificant
00111	0.141	2.408	1	2.408	0.558	Insignificant
11110	0.016	3.33E-02	1	3.33E-02	0.008	Insignificant
11101	0.133	2.133	1	2.133	0.495	Insignificant
11011	-0.008	8.33E-03	1	8.33E-03	0.002	Insignificant
10111	0.05	0.300	1	0.300	0.070	Insignificant
01111	-0.033	0.133	1	0.133	0.031	Insignificant
11111	-0.008	8.33E-03	1	8.33E-03	0.002	Insignificant
Error		1932.400	448	4.313		
Total		5913.792	479			

Table C.4. Effects and ANOVA Results for Number of Destroyed Vehicles Statistics (Model-2)

Source of Variation	Effect	SSx	df	MSx	Fo	
10000	0.218	3.828	1	3.828	0.948	Insignificant
01000	4.381	1535.628	1	1535.628	380.374	Significant
00100	3.656	1069.453	1	1069.453	264.903	Significant
00010	-0.006	3.125E-03	1	3.125E-03	0.001	Insignificant
00001	0.068	0.378	1	0.378	0.094	Insignificant
11000	0.168	2.278	1	2.278	0.564	Insignificant
10100	0.043	0.153	1	0.153	0.038	Insignificant
10010	0.056	0.253	1	0.253	0.063	Insignificant
10001	0.131	1.378	1	1.378	0.341	Insignificant
01100	0.181	2.628	1	2.628	0.651	Insignificant
01010	0.068	0.378	1	0.378	0.094	Insignificant
01001	0.143	1.653	1	1.653	0.409	Insignificant
00110	-0.031	7.812E-02	1	7.812E-02	0.019	Insignificant
00101	0.118	1.128	1	1.128	0.279	Insignificant
00011	0.131	1.378	1	1.378	0.341	Insignificant
11100	-0.006	3.125E-03	1	3.125E-03	0.001	Insignificant
11010	0.056	0.253	1	0.253	0.063	Insignificant
11001	0.081	0.528	1	0.528	0.131	Insignificant
10110	0.006	3.125E-03	1	3.125E-03	0.001	Insignificant
10101	0.006	3.125E-03	1	3.125E-03	0.001	Insignificant
10011	0.093	0.703	1	0.703	0.174	Insignificant
01110	0.093	0.703	1	0.703	0.174	Insignificant
01101	0.193	3.003	1	3.003	0.744	Insignificant
01011	0.256	5.253	1	5.253	1.301	Insignificant
00111	0.056	0.253	1	0.253	0.063	Insignificant
11110	-0.093	0.703	1	0.703	0.174	Insignificant
11101	0.006	0.0031	1	0.0031	0.001	Insignificant
11011	0.043	0.153	1	0.153	0.038	Insignificant
10111	-0.056	0.253	1	0.253	0.063	Insignificant
01111	0.081	0.528	1	0.528	0.131	Insignificant
11111	0.043	0.153	1	0.153	0.038	Insignificant
Error		1162.700	288	4.037		
Total		3795.797	319			

Table C.5. SPSS Output of Maximum Time-in-System Statistics (Model-1)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power(a)
A	72735.851	1	72735.851	16.565	.000	.036	16.565	.982
B	59719.855	1	59719.855	13.601	.000	.029	13.601	.957
C	7141.930	1	7141.930	1.627	.203	.004	1.627	.247
D	1617837.263	1	1617837.263	368.449	.000	.451	368.449	1.000
E	123340.591	1	123340.591	28.090	.000	.059	28.090	1.000
A * B	21583.932	1	21583.932	4.916	.027	.011	4.916	.600
A * C	17107.118	1	17107.118	3.896	.049	.009	3.896	.519
B * C	9875.053	1	9875.053	2.249	.134	.005	2.249	.322
A * B * C	7411.036	1	7411.036	1.688	.195	.004	1.688	.254
A * D	4413.258	1	4413.258	1.005	.317	.002	1.005	.170
B * D	1021.242	1	1021.242	.233	.630	.001	.233	.077
A * B * D	273.159	1	273.159	.062	.803	.000	.062	.057
C * D	33.096	1	33.096	.008	.931	.000	.008	.051
A * C * D	161.751	1	161.751	.037	.848	.000	.037	.054
B * C * D	12752.625	1	12752.625	2.905	.173	.005	2.905	.401
A * B * C * D	1092.637	1	1092.637	.249	.618	.001	.249	.079
A * E	768.057	1	768.057	.175	.676	.000	.175	.070
B * E	181.751	1	181.751	.041	.842	.000	.041	.055
A * B * E	1048.020	1	1048.020	.239	.625	.001	.239	.078
C * E	11398.437	1	11398.437	2.596	.106	.006	2.596	.363
A * C * E	17.787	1	17.787	.004	.949	.000	.004	.050
B * C * E	1510.880	1	1510.880	.344	.558	.001	.344	.090
A * B * C * E	5465.880	1	5465.880	1.245	.265	.003	1.245	.200
D * E	10633.113	1	10633.113	2.422	.120	.005	2.422	.342
A * D * E	1.342	1	1.342	.000	.986	.000	.000	.050
B * D * E	12937.010	1	12937.010	2.946	.087	.007	2.946	.403
A * B * D * E	1.640	1	1.640	.000	.985	.000	.000	.050
C * D * E	14266.357	1	14266.357	3.249	.072	.007	3.249	.436
A * C * D * E	263.974	1	263.974	.060	.806	.000	.060	.057
B * C * D * E	1556.208	1	1556.208	.354	.552	.001	.354	.091
A * B * C * D * E	902.666	1	902.666	.206	.650	.000	.206	.074
Error	1967142.944	448	4390.944					
Corrected Total	3980830.512	479						

A : Vehicle Breakdown B : Air Attack C : Artillery Attack
D : Number of Ammunition Depot Loading Points E : Number of Company Fuel Supply Points

Table C.6. SPSS Output of Maximum Time-in-System Statistics (Model-2)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power(a)
A	6741.519	1	6741.519	3.576	.053	.012	3.576	.461
B	38998.579	1	38998.579	20.687	.000	.067	20.687	.995
C	3069.994	1	3069.994	1.628	.203	.006	1.628	.246
D	336099.479	1	336099.479	178.282	.000	.382	178.282	1.000
E	45919.340	1	45919.340	24.358	.000	.078	24.358	.998
A * B	7533.628	1	7533.628	3.994	.042	.016	3.994	.498
A * C	3235.483	1	3235.483	1.716	.192	.007	1.716	.259
B * C	1375.477	1	1375.477	.730	.394	.003	.730	.136
A * B * C	2294.604	1	2294.604	1.217	.254	.005	1.217	.188
A * D	1179.648	1	1179.648	.626	.430	.002	.626	.124
B * D	1449.764	1	1449.764	.769	.381	.003	.769	.141
A * B * D	159.500	1	159.500	.085	.771	.000	.085	.060
C * D	1084.864	1	1084.864	.575	.449	.002	.575	.118
A * C * D	108.951	1	108.951	.058	.810	.000	.058	.057
B * C * D	100.890	1	100.890	.054	.817	.000	.054	.056
A * B * C * D	35.591	1	35.591	.019	.891	.000	.019	.052
A * E	896.527	1	896.527	.476	.491	.002	.476	.106
B * E	111.935	1	111.935	.059	.808	.000	.059	.057
A * B * E	563.232	1	563.232	.299	.585	.001	.299	.085
C * E	264.446	1	264.446	.140	.708	.000	.140	.066
A * C * E	33.243	1	33.243	.018	.894	.000	.018	.052
B * C * E	1418.517	1	1418.517	.752	.386	.003	.752	.139
A * B * C * E	812.621	1	812.621	.431	.512	.001	.431	.100
D * E	1022.379	1	1022.379	.542	.462	.002	.542	.114
A * D * E	459.026	1	459.026	.243	.622	.001	.243	.078
B * D * E	117.443	1	117.443	.062	.803	.000	.062	.057
A * B * D * E	.232	1	.232	.000	.991	.000	.000	.050
C * D * E	1.656	1	1.656	.001	.976	.000	.001	.050
A * C * D * E	287.775	1	287.775	.153	.696	.001	.153	.068
B * C * D * E	332.479	1	332.479	.176	.675	.001	.176	.070
A * B * C * D * E	379.016	1	379.016	.201	.654	.001	.201	.073
Error	542941.281	288	1885.213					
Corrected Total	988056.122	319						

A : Vehicle Breakdown B : Air Attack C : Artillery Attack
D : Number of Ammunition Depot Loading Points E : Number of Company Fuel Supply Points

Table C.7. SPSS Output of Number of Destroyed Vehicles Statistics (Model-1)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power(a)
A	4.800	1	4.800	1.113	.292	.002	1.113	.183
B	1584.133	1	1584.133	367.259	.000	.450	367.259	1.000
C	2367.408	1	2367.408	548.851	.000	.551	548.851	1.000
D	3.333E-02	1	3.33E-02	.008	.930	.000	.008	.051
E	.533	1	.533	.124	.725	.000	.124	.064
A * B	.408	1	.408	.095	.758	.000	.095	.061
A * C	2.700	1	2.700	.626	.429	.001	.626	.124
B * C	.833	1	.833	.193	.660	.000	.193	.072
A * B * C	1.008	1	1.008	.234	.629	.001	.234	.077
A * D	7.500E-02	1	7.50E-02	.017	.895	.000	.017	.052
B * D	8.333E-03	1	8.33E-03	.002	.965	.000	.002	.050
A * B * D	.533	1	.533	.124	.725	.000	.124	.064
C * D	.833	1	.833	.193	.660	.000	.193	.072
A * C * D	7.500E-02	1	7.50E-02	.017	.895	.000	.017	.052
B * C * D	.408	1	.408	.095	.758	.000	.095	.061
A * B * C * D	3.333E-02	1	3.33E-02	.008	.930	.000	.008	.051
A * E	.675	1	.675	.156	.693	.000	.156	.068
B * E	1.008	1	1.008	.234	.629	.001	.234	.077
A * B * E	.833	1	.833	.193	.660	.000	.193	.072
C * E	.533	1	.533	.124	.725	.000	.124	.064
A * C * E	8.333E-03	1	8.33E-03	.002	.965	.000	.002	.050
B * C * E	.675	1	.675	.156	.693	.000	.156	.068
A * B * C * E	2.133	1	2.133	.495	.482	.001	.495	.108
D * E	1.008	1	1.008	.234	.629	.001	.234	.077
A * D * E	6.533	1	6.533	1.515	.219	.003	1.515	.233
B * D * E	2.133	1	2.133	.495	.482	.001	.495	.108
A * B * D * E	8.333E-03	1	8.33E-03	.002	.965	.000	.002	.050
C * D * E	2.408	1	2.408	.558	.455	.001	.558	.116
A * C * D * E	.300	1	.300	.070	.792	.000	.070	.058
B * C * D * E	.133	1	.133	.031	.861	.000	.031	.054
A * B * C * D * E	8.333E-03	1	8.33E-03	.002	.965	.000	.002	.050
Error	1932.400	448	4.313					
Corrected Total	5913.792	479						

A : Vehicle Breakdown B : Air Attack C : Artillery Attack
D : Number of Ammunition Depot Loading Points E : Number of Company Fuel Supply Points

Table C.8. SPSS Output of Number of Destroyed Vehicles Statistics (Model-2)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power(a)
A	3.828	1	3.828	.948	.331	.003	.948	.163
B	1535.628	1	1535.628	380.374	.000	.569	380.374	1.000
C	1069.453	1	1069.453	264.903	.000	.479	264.903	1.000
D	3.125E-03	1	3.12E-03	.001	.978	.000	.001	.050
E	.378	1	.378	.094	.760	.000	.094	.061
A * B	2.278	1	2.278	.564	.453	.002	.564	.116
A * C	.153	1	.153	.038	.846	.000	.038	.054
B * C	2.628	1	2.628	.651	.420	.002	.651	.127
A * B * C	3.125E-03	1	3.12E-03	.001	.978	.000	.001	.050
A * D	.253	1	.253	.063	.802	.000	.063	.057
B * D	.378	1	.378	.094	.760	.000	.094	.061
A * B * D	.253	1	.253	.063	.802	.000	.063	.057
C * D	7.812E-02	1	7.81E-02	.019	.889	.000	.019	.052
A * C * D	3.125E-03	1	3.12E-03	.001	.978	.000	.001	.050
B * C * D	.703	1	.703	.174	.677	.001	.174	.070
A* B * C * D	.703	1	.703	.174	.677	.001	.174	.070
A * E	1.378	1	1.378	.341	.560	.001	.341	.090
B * E	1.653	1	1.653	.409	.523	.001	.409	.098
A * B * E	.528	1	.528	.131	.718	.000	.131	.065
C * E	1.128	1	1.128	.279	.597	.001	.279	.082
A * C * E	3.125E-03	1	3.12E-03	.001	.978	.000	.001	.050
B * C * E	3.003	1	3.003	.744	.389	.003	.744	.138
A * B * C * E	3.125E-03	1	3.12E-03	.001	.978	.000	.001	.050
D * E	1.378	1	1.378	.341	.560	.001	.341	.090
A * D * E	.703	1	.703	.174	.677	.001	.174	.070
B * D * E	5.253	1	5.253	1.301	.255	.004	1.301	.206
A * B * D * E	.153	1	.153	.038	.846	.000	.038	.054
C * D * E	.253	1	.253	.063	.802	.000	.063	.057
A * C * D * E	.253	1	.253	.063	.802	.000	.063	.057
B * C * D * E	.528	1	.528	.131	.718	.000	.131	.065
A * B * C * D * E	.153	1	.153	.038	.846	.000	.038	.054
Error	1162.700	288	4.037					
Corrected Total	3795.797	319						

A : Vehicle Breakdown B : Air Attack C : Artillery Attack
D : Number of Ammunition Depot Loading Points E : Number of Company Fuel SupplyPoints

APPENDIX-D

RESIDUAL ANALYSIS AND SCATTER PLOTS OF RESIDUALS

Table D.1. Residual Analysis for Maximum Time-in-System Statistics (Model-1)

DESIGN POINTS	y	$\hat{y}$	$e = y - \hat{y}$
00000	553.491	541.550	11.941
10000	590.465	592.194	-1.729
01000	585.465	577.268	8.197
00100	564.697	554.166	10.531
00010	433.142	425.45	7.692
00001	505.48	509.492	-4.012
11000	608.921	601.092	7.829
10100	593.458	580.216	13.242
10010	467.289	476.094	-8.805
10001	515.143	540.136	-24.993
01100	523.435	559.884	-36.449
01010	461.521	461.168	0.353
01001	546.084	545.21	0.874
00110	453.713	438.066	15.647
00101	530.35	522.108	8.242
00011	399.602	393.392	6.21
11100	566.676	588.476	-21.8
11010	474.547	484.992	-10.445
11001	591.549	569.034	22.515
10110	467.971	463.478	4.493
10101	565.373	547.52	17.853
10011	410.584	444.036	-33.452
01110	475.751	473.784	1.967
01101	564.283	557.826	6.457
01011	419.986	429.11	-9.124
00111	409.666	406.008	3.658
11110	499.085	472.376	26.709
11101	587.173	556.418	30.755
11011	438.162	452.934	-14.772
10111	424.257	431.42	-7.163
01111	439.523	441.726	-2.203
11111	459.453	440.318	19.135

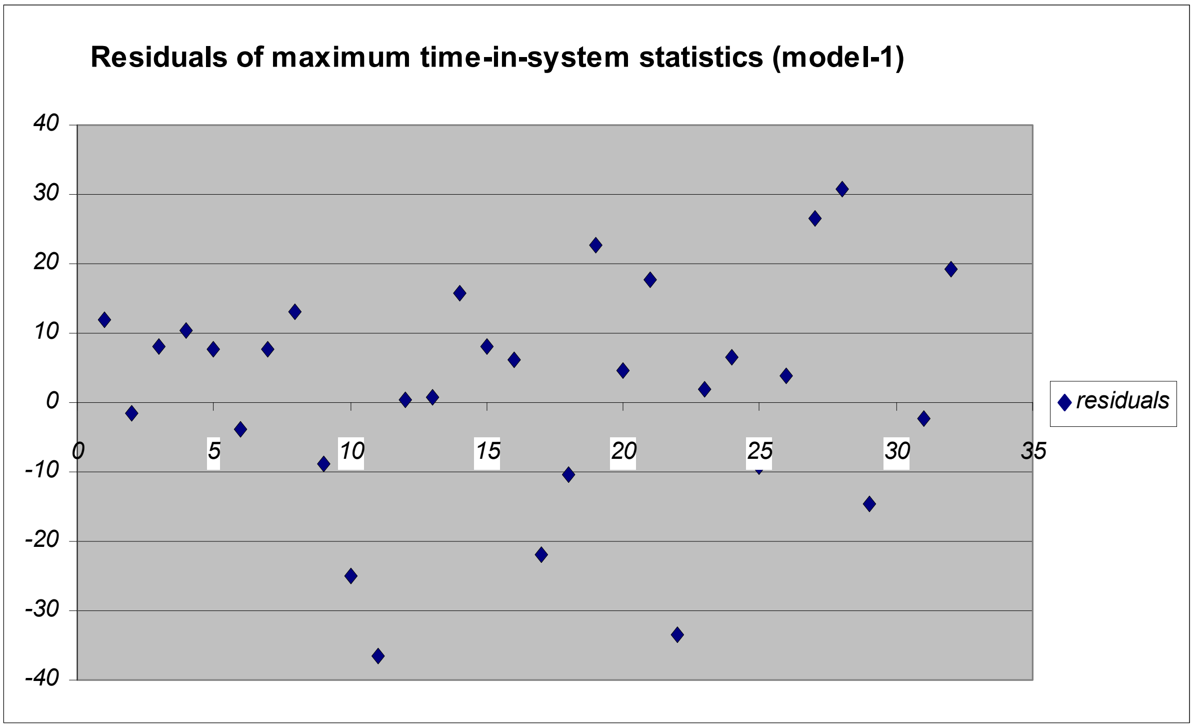


Figure D.1. Scatter Plot of Residuals for Maximum Time-in-System Statistics (Model-1)

Table D.2. Residual Analysis for Maximum Time-in-System Statistics (Model-2)

DESIGN POINTS	y	$\hat{y}$	$e = y - \hat{y}$
00000	410.269	412.484	-2.215
10000	412.717	422.53	-9.813
01000	434.319	444.408	-10.089
00100	409.891	412.484	-2.593
00010	351.179	347.684	3.495
00001	389.708	388.526	1.182
11000	448.088	434.562	13.526
10100	416.731	422.53	-5.799
10010	355.014	357.73	-2.716
10001	406.451	398.572	7.879
01100	437.53	444.608	-7.078
01010	368.196	379.808	-11.612
01001	401.783	420.065	-18.282
00110	357.607	347.684	9.923
00101	388.403	388.526	-0.123
00011	321.923	323.726	-1.803
11100	444.593	434.562	10.031
11010	371.881	369.762	2.119
11001	419.221	410.204	9.017
10110	362.714	357.73	4.984
10101	393.091	398.572	-5.481
10011	329.567	333.772	-4.205
01110	375.837	379.808	-3.971
01101	407.61	420.65	-13.04
01011	331.475	355.85	-24.375
00111	335.034	323.726	11.308
11110	381.773	369.762	12.011
11101	444.805	420.604	24.201
11011	345.325	345.804	-0.479
10111	329.743	333.772	-4.029
01111	350.446	355.85	-5.404
11111	360.424	345.804	14.62

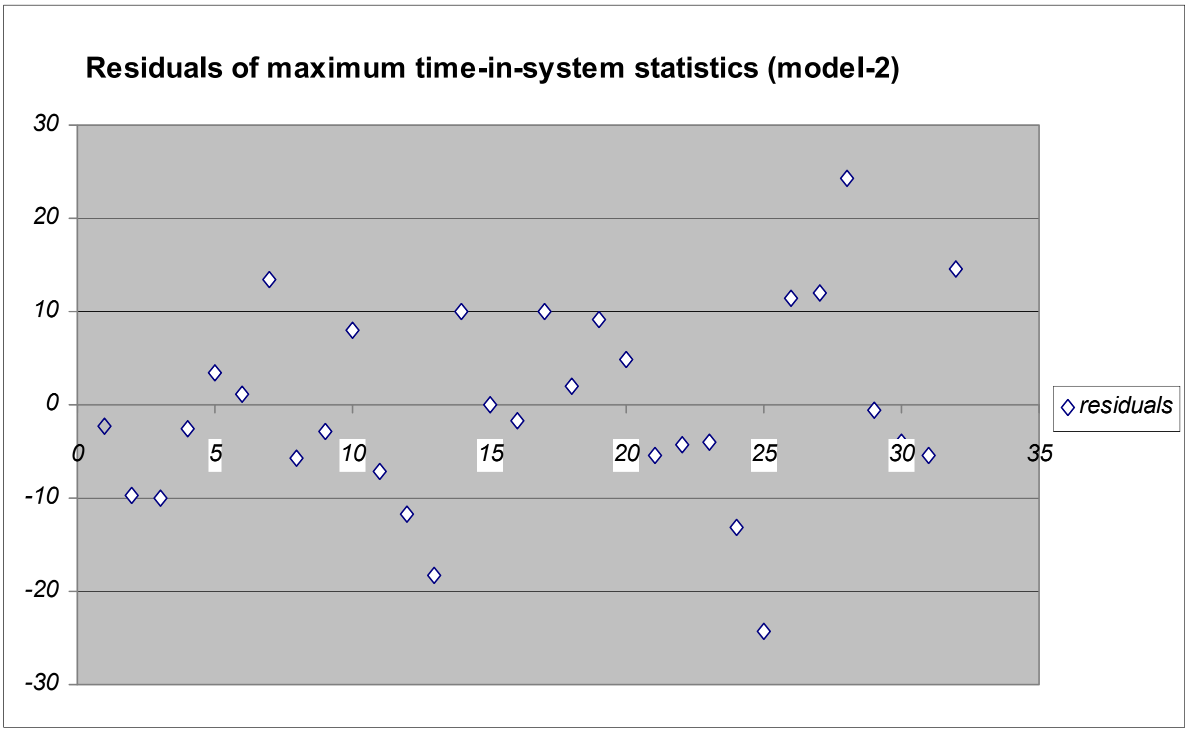


Figure D.2. Scatter Plot of Residuals for Maximum Time-in-System Statistics (Model-2)

Table D.3. Residual Analysis for Number of Destroyed Vehicles Statistics (Model-1)

DESIGN POINTS	y	$\hat{y}$	$e = y - \hat{y}$
00000	1.733	1.943	-0.2096
10000	1.933	1.943	-0.0096
01000	5.6	5.595	0.005
00100	6.266	6.383	-0.1163
00010	2.333	1.943	0.39033
00001	1.866	1.943	-0.0763
11000	5.733	5.595	0.13833
10100	6.933	6.383	0.5503
10010	2.066	1.943	0.1236
10001	1.933	1.943	-0.0096
01100	9.933	10.015	-0.0816
01010	5.666	5.595	0.0716
01001	5.533	5.595	-0.0616
00110	6.333	6.383	-0.0496
00101	6.4	6.383	0.017
00011	1.666	1.943	-0.2763
11100	10.266	10.015	0.2516
11010	5.533	5.595	-0.0616
11001	5.333	5.595	-0.2616
10110	6.333	6.383	-0.0496
10101	6.2	6.383	-0.183
10011	2	1.943	0.057
01110	9.733	10.015	-0.2816
01101	9.733	10.015	-0.281
01011	5.466	5.595	-0.1283
00111	6.133	6.383	-0.2496
11110	9.8	10.015	-0.215
11101	10.133	10.015	0.1183
11011	5.733	5.595	0.1383
10111	6.467	6.383	0.0836
01111	9.667	10.015	-0.3483
11111	10.867	10.015	0.8516

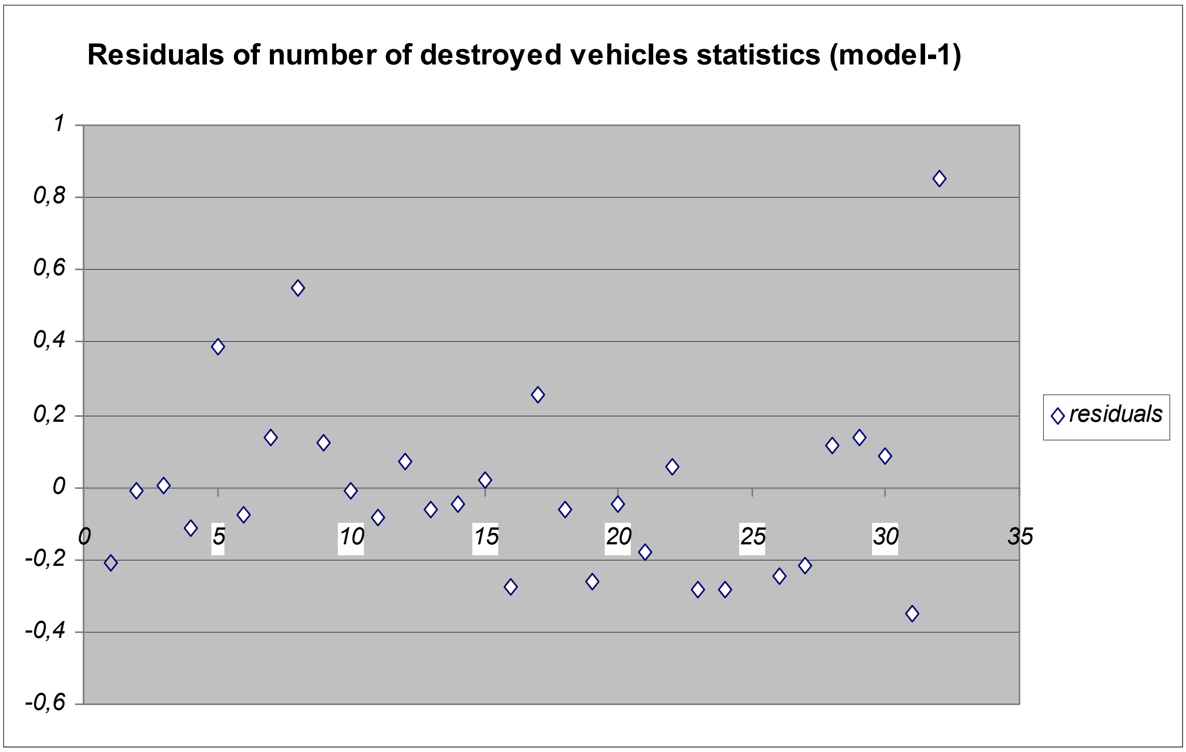


Figure D.3. Scatter Plot of Residuals for Number of Destroyed Vehicles Statistics (Model-1)

Table D.4. Residual Analysis for Number of Destroyed Vehicles Statistics (Model-2)

DESIGN POINTS	y	$\hat{y}$	$e = y - \hat{y}$
00000	2.1	2.185	-0.085
10000	2.3	2.185	0.115
01000	6.6	6.565	0.035
00100	5.9	5.841	0.059
00010	2.5	2.185	0.315
00001	2.3	2.185	0.115
11000	6.7	6.565	0.135
10100	5.8	5.841	-0.041
10010	2.2	2.185	0.015
10001	2.3	2.185	0.115
01100	10.1	10.221	-0.121
01010	6.3	6.565	-0.265
01001	6.2	6.565	-0.365
00110	5.7	5.841	-0.141
00101	5.8	5.841	-0.041
00011	2.2	2.185	0.015
11100	10.4	10.221	0.179
11010	6.5	6.565	-0.065
11001	6.4	6.565	-0.165
10110	5.9	5.841	0.059
10101	5.9	5.841	0.059
10011	2.3	2.185	0.115
01110	9.8	10.221	-0.421
01101	10	10.221	-0.221
01011	6.1	6.565	-0.465
00111	5.4	5.841	-0.441
11110	9.9	10.221	-0.321
11101	10.5	10.221	0.279
11011	7	6.565	0.435
10111	5.6	5.841	-0.241
01111	10.5	10.221	0.279
11111	11.3	10.221	1.079

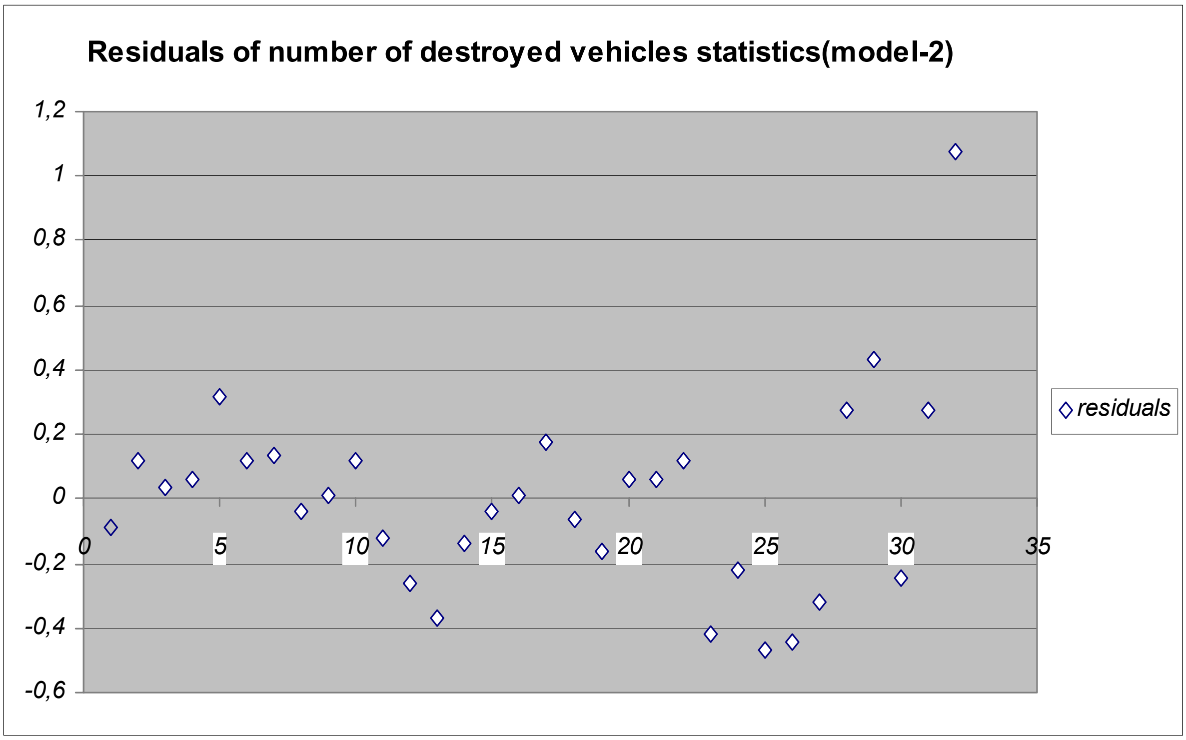


Figure D.4. Scatter Plot of Residuals for Number of Destroyed Vehicles Statistics (Model-2)

APPENDIX-E

ANALYSIS OF NORMAL PROBABILITY PLOTS AND EFFECTS OF MEASURES

Table E.1. Analysis of Normal P-P Plot Effects of Maximum Time-in-System Statistics (Model-1)

ORDER(j)	EFFECT	ESTIMATE	(j - 0.5) / 32
31	1	24.619	0.9531
30	2	22.308	0.9218
29	3-4-5	11.097	0.8906
28	3-5	10.471	0.8593
27	1-2-3	7.916	0.8281
26	3	7.714	0.7968
25	2-3-5	3.548	0.7656
24	1-2-3-4	3.017	0.7343
23	1-2-5	2.955	0.7031
22	2-4	2.917	0.6718
21	1-2-3-4-5	2.742	0.6406
20	1-3-4-5	1.483	0.6093
19	2-5	1.269	0.5781
18	3-4	0.785	0.5468
17	1-3-5	0.384	0.5156
16	1-2-4-5	0.116	0.4843
15	1-4-5	-1.105	0.4531
14	1-3-4	-1.16	0.4218
13	1-2-4	-1.508	0.3906
12	1-5	-2.529	0.3537
11	2-3-4-5	-3.601	0.3281
10	1-4	-6.064	0.2968
9	1-2-3-5	-6.749	0.2656
8	2-3	-9.071	0.2343
7	4-5	-9.413	0.2031
6	2-4-5	-11.383	0.1718
5	3-4-5	-11.903	0.1406
4	1-3	-12.616	0.1093
3	1-2	-13.411	0.0781
2	5	-32.059	0.0468
1	4	-116.11	0.0156

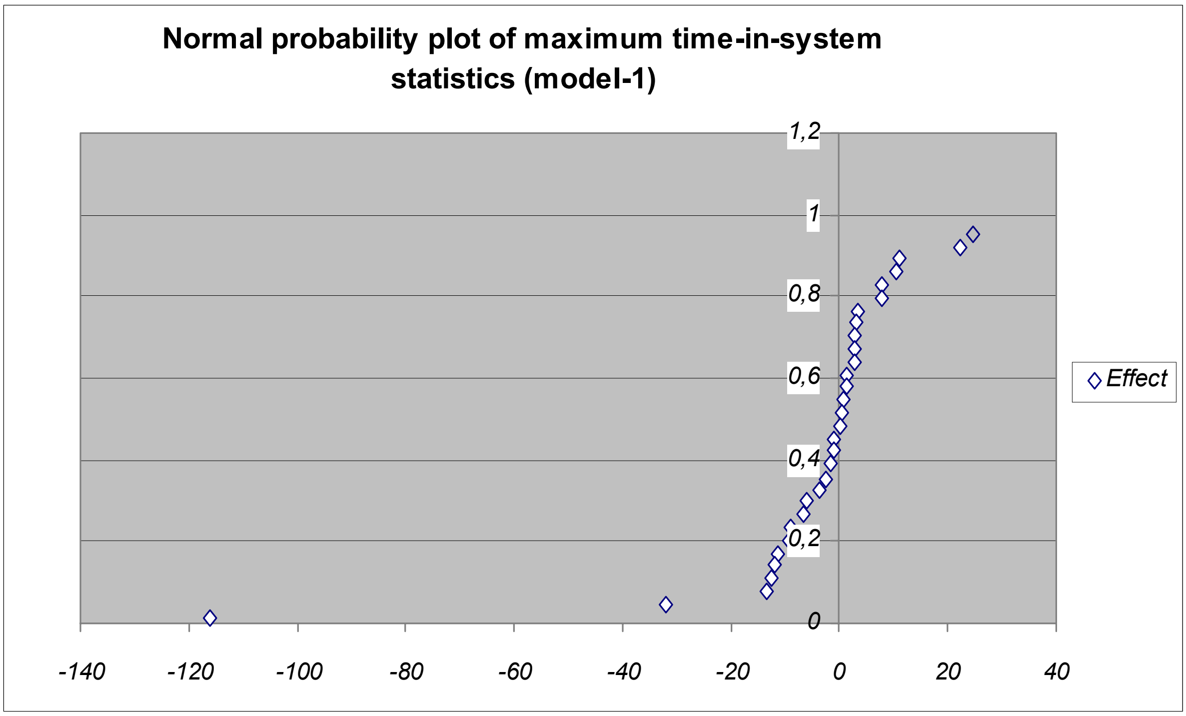


Figure E.1. Normal Probability Plot of Maximum Time-in-System Statistics (Model-1)

Table E.2. Analysis of Normal P-P Plot Effects of Maximum Time-in-System Statistics (Model-2)

ORDER(j)	EFFECT	ESTIMATE	(j - 0.5) / 32
31	2	22.079	0.9531
30	1	9.433	0.9218
29	3	6.194	0.8906
28	1-2-3	5.225	0.8593
27	2-3-5	4.21	0.8281
26	2-3	4.146	0.7968
25	3-4	3.682	0.7656
24	1-5	3.347	0.7343
23	1-2-3-5	3.187	0.7031
22	1-2-5	2.653	0.6718
21	3-5	1.818	0.6406
20	1-4-5	1.211	0.6093
19	3-4-5	0.143	0.5781
18	1-2-4-5	-0.053	0.5468
17	1-3-5	-0.644	0.5156
16	1-2-3-4	-0.667	0.4843
15	2-3-4	-1.123	0.4531
14	1-3-4	-1.167	0.4218
13	2-5	-1.182	0.3906
12	1-2-4	-1.412	0.3537
11	1-3-4-5	-1.896	0.3281
10	2-3-4-5	-2.038	0.2968
9	1-2-3-4-5	-2.176	0.2656
8	1-4-5	-2.395	0.2343
7	4-5	-3.574	0.2031
6	1-4	-3.84	0.1718
5	2-4	-4.257	0.1406
4	1-3	-6.387	0.1093
3	1-2	-10.047	0.0781
2	5	-23.958	0.0468
1	4	-64.817	0.0156

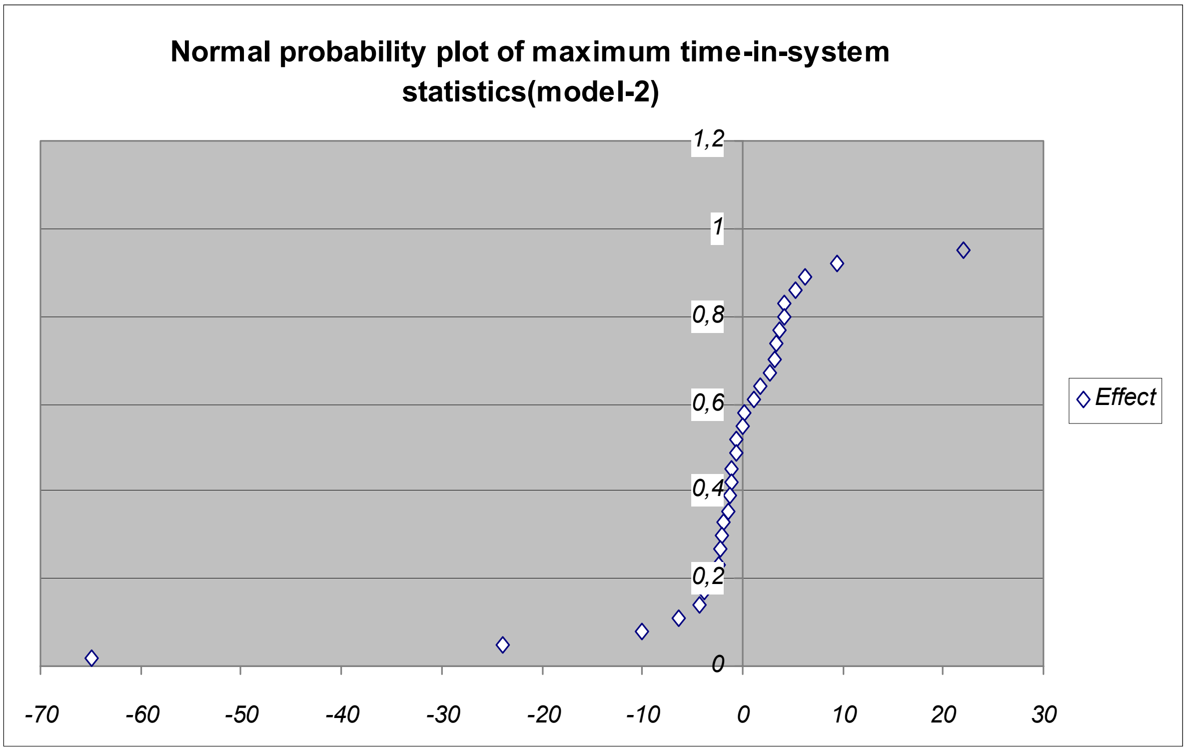


Figure E.2. Normal Probability Plot of Maximum Time-in-System Statistics (Model-2)

Table E.3. Analysis of Normal P-P Plot Effects of Number of Destroyed Vehicles Statistics (Model-1)

ORDER(j)	EFFECT	ESTIMATE	(j - 0.5) / 32
31	3	4.441	0.9531
30	2	3.633	0.9218
29	1-4-5	0.233	0.8906
28	1	0.2	0.8593
27	1-3	0.15	0.8281
26	3-4-5	0.141	0.7968
25	1-2-3-5	0.133	0.7656
24	2-4-5	0.133	0.7343
23	2-5	0.091	0.7031
22	1-2-3	0.091	0.6718
21	4-5	0.091	0.6406
20	1-2-5	0.083	0.6093
19	2-3-5	0.075	0.5781
18	1-5	0.075	0.5468
17	1-2-4	0.066	0.5156
16	3-5	0.066	0.4843
15	2-3-4	0.058	0.4531
14	1-2	0.058	0.4218
13	1-3-4-5	0.05	0.3906
12	1-3-4	0.025	0.3537
11	1-4	0.025	0.3281
10	1-2-3-4	0.016	0.2968
9	4	0.016	0.2656
8	1-3-5	0.008	0.2343
7	2-4	0.008	0.2031
6	2-3	0.001	0.1718
5	1-2-4-5	-0.008	0.1406
4	1-2-3-4-5	-0.008	0.1093
3	2-3-4-5	-0.033	0.0781
2	5	-0.066	0.0468
1	3-4	-0.083	0.0156

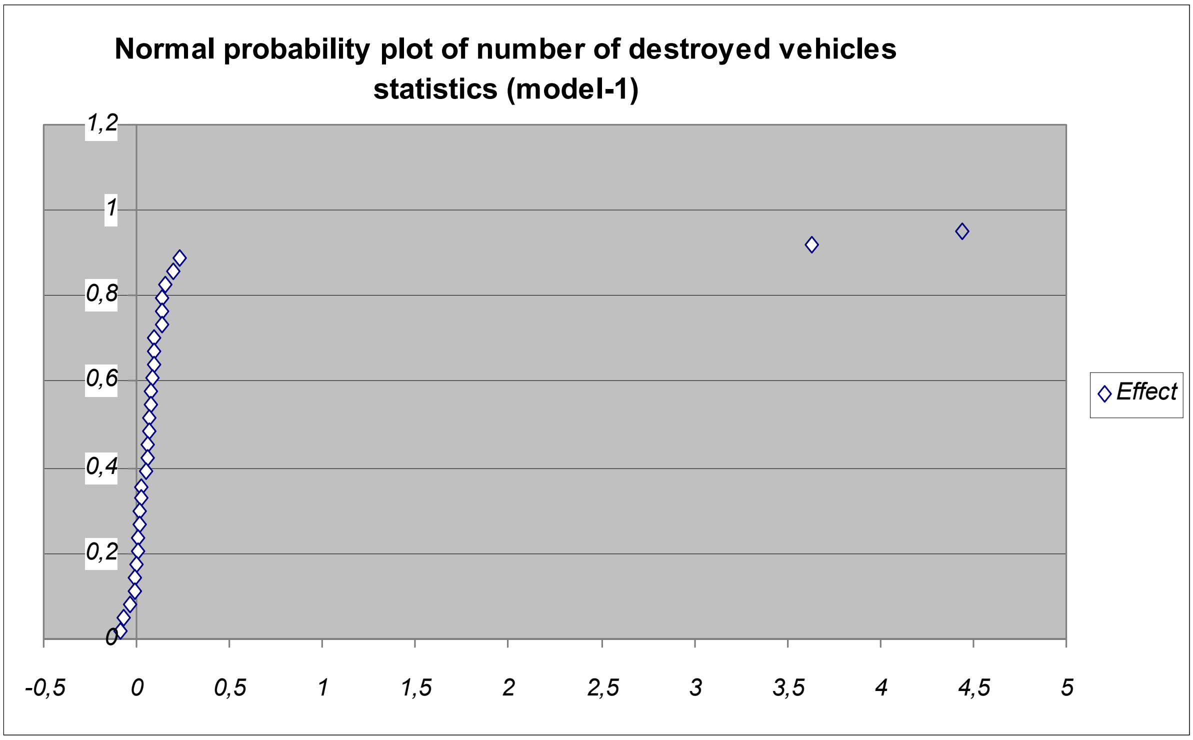


Figure E.3. Normal Probability Plot of Number of Destroyed Vehicles Statistics (Model-1)

Table E.4. Analysis of Normal P-P Plot Effects of Number of Destroyed Vehicles Statistics (Model-2)

ORDER(j)	EFFECT	ESTIMATE	(j - 0.5) / 32
31	2	4.381	0.9531
30	3	3.656	0.9218
29	2-4-5	0.256	0.8906
28	1	0.218	0.8593
27	2-3-5	0.193	0.8281
26	2-3	0.181	0.7968
25	1-2	0.168	0.7656
24	2-5	0.143	0.7343
23	4-5	0.131	0.7031
22	1-5	0.131	0.6718
21	3-5	0.118	0.6406
20	1-4-5	0.093	0.6093
19	2-3-4	0.093	0.5781
18	2-3-4-5	0.081	0.5468
17	1-2-5	0.081	0.5156
16	2-4	0.068	0.4843
15	5	0.068	0.4531
14	1-2-4	0.056	0.4218
13	3-4-5	0.056	0.3906
12	1-4	0.056	0.3537
11	1-2-4-5	0.043	0.3281
10	1-3	0.043	0.2968
9	1-2-3-4-5	0.043	0.2656
8	1-3-4	0.006	0.2343
7	1-3-5	0.006	0.2031
6	1-2-3-5	0.006	0.1718
5	1-2-3	-0.006	0.1406
4	4	-0.006	0.1093
3	3-4	-0.031	0.0781
2	1-3-4-5	-0.056	0.0468
1	1-2-3-4	-0.093	0.0156

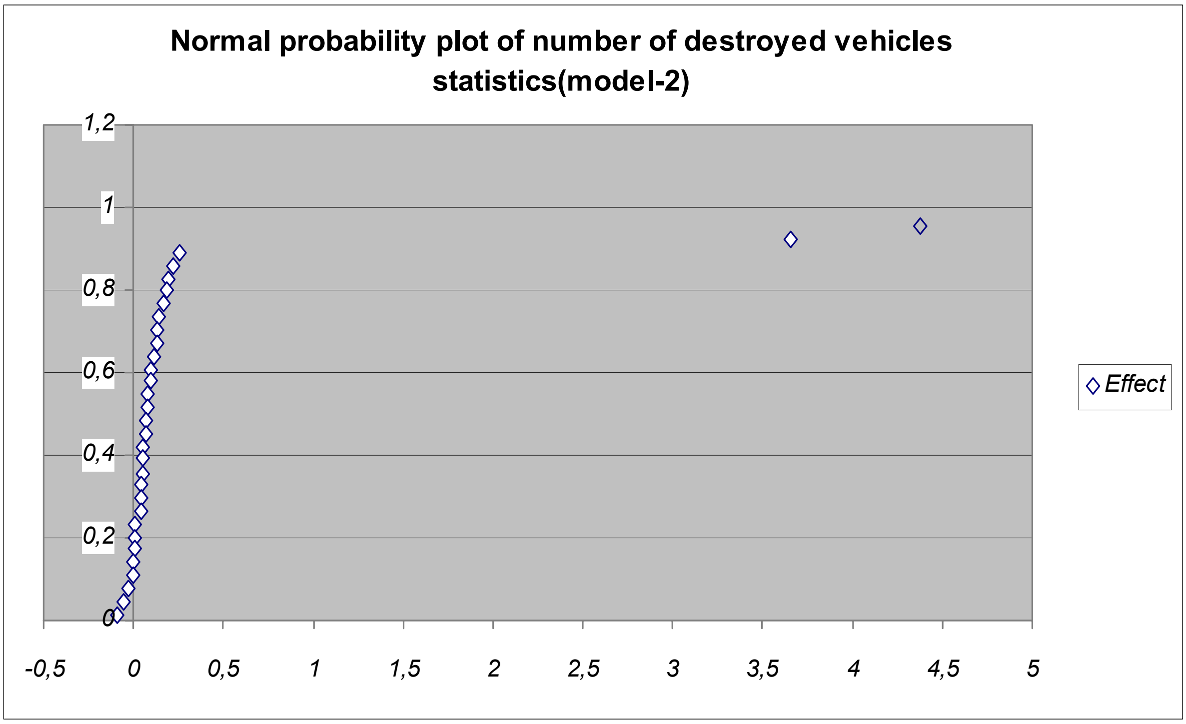


Figure E.4. Normal Probability Plot of Number of Destroyed Vehicles Statistics (Model-2)

APPENDIX-F

SCATTER PLOTS OF VARIANCES OF PERFORMANCE MEASURES

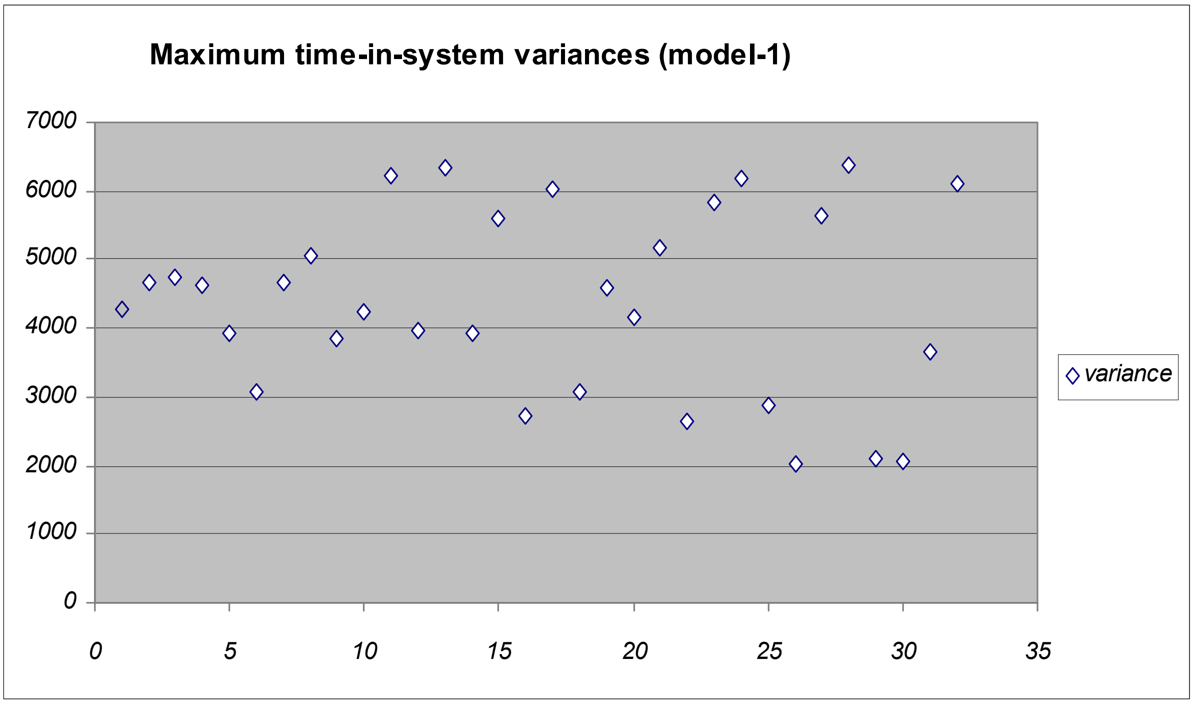


Figure F.1. Scatter Plot of Variances of Maximum Time-in-System Measure (Model-1)

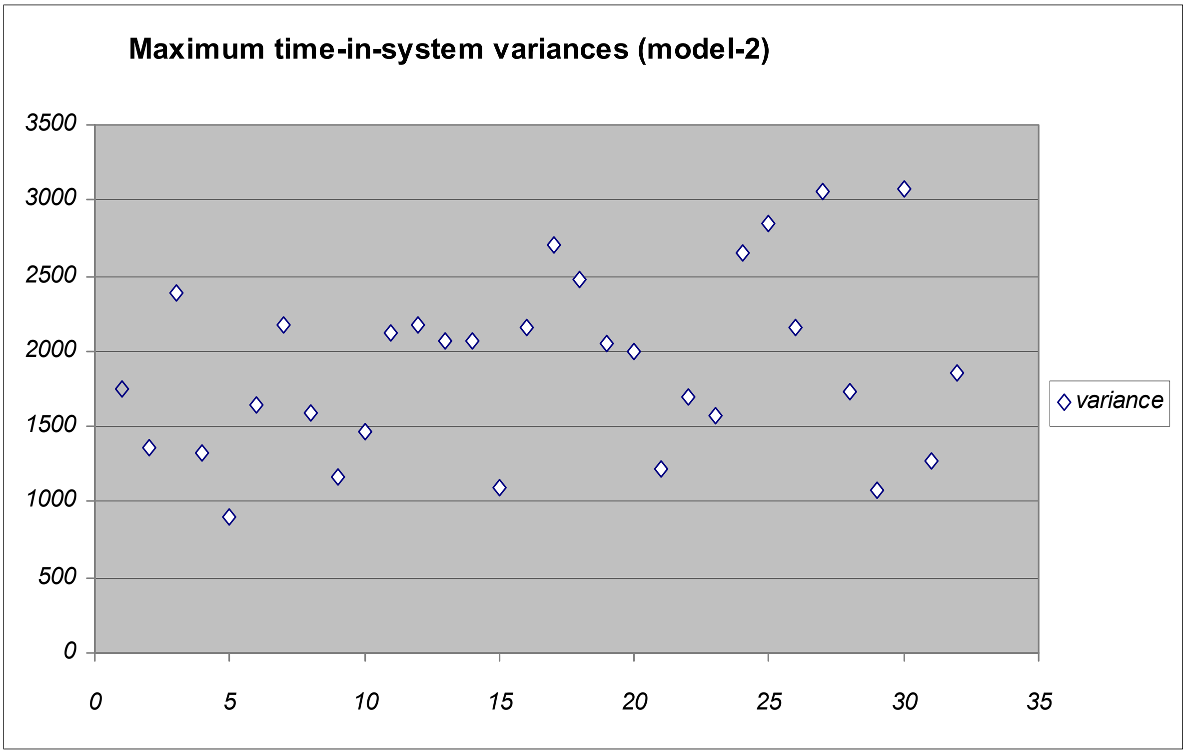


Figure F.2. Scatter Plot of Variances of Maximum Time-in-System Measure (Model-2)

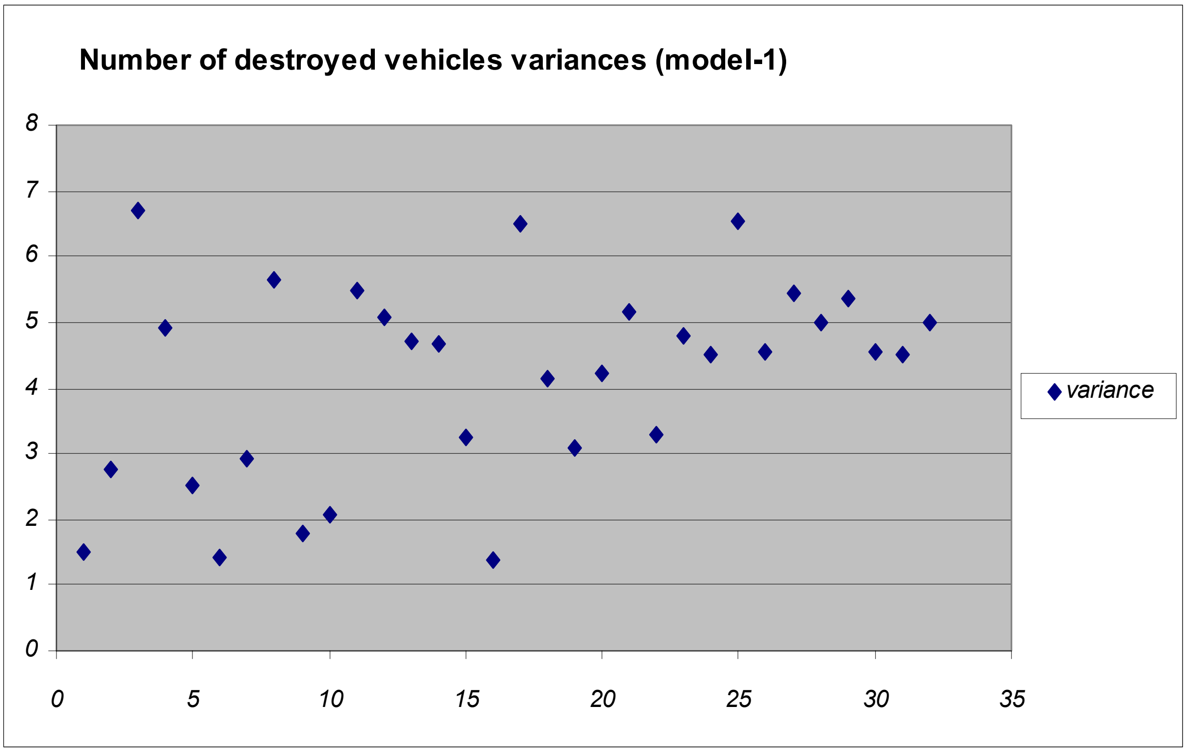


Figure F.3. Scatter Plot of Variances of Number of Destroyed Vehicles Measure (Model-1)

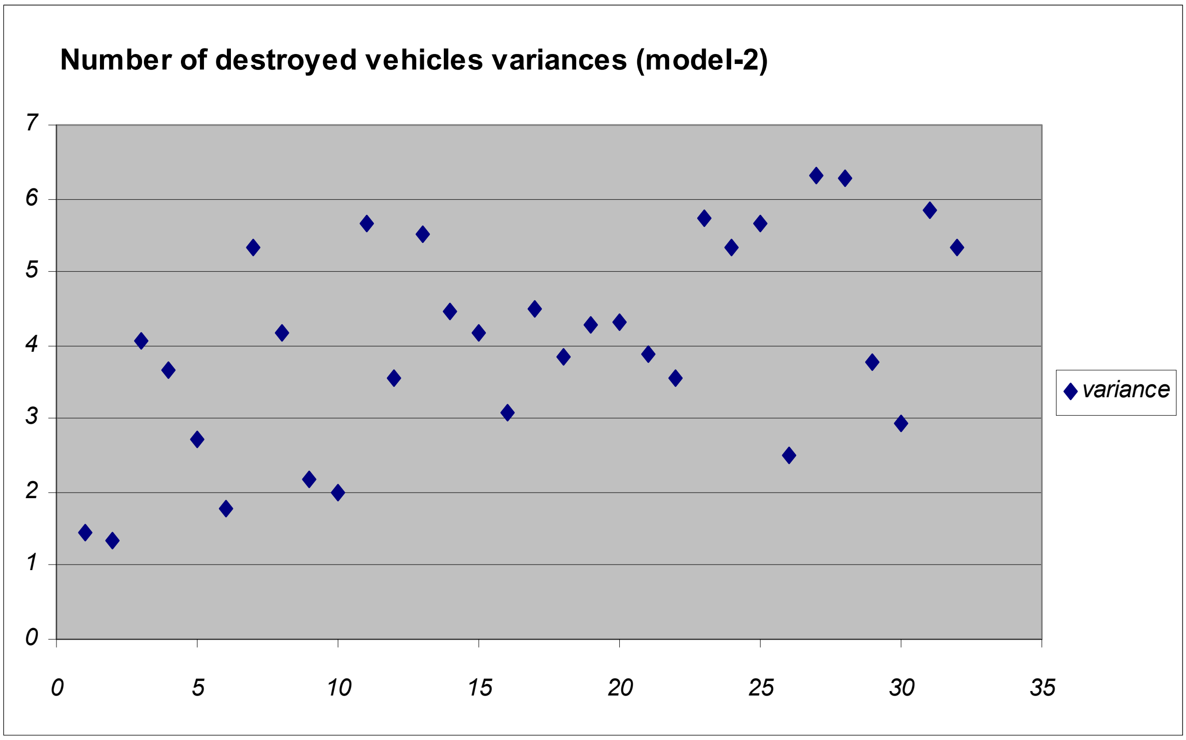


Figure F.4. Scatter Plot of Variances of Number of Destroyed Vehicles Measure (Model-2)

APPENDIX-G

PART OF CODE FOR MODEL-1 (MODEL FRAME)

```
0$             CREATE,        9::MARK(Timeinw);
1$             ASSIGN:        NS=Truck1path:
                              bolukno=1:MARK(march1w)

2$             STATION,       hazirlik1;
Gettruck1      QUEUE,         Truck1q;
3$             REQUEST,       1:Truck1(sds);
4$             TRANSPORT:     Truck1,seq;

5$             STATION,       arizatek1;
6$             BRANCH,        1:
                              With,0.1,dur1,Yes:
                              Else,devam1,Yes;
dur1           BRANCH,        1:
                              With,0.47,git1,Yes:
                              With,0.34,git2,Yes:
                              With,0.16,git3,Yes:
                              Else,harap1,Yes;
git1           ASSIGN:        zayiat1=tria(1,6,11):NEXT(bakim1);
bakim1         FREE:          Truck1;
316$           DELAY:         zayiat1:NEXT(Gettruck1);
git2           ASSIGN:        zayiat1=tria(11,17,23):NEXT(bakim1);
git3           ASSIGN:        zayiat1=tria(30,34,38):NEXT(bakim1);
harap1         COUNT:         BreakHek C1WV,1;
216$           ASSIGN:        c1wvdamaged=c1wvdamaged+1;
254$           FREE:          Truck1;
93$            BRANCH,        2:
                              If,bolukno==1,tekerlek,Yes:
                              Always,enkaz111,Yes;
tekerlek       COUNT:         WV  Hek,1;
248$           ASSIGN:        wvtoplam=wvtoplam+1;
100$           DISPOSE;

enkaz111       COUNT:         Hek C1,1:NEXT(toplam);
toplam         COUNT:         Hek TOTAL,1;
92$            DISPOSE;
devam1         FREE:          Truck1:NEXT(Gettruck1);

7$             STATION,       artillery1;
8$             BRANCH,        1:
                              With,0.2,silah1,Yes:
                              Else,devam11,Yes;
silah1         BRANCH,        1:
                              With,0.55,git4,Yes:
                              With,0.2,git5,Yes:
                              With,0.1,git6,Yes:
                              Else,harap11,Yes;
git4           ASSIGN:        zayiat1=Tria(4,8,12):NEXT(bakim11);
```

```
bakim11         FREE:           Truck1;
337$            ASSIGN:         say1=say1+1;
317$            DELAY:          zayiat1:NEXT(Gettruck1);

git5            ASSIGN:         zayiat1=Tria(15,21,27):NEXT(bakim11);

git6            ASSIGN:         zayiat1=Tria(30,35,40):NEXT(bakim11);

harap11         COUNT:          ArtHek   C1WV,1;

217$            ASSIGN:         c1wvdamaged=c1wvdamaged+1;
408$            FREE:           Truck1;

94$             BRANCH,         2:
                                If,bolukno==1,tekerlek,Yes:
                                Always,enkaz111,Yes;
devam11         FREE:           Truck1;
255$            ASSIGN:         say1=say1+1:NEXT(Gettruck1);
9$              CREATE,         9::MARK(Timeinw);
10$             ASSIGN:         NS=Truck2path:
                                bolukno=2:MARK(march1w);
188$            WAIT:           987,9;

11$             STATION,        hazirlik2;
349$            DELAY:          Tria(22,29,36);
Gettruck2       QUEUE,          Truck2q;
12$             REQUEST,        1:Truck2(sds);
13$             TRANSPORT:      Truck2,seq;

14$             STATION,        arizatek2;
15$             BRANCH,         1:
                                With,0.1,dur2,Yes:
                                Else,devam2,Yes;

dur2            BRANCH,         1:
                                With,0.47,git21,Yes:
                                With,0.34,git22,Yes:
                                With,0.16,git23,Yes:
                                Else,harap2,Yes;
git21           ASSIGN:         zayiat2=tria(1,6,11):NEXT(bakim2);
bakim2          FREE:           Truck2;
311$            DELAY:          zayiat2:NEXT(Gettruck2);

git22           ASSIGN:         zayiat2=tria(11,17,23):NEXT(bakim2);

git23           ASSIGN:         zayiat1=tria(30,34,38):NEXT(bakim2);
harap2          COUNT:          BreakHek C2WV,1;
228$            ASSIGN:         c2wvdamaged=c2wvdamaged+1;
261$            FREE:           Truck2;

95$             BRANCH,         2:
                                If,bolukno==2,tekerlek,Yes:
                                Always,enkaz222,Yes;
```

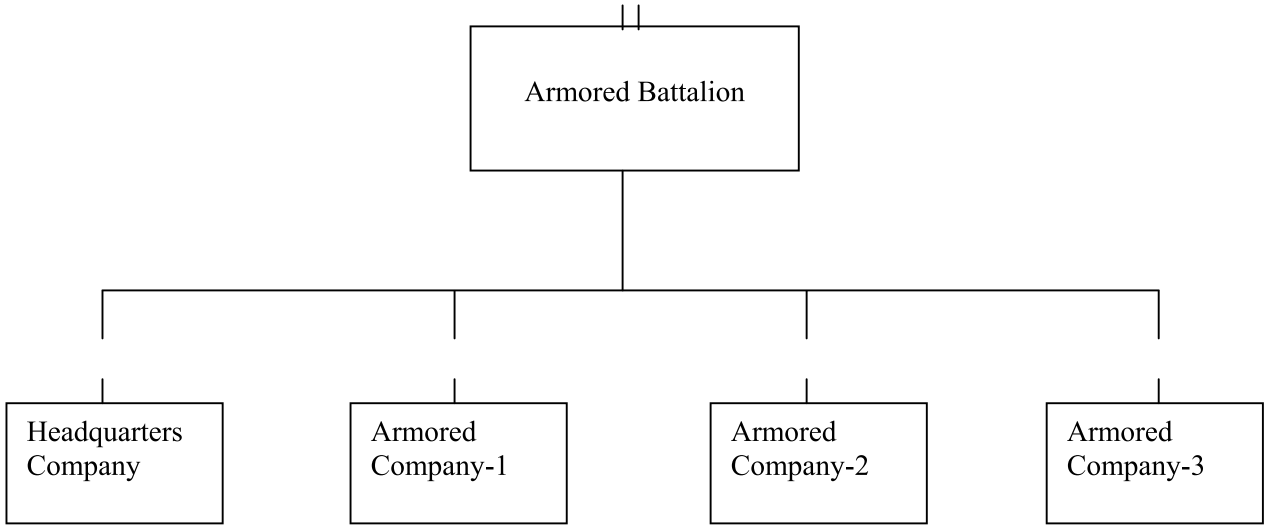
PART OF CODE FOR MODEL-2 (MODEL FRAME)

```
0$              CREATE,         9;
4$              ASSIGN:         bl#=1:NEXT(disperse1);

disperse1       STATION,        garage1;
255$            DELAY:          tria(5,10,15);
peace           QUEUE,          comp1;
war             QUEUE,          company1;
420$            REQUEST,        1:vec1(sds);
562$            DELAY:          tria(1,2,3);
421$            TRANSPORT:      vec1,DA1;

1$              CREATE,         9;
5$              ASSIGN:         bl#=2:NEXT(disperse2);

disperse2       STATION,        garage2;
422$            DELAY:          tria(5,10,15);
438$            BRANCH,         1:
                                If,bl#==2,peace2,Yes:
                                If,bl#==22,war2,Yes;
peace2          QUEUE,          comp2;
439$            REQUEST,        1:vec22(sds);
557$            DELAY:          tria(12,15,18);
440$            TRANSPORT:      vec22,DA2;

war2            QUEUE,          company2;
424$            REQUEST,        1:vec2(sds);
558$            DELAY:          tria(1,2,3);
425$            TRANSPORT:      vec2,DA2;

2$              CREATE,         9;
6$              ASSIGN:         bl#=3:NEXT(disperse3);

disperse3       STATION,        garage3;
426$            DELAY:          tria(5,10,15);
441$            BRANCH,         1:
                                If,bl#==3,peace3,Yes:
                                If,bl#==33,war3,Yes;
peace3          QUEUE,          comp3;
428$            REQUEST,        1:vec33(sds);
561$            DELAY:          tria(12,13,14);
429$            TRANSPORT:      vec33,DA3;

war3            QUEUE,          company3;
442$            REQUEST,        1:vec3(sds);

560$            DELAY:          tria(1,2,3);
443$            TRANSPORT:      vec3,DA3;
```

```
3$              CREATE,         44;
7$              ASSIGN:         bl#=4:NEXT(disperse4);

disperse4       STATION,        garage4;
430$            DELAY:          tria(5,10,15);
432$            QUEUE,          company4;
433$            REQUEST,        1:vec4(sds);
559$            DELAY:          tria(3,6,9);
434$            TRANSPORT:      vec4,DA4;

13$             CREATE,         15;
16$             ASSIGN:         bl#=11:NEXT(disperse1);

14$             CREATE,         13;
17$             ASSIGN:         bl#=22:NEXT(disperse2);

15$             CREATE,         13;
18$             ASSIGN:         bl#=33:NEXT(disperse3);

23$             STATION,        shell2;
24$             BRANCH,         1:
                                With,0.2,done2,Yes:
                                Else,ahead22,Yes;
done2           BRANCH,         1:
                                With,0.33,below44,Yes:
                                With,0.25,below55,Yes:
                                With,0.22,below66,Yes:
                                Else,zayi22,Yes;

below44         ASSIGN:         effect22=Tria(6,12,18):NEXT(wait22);

wait22          DELAY:          effect22;
497$            FREE:           man2;
509$            ASSIGN:         sayi6=sayi6+1:NEXT(ammotruck2);

ammotruck2      QUEUE,          convoy2q;
85$             REQUEST,        1:man2(sds);
86$             TRANSPORT:      man2,seq;

below55         ASSIGN:         effect22=Tria(21,25,29):NEXT(wait22);

below66         ASSIGN:         effect22=Tria(32,37,42):NEXT(wait22);

zayi22          COUNT:          ArtHek   C2AmmoTruck,1;
517$            FREE:           man2;
382$            ASSIGN:         c4wvdamaged=c4wvdamaged+1;
309$            SIGNAL:         862;

26$             BRANCH,         2:
                                If,bl#==42,toplam4,Yes:
                                Always,wheeled,Yes;
toplam4         COUNT:          Hek   C4,1:NEXT(toplam);
toplam          COUNT:          Hek   TOTAL,1;
```

APPENDIX-H

STRUCTURE OF AN ARMORED BATTALION



APPENDIX-I

PAIRWISE COMPARISON AND NORMALIZED MATRICES

We name the regions of Turkey as Region-1.....Region-8 for simplicity. We give the list of names below.

Greek border : Region-1

Aegean : Region-2

Iranian border : Region-3

Iraqi border : Region-4

Syrian border : Region-5

Bulgarian border : Region-6

Eastern Black Sea: Region-7

Mediterranean : Region-8

There are two criteria in our study and these are:

Criterion-1 (C1) : Maximum time-in-system

Criterion-2 (C2) : Number of destroyed vehicles

We present the pairwise comparison matrix of criteria below.

$$\begin{array}{c c} & \begin{array}{cc} C1 & C2 \end{array} \\ \begin{array}{c} C1 \\ C2 \end{array} & \begin{bmatrix} 1 & 6/5 \\ 5/6 & 1 \end{bmatrix} \end{array}$$

Reference region names on p. 150

Pairwise Comparison Matrix of Regions According to Maximum Time-in-System Criterion (Model-1)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	1	2.52	3.83	4.85	5.61	7.19	8.59	10
Region-2	0.39	1	1.31	2.33	3.09	4.67	6.07	7.47
Region-3	0.26	0.76	1	1.03	1.77	3.36	4.76	6.17
Region-4	0.21	0.43	0.97	1	1.02	2.33	3.74	5.14
Region-5	0.18	0.32	0.56	0.98	1	1.59	2.99	4.39
Region-6	0.14	0.21	0.29	0.43	0.63	1	1.41	2.81
Region-7	0.11	0.16	0.21	0.26	0.33	0.71	1	1.4
Region-8	0.1	0.13	0.16	0.19	0.22	0.35	0.71	1

Normalized Matrix According to Maximum Time-in-System Criterion (Model-1)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	0.42	0.45	0.46	0.44	0.41	0.39	0.41	0.37
Region-2	0.16	0.18	0.16	0.20	0.22	0.22	0.27	0.20
Region-3	0.11	0.13	0.12	0.10	0.13	0.16	0.18	0.17
Region-4	0.08	0.07	0.10	0.09	0.07	0.11	0.14	0.14
Region-5	0.07	0.06	0.06	0.08	0.07	0.07	0.10	0.11
Region-6	0.05	0.04	0.03	0.04	0.05	0.05	0.07	0.07
Region-7	0.04	0.03	0.02	0.03	0.02	0.03	0.04	0.04
Region-8	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.03

Reference region names on p. 150

Pairwise Comparison Matrix of Regions According to Number of Destroyed Vehicles Criterion (Model-1)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	1	3.68	0.96	1.92	1.39	2.79	5.94	9.47
Region-2	0.27	1	0.23	0.56	0.44	0.98	2.26	5.78
Region-3	1.04	4.21	1	2.44	1.92	3.31	6.47	10
Region-4	0.51	1.76	0.41	1	0.97	1.05	4.02	7.55
Region-5	0.72	2.28	0.52	1.03	1	1.38	4.55	8.08
Region-6	0.36	1.02	0.30	0.95	0.72	1	3.15	6.68
Region-7	0.19	0.44	0.15	0.25	0.22	0.32	1	3.52
Region-8	0.11	0.17	0.1	0.13	0.12	0.15	0.28	1

Normalized Matrix According to Number of Destroyed Vehicles Criterion (Model-1)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	0.23	0.25	0.26	0.23	0.21	0.25	0.21	0.19
Region-2	0.06	0.07	0.06	0.06	0.06	0.08	0.08	0.10
Region-3	0.24	0.29	0.27	0.29	0.28	0.3	0.24	0.21
Region-4	0.12	0.12	0.11	0.12	0.14	0.1	0.14	0.14
Region-5	0.17	0.15	0.14	0.13	0.15	0.12	0.16	0.15
Region-6	0.08	0.07	0.08	0.11	0.1	0.09	0.11	0.12
Region-7	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.05
Region-8	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.02

Reference region names on p. 150

Pairwise Comparison Matrix of Regions According to Maximum Time-in-System Criterion (Model-2)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	1	2.43	1.03	3.45	6.82	4.85	8.78	10
Region-2	0.41	1	0.71	1.02	4.39	2.43	6.35	7.57
Region-3	0.97	1.40	1	2.42	5.79	3.83	7.75	8.97
Region-4	0.29	0.98	0.41	1	3.36	1.41	5.32	6.54
Region-5	0.14	0.22	0.17	0.30	1	0.51	1.95	3.17
Region-6	0.20	0.42	0.26	0.71	1.96	1	3.92	5.14
Region-7	0.11	0.16	0.13	0.19	0.51	0.26	1	1.21
Region-8	0.1	0.13	0.11	0.15	0.31	0.19	0.83	1

Normalized Matrix According to Maximum Time-in-System Criterion (Model-2)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	0.31	0.36	0.27	0.37	0.28	0.34	0.25	0.25
Region-2	0.12	0.15	0.18	0.12	0.18	0.16	0.17	0.17
Region-3	0.30	0.21	0.26	0.26	0.24	0.26	0.21	0.21
Region-4	0.09	0.14	0.11	0.11	0.14	0.10	0.14	0.12
Region-5	0.04	0.03	0.05	0.03	0.04	0.03	0.05	0.07
Region-6	0.06	0.06	0.08	0.07	0.08	0.07	0.10	0.11
Region-7	0.03	0.02	0.04	0.02	0.02	0.02	0.02	0.03
Region-8	0.03	0.02	0.03	0.02	0.01	0.01	0.02	0.02

Reference region names on p. 150

Pairwise Comparison Matrix of Regions According to Number of Destroyed Vehicles Criterion (Model-2)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	1	2.38	0.95	1.10	1.43	2.50	5.54	9.52
Region-2	0.42	1	0.35	0.62	0.98	1.04	3.16	7.14
Region-3	1.05	2.85	1	1.26	1.90	3.33	6.01	10
Region-4	0.91	1.59	0.79	1	1.08	2.07	4.76	8.73
Region-5	0.69	1.02	0.53	0.92	1	1.43	4.12	8.09
Region-6	0.40	0.96	0.30	0.48	0.69	1	2.69	6.66
Region-7	0.18	0.31	0.16	0.21	0.24	0.37	1	3.97
Region-8	0.11	0.16	0.10	0.12	0.14	0.19	0.25	1

Normalized Matrix According to Number of Destroyed Vehicles Criterion (Model-2)

	Region-1	Region-2	Region-3	Region-4	Region-5	Region-6	Region-7	Region-8
Region-1	0.21	0.23	0.22	0.19	0.19	0.21	0.20	0.18
Region-2	0.09	0.10	0.08	0.10	0.12	0.09	0.11	0.13
Region-3	0.22	0.27	0.24	0.22	0.25	0.28	0.22	0.19
Region-4	0.19	0.15	0.19	0.18	0.16	0.17	0.17	0.16
Region-5	0.14	0.11	0.12	0.16	0.14	0.12	0.15	0.15
Region-6	0.08	0.09	0.07	0.08	0.09	0.08	0.09	0.12
Region-7	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.06
Region-8	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02

APPENDIX-J

RINOTT PROCEDURE RESULTS FOR EACH REGION

Table J.1. Averages and Variances of 15 Replications According to Maximum Time-in-System Statistics for Regions (Model-1)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern Black Sea	Aegean	Medit.
1	533.67	468.73	532.17	517.26	538.58	428.75	562.18	428.76
2	634.98	527.76	423.07	438.91	527.06	512.06	624.96	521.75
3	601.56	578.97	501.24	648.93	463.82	533.75	462.17	438.65
4	554.87	435.76	441.69	549.73	447.92	468.98	544.82	497.68
5	642.67	488.36	598.45	473.18	631.78	510.75	582.72	541.42
6	499.78	458.23	567.87	527.74	589.46	543.27	637.75	499.67
7	486.56	586.01	604.41	514.96	545.32	575.32	609.42	525.85
8	677.82	512.32	588.53	600.01	439.73	454.71	479.37	467.45
9	634.55	564.11	530.78	559.37	675.63	455.03	583.14	584.98
10	538.96	432.98	522.03	611.83	548.01	527.48	643.08	437.64
11	685.99	509.63	497.21	596.36	501.37	426.83	474.72	453.65
12	502.43	577.69	566.73	585.73	599.63	595.42	457.34	527.08
13	624.09	554.32	584.38	656.69	478.72	488.65	654.87	427.86
14	578.31	445.37	615.87	489.66	582.27	503.35	614.73	475.74
15	685.21	590.65	408.37	495.27	531.35	479.72	549.77	452.08
Average	592.091	515.39	532.18	551.04	540.04	500.27	565.40	485.35
Variance	4832.83	3347.85	4477.72	4190.37	4609.16	2487.282	4745.89	2258.7
St.Dev.	69.518	57.868	66.91	64.738	67.893	49.876	68.89	47.525

Table J.2. Total Sample Sizes (N_i) Needed for Each Region and Averages of Total Sample Sizes According to Maximum Time-in-System Statistics (Model-1)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern Black Sea	Aegean	Medit.
N_i	27	23	26	25	26	20	27	18
Average	587.82	518.73	526.77	549.26	545.37	492.27	558.27	479.25

Table J.3. Averages and Variances of 15 Replications According to Number of Destroyed Vehicles Statistics for Regions (Model-1)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern Black Sea	Aegean	Medit.
1	6	7	7	5	6	3	4	3
2	3	2	2	3	1	0	7	0
3	7	5	4	10	4	2	1	1
4	8	1	2	6	7	1	6	2
5	8	7	8	4	7	2	3	0
6	4	6	7	5	6	5	7	3
7	7	3	2	9	5	6	3	5
8	5	2	6	7	3	3	3	3
9	6	8	5	3	5	4	4	2
10	2	5	6	2	7	6	5	1
11	4	7	7	4	9	3	7	3
12	2	4	6	9	2	4	3	0
13	6	5	7	8	3	5	2	3
14	9	4	4	4	5	4	5	2
15	8	3	4	9	4	3	4	3
Average	5.667	4.6	5.133	5.867	4.933	3.4	4.267	2.067
Variance	5.095	4.542	4.123	6.382	4.328	2.773	3.262	1.928
St.Dev.	2.257	2.131	2.030	2.614	2.153	1.723	1.869	1.437

Table J.4. Total Sample Sizes (N_i) Needed for Each Region and Averages of Total Sample Sizes According to Number of Destroyed Vehicles Statistics (Model-1)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern BlackSea	Aegean	Medit.
N_i	15	15	15	15	15	15	15	15
Average	5.667	4.6	5.133	5.867	5.067	3.4	4.267	2.067

Table J.5. Averages and Variances of 15 Replications According to Maximum Time-in-System Statistics for Regions (Model-2)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern Black Sea	Aegean	Medit.
1	572.73	436.82	508.53	591.36	475.19	473.19	481.98	466.17
2	498.27	509.71	419.03	537.18	538.27	377.28	562.17	483.21
3	453.18	578.28	419.53	419.38	452.61	401.27	498.18	355.05
4	605.34	473.32	415.62	483.28	421.63	428.52	451.29	378.63
5	562.31	416.83	490.53	423.84	571.82	396.73	587.32	421.38
6	589.34	429.67	400.47	503.22	528.08	464.94	426.64	369.53
7	442.09	401.72	495.04	539.51	423.43	401.37	414.29	394.36
8	480.42	528.87	415.79	482.41	401.26	373.49	501.21	405.21
9	613.27	478.26	412.72	452.09	503.43	367.06	599.03	383.24
10	472.21	442.37	408.69	519.01	517.88	489.52	451.26	405.28
11	588.05	430.74	397.47	448.29	490.71	417.93	428.42	362.12
12	452.79	472.19	537.98	581.64	429.17	486.53	403.52	411.34
13	501.36	401.08	403.39	409.03	417.53	415.86	539.01	448.74
14	437.73	488.51	399.86	553.71	563.14	375.18	435.95	383.04
15	412.78	420.92	474.42	582.18	404.25	403.43	510.23	417.29
Average	512.125	460.619	439.938	501.742	475.893	418.153	486.033	405.639
Variance	4789.14	2539.57	2225.04	3860.96	3478.62	1747.47	4024.1	1398.67
St.Dev.	69.2036	50.3942	47.1703	62.1366	58.9798	41.8027	63.4358	37.3989

Table J.6. Total Sample Sizes (N_i) Needed for Each Region and Averages of Total Sample Sizes According to Maximum Time-in-System Statistics (Model-2)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern Black Sea	Aegean	Medit.
N_i	27	19	18	24	23	16	24	15
Average	519.62	462.81	446.32	507.27	481.61	411.53	490.02	405.63

Table J.7. Averages and Variances of 15 Replications According to Number of Destroyed Vehicles Statistics for Regions (Model-2)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern Black Sea	Aegean	Medit.
1	5	3	6	6	3	2	4	1
2	3	7	3	7	9	7	6	3
3	9	2	8	3	10	2	8	0
4	4	8	4	5	6	5	5	2
5	3	6	7	7	7	3	3	1
6	5	4	5	10	4	4	5	3
7	7	3	8	7	5	2	3	2
8	8	3	3	5	3	3	6	1
9	6	5	3	3	9	6	3	2
10	7	4	6	4	4	3	5	1
11	6	3	9	7	5	2	6	3
12	3	8	3	9	4	3	9	4
13	6	5	5	3	7	4	3	0
14	7	3	3	11	3	4	4	3
15	9	6	6	4	4	3	3	2
Average	5.867	4.667	5.267	6.067	5.533	3.533	4.867	1.867
Variance	4.123	3.809	4.352	6.495	5.552	2.266	3.552	1.409
St.Dev.	2.030	1.951	2.086	2.548	2.356	1.505	1.884	1.187

Table J.8. Total Sample Sizes (N_i) Needed for Each Region and Averages of Total Sample Sizes According to Number of Destroyed Vehicles Statistics (Model-2)

	Greek border	Bulgarian border	Syrian border	Iranian border	Iraqi border	Eastern Black Sea	Aegean	Medit.
N_i	15	15	15	15	15	15	15	15
Average	5.866	4.666	5.267	6.067	5.533	3.533	4.867	1.867