MODELING AND ANALYSIS OF MOVEMENT OF A TURKISH ARMORED BATTALION TO MOBILIZATION TASK AREA USING SIMULATION

A THESIS

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BY

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August, 2002

I certify that I have read this thesis and that 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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M.S. in Industrial Engineering

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August, 2002

Beginning with the cold war era especially the Combat Readiness and Peacekeeping missions become more important than the other tasks of the armies. The War Gaming and the Combat Simulations, which are developed especially for the purpose of evaluating combat between heavily armored forces, have recently been dealing with these new missions. The movement of ground forces, which is one of the major tasks of any ground commander, becomes a very significant operation in these new missions.

In this study, the existing movement plan of a Turkish Armored Battalion is studied by using a simulation model of the system. This simulation model helps staff officers of the headquarters which are the planners of military operations to build movement plans for the armored battalions early in decision process, identifies the problem areas in the movement plan, and takes necessary precautions, and evaluates the risk management before conducting a real operation.

This thesis aims for modeling and evaluating the movement of a Turkish armored battalion emplaced next to border from assembly area to the mobilization task areas, determining the amount of time delay of each retarding event caused both by terrain and the enemy and analyzing the cost for using the semi-trailers to carry armored vehicles of the battalion. The output of the model is analyzed by appropriate statistical methods. The code of the simulation is written in Arena simulation program.

Key Words: Military Simulation, War Gaming, Movement of Ground Forces, Experimental Design, Multi-criteria Decision Making.

ÖZET

BİR TANK TABURUNUN SEFERBERLİK GÖREV YERİNE İNTİKALİNİN MODELLENMESİ VE SİMÜLASYON YOLUYLA İNCELENMESİ

Burhan ÜREK

Endüstri Mühendisliği Bölümü Yüksek Lisans
Tez Danışmanı: Doç. Dr. İhsan SABUNCUOĞLU

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Soğuk savaş döneminin başlamasıyla birlikte Muharebeye Hazır Olma ve Barışı Koruma görevleri günümüz ordularının diğer görevlerinden daha çok önem kazanmıştır. Özellikle ağır zırhlı birlikler arasındaki muharebenin incelenmesi amacıyla geliştirilmiş olan Harp Oyunları ve Muharebe Simülasyonu son zamanlarda bu görevlerle daha çok ilgilenmektedir. Bütün kara birlik komutanlarının en önemli görevlerinden biri olan kara birliklerinin intikali bu görevlerin en önemli bölümlerinden birini teşkil eder.

Bu çalışmada bir Tank Taburunun intikal planı sistemin bir simülasyon modeli kullanılarak incelenmiştir. Bu simülasyon modeli, askeri harekatların planlayıcıları olan karargah kurmay subaylarına henüz karar aşamasında iken tank taburlarının intikal planlarının hazırlanmasına, intikal planlarındaki problemlerin tespitine, bu problemler için gerekli önlemlerin alınmasına ve gerçek bir operasyon icra edilmeden önce operasyonun risk yönetiminin incelenmesine yardımcı olacaktır.

Bu tez çalışması, sınıra yakın konuşlu bir tank taburunun alarm toplanma bölgesinden seferberlik görev yerine olan intikalinin incelenmesini, bu intikali etkileyen her bir faktörün toplam intikal süresi içindeki payının tespit edilmesini ve taburun zırhlı araçlarının taşınmasında kullanılan tank taşıyıcı araçların (çekicilerin) kullanılmasıyla ortaya çıkacak maliyet analizinin yapılmasını amaçlar. Model ARENA 3.0 simülasyon programı kullanılarak yazılmış, modelin çıktı veri analizi uygun istatistiksel metotlar kullanılarak incelenmiştir.

Anahtar Kelimeler: Askeri Simülasyon, Harp Oyunları, Kara Birliklerinin İntikali, Deneysel Tasarım, Karar Verme.

In memory of my beloved father…

ACKNOWLEDGEMENT

I would like to express my gratitude to Assoc. Prof. Dr. İhsan Sabuncuoğlu for his guidance, understanding, motivating suggestions, and patience throughout all this work.

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I cannot fully express my gratitude to my friends and commanders in Armored Units School and Training Division Commandant for their support and encouragement.

To my family, I thank them for their sacrifice, support and patience during the preparation of this thesis.

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CHAPTER I

Introduction

1.1. Movement

Movement is the movement of any unit from one place to another by any available means. The capability to convey a quick movement to concentrate the effects of combat power at conclusive points is the most important feature of the battlefield agility.

All commanders want to increase their effectiveness by trying to prevent the enemy from moving enemy forces into predominant positions meanwhile by concentrating their forces to these key positions. It is necessary to hold all the key positions in the theater from the beginning of any operation. Therefore, the movement is one of the most important military tasks for all commanders.

There are three types of unit movement: 1.Administrative Movement, 2.Tactical Road March and 3. Approach March.

Administrative Movement

Administrative movement is a kind of movement applied when no enemy interference is expected except enemy air attack. Administrative movements are conducted only in secure areas in which units and vehicles are arranged to accelerate the movement for the purpose of saving time and energy.

Tactical Road March

Tactical road march is a kind of movement applied when the enemy contact is possible and expected. In the tactical road march the attack of enemy ground forces is not expected but the moving units always take precautions against an enemy or paramilitary ambush. The main purpose of the tactical road march is to position the units within the theatre as fast as possible.

The primary consideration of the tactical road march is rapid movement. However, the moving force employs security measures, even when contact with enemy ground forces are not expected. Units conducting road marches may or may not be organized into a combined arms formation. During a tactical road march, the commander is always prepared to take immediate action if the enemy attacks.

Approach March

Approach march is a kind of movement applied when direct contact with the enemy forces is expected. It is conducted when the enemy's location is known almost sure. In this movement speed is very important and the psychical security and dispersion has the second role.

1.2. Movement Planning and Organization

In Turkish Army the planning process is based on five basic factors regardless of the operation. According to the kind of operation there are always other secondary factors influencing the operation but the basic factors remain same. These basic factors are: **M**ission**, E**nemy**, T**errain, **T**roops + **T**ime.

Other influencing factors for these types of operations are number of vehicles, roads, and training of the drivers.

Motorized movements are organized and controlled by arranging the moving unit's vehicles into convoys. The convoy is the column of vehicles organized for the aim of control by a single commander. Convoys are used in:

1. Administrative movement of personnel and equipment,
2. Administrative movement of logistic units,
3. Tactical movement of combat forces.

The number of vehicles in a convoy varies from 2 to 300.

1.3. Defense Against Enemy Attacks in the Movement of Armored Forces

A unit cannot be regarded as in safe if it has no all around security. In addition to the operational threats the moving units must always be ready against an enemy or paramilitary ambush or sabotage. A successful mission can only be accomplished with the security measures taken against the enemy attacks. Besides, the losses and the vulnerability can be reduced with these security measures. Training is the key for the safety of the operation.

1.3.1. Enemy Artillery Attack or Indirect Fire

Tactical movement of armored troops may be harassed or retarded by the enemy indirect fire or artillery units. The course of action when an enemy artillery attack occurs is the following:

A. *Artillery Concentration Is Ahead of The Convoy*: In this case the convoy should be halted. The commander of the convoy searches for an alternate road around the impact area. If there is any road around the impact area the convoy immediately speeds up and passes around the impact area by dispersing as much as possible. If there isn't any alternate road the convoy disperses to the area as much as terrain allows and wait for the artillery attack to pass by.

B. *Artillery Concentration Is Behind or On The Flanks of The Convoy*: If this is the case, the convoy should immediately increase its speed and pass away the impact area as fast as possible.

C. *Artillery Concentration is On The Convoy*: In this case the convoy disperses quickly to the area as much as the terrain allows to decrease the casualty and gets out of impact area by speeding up.

1.3.2. Enemy Air Attack

The assets for the enemy air attack are attack aircraft, attack helicopters and the long-ranged missiles. The enemy air attack is one of the most hazardous operations for the convoys especially moving along open roads. The convoy has two courses of action against the enemy air attack:

A. *Passive Defense*: When an enemy aircraft is spotted the convoy commander has two options: halt the convoy or disperse quickly to the terrain. The convoy commander may choose halting the convoy because it is difficult to see a halted convoy for the enemy pilots compared to a moving convoy. But this option has the disadvantage that a halted convoy makes a good target and in case of an attack the loss will be greater. The second option is dispersing quickly to terrain, taking cover and staying in concealed positions not to be noticed by enemy pilots. Dispersing vehicles hardens to be detected by enemy pilots and in case of an air raid decreases the casualty.

B. *Active Defense*: This course of action is applied when the enemy pilot notices and attacks to convoy. The active defense against the enemy air attack means to fire against the enemy aircraft or helicopters with suitable guns. The basic principle of firing against aircraft or helicopters is to concentrate all fires on the targets and putting a large volume of interdiction fire according to type and the flight direction of the targets.

1.3.3. Enemy Ambush

In the tactical road marches especially the security and escort vehicles may be ambushed by the enemy or guerilla forces. The first rule of minimizing the casualty caused by an ambush is to apply the techniques of passing through the dangerous zones. Generally, a part of a convoy either the head, the main body or the trail is ambushed. The part that is ambushed should immediately exit the kill zone as fast as possible if the road or the terrain is available. The following vehicles push the vehicles, which are destroyed or disabled to move by the enemy fire, away from the road. Other parts of the convoy, which are behind the kill zone, do not enter this zone or if they are ahead of the kill zone they continue to march. The security or armed escort vehicles, which are ordered before the movement by the convoy commander to return fire to the enemy, attack to enemy forces. The vehicles in the kill zone return fire to the enemy while exiting the kill zone.

1.3.4. Mines and Booby Traps

The enemy uses mines or booby traps generally for blocking the movement road to harass the vehicles and to retard the movement. If the mine or the booby traps are noticed, vehicle commander stops his vehicle and reports it to the convoy commander then searches for if there is a road around the mine or booby trap. If there is an alternate way to pass around, the mine or booby trap zone is signalized and the following vehicles are guided around this zone by a soldier. If there is no possibility to pass around this area, the mine cleared away and the convoy goes on marching.

If any vehicle is destroyed or disabled by a mine, which planted on the road, the convoy stops. The vehicle that is destroyed or disabled is cleared away from the road. If there is a possibility to repair the vehicle, the maintenance and repairing team repairs it while other vehicles go on marching. If the vehicle has failed catastrophically it is left in a secured area with its crew.

1.4. Usual Breakdowns

Usual breakdowns are one of the important factors that affect the movement. When usual breakdown occurs the vehicle moves out of the road and waits for the maintenance and repairing team if it is possible to repair it. After repairing, the vehicle goes on marching by joining the trail of the convoy. If there is a breakdown, which disables the vehicle to move any longer, the vehicle is left in a secure place with its crew.

1.5. Movement of an Armored Battalion Emplaced Next to Border From Assembly Area to Mobilization Task Area

The movement of armored battalions, which are emplaced next to any border of Turkey, from assembly area to their mobilization task areas is one of the most important and critical tasks. The task is graphically explained in Figure 1.1.

This task is not a kind of task, which is conducted frequently by these units. This task is conducted only at times of crisis or war. Since it is performed at times of war or crisis, the contact with enemy forces is possible and expected at these times. Therefore, it can be regarded as a tactical road march. Any failure or fault that retards this mission directly affects the success of the next operations. This causes the failure to hold the key positions in the theatre and gives the enemy the opportunity to take the initiative from the beginning of war. This mission plays a vital role for the next operations. So, this movement should be completed with minimum loss and in a very short time. The units must be fresh and less harassed for the next operations so it should be completed with minimum loss. Especially, the time is very important for this mission because all units must be on their task areas at the same time for the next operation (attack or defense). Any lateness of any units will cause next operations to begin late so it should be completed exactly in planned time.

Since the time, namely the rapid movement, is the most important factor of this movement, Turkish Army wants to accelerate this movement. There are several ways of speeding up this movement. One of them is to emplace these units near to or on these areas.

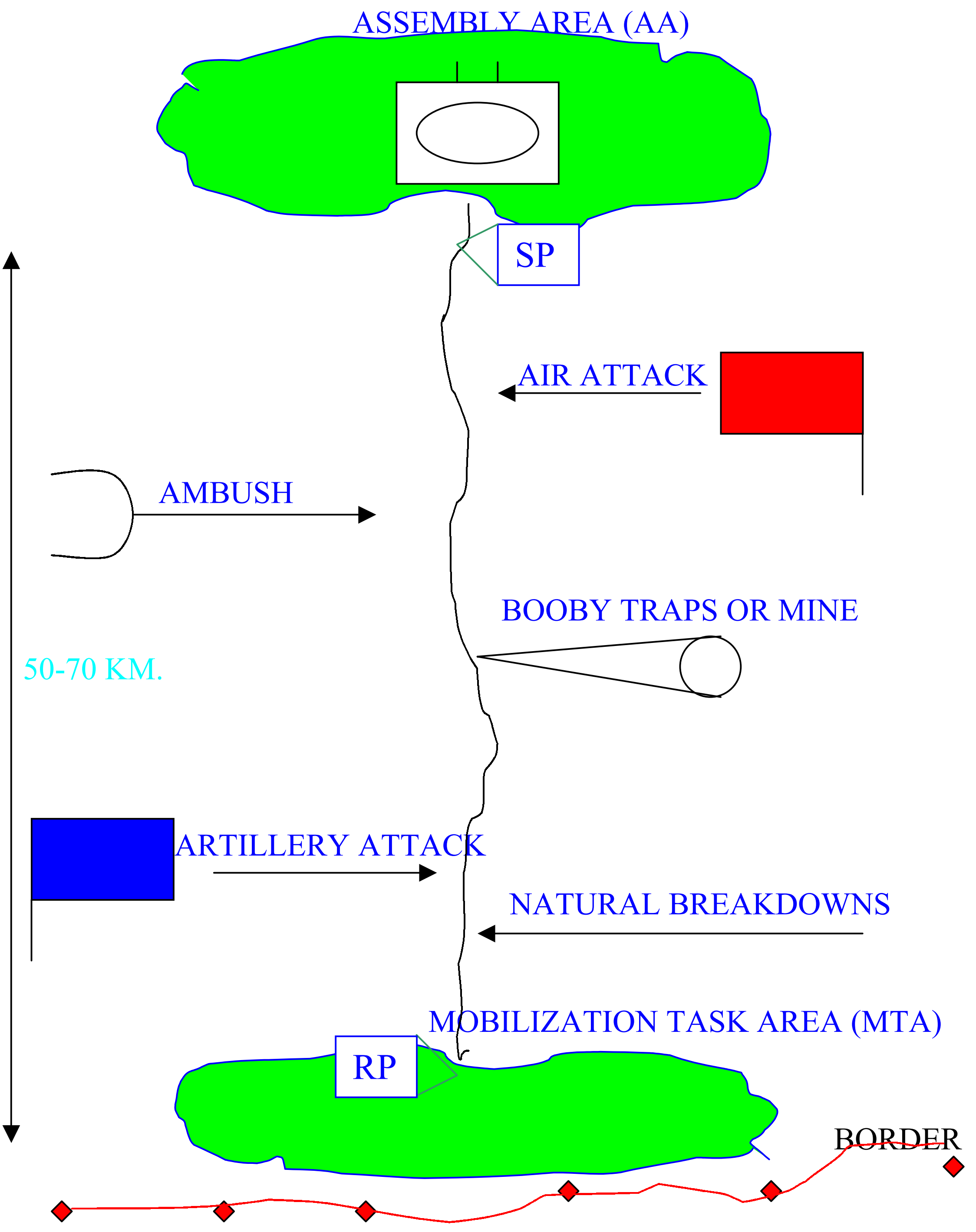


Figure 1.1 Movement of A Turkish Battalion to Mobilization Task Area.

But this has the disadvantage of disability to conduct the inner country security tasks especially in a country like Turkey and this causes some problems in intelligence. Another solution is to increase the movement speed. But this will cause fatal accidents on road and results in casualties that are unwanted. Another way of increasing the speed is to carry the vehicles, which slow down the convoy speed. Especially, the heavy armored vehicles slow down this movement. So, the semi-trailers can be used for the rapid movement.

Turkish Army has been using these kinds of vehicles since 1988 but there isn't enough number of semi-trailers in Turkish Army inventory to carry all the armored battalions next to any border at once. Therefore, in such a movement operation armored vehicles of some battalions are transported with semi-trailers while armored vehicles of remaining battalions march on foot. The detailed information about semi-trailers is given in Appendix A.

1.6. Thesis Outline

The remaining parts of the thesis are organized as follows. Chapter 2 presents the literature review related with the simulation software and methodology, military simulation and movement of ground forces. In Chapter 3, we develop the simulation model of the movement of an armored battalion, which is emplaced next to border, from assembly area to its mobilization task area. In Chapter 4, we give the design and analysis of experiments with graphical and numerical results. Chapter 5 deals with the output data analysis, which evaluates the results of the simulation model by the help of multi-criteria decision-making methods. In Chapter 6, we determine the effects of Logistics Information System (LIS) on the movement. In Chapter 7 we interpret the results of this study and give the concluding remarks and insights for future researches. Appendices consist of figures and tables used in constructing this study, outputs and the code of the simulation model.

Chapter 2

Literature Review

In our literature review, we come across only one study that is related to our topic. "The Evaluation of Mobilization and Deployment Plan of A Turkish Armored Battalion Via Simulation" by Müslüm and Sabuncuoğlu (2001). The other studies are not directly related to ours, but in military simulation area. Hence, we explain them briefly under these subtitles:

- Military simulation
- Combat modeling and tactical simulation.

We start with the study directly related to our topic. In the study of Müslüm and Sabuncuoğlu (2001), they evaluate the mobilization and deployment system of an armored battalion, find out the significant factors of enemy threats on the deployment plan and check the mobilization and deployment system limits.

Their study aims for checking the efficiency of the mobilization and deployment system, detecting the bottlenecks of the system, selecting the most vulnerable region of Turkey against enemy attacks and checking the limits of the deployment plan.

There are some similarities and differences between their study and our study. The main differences are as follows:

- They model the mobilization and deployment plan of an armored battalion. In this plan, the armored battalion completes their preparations and march from their garrison to assembly areas. On the other hand, we model the movement of an armored battalion, emplaced next to borders, from assembly area to the mobilization task area.

- The operation they model is the previous operation of our model and it is a kind of preparatory operation for the movement to the mobilization task area. The movement to the mobilization task area is the previous operation of the main operation such as attack or defense can be regarded as the first step of the war. Thus, it is more critical than movement to the assembly areas.
- The movement operation to the mobilization task areas which are located in the borderlines is performed very close to enemy forces so the probability to contact with the enemy forces of this operation is higher than that of operation they model in their study.
- The average distance between assembly area and mobilization task area is approximately 70 kilometers whereas the average distance from garrison to the assembly area is approximately 20 kilometers. Thus, the operation we model is a long-ranged operation and command, control and coordination measures are more important in our case.

These are the differences between the operation they model and the operation we model. There are also some other differences of our study. These differences are as follows:

- The rapid movement is very important in movement to the mobilization task area and semi-trailers are used to transport the armored vehicles of the some battalions. We model this case as an alternative scenario and find out the differences between existing system scenario and this alternative scenario.
- We test the movement operation for these alternative scenarios under different cases such as best case, most possible case and worst case and try to evaluate the behavior of the system under these cases and compare these scenarios for different performance measures.
- We also model the partial transportation of armored battalions as alternative scenarios and find the effects of each partial transportation types.
- We include the cost of using semi-trailers into our model and find the value of alternative scenarios by using multi-criteria decision-making methods.
- We search the effects of some projects affecting the movement operation.

The similarities between our study and their study are as follows:

- The movement operation performed in deployment plan can be regarded as a tactical road march if it is performed under war conditions. Therefore, the factors affecting this operation are same with our factors affecting our operation.
- The movement planning and organization procedures are the same.
- In both study the same unit (armored battalion) is studied.

The other related studies in military simulation and combat modeling are as follows. A summary table of these studies is also presented in Table 2.1 to simplify the explanations.

2.1. Military Simulation

In this section we give information about research papers in military simulation. These research papers help us to understand the analyzing the outputs of the military simulation models and modeling of military systems in our study. Besides we use these papers to learn the techniques of verification and validation of the military simulation models.

Sisti (1996) discusses the research issues in simulation science being addressed by presented by academia, industry and Government and their application of these research issues to the military domain; specifically to the problems of Intelligence.

Hartley (1997) studies on the difficulties such as achieving the steady state in combat simulations, repeatability of military simulations caused by employing human decision-making in military simulations. He also explains the cost of validation and verification of military simulations and compares the verification and validation of military simulation models with that of other simulation applications.

Kang and Roland (1998) discuss on the military simulation, give a detailed history of military simulation. They classify the simulation models and give some explanations about simulation as a training tool for military.

Smith (1998) stresses on the basic principles of military simulation modeling. He gives a brief historical introduction and explains the essential methods for military training simulations. He emphasizes on the importance of physical objects involved in the activities of moving and perceiving other objects in military simulations.

Garrabrants (1998) discusses the importance of simulation in support of all levels of command and control and explains an advanced simulation system, which models all aspects of Marine combat.

2.2. Combat Modeling and Tactical Simulation

Henry (1994) explains the techniques of to transform Corps Battle Simulation for the aim of training the staff officers and commanders in U.S. Army. He models the Corps Battle Simulation using Lanchester-type equations and discusses the evolution of the Corps Battle Simulation.

Kruger (1992) explains the pitfalls in combat simulations. He stresses on the training simulations of staff officers in Corps Battle Simulation and Brigade Battalion Simulation.

Adelantado and Siron (1996) describe the Air-Ground Combat Simulation application. They discuss on the multi-resolution representation of entities (patrols and aircraft') in combat simulation.

Blais (1994) gives an outline of the hardware and software of Marine Tactical Warfare Simulation system. He explains the basic principles of designing and combat modeling approach.

Baker (2001) discusses several approaches used to model teaming within Advanced Tactical Combat Model (ATCOM) and gives the implementation issues and preliminary trends in performance and outcome of model teaming.

Sawyers (1998) explains the modeling capabilities of the Marine Corps. He describes the new Mission Area Analysis process to determine the operational requirements and deficiencies.

Childs and Lubaczewski (1987) explain a simulation model used for training the Brigade and Battalion commanders and exercising the decision-making skills. They give the background of command and control training.

Martin (1999) explains a concept for tactical development system. In this concept, the analyst is able to study tactics and change the order of steps without having to break to open the model in each step.

Table 2.1 Summary Table of Literature Review.

CLASSIFICATON	PUBLICATION	SUBJECT
Military Simulation	Sisti (1996)	Application of research issues in simulation to military domain
	Hartley (1997)	Verification and validation of military simulations
	Kang and Roland (1998)	Classification of simulation models for military training
	Smith (1998)	Basic principles of military simulation modeling
	Garrabrants (1998)	Importance of simulation in command and control of Marine combat
Combat Modeling and Tactical Simulation	Henry (1994)	Corps battle simulation
	Kruger (1992)	Pitfalls in combat simulation
	Adelantado and Siron (1996)	Air-Ground Combat Simulation
	Blais (1994)	Marine Tactical Warfare Simulation
	Baker (2001)	Model teaming in Advanced Tactical Combat Model
	Sawyers (1998)	Operational requirements and deficiencies in Mission Area Analysis
	Childs and Lubaczewski (1987)	Training simulation of Brigade and Battalion commanders
	Martin (1999)	Tactical development systems of warfare simulation

CHAPTER 3

THE SIMULATION MODEL

3.1. Problem Formulation and Setting Objectives

In this thesis, the movement of an armored battalion, which emplaced next to border, from assembly area to the mobilization task area is modeled and evaluated via simulation. This mission plays a very important role due to the reason that this mission is the beginning of main combat operations such as attack or defense. It is very important for any army to be fresh and ready for the main combat operations. Besides, it is very important for the headquarter commanders who are the decision-makers and staff officers who are the planners of the operation to know the time needed for this kind of operation and the estimated casualty after this mission to decide and plan more efficiently before performing the real operation. The objectives of this study are the following:

- To evaluate the movement (transportation) of an armored battalion, emplaced next to border, from assembly area to the mobilization task areas,
- To analyze the effects of random events (breakdowns, air attacks, artillery assaults, minefields and ambush of the enemy or the partisans) caused by both terrain and the enemy,
- To determine the amount of time delay namely to determine the time standards of each random event (factor),
- To test the movement under different scenarios and to find the cases where the movement plan does not work properly,
- To try to identify the problem areas of the system,

- To perform risk management before performing the real operation.

And in this study the following *research questions* will be answered:

- Is the existing movement plan of the Turkish Armed Forces efficient for necessity of rapid movement?
- Where do the bottlenecks occur in the system?
- How do the random events (artillery assault, ambush, mine fields, air attack and the natural breakdowns) affect the performance of the system?
- How does each random event (factor) affect the total movement time and what should be the time standards for each affecting factor?
- How much is the cost of transporting an armored battalion from assembly area to its mobilization area by using the semi-trailers?
- What are the trade-offs between the performance measures and which decisions make the movement more efficient?
- What is the effect of new Logistics Information System (LIS) on the system?

Our system represents the conditions of crisis or war. Thus, it is hard to find the data, which fits the real operation conditions and it is hard since the data are intelligence information.

The *Data Requirements* of the model are:

- Velocities of the semi-trailers, tanks and the wheeled trucks in the movement,
- Repairing time distributions of the damaged vehicles,
- The probability of occurring of each random event,
- The average distance from assembly areas to the mobilization task areas.

- The enemy assets and the hit and kill probabilities of each asset,
- The cost and the properties of semi-trailers, such as movement range and fuel depot capacity,
- Average number of armored and wheeled vehicles in an armored battalion.

By examining the system in this thesis, especially the headquarters commanders which are the end users of the study will able to see how the movement of ground forces plan is working, how do the random events change the system behavior and will easily decide on the plans of the movement of the ground forces.

Assumptions:

- The movement time of the semi-trailers from their units to the loading point (assembly area) and the loading time of the tanks and the armored vehicles on these vehicles are not considered. Because during the crisis between two countries and before the war get started these activities are done and in our study only the movement behaviors are examined.
- The road, on which the movement is executed, is either open just for the military unit movement or the civilian traffic flow does not affect the military movement because of the traffic signalization on road by military police.
- Average velocity of the semi-trailers and the wheeled trucks are 45 km/h. as specified in the movement order of the Turkish Armed Forces.
- Average velocity of tanks is 32 km/h. as specified in the movement order of the Turkish Armed Forces.

- Average gap between the vehicles is 50 m. as specified in the movement order of the Turkish Armed Forces. It varies according to terrain and enemy but 50 m. gap is used for normal marching conditions.

3.2. Model Development

We developed our simulation model starting with the conceptual model by interviewing with both headquarter commanders which are the planners of this movement and battalion and company commanders which are the executors of this movement in theater. Then we constructed the logical model of the system. The code of the model is then written on Arena Software. The model development is illustrated in Figure 3.1.

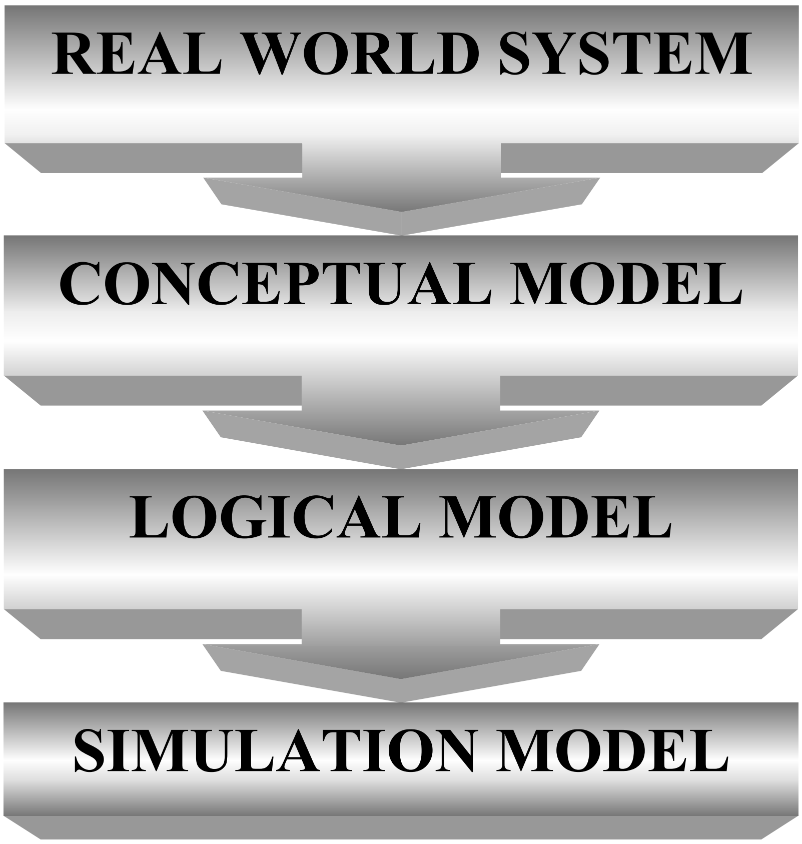


Figure 3.1 Model Development.

3.2.1. Conceptual Model

The conceptual model is written by shrinking the real world system into an assumed system with certain assumptions and then the certain characteristics and the components of the system are examined. The graphical explanation of conceptual model is given in Figure 3.2. Then the basic elements of this simulation model are determined by the certain characteristics, components and the structure of the assumed system.

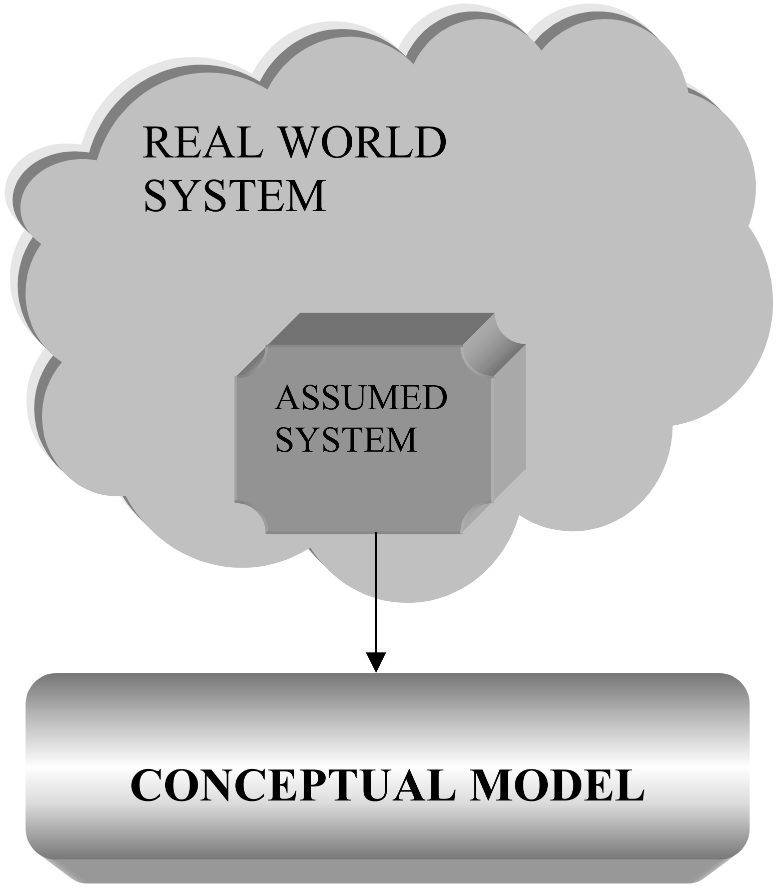


Figure 3.2 Conceptual Model.

3.2.2. Components of the System

Entity: is an object of an interest in the system, which requires an explicit representation in the system. In our system there is only one type of entity.

- Vehicles of armored battalion.

Attributes: are the characteristics of an entity.

- The beginning time of the movement,
- Priority of the vehicles,
- Damage type that the vehicles takes,
- The ending time of the movement.

System State: a collection of variables that contains all the information necessary to describe the system at any time.

- The number of vehicles in the system,
- Status of vehicles (damaged, destroyed or safe),
- The number idle maintenance and repairing team.

Events: an instantaneous occurrence that changes the state of the system.

- *The Marching Order*: The march order is given to the armored battalion from the armored brigade commandant and is the beginning of the movement from starting point (assembly area).
- *Breakdowns of The Vehicles On The Road*: Any vehicle of the battalion that is broken down on the road, is immediately driven off the road and is repaired by the maintenance and repairing team.

- *Artillery Assault On The Road*: Any vehicle of the battalion which is damaged caused by the artillery assault of the enemy is immediately driven off the road and is repaired by the maintenance and repairing team after the assault. If it is totally destructed it is left in a safe area with its crew.
- *Air Attack On The Road*: Same procedure with artillery assault.
- *Ground Mines On The Road*: Same procedure with artillery assault.
- *Ambush On The Road*: Same procedure with artillery assault.
- *Repairing Of The Damaged or Broken Vehicles*: Maintenance and repairing team beginning with the armored vehicles immediately repair damaged or broken vehicles.
- *Arrival of The Vehicles To The Mobilization Task Areas*: Every vehicle, which reaches the releasing point, marches immediately to mobilization task areas.

Variables:

1. ***Exogenous Variables***: These are the input variables that are external to the model. They exist independently of the model. There are two kinds of exogenous variables:
   a. Controllable Variables (Decision Variables)
   b. Uncontrollable Variables (Parameters)

a. Controllable Variables:

- Velocity of the vehicles of armored battalion and semi-trailers,

b. Uncontrollable Variables:

- Repairing time of broken vehicles due to the breakdowns.
- Repairing time of damaged vehicles due to artillery assault, ambushes, air attacks and mine fields.

2. ***Endogenous Variables:*** These are the output variables that are internal to the model and are the function of the exogenous variables and the model structure. There are two kinds of endogenous variables:

    a. State Variables,

    b. Performance Measures.

a. State Variables:

- Number of vehicles waiting in the artillery assault repairing queue,
- Number of vehicles waiting in the air attack repairing queue,
- Number of vehicles waiting in the minefield repairing queue,
- Number of vehicles waiting in the ambush repairing queue,
- Number of vehicles waiting in the breakdown repairing queue,
- Number of safe vehicles in the convoy,
- State of the maintenance and repairing team (idle or busy).

b. Performance Measures:

The *Performance Measures* of the model are:

- Maximum time-in-system (MTIS) measure of the last vehicle reaching the releasing point,
- Number of destroyed vehicles (NODV),
- Total number of damaged vehicles,
- Average waiting time of vehicles in each random event,
- Average time in system measures of vehicles,
- Average waiting time of vehicles in the artillery assault repairing queue,
- Average waiting time of vehicles in the air attack repairing queue,
- Average waiting time of vehicles in the minefield repairing queue,
- Average waiting time of vehicles in the ambush repairing queue,
- Average time in system measure of last vehicle reaching the releasing point (Mobilization task area),
- Number of damaged armored vehicles due to artillery assault,
- Number of damaged armored vehicles due to air attack,
- Number of damaged armored vehicles due to minefield,
- Number of damaged armored vehicles due to ambush,
- Number of damaged wheeled vehicles due to artillery assault,
- Number of damaged wheeled vehicles due to air attack,
- Number of damaged wheeled vehicles due to minefield,
- Number of damaged wheeled vehicles due to ambush,

- Number of damaged wheeled vehicles due to breakdown,
- Number of destroyed armored vehicles due to artillery assault,
- Number of destroyed armored vehicles due to air attack,
- Number of destroyed armored vehicles due to mine field,
- Number of destroyed wheeled vehicles due to artillery assault,
- Number of destroyed wheeled vehicles due to air attack,
- Number of destroyed wheeled vehicles due to minefield,
- Number of destroyed wheeled vehicles due to ambush,
- Number of destroyed wheeled vehicles due to breakdown,
- Total number of destroyed vehicles,
- Total number of damaged vehicles.

3.2.3. Logical Model (Flowchart of the System)

Logical model (flowchart of the system) shows the relationships among the elements of the model. The summary flowchart of the model is illustrated in Figure 3.3. The detailed flowchart is given in Appendix C.

The Starting Event: The announcement of movement order to battalion commander.

The Ending Event: The occupation of the Mobilization Task Area.

The Main Events:

- The movement from Assembly Area to Mobilization Task Area,
- The natural breakdowns of vehicles,
- The retarding events that caused both by enemy and terrain.

By Enemy:

- Air attacks,
- Artillery assaults,
- Mines and Booby Traps,
- Ambush and/or sniper fire.

By Terrain:

- Natural breakdowns of vehicles.

3.2.4. Simulation Model (Computer Code)

In this thesis we model the movement by using ARENA 3.0 Simulation Software Package. Arena Simulation Software Package allows users to create graphical models with animation and also helps its user in input and output data analysis with the output and input analyzer.

We model the movement operation in Arena 3.0 by using a Model Frame, in which we describe the components of our system and their interactions, and an Experimental Frame in which we define experimental conditions to generate specific output data that we need.

We model our system by using a process orientation in which we study the entities (vehicles of the armored battalion) that move through this system. Each entity has some attributes such as, company identification number, vehicle type, priority, etc. Firstly, we develop a description for the movement operation's process. In developing description of our system we define the movement operation entities. Then we describe the process through which the entities move.

We model the random events by using a block diagram, which is a flow graph that shows the process through which the entities move in the movement system. We combine standards blocks of Arena into a block diagram, which describes the random events being modeled.

The block diagram we use for modeling the random events during the movement is the static component of our model whereas the entities (vehicles of the armored battalion) are the dynamic component, that moves through the block diagram activating the random events.

We develop station sub-models, which represent each random event and then combined them to represent the overall movement operation. We use transfer blocks for transferring the entities between these station sub-models to model all the movement between stations (random events) and we use free-path transporters to model the entity transfer between station sub-models. Each entity is transported with a free-path transporter.

We define a transporter's system map by specifying travel distances between all stations that free-path transporter may visit. Besides, we specify the movement velocity (32 km/h. or 45 km/h.) as the velocity of the free-path transporters.

We model the breakdowns caused by random events by using conditional and probabilistic branches in station sub-models. We define the maintenance and repair team as resources that are allocated to vehicles waiting to be repaired. Finally, we collect the statistics that we need by collecting the observational and time-dependent data from our model.

The details about the computer code are given in Table 3.1. Some part of the computer code is given in Appendix B.

Table 3.1 Technical Information About Simulation Model.

Size (with animation)	**5.39 MB**
Size (w/o animation)	**4.85 MB**
Simulation Run Time (Speed factor 20)	**0.03 minutes**
<u>Model File</u>	
Size	**111 KB**
Number of Lines	**1539**
<u>Experimental File</u>	
Size	**66 KB**
Number of lines	**488**

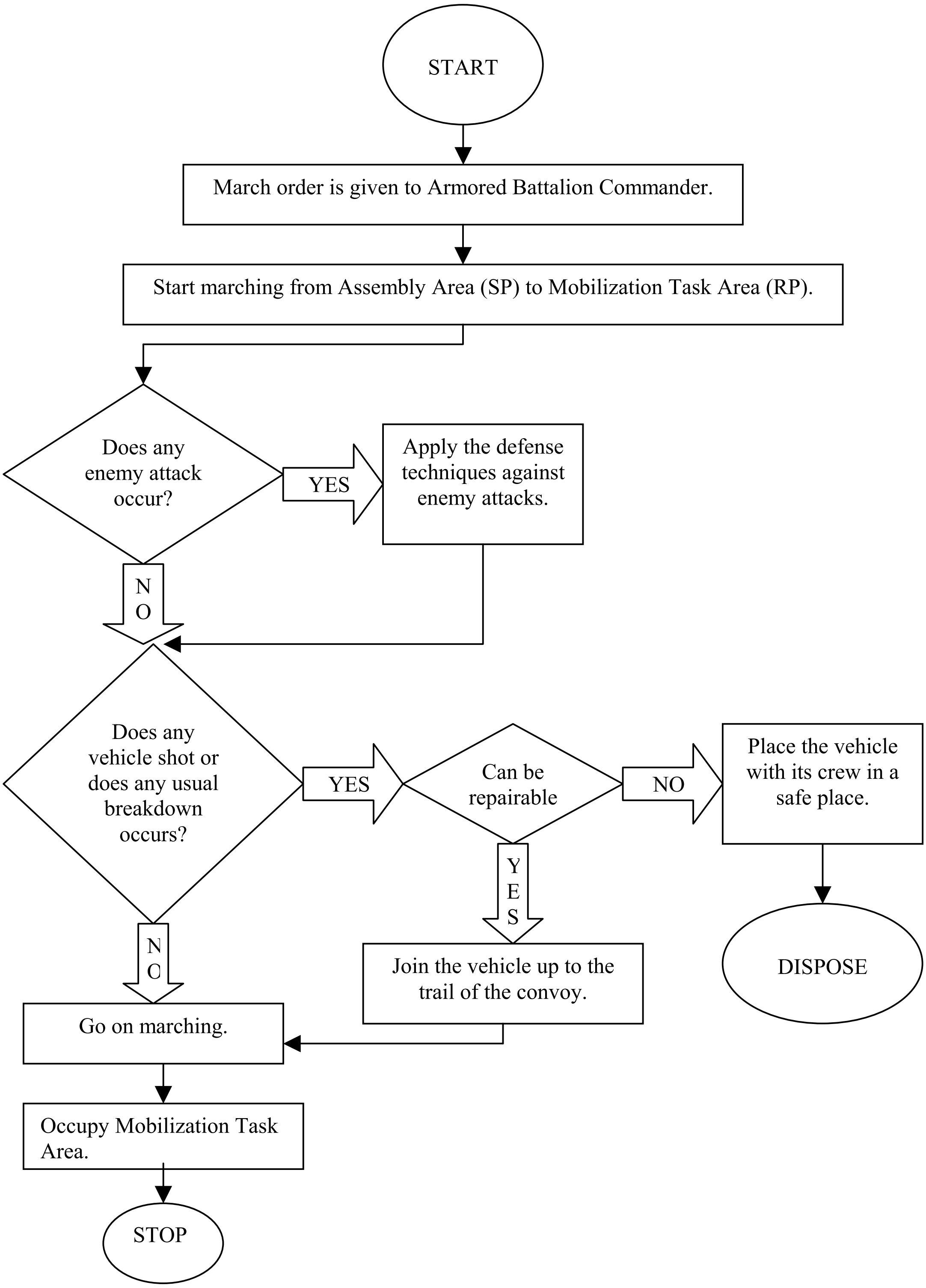


Figure 3.3 General Flowchart of the System.

3.3. Input Data Analysis

The input data we collected in our simulation model are from the following sources:

1. KKT 190-1 (A) Manevra ve Tatbikatların Sevk ve İdaresi (July 1998),
2. KKYY 315-1 Kara Harp Silah Araç ve Gereçleri (July 2000),
3. Database of JANUS Software,
4. Staff Officers and Armored Battalion Commanders, Tank Company Commanders: Since these personnel are the planners and the executors of this type of an operation, they are experts on this subject. We are lack of some of real life data due to the reason that there is no opportunity to collect the wartime data. So we interview with these experts and collect data of some activities.

Since we are lack of some real life data, we convert the data, which we collected by interviewing the experts, into triangular distribution as recommended by Banks (1998), and Smith (1998).

There are totally 69 variables in our model. 49 of these variables are random variables. The list of the input data we use in our model is given in Appendix D.

3.4. Model Verification And Validation

We conduct Verification and Validation of our model considering the techniques stated in Balci (1998) and Pegden, Shannon, and Sadowski (1995).

3.4.1. Verification of the Model

We use the following techniques:

- **ARENA Run Controller:** ARENA Simulation Software Package has a run controller function, which allows users to monitor and control model execution. The run controller is designed for searching for errors in the model and performing walkthroughs during verification. We use ARENA run controller to verify our model.

- **Model and Experiment Walkthroughs:** We conduct model and experimental walkthrough with the officers from our department who are familiar with the system and ARENA programming language.

- **Test Runs:** We perform test runs to exercise the model under different and extreme conditions by using extreme parameter settings, such as increasing the number of vehicles in the system, increasing the rate of occurrence of breakdowns, reducing the service rate of maintenance and repairing team, etc.

- **Animation:** Animation is a more powerful verification aid than the other techniques since it has the capability to show the moving pictures of the many events during the simulation process. We use animation to see all the interactions simultaneously and to correct the errors. A screenshot from our model is given in Figure 3.4.

- **Statistical Data:** ARENA Simulation Software Package enables us to build model and conduct statistical analysis to make some inferences about the system we modeled. We use this feature of ARENA, which collects statistics automatically.

3.4.2. Validation of the Model

3.4.2.1. Tests for Reasonableness

- **Continuity:** We make some small changes in our model to test whether these changes in the input variables cause small changes in the outputs or not, not in the magnitude but in the direction. For instance, we increase the number of vehicles of the armored battalion, and we see that the average waiting time of the vehicles in the repair queue increases.

- **Consistency:** We change the random-number seeds and take some runs to test whether our model yields similar results by making similar runs or not. We reach the almost the same results after changing the random-number seed.

- **Degeneracy**: We test our model by decreasing the number of technicians in the maintenance and repairing team, namely by removing some features of the model, and observe if our model respond to removals. We observe that by decreasing the capacity of technicians (removing a few technicians) from the system, time-in-system performance measure increases.

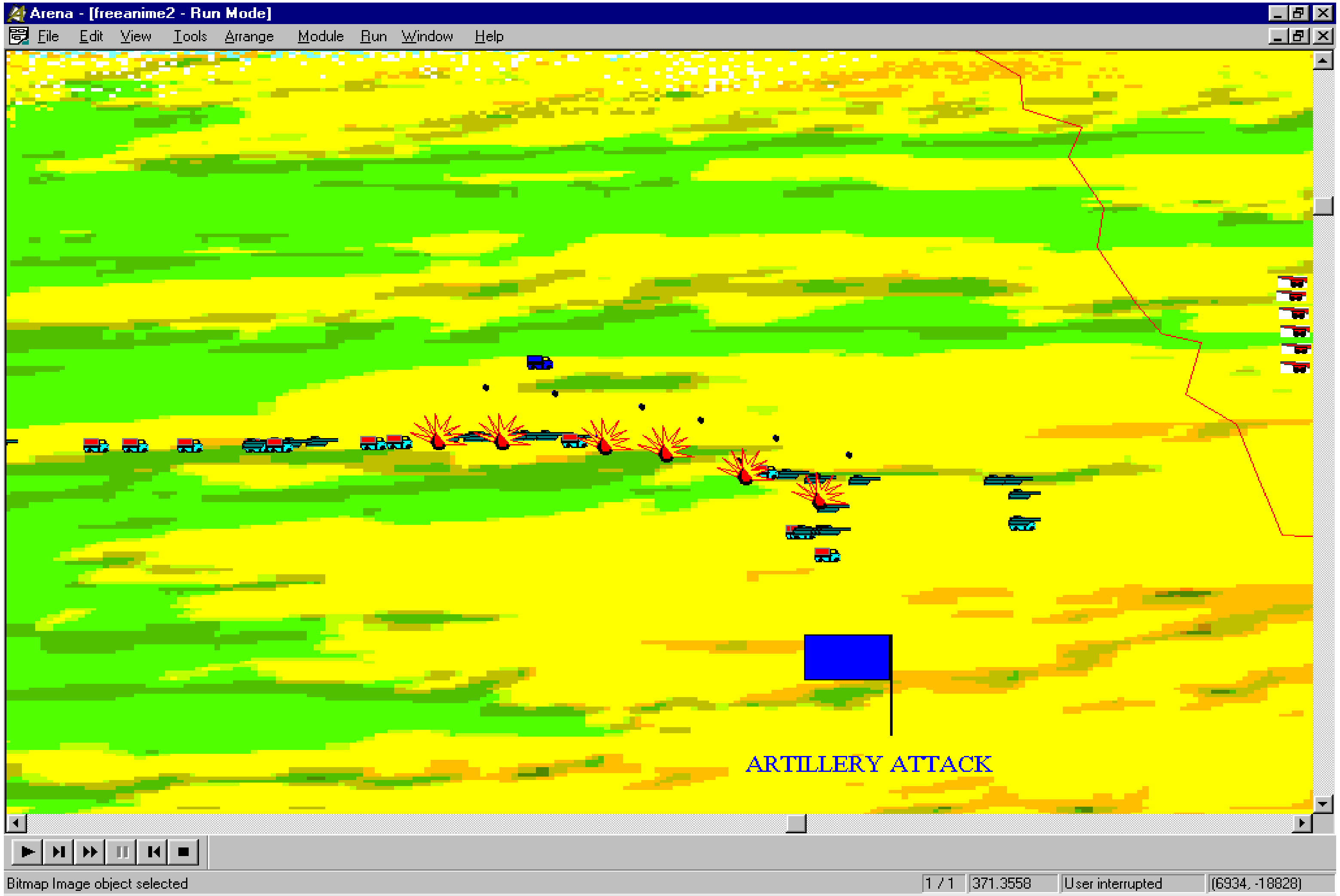


Figure 3.4 A Screen Shot From Model.

3.4.2.2. Model Structure and Data Tests

- **Face Validity:** This technique is used to validate the correctness of the logic in the model and performed by asking persons familiar with the system. We perform face validity by interviewing with armored battalion and tank company commanders who are the executors of this operation. Also, we consult the conceptual model, logical model and assumptions with the training officers and NCO technicians in Armored Units School and Training Division Commandant, Ankara, Turkey, who are the experts on the movement operation of armored units, from the beginning of building the model to the end of interpreting the outputs.

- **Sensitivity Analysis:** This technique is achieved by observing the behavior of the model caused by small changes in the model's parameters. We make some changes in our model's parameters and see how these changes affect the behavior of the model. We see that slight changes in the parameters do not conflict with our expectations of the movement operation due to the reason that these changes do not produce different decisions.

CHAPTER 4

Design and Analysis of Experiments

The design of experiments is a powerful tool to design and evaluate experiments for the purpose of estimating how changes in input variables affect the output variables (response). This tool helps us to understand the reasons of changes in the response caused by changing input variables, to have more information on system behavior and to improve the system performance. Since our aim is to understand the behavior of the movement operation, we can use experimental design to characterize our system.

4.1. Comparative Experiments

The main idea in comparative experiments is to compare two systems, scenarios or conditions. As we mentioned in Chapter 1, there is not enough number of semi-trailers to transport armored vehicles of all battalions next to any border at once. Armored vehicles of some battalions are transported while armored vehicles of remaining battalions march to their mobilization task areas on foot. Thus, we have two scenarios:

Scenario 1. All vehicles of the armored battalion march on foot,

Scenario 2: Semi-trailers transport armored vehicles of the armored battalion while wheeled vehicles of the armored battalion march on foot with semi-trailers.

We have also three cases for these scenarios. These cases are the following:

- *Best Case (Case 1)*: There is no retarding event of enemy (air attack, artillery attack, ambush and mine). There is only breakdown of vehicles with certain probability as a stochastic event.

- *Most Possible Case (Case 2)*: All retarding events of enemy forces and breakdown of vehicles are involved with certain probabilities.

- *Worst Case (Case 3)*: All retarding events of enemy forces are involved with probability 1 and breakdown of vehicles is with certain probability. The critical point is probability of occurrence 1 does not mean that all these events damage or destroy vehicles. For example, enemy artillery attack occurs with probability one; but if the artillery concentration is ahead or behind the convoy none of the vehicles is damaged or if the mine is noticed there will be no loss.

We can now make comparative experiments with these scenarios. But, first of all we should start with determining the sample size to achieve the desired accuracy to make correct estimations on true unknown parameters that we want to estimate and to compare these scenarios with a sufficiently small experimental error.

4.1.1. Determination of Sample Size

Determining the sample size is an important part of experimental design to achieve the desired accuracy on the estimates and to have a sufficiently small experimental error.

We perform the Sequential Procedure (Law and Kelton), with the absolute precision criterion to determine the sample size as follows:

Sequential Procedure:

1st Step: Make n_o replications $n = n_o$

2nd Step: Compute $\overline{X}(n)$ and $\delta(n,\alpha)$

Where $\overline{X}(n) = \frac{1}{n}\sum_{i=1}^{n} X_i$ and $\delta(n,\alpha) = t_{n-1,\, 1-\alpha/2}\sqrt{s^2(n)/n}$.

3rd Step: If $\delta(n,\alpha) < \beta$, stop; else, n=n+1 and go to 2nd Step.

We have two performance measures:

1. Maximum time-in-system (MTIS) measure of last vehicle reaching the releasing point (mobilization task area).
2. Total number of destroyed vehicles (NODV) during the movement.

We consulted with the staff officers and armored battalion commanders and specify that for the first performance measure β=15 minutes and for the second performance measure β=5 vehicles of absolute precision is normal with %95 accuracy.

We computed the sample sizes for two performance measures according to these scenarios and under these cases. The results are given in Appendix E.

4.1.2 Building Confidence Intervals

After determining the sample size we need, now we build confidence intervals on the means of our performance measures. Table 4.1 and Table 4.2 show the summary results of confidence intervals for MTIS and NODV respectively.

Assuming that μ is the true unknown parameter that we want to estimate; to build a confidence interval we need to find the upper limit (U) and the lower limit (L) statistics such that $P(L \leq \theta \leq U) = 1-\alpha$ is true. In our case $\alpha = 0.05$.

- **100(1-α) % Confidence Interval for the Mean of MTIS**

Table 4.1 Summary Table of 100(1-α) % Confidence Interval for MTIS.

		# of REP.	MEAN	VARIANCE	HALF-LENGTH	L	U
SCENARIO 1	CASE 1	5	193.58	66.344	10.126	183.454	203.706
	CASE2	7	261.943	229.633	14.032	247.911	275.975
	CASE3	13	303.284	614.867	14.99	288.294	318.274
SCENARIO 2	CASE1	5	149.138	42.717	8.12	141.018	157.258
	CASE2	5	201.506	63.701	9.922	191.584	211.428
	CASE3	5	241.372	50.156	8.804	232.568	250.176

- **100(1-α) % Confidence Interval for the Mean of NODV**

Table 4.2 Summary Table of 100(1-α) % Confidence Interval for NODV.

		# of REP.	MEAN	VARIANCE	HALF-LENGTH	L	U
SCENARIO 1	CASE 1	5	0	0	0	0	0
	CASE2	5	4.4	2.3	1.885	2.515	6.285
	CASE3	5	7.8	1.7	1.621	6.179	9.421
SCENARIO 2	CASE1	5	0	0	0	0	0
	CASE2	5	5.6	9.8	3.89	1.71	9.49
	CASE3	5	7	10	3.931	3.069	10.931

4.1.3. Comparison of Alternative System Design

Comparison of alternative system designs is one of the important uses of simulation. We can compare two alternative scenarios, different operating policies, alternative production plans or different system designs by the help of simulation.

In our model, as we mention we have two scenarios (Scenario-1 and Scenario-2). In Scenario-1 armored battalion march on foot whereas in Scenario-2 all armored vehicles of the battalion are transported on semi-trailers. In Scenario-1 the velocity of the convoy is 32 km/h. and in Scenario-2 the velocity of the convoy is 45 km/h. It is intuitively expected that Scenario-2 is better than the Scenario-1 for the maximum time-in-system (MTIS) performance measure. Because the velocity of the convoy in Scenario-2 is higher than that of Scenario-1. But, there is a fact that the wheeled vehicles are more vulnerable to enemy attacks than the armored vehicles. Therefore, the probability of being damaged for wheeled vehicles is higher than that of armored vehicles. This means that, there may probably be more damaged vehicles when there are more wheeled vehicles in the convoy and this causes more repair time. In Scenario-1 there are 67 armored vehicles and 86 wheeled vehicles whereas in Scenario-2 all 153 vehicles are wheeled because all armored vehicles are transported on semi-trailers. Thus, this fact has an adverse effect for MTIS measure in Scenario-2.

We cannot intuitively decide whether Scenario-2 is better than Scenario-1 under these conditions unless we perform the movement under war conditions and observe behavior of the system. Therefore, we use simulation model of movement operation.

We run our simulation model and obtain the results of two scenarios under best, most possible and worst cases. Our aim is to decide whether there is a statistically significant difference between two scenarios. Since maximum number of replication needed to achieve desired accuracy is 13 we make our computations based on 15 replications. We compare the corresponding cases in these two scenarios, i.e. Scenario-1 best case vs. Scenario-2 best case. We use Paired-t Test for comparing these scenarios.

Let X_i and Y_i be the results of the ith replication of Scenario-1 and Scenario-2 respectively. And let Z_i be the difference of X_i - Y_i and let n be the number of replications.

Average of differences is, $\overline{Z}(n) = \frac{1}{n}\sum_{i=1}^{n} Z_i$ and variance of differences $V(\overline{Z}(n)) = \frac{V(Z_i)}{n}$

where $V(Z_i) = \frac{1}{n-1}\sum_{i=1}^{n}(Z_i - \overline{Z})^2$.

100(1-α) % CI for the mean of differences is;

$$\overline{Z}(n) \pm t_{n-1,1-\alpha/2}\sqrt{V(\overline{Z}(n))} .$$

We can state our hypothesis testing as follows:

$$H_o: \overline{Z}(n) = 0$$

$$H_{1:} \overline{Z}(n) \neq 0$$

- **Paired-t Test for MTIS**

Case 1 (Best Case):

Table 4.3 Results of Paired-t Test for the Best Case.

REP. #	X_i	Y_i	Z_i
1	187.28	153.45	33.83
2	207.45	158.53	48.92
3	194.13	144.25	49.88
4	189.38	145.54	43.84
5	189.66	143.92	45.74
6	194.6	162.19	32.41
7	187.84	144.54	43.3
8	190.94	142.49	48.45
9	192.15	147.69	44.46
10	194.28	155.19	39.09
11	192	145.05	46.95
12	221.07	144.09	76.98
13	180.23	135.33	44.9
14	193.36	164.15	29.21
15	208.92	141.54	67.38
The difference is significant		$\overline{Z}$ (n)	**46.356**
		$V(Z_i)$	**151.68**
Reject Ho		$V(\overline{Z}(n))$	**10.11**
		100(1-α) % CI	**(39.552 , 53.16)**

We give the results of Best Case in Table 4.3. We compute the results of remaining cases and give the summary table of our findings in Table 4.4 and the data lists we use in Paired-t Test are given in Appendix F.

The results we present in Table 4.4 show that the difference between two scenarios for MTIS performance measure is statistically significant. Consequently, we can say that Scenario-2 is better than Scenario-1 for MTIS performance measure since the purpose is to minimize the MTIS.

Table 4.4 Summary Table of Paired-t Test Results for MTIS.

	CASE1	CASE2	CASE3
$\overline{Z}$ (n)	46.356	53.684	56.9
$V(Z_i)$	151.68	892.08	1914.18
$V(\overline{Z}(n))$	10.11	59.47	127.61
100(1-α) % CI	(39.552 , 53.16)	(37.181 , 70.187)	(32.726 , 81.074)
Result	Reject Ho	Reject Ho	Reject Ho

- **Paired-t Test for Number of Destroyed Vehicles**

We apply Paired-t test for our second performance measure to determine whether there is a statistically significant difference between two scenarios for each cases or not. The results are given in Table 4.5 and the data lists we use in our computations are given in Appendix E.

Table 4.5 Summary Table of Paired-t Test Results for NODV.

	CASE1	CASE2	CASE3
$\overline{Z}$ (n)	0.07	0.903	0.867
$V(Z_i)$	0.07	11.209	7.267
$V(\overline{Z}(n))$	0.004	0.747	0.484
100(1-α) % CI	(-0.065 , 0.205)	(-2.78 , 0.92)	(-0.618 , 2.358)
Result	Do Not Reject Ho	Do Not Reject Ho	Do Not Reject Ho

When we observe the Table 4.5 we can easily state that there is not a statistically significant difference between two scenarios for number of destroyed vehicles. It is an expected result, because tank-carrying vehicles are not armored and have no feature to protect the vehicles, which they carry, they are used to transport the armored vehicles just to speed up the movement. Therefore, it is normal that there is not a significant difference between two scenarios for the second performance measure.

4.2. 2^k Factorial Design

Factorial designs are widely used in experiments involving several factors where it is necessary to study the joint effect of the factors on a response (Montgomery, 1992). Factorial design is useful strategy, which allows each factor to assume only two levels i.e. high (+) and low (-). In factorial design 2^k possible factor level combinations are investigated in each complete trial of experiment.

In our study we apply 2^k factorial design to find main effects and interactions between factors according to our performance measures. Before conducting the 2^k factorial design, we validate the following assumptions:

1. *The designs are completely randomized*.

To ensure the randomization of design points we used different seeds for each design point.

2. *The factors are fixed.*

In this study we have five different fixed factors with two levels i.e. high (1) and low (0). The factor descriptions, low and high levels of factors are given in Table 4.6.

Table 4.6 The Factor Description and Factor Levels.

FACTOR	FACTOR DESCRIPTION	LOW LEVEL (0)	HIGH LEVEL
A	AIR ATTACK	0	1
B	AMBUSH	0	1
C	MINE	0	1
D	ARTILLERY ATTACK	0	1
E	BREAKDOWN	0.04	0.16

The low levels of four factors A, B, C and D, which are the enemy retarding events, are 0. Because these events may not occur during movement and this case also represents our best case. In such a long-ranged movement operation it is unavoidable to have no breakdown of vehicles. Therefore, low level of breakdown factor is not zero but 0.04.

The high level for factors A, B, C and D is 1. Since we try to evaluate the war conditions these levels also represents our worst case. The high level of breakdown is 0.16. We specify the low and high levels of breakdown factor by interviewing with the technicians of armored battalions. Since we have 5 factors, we have totally 32 design points. The design matrix for 2^5 factorial design is given in Appendix G. We make 15 replications for each design point. The outputs of design points for each performance measure are given in Appendix G.

4.2.1. Diagnostic Checking

Our purpose is to find the significant factors and interactions between factors in this study. We perform ANOVA to achieve our purpose but before performing ANOVA we should check the validity of two important assumptions. These assumptions are normality assumption and the assumption of homogeneity of variance.

A. Normality Assumption.

Diagnostic checking tools are generally based on residuals. Thus, we examine residuals to check the validity of normality assumption. The residuals in our model can be defined as:

$$e_{ij} = y_{ij} - \hat{y}_{ij}$$

This equation can be stated as the residuals for the ith design point are found by subtracting mean of design point from each observation in that design point. In our model we computed the residuals by using regression model. We give the regression models and the list of residuals for each performance measure in Appendix H.

After computing the residuals we draw the scatter plots of these residuals and normal probability plots of residuals for each performance measure.

- **Plot of Residuals**

  The plot of residuals should not indicate any structure or any obvious pattern. Our plots of residuals are given in Figure 4.1 and Figure 4.2 for MTIS and NODV respectively. We can observe from our plots easily that none of the plots has an obvious pattern or structure for each performance measure.

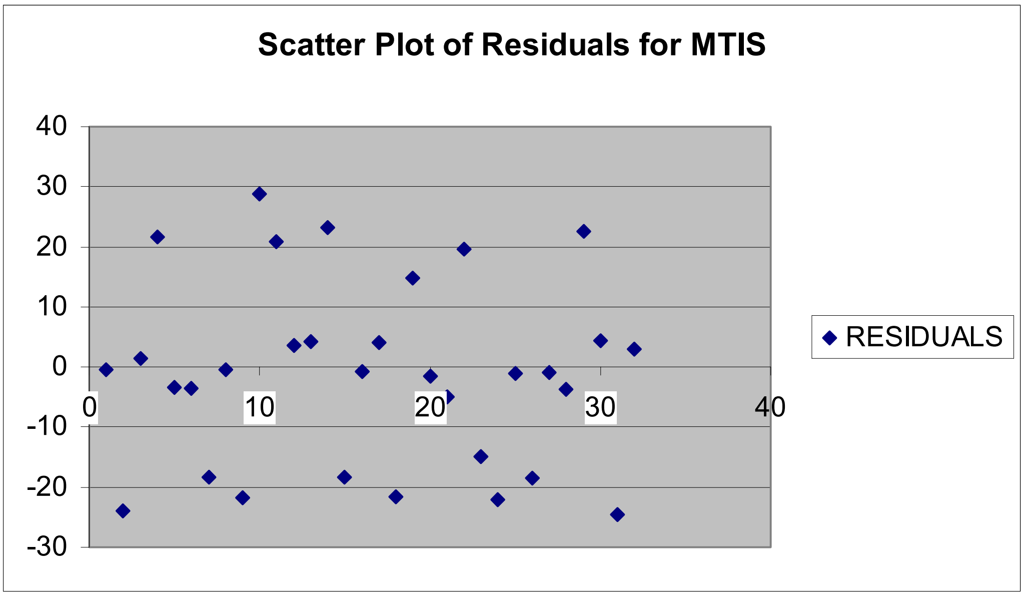


Figure 4.1 Scatter Plot of Residuals for MTIS.

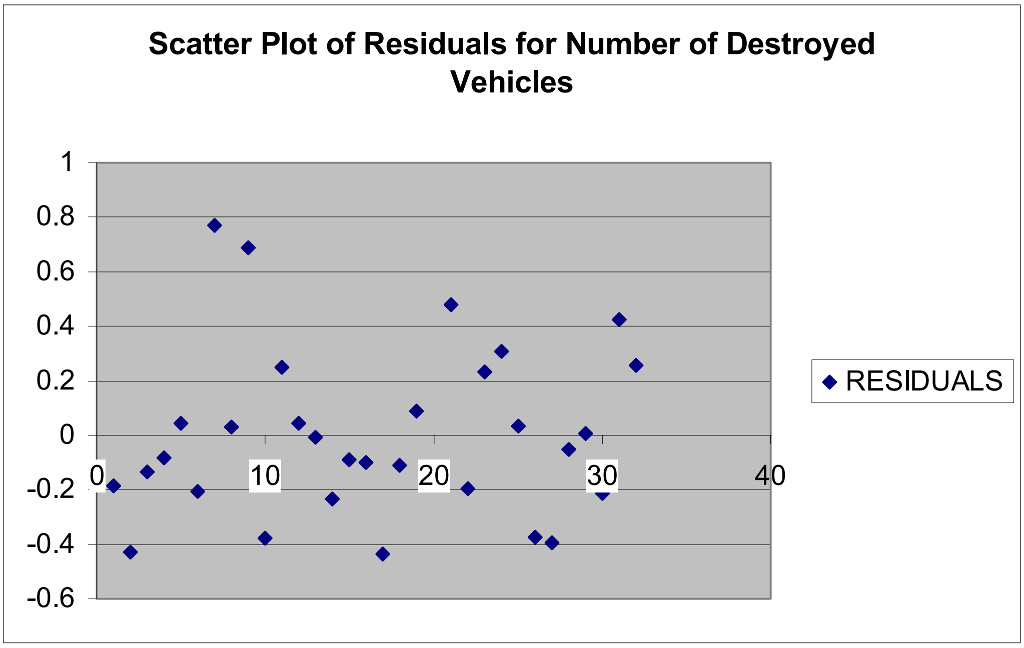


Figure 4.2 Scatter Plot of Residuals for NODV.

- **Normal Probability Plot of Residuals**

After plotting the scatter plot of residuals, we draw the normal probability plots of residuals. We arrange the residuals in an increasing order and then draw the kth of these ordered residuals versus cumulative probability point $P_k = (k - ½) / N$. this plot should resemble a straight line. Our plots for MTIS and NODV measures are given in Figure 4.3 and Figure 4.4 respectively.

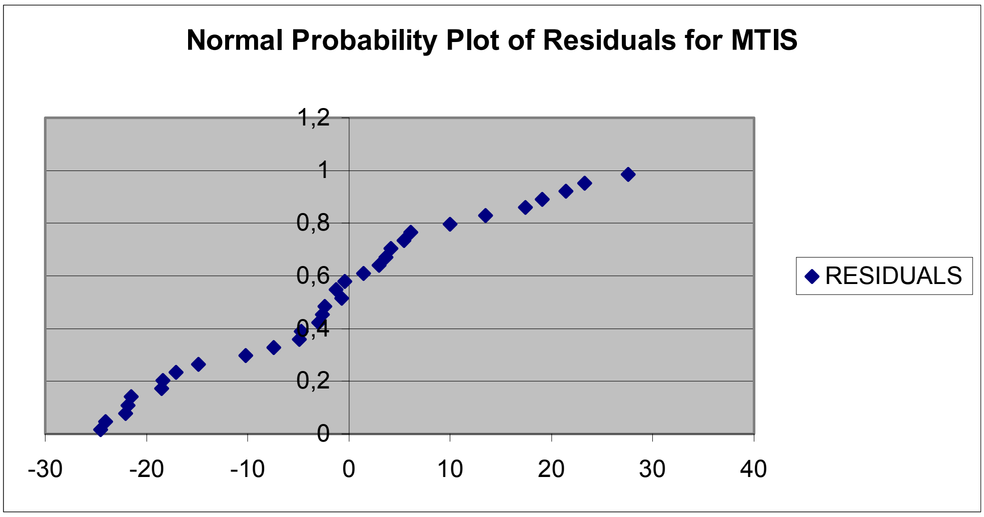


Figure 4.3 Normal Probability Plot of Residuals for MTIS.

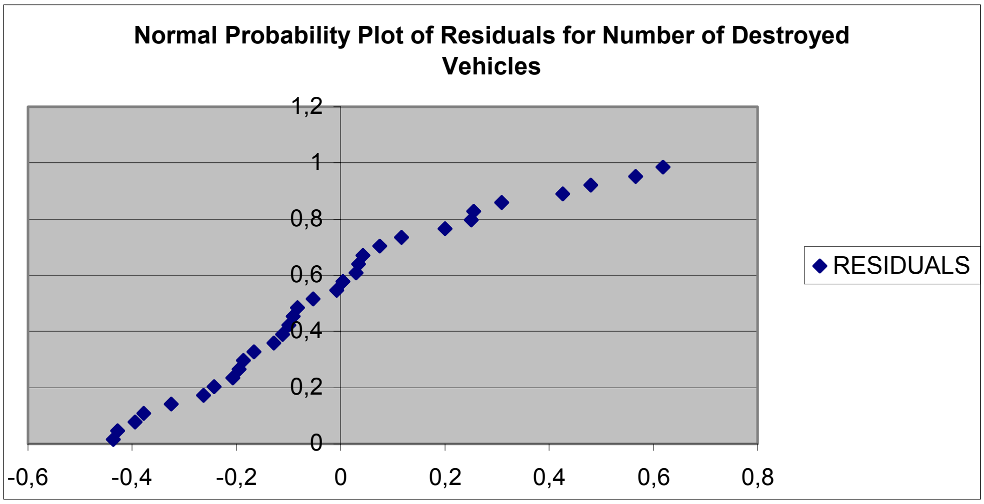


Figure 4.4 Normal Probability Plot of Residuals for NODV.

We can again safely state that our normal probability plots of residuals resemble a straight line.

B. Assumption of Homogeneity of Variance.

Our second assumption is the homogeneity of variance. There are several tests to check the equality of variances. We perform Bartlett's Test (Montgomery, 1992). We can state the hypothesis test as follows:

$$H_0 = \sigma_1^2 = \sigma_2^2 = \ldots\ldots = \sigma_a^2$$

$H_1 =$ Above is not true for at least one σ_i^2 where,

a is the number of design points we experiment.

Bartlett's test procedure (Montgomery, 1992) is to compare the test statistic with sample distribution, which approximated by the chi-square distribution with a-1 degree of freedom. The test statistics is:

$$\chi_0^2 = 2.3026\frac{q}{c}$$

where $$q = (N-a)\log_{10} S_p^2 - \sum_{i=1}^{a}(n-1)\log_{10} S_i^2$$

$$c = 1 + \frac{1}{3(a-1)}\left(\sum_{i=1}^{a}(n-1)^{-1} - (N-a)^{-1}\right)$$

$$S_p^2 = \frac{\sum_{i=1}^{a}(n_i-1)S_i^2}{N-a}$$ and S_i^2 is the sample variance of ith population.

We reject Ho if $\chi_0^2 > \chi_{\alpha,a-1}^2$.

Table 4.7 Bartlett's Test Result for MTIS.

	q	c	S_p^2	χ_o^2	$\chi_{\alpha,a-1}^2$	**RESULT**
MTIS	34.917	1.025	258.596	**78.439**	**45**	**Reject Ho**

We perform Bartlett's test for MTIS and the result is given in Table 4.7. According to test result we reject the null hypothesis since the variances are not homogenous.

There are several ways to deal with non-constant variance. One of them is to apply a variance-stabilizing transformation (Montgomery, 1992).

We can choose the form of the transformation if we know the relationship between the variance of the observation and the mean.

Assuming that the standard deviation of y is proportional to a power of the mean of y. In this case:

$\sigma_y \propto \mu^{\alpha}$ and suppose that the transformation is a power of y such that

$y^* = y^{\lambda}$. Then we can state that

$\sigma_{y^*} \propto \mu^{\lambda+\alpha-1}$ and if we set $\lambda = 1-\alpha$ then the variance of the transformed data is constant.

<u>Empirical Selection of α:</u> (Montgomery, 1992). We have replications of data. Therefore, we can empirically estimate α from our data. Since in the ith design point

$\sigma_{y_i} \propto \mu_i^{\alpha} = \theta\mu_i^{\alpha}$ where θ is a constant of proportionality we can take logs to obtain

$$\log\sigma_{y_i} = \log\theta + \alpha \log \mu_i$$

The plot of log σ_{y_i} versus $\log\mu_i$ should be straight line with slope α. We can use the estimates of σ_{y_i} and μ_i. We use the standard deviations S_i and the averages of design points and plot log S_i versus log $\bar{y}_i$. The plot is shown in Figure 4.5. The slope of the straight line passing through the points is approximately 3/2. Hence, we can use reciprocal square root transformation (Design and Analysis of Experiments, D. C. Montgomery, 1992, Table 4-3, p.104).

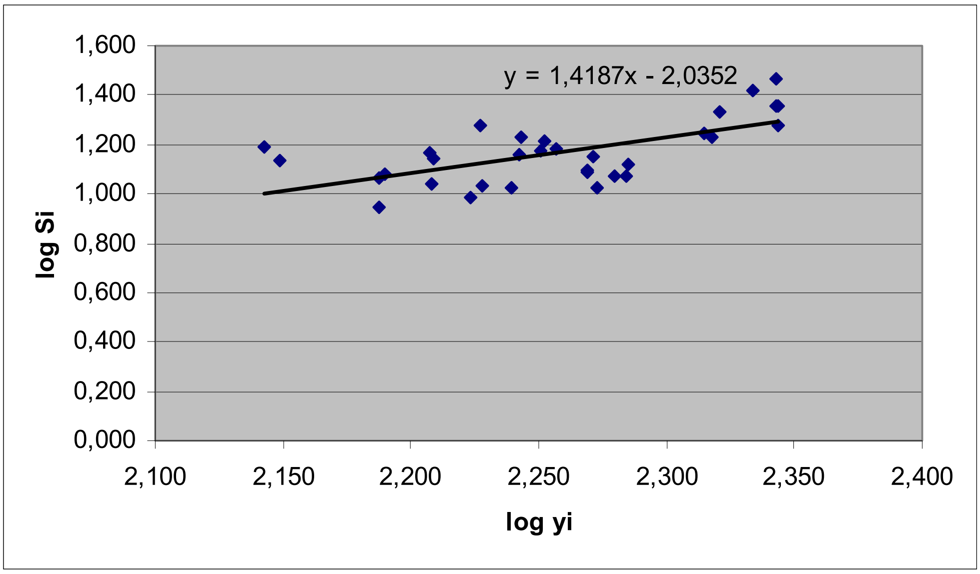


Figure 4.5. Plot of log S_i versus log $\bar{y}_i$.

We perform Bartlett's test to see if the variance of the transformed data is stabilized or not. The result is shown in Table 4.8. The result of the Bartlett's test shows us that we stabilize the variance. Also, we perform ANOVA with transformed data and observe that there is not a significant difference between the ANOVA results of normal data and the transformed data. The ANOVA results of transformed data are given in Appendix I.

Table 4.8 Bartlett's Test Result for MTIS with Transformed Data.

	q	c	S_p^2	χ_o^2	$\chi^2_{\alpha,a-1}$	**RESULT**
MTIS	19.046	1.025	0.00001	**42.785**	**45**	**Do Not Reject Ho**

Bartlett's test is not applicable for NODV performance measure since the variance of the first design point of this performance measure is zero and we cannot take the log of the variance of this design point to calculate the test statistic of Bartlett's test. We just examine the scatter plot of variances to check the homogeneity of variance assumption. We observe the scatter plot of variances (Figure 4.6) and see that there is not any obvious pattern or structure in the plot.

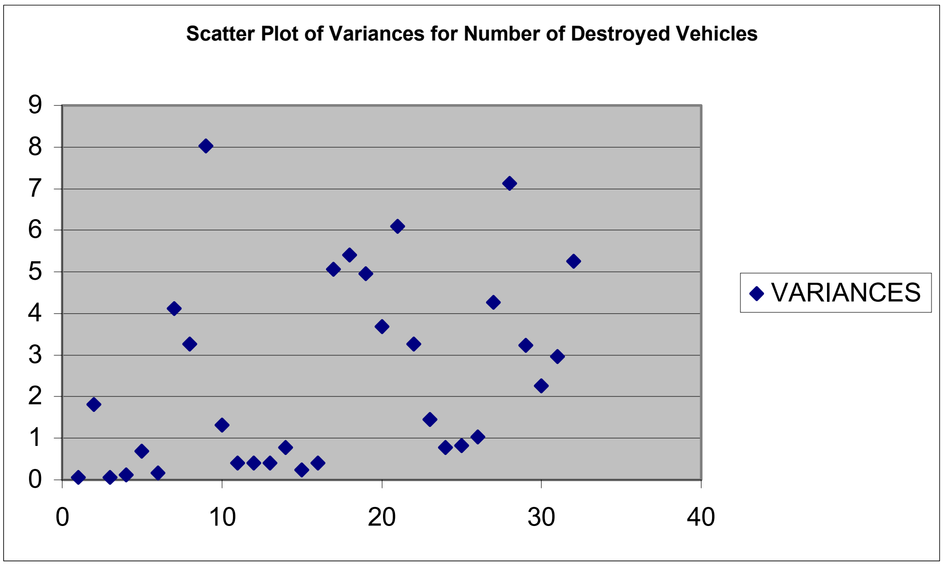


Figure 4.6 Scatter Plot of Variances for NODV.

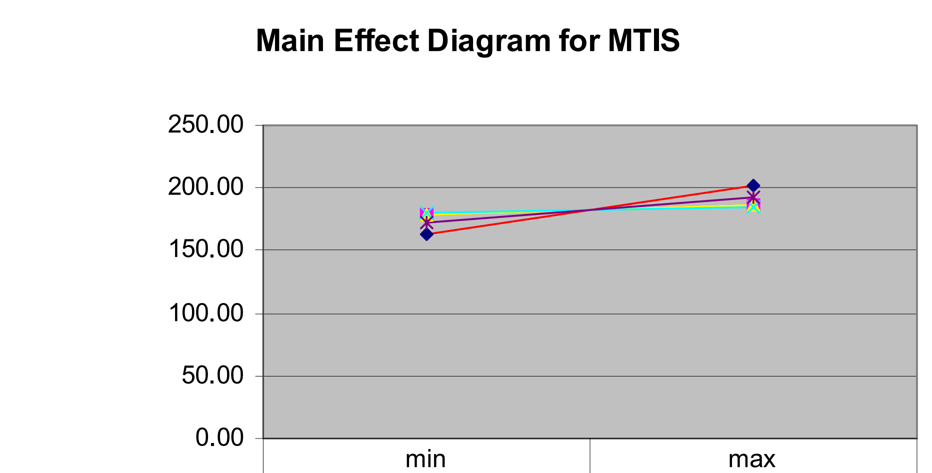
As a conclusion, after we satisfy the assumptions we can safely perform and interpret the results of ANOVA.

4.2.2. Analysis of ANOVA the Results

We perform ANOVA by using SPSS 11.0 software to find out the significant factors affecting our performance measures and their interactions. The results of ANOVA for each performance measure are given in Appendix I.

4.2.2.1. Evaluation of Main Effects and Interactions for MTIS

We perform ANOVA for MTIS and find out the main effects and interactions between factors. Then we plot the diagrams of main effects and interactions. We evaluate the results and draw some conclusions using these plots. We have 5 significant factors and 4 interactions between these factors for MTIS performance measure. The plot of main effects is given in Figure 4.7. All the factors we present in Table 4.12 are significant and they have positive effects on MTIS performance measure. Air attack is the most significant factor of all factors and followed by breakdown factor. All the vehicles in the convoy are affected by enemy air attack, which is the most hazardous asset of enemy. Turkish Army is modernizing the vehicles in its inventory as much as possible but it is a fact that most of the vehicles are not sufficiently new and the possibility to have breakdowns in such a long-ranged operation is high. Ambush and mine do not have as much effect as air attack and breakdown have. Because during ambush of enemy only 4 or 5 vehicles damaged or destroyed. The width of kill zone of an ambush is 200 m. or at most 300 m. changing with the size of the ambush team. Since the gap between vehicles in convoy 50 m. there are only four or five vehicles in the kill zone. It means that, only the vehicles in the kill zone are damaged if they are hit. So, MTIS is affected by the repairing time of these damaged vehicles. This case also holds for the mine. In the mine operation at most 2 or 3 vehicles are damaged. There will be no time delay caused by mine if the mine is noticed or if the vehicles are not destroyed. Artillery attack has the smallest effect on MTIS. Because, the artillery attack of the enemy in such a movement operation is a kind of indirect fire and there will be no time delay if the artillery concentration is not on or ahead of the convoy.



	min	max
Air Attack	163.42	201.35
Ambush	178.68	186.09
Mine	178.93	185.85
Artillery Attack	179.95	184.82
Breakdown	171.78	192.99

Figure 4.7 The Plot of Main Effects for MTIS.

We can observe these explanations in the plot of main effects. As we can observe, the slope of air attack and breakdown is steeper than that of other factors. Other factors have significant but a little effect on MTIS.

We plot also the diagrams of interactions between factors. There are four significant interactions between our factors. These are breakdown-mine, air attack-breakdown, air attack-ambush and air attack-mine.

We begin with the interpretation of interaction between air attack and ambush. Figure 4.8 shows the interaction between these two factors. The blue line indicates change in MTIS when air attack factor is its low level while ambush factor is shifting from 0 to 1. The slope of this line is steeper than that of black line, which indicates the change in MTIS when air attack factor is its high level while ambush factor is shifting 0 to 1.

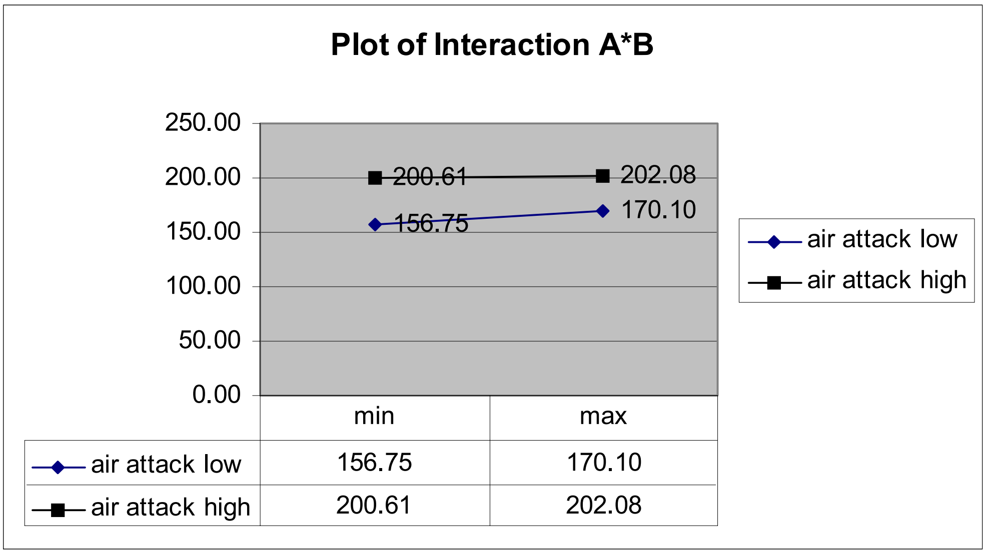


Figure 4.8 The Plot of Interaction Between Air Attack and Ambush

Because, when air attack is its high level, namely that when air attack occurs, the vehicles in the convoy disperse and the effect of the ambush on vehicles decreases. This decrease makes the slope of blue line less steep.

Another interaction is between breakdown and mine. The plot of this interaction is given in Figure 4.9. The blue line indicates the change in MTIS measure when breakdown factor is its low level while mine factor shifting from its low level to its high level. The black line indicates the change in MTIS measure when breakdown factor is its high level while mine factor is shifting from its low level to its high level. We observe that the slope of the change in MTIS is steeper when the breakdown factor is its low level. Because when the breakdown is its low level there is less number of vehicles in the breakdown repairing queue and time delay caused by mine appears significant. So, the slope of change in MTIS is steeper. On the other hand, when the breakdown is its high level there are more vehicles

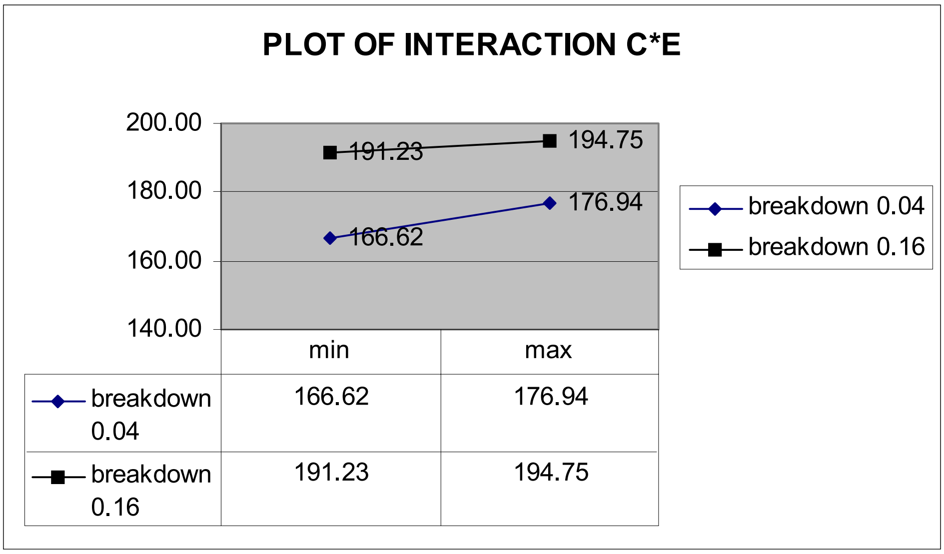


Figure 4.9 The Plot of Interaction Between Breakdown and Mine for MTIS.

in the breakdown- repairing queue. The time delay caused by mine is included in total time delay caused by both breakdown and mine and constitutes a small part of total time delay. Therefore, time delay caused by mine is not as significant as and the slope of change in MTIS is not as steep as when the breakdown is its low level.

Our third interaction is between air attack and mine factors. As can be seen in Figure 4.10 the blue line indicates the change in MTIS when air attack is its low level while mine probability is shifting from 0 to 1. The black line shows the change in MTIS when air attack is its high level while mine probability is shifting again from 0 to 1. The same reasoning, which we made for the interaction between breakdown and mine, is also valid in this case. Also the effect of this interaction is very small and it can be regarded as negligible when compared to that of other interactions.

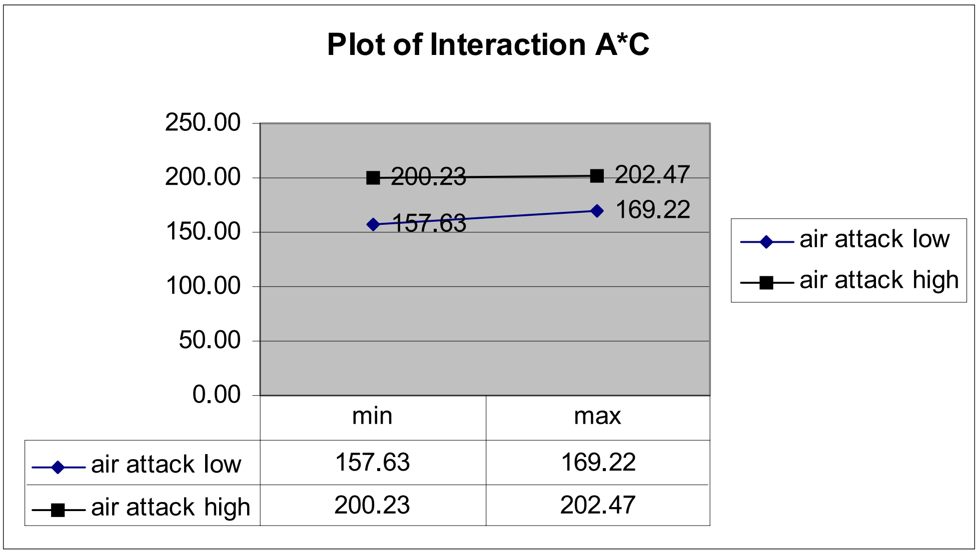
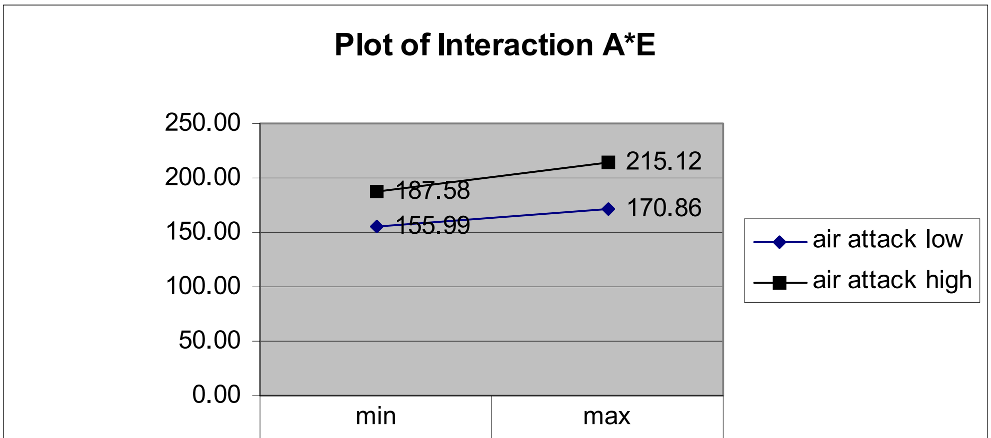


Figure 4.10 The Plot of Interaction Between Air Attack and Mine.

The last interaction is the interaction between air attack and breakdown. The plot of this interaction is given in Figure 4.11. The blue line indicates the change in MTIS when air attack is its low level while breakdown probability is shifting from its low level to its high level whereas, the black line indicates the change in MTIS when air attack is its high level. This interaction has a different meaning from the previous ones. Because, when the air attack is its high level (black line) while breakdown probability is shifting from 0 to 1, the change in MTIS has a steeper increase. This means that when air attack occurs more vehicles are damaged and more damaged vehicles causes more vehicles in breakdown repairing queue. Since the armored battalion has limited capacity of technicians (11) in the maintenance and repairing team, the damaged vehicles in the repairing queue wait longer. Besides, air attack and breakdown have more effects on MTIS than other factors have. This means more damaged vehicles cause much time delay and this increases time-in-system measure.



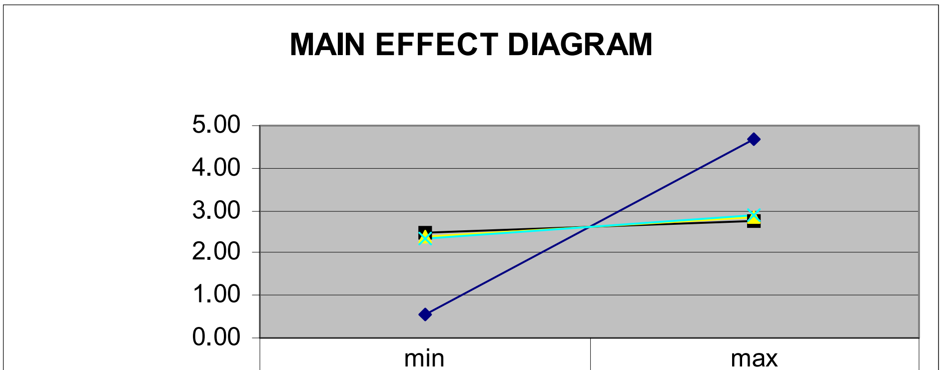
	min	max
air attack low	155.99	170.86
air attack high	187.58	215.12

Figure 4.11 The Plot of Interaction Between Air Attack and Breakdown.

4.2.2.2. Evaluation of Main Effects and Interactions for NODV

We perform ANOVA for our second performance measure and find main effects and interactions between factors. Then we plot their diagrams and evaluate the results as in the case of MTIS.

In this case we have four significant factors (main effects) and only one interaction between factors. Our main effects are air attack, artillery attack, breakdown and mine. Ambush does not have a significant effect on number of destroyed vehicles. Because the assets of the enemy, namely that the guns that the enemy use in ambush, do not have as much power as the other factors have to destroy the vehicles in the convoy. Therefore, ambush is not a significant factor in number of destroyed vehicles measure.



	min	max
air attack	0.53	4.70
mine	2.46	2.78
artillery attack	2.39	2.85
breakdown	2.36	2.88

Figure 4.12 The Plot of Main Effects for Number of Destroyed Vehicles.

As can be observed from Figure 4.12 the most significant factor is the air attack, other factors have approximately the same effect but not as much as air attack has. This is again related with the power of the enemy assets, which are used in these retarding events of enemy.

There is only one interaction in this case. This interaction is between air attack and breakdown factors as shown in Figure 4.13.

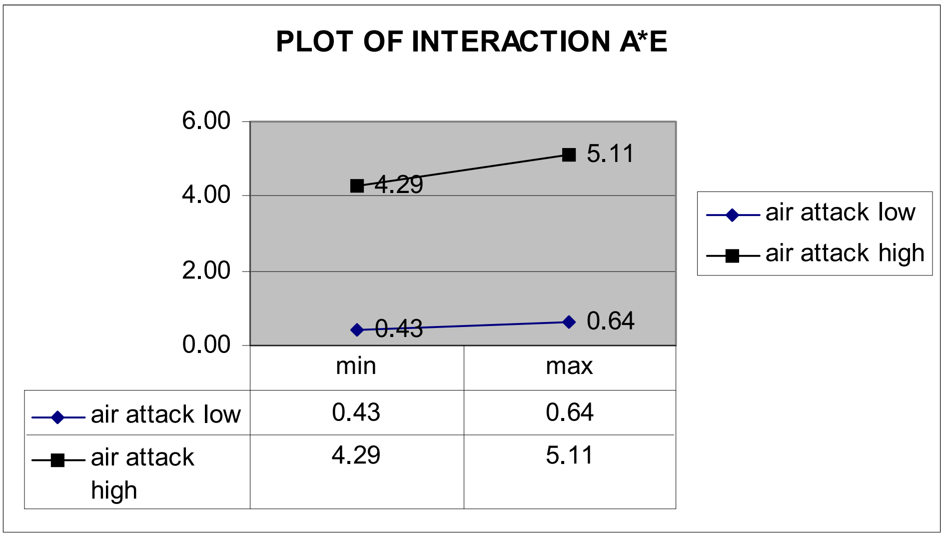


Figure 4.13 The Plot of Interaction Between Air Attack and Breakdown for NODV.

The blue line indicates the change in number of destroyed vehicles measure when air attack is its low level while breakdown probability is shifting from 0 to 1. The slope of this line is not as steep as that of black line, which shows the change in number of destroyed vehicle when air attack is its high level. Because, air attack affects all the vehicles in convoy and if enemy air attack occurs during the breakdown, the vehicles in the breakdown repairing queue are the perfect targets of enemy aircraft due to the reason that they can not disperse to decrease their vulnerability and their losses. As a result, the number of destroyed vehicles in breakdown event when enemy air attack occurs is much more than when there is no enemy air attacks.

4.3. Conclusions

In Chapter 4 we perform design and analysis of experiments for our model. We can summarize our findings as follows:

- We determine the sample size firstly to achieve the desired accuracy and to make our experiments with a sufficiently small experimental error.

- We build confidence intervals on the mean of MTIS and NODV performance measures to make comparative experiments. We compare our scenarios and find out that for MTIS measure Scenario-2 in which the armored vehicles are transported with semi-trailers is better than Scenario-1 whereas there is not a statistically significant difference between two scenarios for the NODV. This is an anticipated result since the semi-trailers (semi-trailers) have a speed of 45 km/h whereas armored vehicles have a speed of 32 km/h. during the movement. But semi-trailers do not have a feature to protect the vehicles, which they carry. This causes no change in the second performance measure so there is no statistically significant difference between two scenarios.

- We perform 2^k factorial experimental design to find the significant factors and interactions for our performance measures. All factors are significant for MTIS performance measure and we have four significant interactions between factors. The most significant factor is air attack and it is followed by breakdown factor. The significant interactions are breakdown-mine, air attack-breakdown, air attack-ambush and air attack-mine.

- We have four main effects and one interaction between factors for number of destroyed vehicles performance measure. Main effects are air attack, ambush, breakdown and mine. Here again, air attack and breakdown are more significant than other factors. The interaction is between air attack and breakdown factors. The summary table of significant factors and interactions is given in Table 4.9.

- We perform design and analysis of experiments and obtain very important information about our model. This information is very important for Turkish Army. Turkish Armed Forces try to perform all operations with minimum time and casualty. It is very important for Turkish Army to know the possible casualty and necessary time for any operation before conducting the operation. Besides, especially the planners of these operations would like to know the significant factors affecting the time and casualty measures and to take necessary precautions against these significant factors in the phase planning of these operations. This information is also very important for the commanders of the units, which performing these operations. They can concentrate more on training of defense techniques against significant factors to decrease their casualties.

Table 4.9 Summary Table of Significant Factors and Interactions.

FACTORS AND INTERACTIONS	MTIS	NUMBER OF DESTROYED VEHICLES
AIR ATTACK	**SIGNIFICANT**	**SIGNIFICANT**
AMBUSH	**SIGNIFICANT**	INSIGNIFICANT
MINE	**SIGNIFICANT**	**SIGNIFICANT**
ARTILLERY ATTACK	**SIGNIFICANT**	**SIGNIFICANT**
BREAKDOWN	**SIGNIFICANT**	**SIGNIFICANT**
AIR ATTACK-BREAKDOWN	**SIGNIFICANT**	**SIGNIFICANT**
AIR ATTACK-AMBUSH	**SIGNIFICANT**	INSIGNIFICANT
AIR ATTACK-MINE	**SIGNIFICANT**	INSIGNIFICANT
BREAKDOWN-MINE	**SIGNIFICANT**	INSIGNIFICANT

Chapter 5

Further Analysis of Scenario-1 and Scenario-2 Including the Cost Criterion into Model

We have mentioned in Chapter 4 that there is not enough number of semi-trailers in Turkish Army inventory and stated that armored vehicles of some battalions are transported with semi-trailers while armored vehicles of some battalions march on foot during movement to mobilization task areas.

Another and most widely used application of transporting armored vehicles of an armored battalion is partial transportation of armored vehicles. In this application armored vehicles of some companies of the battalion are transported with semi-trailers.

There are three armored (tank) companies and one Headquarters and Headquarters Company in an armored battalion. Each armored company has 16 armored vehicles and 6 wheeled vehicles. Headquarters and headquarters company has 19 armored vehicles and 68 wheeled vehicles. There are 2 technicians in each armored company who are responsible for maintenance of these vehicles. Headquarters and Headquarters company has 5 technicians in its maintenance and repairing team. There are total number of 67 armored vehicles and 86 wheeled vehicles in an armored battalion. Armored battalion has totally 11 technicians for maintenance of these vehicles. Basic unit of an armored battalion is the armored company. Headquarters and Headquarters company moves with the big part of armored battalion.

So, we have four types of transportation in this application. These are the following:

Type 1. Armored Battalion Marches On Foot: This is the type of movement described in Chapter 4. None of the armored vehicles is transported with semi-trailers.

Type 2. One Armored Company is Transported (1/3): In this type of transportation, only armored vehicles of one company are transported with semi-trailers while armored vehicles of remaining companies march on foot. Wheeled vehicles of transported company move with semi-trailers. In this case 6 armored vehicles of Headquarters and Headquarters company are also transported with this company for the support of maintenance and repairing. Totally, 22 armored vehicles are transported by semi-trailers. Besides, one technician of Headquarters and Headquarters company is attached to transported company.

Type 3. Two Armored Company is Transported (2/3): Armored vehicles of two tank companies of the armored battalion are transported with semi-trailers. Again wheeled vehicles of these companies move with semi-trailers. Headquarters and Headquarters company moves with this part (big part) but 6 armored vehicles and again 1 technician of this company are attached to the company that marches on foot for maintenance support. In this case semi-trailers transport 45 armored vehicles.

Type 4. Whole Battalion is Transported: In this type of movement all armored vehicles of the battalion are transported with semi-trailers.

5.1. Cost for Using Transporters

Speed is a very important factor for the movement to the mobilization task areas during a crisis or war. Turkish Army would like to complete this operation with minimum time and casualty. Semi-trailers (tank-carrying vehicles) speed up this movement. Armored vehicles march with a speed of 32 km/h whereas semi-trailers can move with a speed of 45 km/h during this movement. But, there is a cost of using these transporters.

The staff officers (decision-makers) who plan these operations face with four decisions (alternatives) each representing the type of transportation. Besides, they have three important criteria affecting these movements. These are our performance measures (MTIS and NODV) and the cost for using transporters.

The total cost for using transporters consists of cost per usage and maintenance and repair cost per usage in this operation. The semi-trailers in Command of Land Forces are not used just for transporting the armored vehicles during this movement but they are used for any transportation activity. Thus, we used the cost per usage in our model.

A semi-trailer in Command of Land Forces is used approximately 233 times during its lifetime and the cost of a semi-trailer is $120000. Thus, the cost per usage for any semi-trailer is approximately is $515. Maintenance and repair cost per usage for any semi-trailer is approximately $205. Thus, cost for using one semi-trailer in this operation is $720. The costs for using transporter for each type of transportation are as follows:

Type 1: $0, Type 2: $15840, Type 3: $32400 and Type 4: $48240.

In this Chapter we perform Multi-attribute Utility Theory to determine the best decisions for our three cases i.e. best case, most possible case and worst case.

5.2. Multi-attribute Utility Theory (MAUT)

Multi-attribute Utility Theory (MAUT), (Raiffa and Keeney, 1976) is an approach applied to multi-criteria selection problems. In these selection problems, decision-makers (DM) have m choices (decisions, alternatives) and q criteria. DM picks one among these choices. Therefore, DM has a matrix similar to Figure 5.1, which consists of these choices and criteria.

We use MAUT in analysis of transportation decisions (alternatives) in our study. MAUT is an appropriate method for our analysis for the reasons we explain below:

- MAUT has the ability to separate the facts and values.
- Professional judgments can be identified for decisions.
- It is possible to make a peer review.
- The choices available to the DM can be described by the payoff values.
- The DM can express preference or indifference between any pair of tradeoffs.

The rationale behind the utility theory is to apply objective measurement to decision making. If alternative performances, which have measurable attributes, are compared in an unbiased manner, it results in sounder decisions. The value of an alternative is assumed to consist of measures over the criteria that converted to a common scale of utilities (U). In this theory, the principle is that in any decision problem, there is a real-valued function U defined on the set of alternatives, which DM would like to maximize. This function aggregates the criteria $C_1, C_2, \ldots C_q$.

$$A = \begin{matrix} & C_1 & . & . & C_q \\ d_1 & \\ . & \\ d_m & \end{matrix} \begin{pmatrix} a_{11} & \cdots & a_{1q} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mq} \end{pmatrix}$$

Figure 5.1 Decision Matrix.

d_i : decision i, a_{ij} : achievement of decision i for criterion j

There are four basic steps in MAUT.

<u>Step1: Convert matrix A to utility matrix U</u>. In this step we convert the decision matrix A into utility matrix U. We use 0 and 1 for extreme points of achievement. We give 0 for worst achievement and 1 for the best achievement. Then, we find the utilities of achievement between best and worst achievement by using the following formulas:

For Profit: $U(a) = \dfrac{a_{ij} - \underline{a}}{\overline{a} - \underline{a}}$, For Loss: $U(a) = \dfrac{\overline{a} - a_{ij}}{\overline{a} - \underline{a}}$

Where $\overline{a}$: highest value, $\underline{a}$: lowest value.

$$U = \begin{matrix} & C_1 & . & . & C_q \\ d_1 & \\ . & \\ d_m & \end{matrix} \begin{pmatrix} u_{11} & \cdots & u_{1q} \\ \vdots & \ddots & \vdots \\ u_{m1} & \cdots & u_{mq} \end{pmatrix}$$

Figure 5.2 Utility Matrix.

Step 2: Find the tradeoffs between criteria.

i. First we choose a base criterion C_i.

ii. Then we consider one pair of criteria (C_i, C_j). This pair generates one linear equation. After considering all possible pairs we have (q-1) pairs and each pair generates one linear equation. The last linear equation is sum of weights is equal to 1. $\sum_{i=1}^{q} w_q = 1$.

iii. We ask decision maker following 2 questions:

1. Compare $\left[U(\underline{a}_i), U(\overline{a}_j)\right]$ vs. $\left[U(\overline{a}_i), U(\underline{a}_j)\right]$ where,

$\underline{a}_j$: Lowest achievement (0) on criterion j.

$\overline{a}_j$: Highest achievement (1) on criterion j.

$\underline{a}_i$: Lowest achievement (0) on criterion i.

$\overline{a}_i$: Highest achievement (1) on criterion i.

<u>*Case 1*</u>: Suppose that decision maker chooses the first pair.

$[0,1]$ f $[1,0]$ where "ϕ"means preferred over. This preference is graphically explained in Figure 5.3. In this case, second question to be asked to decision maker is:

2. Determine $\hat{a}_j$ such that $\left[U(\underline{a}_i), U(\overline{a}_j)\right] \approx \left[U(\overline{a}_i), U(\hat{a}_j)\right]$. That is, the theory asks the decision maker to increase lowest achievement on the second pair until it is equally attractive with the first pair.

iv. After determining the $\hat{a}_j$, we add weights to formulation as follows:

$$\underbrace{w_i \overbrace{U(\underline{a}_i)}^{0}}_{0} + \underbrace{w_j \overbrace{U(\overline{a}_j)}^{1}}_{w_j} = \underbrace{w_i \overbrace{U(\overline{a}_i)}^{1}}_{w_i} + w_j U(\hat{a}_j)$$

so, we have $w_j = w_i + w_j U(\hat{a}_k)$.

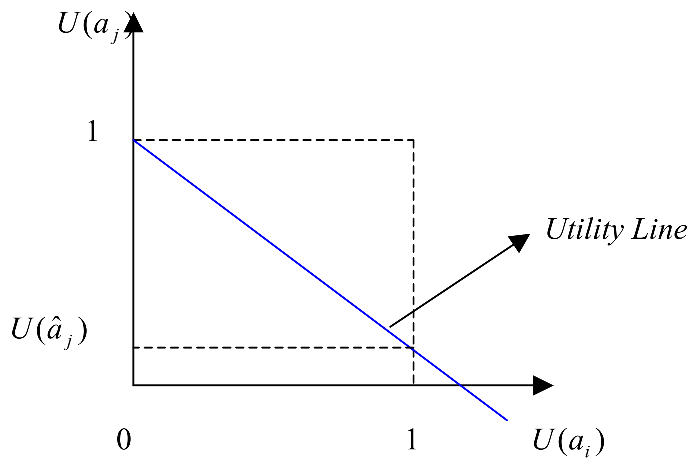


Figure 5.3 Preference Diagram for Case 1

<u>*Case 2:*</u> Suppose that decision maker preferred the second pair. $[0,1] \prec [1,0]$

The graph of Case 2 is illustrated in Figure 5.4. In Case 2 second question to be asked to decision maker is determine $\hat{a}_i$ such that $\left[U(\overline{a}_i), U(\underline{a}_j)\right] \approx \left[U(\hat{a}_i), U(\overline{a}_j)\right]$. That is, theory asks decision maker to increase lowest achievement on the first pair until it is equally attractive with the second pair.

Again adding weight to formulation we have the following formula:

$$\underbrace{w_i \overbrace{U(\bar{a}_i)}^{1}}_{w_i} + \underbrace{w_j \overbrace{U(\underline{a}_j)}^{0}}_{0} = w_i U(\hat{a}_i) + \underbrace{w_j \overbrace{U(\bar{a}_j)}^{1}}_{w_j}$$

so, we have $w_i = w_i U(\hat{a}_i) + w_j$

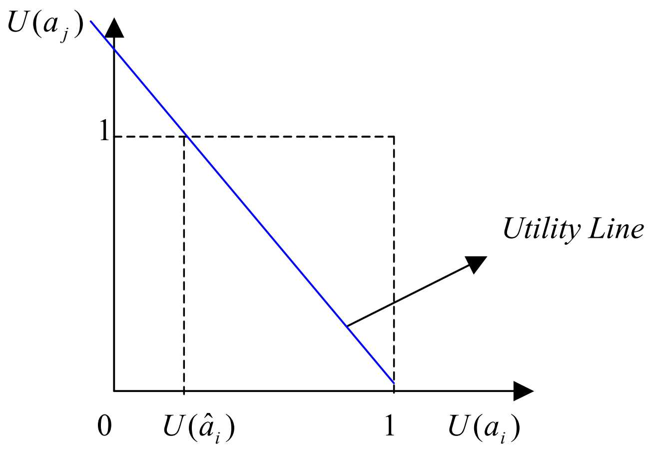


Figure 5.4 Preference Diagram for Case 2.

<u>Step 3: Find the value of each decision.</u>

In this step we find the value of each decision by using the following formula:

$$V(d_i) = \sum_j w_j u_{ij}, \forall_i .$$

Step 4: Pick or reject decisions.

In this last step we pick any decision, which appears to be the best, according to its value.

5.2.1. MAUT for the Best Case

As we mention before, we have four types of transportation, that is four alternative decisions, and three important criteria for our model. We denote these decisions and criteria as follows:

d_1: Type 1 Transportation $\quad$ C_1: COST ($1000)

d_2: Type 2 Transportation $\quad$ C_2: MTIS (min.)

d_3: Type 3 Transportation $\quad$ C_3: NODV

d_4: Type 4 Transportation

Thus, our decision matrix is as follows:

$$\begin{array}{c} \\ d_1 \\ d_2 \\ d_3 \\ d_4 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{pmatrix} 0 & 194.886 & 0 \\ 15.84 & 183.591 & 0 \\ 32.40 & 167.304 & 0 \\ 48.24 & 148.530 & 0 \end{pmatrix} \end{array}$$

Then, we convert this matrix to utility matrix. Since our aim is to minimize all these criteria, we give 0 to highest values and 1 to lowest values for each criterion. The NODV measure is zero for all alternatives so we can erase this criterion from our matrix. Our utility matrix is as follows:

$$
\begin{array}{c}
 \\ d_1 \\ d_2 \\ d_3 \\ d_4
\end{array}
\begin{array}{c}
\begin{array}{cc} C_1 & C_2 \end{array} \\
\begin{pmatrix}
1 & 0 \\
0.672 & 0.304 \\
0.328 & 0.627 \\
0 & 1
\end{pmatrix}
\end{array}
$$

After converting our matrix to utility matrix we choose the MTIS (C_2) as the base criterion. Since we have two criteria now we have one (2-1) possible comparison. Before making the comparison we consult with the staff officers who are the decision makers and planners of movement operation. For Turkish Army the most important factor of three factors is the time, that is MTIS measure and followed by casualty, namely that the number of destroyed vehicles (NODV). Thus, we can state the preference of Turkish Army for movement operation as follows:

$$\text{MTIS} \succ \text{NODV} \succ \text{COST}.$$

We compare MTIS vs. cost criteria. (C_2, C_1). We state the compared pairs as follows:

$$[0,1]\, vs\, [1,0] \text{ or } [MTIS = 194.886\,\text{min.}, Cost = \$0]\, vs\, [MTIS = 148.53\,\text{min.}, Cost = \$48.24]$$

Since, MTIS is preferred over cost measure by staff officers we choose the second pair, namely that we are in Case 2. Our second question to DM is to increase the lowest achievement until that is equally attractive with the preferred pair. During interview with the staff officers we determine the rate of this increase. Their decision on this subject is; the increase should be at least 70 percent of the difference between the lowest and highest achievement of MTIS measure to be equally attractive with the preferred pair. Now, we have the following equations:

$$\left[MTIS = 148.53 \min., Cost = \$48.24\right] \approx \left[MTIS = 162.437 \min., Cost = \$0\right]$$

$$\left[U(\bar{a}_2), U(\underline{a}_1)\right] \approx \left[U(162.437), U(\bar{a}_1)\right]$$

Then we add the weights to formulation and we have:

$$\underbrace{w_2 U(\bar{a}_2)}_{w_2} + \underbrace{w_1 U(\underline{a}_1)}_{0} = w_2 U(162.437) + \underbrace{w_1 U(\bar{a}_1)}_{w_1}$$

where $U(162.437) = 0.70$.

Now our linear equation is: $w_2 = 0.70 w_2 + w_1$.

Adding the last linear equation we have following two linear equations:

$$w_2 = 0.70 w_2 + w_1$$

$$w_1 + w_2 = 1$$

We find weights for each criterion by solving these three equations. The weight of each criterion is: $w_1 = 0.231$ and $w_2 = 0.769$

Then we find the value of each decision. The value of decisions as follows:

$$V(d_1) = (0.231*1) + (0.769*0) = 0.231$$
$$V(d_2) = (0.231*0.672) + (0.769*0.304) = 0.389$$
$$V(d_3) = (0.231*0.328) + (0.769*0.627) = 0.558$$
$$V(d_4) = (0.231*0) + (0.769*1) = 0.769$$

We observe the value of each decision and find out that fourth decision appears to be the best of all four decisions. The third decision is better than remaining two decisions and the first decision is the worst of all. This is an anticipated result because there is only breakdown factor affecting the MTIS measure and there is not many damaged vehicles waiting to be repaired. Thus, the speed factor is very efficient in the movement and this efficiency is reflected to the value of the decisions.

5.2.2. MAUT for the Most Possible Case

We applied MAUT for the most possible case. The decision matrix for the most possible case is as follows:

$$\begin{array}{c} \\ d_1 \\ d_2 \\ d_3 \\ d_4 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{pmatrix} 0 & 255.134 & 5.2 \\ 15.84 & 263.195 & 5.8 \\ 32.40 & 243.081 & 5.267 \\ 48.24 & 201.45 & 6.133 \end{pmatrix} \end{array}$$

When we observe the decision matrix we notice that values of the second decisions are bigger than that of the first decision. Since we try to minimize all criteria, second decision is dominated by the first decision. Thus, we can erase the second decision. Now, we can convert our matrix to utility matrix. Utility matrix for the most possible case is:

$$\begin{array}{c} \\ d_1 \\ d_3 \\ d_4 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{pmatrix} 1 & 0 & 1 \\ 0.328 & 0.225 & 0.928 \\ 0 & 1 & 0 \end{pmatrix} \end{array}$$

We choose again MTIS measure as the base criterion. We compare again MTIS vs. Cost criteria. (C_2, C_1). We state the compared pairs as follows:

$[0,1]vs[1,0]$ or $[MTIS = 255.134\min., Cost = \$0]vs[MTIS = 201.45\min., Cost = \$48.24]$

The preference order and the rate of increase in the lowest achievement of the pair, that is not preferred, are the same. Again we are in Case 2. Thus, our first linear equation is as follows:

$$w_2 = 0.70w_2 + w_1$$

Then we compare MTIS vs. NODV measure (C_2 vs. C_3) and state the compared pairs as follows:

$$[MTIS = 255.134\min., NODV = 5.2]vs[MTIS = 201.45\min., NODV = 6.133]$$

MTIS measure is preferred over NODV by the staff officers so we are in Case 2. The increase in the lowest achievement of the pair, that is not preferred, is again determined by staff officers that we consulted. The rate should be at least 60 percent of the difference between the lowest and highest achievement of MTIS measure to be equally attractive with the preferred pair. Now, we have the following equations:

$$\left[MTIS = 201.45\min., NODV = 6.133\right] \approx \left[MTIS = 222.924\min., NODV = 5.2\right]$$

$$\left[U(\bar{a}_2), U(\underline{a}_3)\right] \approx \left[U(222.924), U(\bar{a}_3)\right]$$

Then we add the weights to formulation and we have:

$$\underbrace{w_2 \overbrace{U(\bar{a}_2)}^{1}}_{w_2} + \underbrace{w_3 \overbrace{U(\underline{a}_3)}^{0}}_{0} = w_2 U(222.924) + \underbrace{w_3 \overbrace{U(\bar{a}_3)}^{1}}_{w_3}$$

where $U(222.924) = 0.60$.

Now our linear equation is: $w_2 = 0.60w_2 + w_3$.

Adding the last linear equation we have following three linear equations:

$$w_2 = 0.70w_2 + w_1$$

$$w_2 = 0.60w_2 + w_3$$

$$w_1 + w_2 + w_3 = 1$$

We find the weight of each criterion. The weight of each criterion is: $w_1 = 0.176$, $w_2 = 0.588$ and $w_3 = 0.236$

Then we find the value of each decision. The value of each decision is as follows:

$$V(d_1) = (0.176*1) + (0.588*0) + (0.236*1) = 0.412$$
$$V(d_3) = (0.176*0.328) + (0.588*0.225) + (0.236*0.928) = 0.409$$
$$V(d_4) = (0.176*0) + (0.588*1) + (0.236*0) = 0.588$$

The fourth decision again appears to be the best of all as in the best case. So, we choose the fourth decision. Interesting point is that using transporter to carry the armored vehicles of one company (Type 2) has no positive effect on the movement. Also, marching on foot to mobilization task area appears to be better than transporting armored vehicles of two companies of the battalion.

When we observe the results carefully, values of the third and the first decisions are very close to each other. It seems that there is no significant difference between transporting one part of the battalion and marching on foot. This is an unexpected result. Because it is intuitively expected that even transporting armored vehicles of one company gives better results than marching on foot. But the solution of the MAUT shows this counterintuitive conclusion.

We search for the reason of this result and find out that there is not a significant difference between the first (Type 1) and second (Type 2) decisions for MTIS performance measure. Semi-trailers speed up the movement but when the armored battalion is split into two groups, the capacity of the maintenance team also split into two. In the second decision, in which the armored vehicles of one company are transported (Type 2), there are 8 technicians in the big party whereas there are 3 technicians in the small party (transported party). There is only breakdown factor affecting the MTIS measure in the best case but air attack, artillery attack and ambush are also effective for MTIS in most possible case. When we observe the average waiting time of vehicles in the air attack repair queue we notice that in Type 2 transportation the average waiting time of vehicles in air attack repair queue is 27.38 minutes whereas 18.23 minutes when marching on foot (Type 1). Average waiting time of damaged vehicles in the artillery attack repair queue 9.47 minutes and 0 minutes for Type 2 and Type 1 respectively. There are 11 technicians in Type1 repairing these vehicles whereas there are 8 technicians in the big party and 3 technicians in the small party of Type 2 transportation. There is no problem in the big party but the capacity of the technicians in the small party is not enough and some vehicles in the breakdown repair queue has to wait. This reason decreases the efficiency of the transporters. Thus, there is an increase in MTIS in Type 2 transportation when using transporters. Same problem occurs in the Type 3 transportation in the small party, which marches on foot, but since the big party is transported on semi-trailers, there is a slight decrease in the MTIS measure.

As a result, this reason masks the efficiency of transporter completely in Type 2 and decrease the efficiency of transporters severely in Type 3 transportation. Consequently, we say that insufficient maintenance support masks the efficiency of transporters and maintenance support is a very important factor in movement operation.

5.2.3. MAUT for the Worst Case

Our decision matrix for the worst case is:

$$\begin{array}{c} \\ d_1 \\ d_2 \\ d_3 \\ d_4 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{pmatrix} 0 & 305.481 & 8.067 \\ 15.84 & 405.718 & 13.60 \\ 32.40 & 401.986 & 9.267 \\ 48.24 & 248.584 & 7.200 \end{pmatrix} \end{array}$$

When we check our decision matrix for the dominance we notice that the first decision dominates the second and the third decisions. So, we can erase these dominated decisions. Our utility matrix is then as follows:

$$\begin{array}{c} d_1 \\ \\ d_4 \end{array} \begin{pmatrix} 1 & 0 & 0 \\ & & \\ 0 & 1 & 1 \end{pmatrix}$$

Again our preference order and rate of increase in the lowest achievement of the pair, which is not preferred, is the same; so weights of criteria remain same as in most possible case. The values of the decisions are:

$$V(d_1) = (0.176 * 1) + (0.588 * 0) + (0.236 * 0) = 0.176$$
$$V(d_4) = (0.176 * 0) + (0.588 * 1) + (0.236 * 1) = 0.824$$

We choose the fourth decision, which appears to be better than the first decision. The reasons we explained in the previous cases are also valid in this case. As a result, splitting the armored battalion for transportation is of no use but has disadvantages.

5.3. Conclusions

In this chapter we perform a further analysis for Scenario-1 and Scenario-2 including the cost criterion into our model. We apply MAUT for transportation types, each representing a decision, and find the value of each decision under best, most possible and worst cases. The summary of the results that we obtained from Chapter 5 is below:

- We observe that transporting all armored vehicles of the battalion (Type 4) is the best decision for the best case. This is an expected result. But we observed that splitting the armored battalion into two groups for the movement and transporting armored vehicles of one group has no significant advantage. The reason is insufficient maintenance support caused by splitting the maintenance and repair team into two groups.

- In the most possible and the worst cases again the best decision is to transport all the armored vehicles in the battalion. Partial transportation again has no or little positive effect on performance measures but has some disadvantages. Insufficient capacity of technicians for the groups when we split the battalion in to two is the main reason. In this case average number of vehicles waiting in the repair queues increase since we have less capacity of technicians compared to the cases when all vehicles are transported or march on foot.

- We have mentioned there is not sufficient number of transporters in Turkish Army inventory to transport the all battalions at once. Thus, partial transportation is widely used to transport the armored vehicles of one or two companies of the battalions. But, MAUT results indicate that this type of transportation (partial) gives worse results than marching on foot and transportation of all armored vehicles of the battalions. This is an important result for the transportation of units to the mobilization task area in Turkish Army. Turkish Army should make a choice between marching on foot and transporting all units at once with transporters. But transporting all units is a big economic burden for Turkish Army. As a result, we can state that whole battalion should be transported to the mobilization task area. Armored battalion should not be split for movement operation or if it is necessary to split the battalion sufficient maintenance support should be provided for split parties.

- Another point we should emphasize is that if the enemy splits its any unit into groups of small units and if there is not sufficient maintenance and logistic support for any small unit it is more effective to attack this small group, which has insufficient maintenance and logistic support, to retard the operation of the enemy.

Chapter 6

Effects of Logistics Information System (LIS) on Movement

6.1. Logistics Information System (LIS)

One of the important missions of armies is to fall into step with changing technology. Armies produce some projects to achieve this mission. There are a lot of ongoing important project in Turkish Army. One of these important projects is the Logistics Information System (LIS).

LIS is a very big and important project, which launched in 1998 and will begin to be applied in 2004. One of the purposes of LIS is to update the existing maintenance system according to the changes in geo-strategic threats, technological progress, changing concepts of war and the progress in the force structure of Turkish Army.

This system has some primary goals as follows:

1. Specialization in maintenance activities.
2. Effectiveness and productivity in maintenances system.
3. Conducting the maintenance system in war and peace conditions with the same operating procedures.
4. Modular and mobile maintenance structure.
5. Personnel and resource saving.

This project will increase the effectiveness of preventive maintenance, decrease the repair times and number of breakdowns. With this project there are some changes in the Turkish Army Maintenance System. In Turkish Army there are 5 echelons of maintenance in the existing system These are:

1. First Echelon Maintenance: The users of the army assets apply this maintenance. Daily and weekly maintenance is applied in this echelon.

2. Second Echelon Maintenance: The personnel who are educated on technical maintenance apply this maintenance in battalions. Monthly maintenance is applied in this echelon.

3. Third Echelon Maintenance: Specialized trained personnel apply this maintenance in the maintenance units of Division.

4. Fourth Echelon Maintenance: This maintenance echelon supports the subordinate maintenance units. These are either half-mobile or fixed maintenance and repair shops.

5. Fifth Echelon Maintenance: These are the military maintenance and repair factories.

LIS make some changes in this system by abolishing the second echelons maintenance units. With this change the technicians in these echelons are attached to third echelon maintenance. Thus, the number of technicians in the battalions is decreased. These technicians are attached to the direct support maintenance teams. These direct support teams are in command and control of divisions but they are attached to battalions during an operation to support these battalions.

There are some other changes in maintenance system but especially abolishing the second echelon maintenance affect our movement operation.

6.2. Effects of LIS on the Movement of Armored Battalions to Mobilization Task Area

As we already mentioned in Chapter 5 there are totally 11 technicians in an armored battalion in the existing system. In LIS it is proposed that the number of technicians in an armored battalion should be 5 and these battalions should be supported with direct support teams in which there are 4 technicians. Thus, with the new system (LIS) the number of technicians in the maintenance and repair team is decreased by 18 percent.

We observed that the capacity of the maintenance and repair team is an important factor in a movement operation. It is intuitively expected that the decrease in the capacity of maintenance and repair team cause an increase in MTIS measure. As stated before, one of the purposes of LIS is to decrease the repair times of vehicles by using technicians who have specialized training and by using new and modern maintenance and repair equipments. Thus, there is an improvement on repair times.

One of the main purposes of the simulation is to observe and understand the behavior of a system under different operating policies. In this Chapter we determine effect of LIS on MTIS measure when the capacity is decreased by 18 percent and also we determine the minimum improvement rate of LIS on repair times to reach the results of existing system. We observe these effects for Scenario-1 and Scenario-2 under the best, most possible and worst cases.

<u>Scenario-1</u>

A. Best case:

In the best case the average of 15 replications for MTIS measure is 194.88 minutes. We decrease the capacity to 9, run our model, and find out that the average of 15 replications for MTIS measure is the same as the existing system. It is expected because the average number of vehicles waiting in the breakdown repair queue is 3.27 and for both existing and the new system the capacity is sufficient in the best case. Thus, there is no need to improve the repair times for this case.

B. Most Possible Case:

In this case average of 15 replications for MTIS measure is 255.13 minutes in the existing system. We decrease the capacity to 9, take 15 replications, and find that the average of 15 replications for MTIS measure is 279.14 minutes. That is, decreasing the capacity by 18 percent cause an increase in MTIS by 9.41 percent. The comparison of two systems is graphically illustrated in Figure 6.1.

Then we decrease the repair times in the new system until we achieve the results of existing system to determine the minimum improvement rate on repair times. We find out that the minimum improvement rate on repair times should be approximately 10 percent.

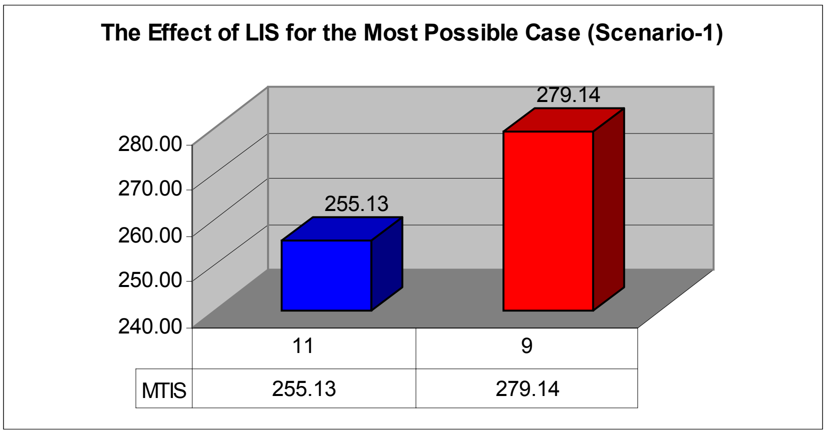


Figure 6.1 The Effect of LIS on MTIS for the Most Possible Case (Scenario-1).

The average of 15 replications for MTIS with an improvement by 10 percent is 259.53 minutes. The graph, which shows the effect of LIS and necessary improvement rate for achieving the results of existing system, is shown in Figure 6.2.

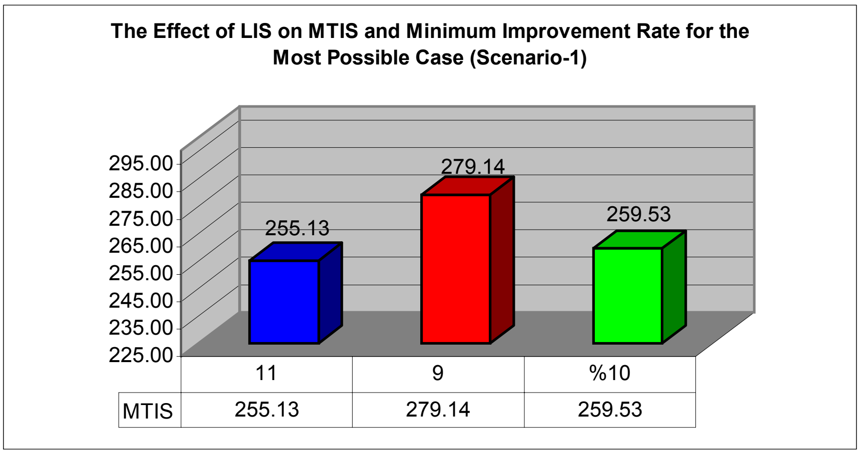


Figure 6.2 The Effect of LIS on MTIS and Minimum Improvement Rate for the Most Possible Case (Scenario-1).

In Figure 6.2 blue bar shows the average value of MTIS in existing system (11 technicians) whereas the red bar shows the value of MTIS in LIS (9technicians). The green bar shows the value of MTIS when we decrease the repair times by 10 percent.

C. Worst Case:

In the worst case, the average of MTIS measure is 305.48 minute in the existing system whereas the average of MTIS measure is 338.19 minutes. That is, the increase in MTIS measure is 10.71 percent when we decrease the capacity by 18 percent. Figure 6.3 shows the comparison of two systems for MTIS in the worst case.

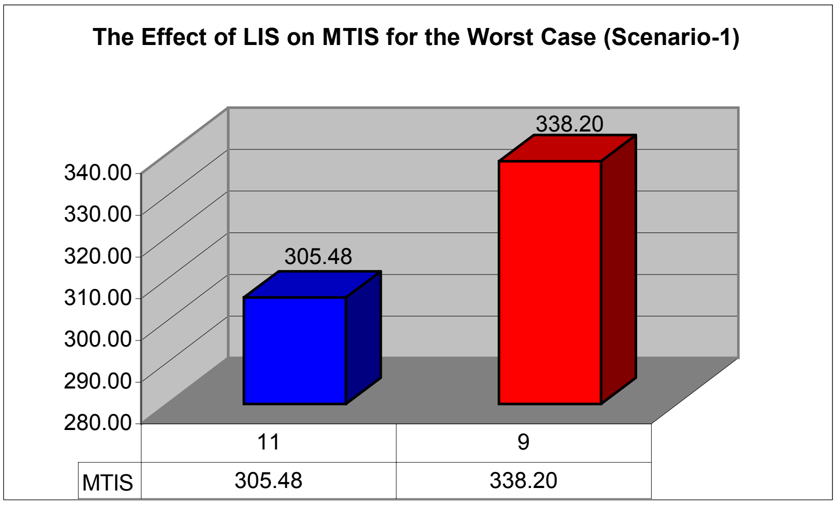


Figure 6.3 The Effect of LIS on MTIS for the Worst Case (Scenario-1).

Then we determine the minimum improvement rate on repair times and it should be approximately 10 percent. This is graphically illustrated in Figure 6.4.

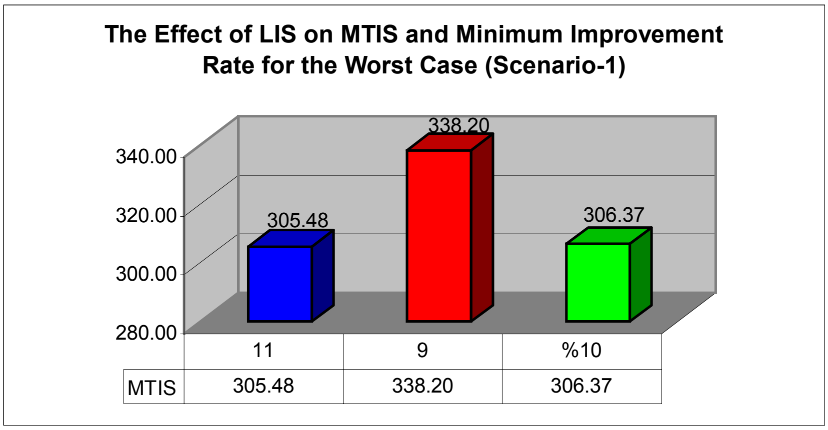


Figure 6.4 The Effect of LIS on MTIS and Minimum Improvement Rate for the Worst Case (Scenario-1).

<u>Scenario-2</u>

A. Best Case:

In Scenario-2 the armored vehicle of the battalion are transported on semi-trailers. The average of MTIS measure in the existing system (148.53 min.) is the same as the average of MTIS measure in LIS. The reason is the same that we explained in the best case of Scenario-1.

B. Most Possible Case:

In this case the average of MTIS measure is 201.45 minutes in the existing system whereas 240.19 minutes in LIS. There is an increase in the average of MTIS measure by 19.23 percent. The graph of this comparison is shown in Figure 6.5.

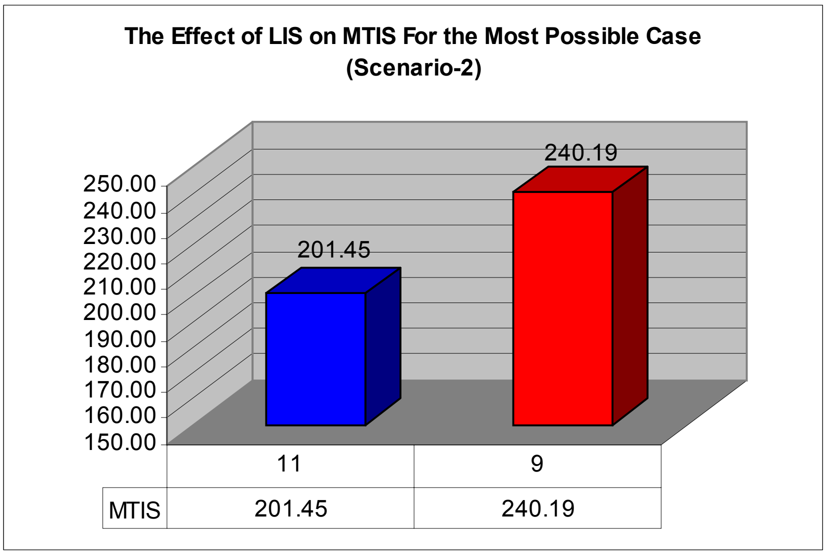


Figure 6.5 The Effect of LIS on MTIS for the Most Possible Case (Scenario-2).

This increase is bigger than that of most possible case in Scenario-1. Because in Scenario-2 all of the vehicles are wheeled and the probability of being damaged for the wheeled vehicle is higher than that of armored vehicles.

Then we determine the improvement rate on repair times and find that it is sufficient to decrease the repair times by 15 percent as shown in Figure 6.6.

C. Worst Case:

The average of MTIS is 248.58 minutes in the existing system whereas it is 302.97 minutes in LIS. The increase rate in MTIS measure is 21.87 percent. We decrease the repair times by 15 percent and reach the value of MTIS in the existing system. The minimum improvement rate should be approximately 15 percent. The increase rate in MTIS in LIS

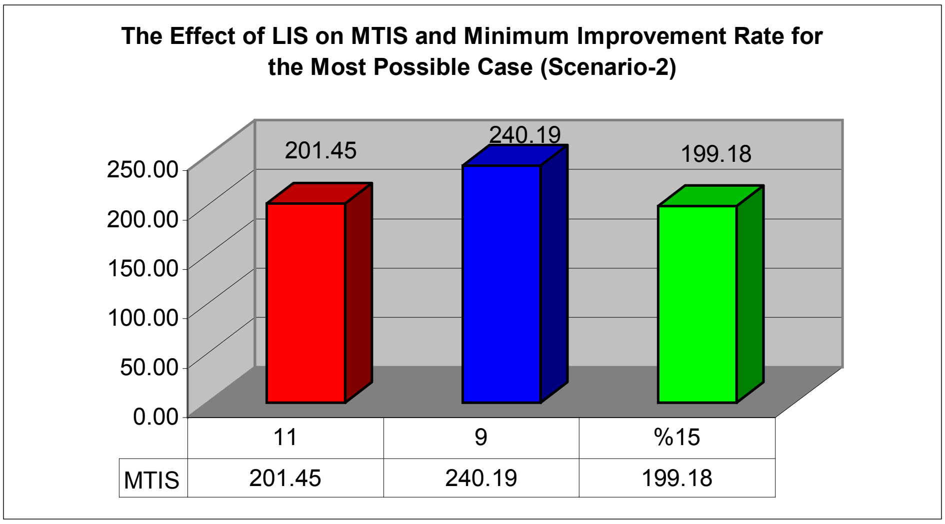


Figure 6.6 The Effect of LIS on MTIS and Minimum Improvement Rate for the Most Possible Case (Scenario-2)

for the worst case and the graph of minimum improvement rate together with the effect of LIS on MTIS are shown in Figure 6.7 and Figure 6.8 respectively.

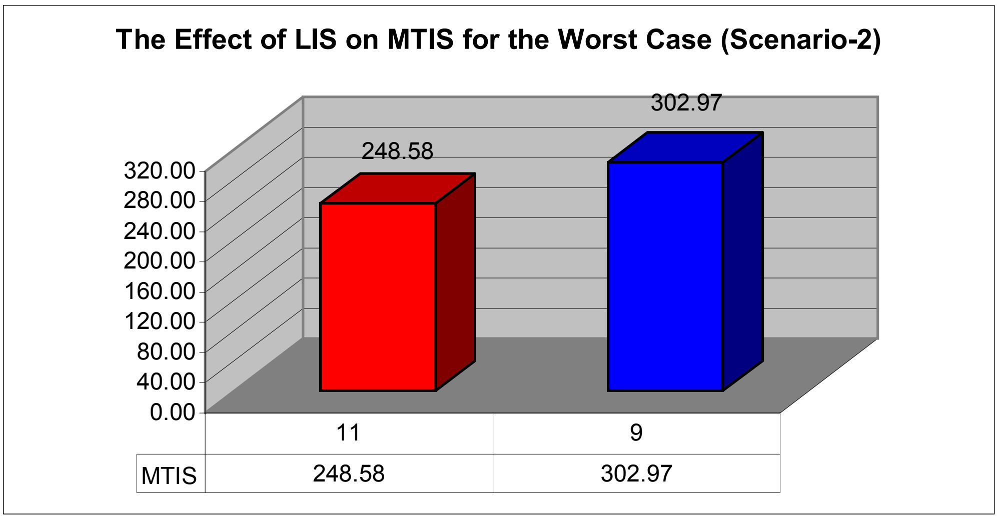


Figure 6.7 The Effect of LIS on MTIS for the Worst Case (Scenario-2).

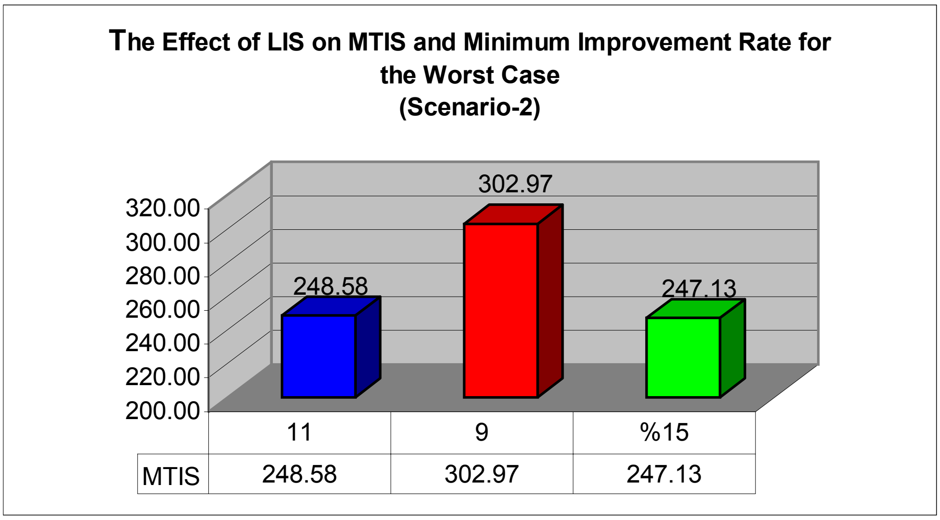


Figure 6.8 The Effect of LIS on MTIS and Minimum Improvement Rate for the Worst Case (Scenario-2).

6.3. Conclusions

In this chapter we evaluate a big logistics project of Turkish Army (LIS) and find out the effects of this system on our system. We also determine an improvement target for this project. As a summary of the results that we obtain from Chapter 6 is below:

- LIS is an important project and in this project the capacity of maintenance teams is decreased by 18 percent. This causes an increase in our MTIS performance measure. But in LIS it is aimed to decrease the repair times of Turkish Army assets by using specialized trained technicians and modern maintenance equipments. Thus, there is an improvement on repair times of vehicles. But this improvement rate is not determined as a target. In our study, we determine the percentage of the increase in MTIS caused by LIS on the movement system and also we determine the minimum improvement rate of repair times to compensate this increase in MTIS measure.

- We determine these rates for Scenario-1 and Scenario-2 under different cases i.e. best case, most possible case, and worst case.
- In the best case of both scenarios there is no increase in MTIS measure when we decrease the capacity of maintenance team. Because the capacity of maintenance and repair team is sufficient for the number of vehicles waiting in the breakdown queue.
- In the most possible case and worst case of Scenario-1 the increase rates in MTIS are 9.41 and 10.71 percent respectively. The minimum improvement rate of repair times needed to reach the values of existing system for these cases is approximately 10 percent. In the most possible case and worst case of Scenario-2 these rates are higher than that of Scenario-1 because in Scenario-2 all armored vehicles are transported with semi-trailers and the probability of being damaged for wheeled vehicles is higher than that of armored vehicles. Thus, the average number of damaged vehicles is higher in Scenario-2 when compared to Scenario-1. In Scenario-2 the increase rates in MTIS are 19.23 and 21.87 percent for the most possible case and worst case, respectively. The minimum improvement rate should be 15 percent for these cases.
- These minimum improvement rates can be used as a target in LIS.

Chapter 7

Conclusions

7.1. General

In this study, we developed a simulation model for the movement of a Turkish Armored Battalion, emplaced next to border, from assembly area to mobilization task area. The objectives of this study are as follows:

- To evaluate the movement plan of an armored battalion, emplaced next to border, from assembly area to mobilization task area.
- To find out the effects of random events (breakdowns, air attacks, artillery assaults, mines, and ambushes of enemy), caused by both terrain and enemy, affecting this movement.
- To determine the amount of time delay of each random event.
- To test the movement plans under different scenarios and conditions and to understand the behavior of our system.
- To try to identify the problem areas of this system.

Our model is a flexible model that we can use this model for battalions of different branches. Besides, our model can be used in the future by making some small modifications according to changing technological conditions, progress in weapons of enemy and progress in force structure of Turkish Army, such as changing the hit and kill probabilities of enemy weapons, velocity of vehicles of the convoy, and probabilities of retarding events of enemy.

In this thesis, we analyze the movement of a Turkish Armored Battalion, determine the significant factors and interactions affecting this operation, determine the best transportation types for the movement including the cost criterion into our model, and finally determine the effects of Logistics Information System (LIS) on movement.

7.2. Design and Analysis of Experiments

We perform comparative experiments to compare Scenario-1, in which the vehicles armored battalion march on foot to their mobilization task area, and Scenario-2, in which the armored vehicles of the battalion are transported to mobilization task area on semi-trailers, under best, most possible, and worst cases. Then we perform 2^k factorial experimental design to determine the significant factors and their interaction for MTIS and NODV performance measures. The results we obtain are the following:

- In comparative experiment, we observe that Scenario-2 is better than Scenario-1 for MTIS performance measure despite the fact that the probability of being damaged for the wheeled vehicles is higher than that of armored vehicles.

- For the NODV performance measure, there is no statistically significant difference between these two scenarios. Because semi-trailers are not armored vehicles and have no feature to protect vehicles which semi-trailer carries. Semi-trailers are used just to speed up the movement operation.

- In factorial design of experiments, we observe that for MTIS performance measure, all factors (air attack, ambush, mine, artillery attack and breakdown) are significant. The most significant factor is air attack and it is followed by breakdown factor. The significant interactions are between: air attack-ambush, air attack-mine, air attack-breakdown, and breakdown-mine factors.

- The significant factors for NODV performance measure are air attack, artillery attack, breakdown and mine. Again the most significant of all is the air attack factor. There is only one interaction affecting NODV and it is between air attack and breakdown factors.

The results we obtain in experimental design are very important information for Turkish Army. This information can be used in planning and training phases of movement operation.

The staff officers, who are the planners of this operation, will know the significant factors, the time needed to complete this operation and the possible casualty by using the results of our study. Besides, this information help to prepare an efficient and realistic time planning, which is very important and critical factor in planning phase of any operation.

The armored battalion commanders who are the executors of this operation can train their units in the light of these results and give extra care for the defense training against the significant factors, such as air attack.

In the movement operation air attack and breakdown are the most significant factors. Turkish Army should concentrate more on these factors. Air defense system should be stronger and preventive measures should be increased during such an operation. Besides, maintenance and repair activities should be more efficient and the vehicles and army assets, which are used in this operation, should always be kept in good conditions by making their protective maintenance.

7.3. Further Analysis of Scenario-1 and Scenario-2 Including the Cost Criterion into Model

We perform MAUT to determine the best transportation types under best, most possible and worst case including the cost criterion into our model. The results are as follows:

- The best decision for all cases is to transport all armored vehicles of the battalion with semi-trailers.
- Partial transportation has no or little advantage for the movement because splitting the armored battalion up causes insufficient maintenance support.

- Armored battalion should either march on foot or all armored vehicles of the battalion should be transported on semi-trailers. If it is a must to split the armored battalion into groups, sufficient maintenance support should be provided for small groups.
- We obtain tactical information in this part; it is more useful to attack on the small units of enemy, which has insufficient logistics and maintenance support to retard these types of enemy operations.

7.4. Effects of Logistics Information System (LIS) on Movement

Logistics Information System is a very big and important project of Turkish Army. This project has some effects on our system. In Chapter 4 we find out that breakdown factor is a very important factor for the movement. Therefore, maintenance support gains more important in this operation.

In the operating policy of LIS, the capacity of maintenance team is decreased by 18 percent. This causes an increase in MTIS performance measure. On the other hand, one of the main purposes of the LIS is to decrease the repair times of army assets. This causes an improvement on repair times of the vehicles of the armored battalion for our system. In our study we determine the magnitude of this increase in MTIS and minimum improvement rate to reach the results of existing system. We run our system under the operating policies of LIS, observe the changes in the behavior of our scenarios under best, most possible and worst cases and determine the rate of these effects. The results we obtain are as follows:

- The decrease in the capacity of maintenance team does not affect MTIS measure in Scenario-1 and Scenario-2 for the best case.
- In the most possible and worst cases of Scenario-1 the rate of the increase in MTIS is approximately 10 percent. The minimum improvement rates on repair times of vehicles should be approximately 10 percent.
- For Scenario-2, the rate of the increase in MTIS in most possible and worst cases is approximately 20 percent and the minimum improvement rates should be approximately 15 percent.

7.5. Concluding Remarks

We obtain the following conclusions from results of our study:

- The significant factors affecting the movement operation are enemy air attack, breakdown, enemy artillery attack, enemy ambush and mine.
- Air defense system should be strengthened and commanders should concentrate more on defense techniques against enemy attacks during training their units.
- Partial transportation of armored battalion has no or little positive effect on movement.
- Maintenance support and the capacity of maintenance and repair team are very important factors affecting the movement time.

- LIS should make an improvement on repair times of the vehicles as much as the rate of increase in MTIS caused by decreasing the capacity of maintenance team so as to reach time standards of existing system.

7.6. Future Research Topics

The movement from assembly areas to mobilization task areas is one of the vital operations in Turkish Army. Since this operation is the beginning of the main operations such as defense or attack, it can be regarded as the first step of the war.

War gaming and combat simulation are very powerful tools to examine, evaluate and understand the behavior of the military operations. By the help of these tools, military operations can be evaluated with less money, no casualty and in a very short time.

In our study we model the movement of a Turkish Armored battalion. We do not include the movement of semi-trailers from their units to assembly areas (loading points) and loading activities in the assembly areas. A further study can be made including these activities.

This study deals with the movement of an armored battalion. The movement of battalions of other branches such as infantry, engineering and artillery, can be studied in future studies. Besides, by changing the size of the moving units, the movement of smaller or bigger units such as company, brigade, division and corps can be studied.

The movement we study on is conducted in our terrain. The movement, which is executed in enemy terrain (approach march), can be studied in future research.

We do not deal with the activities in the mobilization areas such as reorganization of units and supply support activities. A future study can also be executed including these activities.

Appendix A

TANK-CARRYING VEHICLES

There are three kinds of semi-trailers (tank-carrying vehicles) in Turkish Army. The properties of these vehicles are as follows:

A. 3850 AS MERCEDES: This vehicle had entered Turkish Land Forces Inventory in 1993.

PROPERTIES:

Length: 7.6 m.

Width: 2.765 m.

Height: 3.46 m.

Weight: 110 ton

Carrying Capacity: 60 ton

Fuel Depot Capacity: 600 liters

Maximum Movement Range: 1000 km

Maximum Speed: 90 km/h

Cab: 7

Configuration: 6x6

B. FAUN HZ 40.45: This vehicle had entered Turkish Land Forces Inventory in 1988.

PROPERTIES:

Length: 9.1 m.

Width: 2.75 m.

Height: 3.65 m.

Weight: 45 ton

Carrying Capacity: 60 ton

Fuel Depot Capacity: 900 liters

Maximum Movement Range: 600 km

Maximum Speed: 63.6 km/h

Cab: 7

Configuration: 6x6

C. MZKT-74925 VOLAT: This vehicle had entered Turkish Land Forces Inventory in 1996.

<u>PROPERTIES:</u>

Length: 9.710 m.

Width: 3.07 m.

Height: 3.6 m.

Weight: 45.85 ton

Carrying Capacity: 48 ton

Fuel Depot Capacity: 770 liters

Maximum Movement Range: 730 km

Maximum Speed: 65 km/h

Cab: 7

Configuration: 8x8

Appendix B

Computer Code of the Simulation Model

Model Frame:

```
37$         CREATE,      6,1.8:,1;
38$         ASSIGN:      vtype=2:c#=1:priority=vtype:NEXT(84$);
84$         QUEUE,       aralamaq1,,85$;
85$         SEIZE,       1:aralayici1,1;
86$         DELAY:       0.1;
87$         RELEASE:     aralayici1,1:MARK(timein);

cekpath     STATION,     basla1;
527$        BRANCH,:     If,vtype.eq.1,baslasana1 c,Yes:
                         If,vtype.eq.2,baslasana2 c,Yes;
baslasana1 c  QUEUE,     vehicle1q c,,523$;
523$        REQUEST,     1:vehicle1(sds),750;
524$        TRANSPORT:   vehicle1,enter c,750;
baslasana2 c  QUEUE,     vehicle2q c,,525$;
525$        REQUEST,     1:vehicle2(sds),750;
526$        TRANSPORT:   vehicle2,enter c,750;
521$        STATION,     enter c;
522$        TRANSPORT:   ,aircheck c,750;
344$        STATION,     aircheck c;
```

```
346$         BRANCH,:      If,nc(flag c).eq.0,airgir c,Yes:
                           If,nc(flag c).ne.0,postpone c,Yes;
airgir c     BRANCH,:      With,0.3,sinyal c,Yes:
                           With,0.7,air cont c,Yes;
sinyal c     COUNT:        flag c,1;
345$         SIGNAL:       20000;
350$         DELAY:        tria(15,20,25);
382$         SIGNAL:       55000;
postpone c   WAIT:         55000:NEXT(belirle c);
belirle c    BRANCH,:      With,0.20,airbreak c,Yes:
                           With,0.80,airarala c,Yes;
airbreak c   TRANSPORT:    ,air break c,375:MARK(air arrtime c);
airarala c   QUEUE,        aralamaq2 c,,494$;
494$         SEIZE,        1: aralayici2 c,1;
495$         DELAY:        0.1;
496$         RELEASE:      aralayici2 c,1;
air cont c   TRANSPORT:    ,aircont c,750;
352$         STATION,      aircont c;
353$         TRANSPORT:    ,check1 c,750;
321$         STATION,      check1 c;
322$         BRANCH,:      With,0.05,onarim1 c,Yes:
                           With,0.95,git1 c,Yes;
onarim1 c    TRANSPORT:    ,break1 c,375:MARK(arrtime1 c);
git1 c       TRANSPORT:    ,cont1 c,750;
…………………………………………………………………………………………………...
```

Experimental Frame:

PROJECT, movement plan, burhan urek,,Yes;

ATTRIBUTES: priority:

ambush reptime c:

ambusharrtime c:

c#:

mine reptime c:

reptime1 c:

artillery reptime:

timein:

vehicle#:

reptime2 c:

mine reptime:

arrtime1 c:

reptime3 c:

air reptime c:

arrtime2 c:

reptime4 c:

artillery reptime c:

arrtime3 c:

ambusharrtime:

reptime1:

artilleryarrtime:

arrtime4 c:

reptime2:

artilleryarrtime c:

air arrtime c:

reptime3:

reptime4:

air arrtime:

minearrtime c:

vtype:

minearrtime:

arrtime1:

ambush reptime:

arrtime2:

arrtime3:

air reptime:

arrtime4;

QUEUES: 1,vehicle1q,FirstInFirstOut:

2,vehicle2q,FirstInFirstOut:

vehicle2q c,FirstInFirstOut:

aralamaq1 c,FirstInFirstOut:

ambushq1 c,FirstInFirstOut:

ambushq1,FirstInFirstOut:

vehicle1q c,FirstInFirstOut:

aralamaq2 c,FirstInFirstOut:

pq,FirstInFirstOut:

break4q c,LVF(priority):

ambushq2 c,FirstInFirstOut:

…………………………………………………………………………………………………...

Appendix C

Flowchart of the System

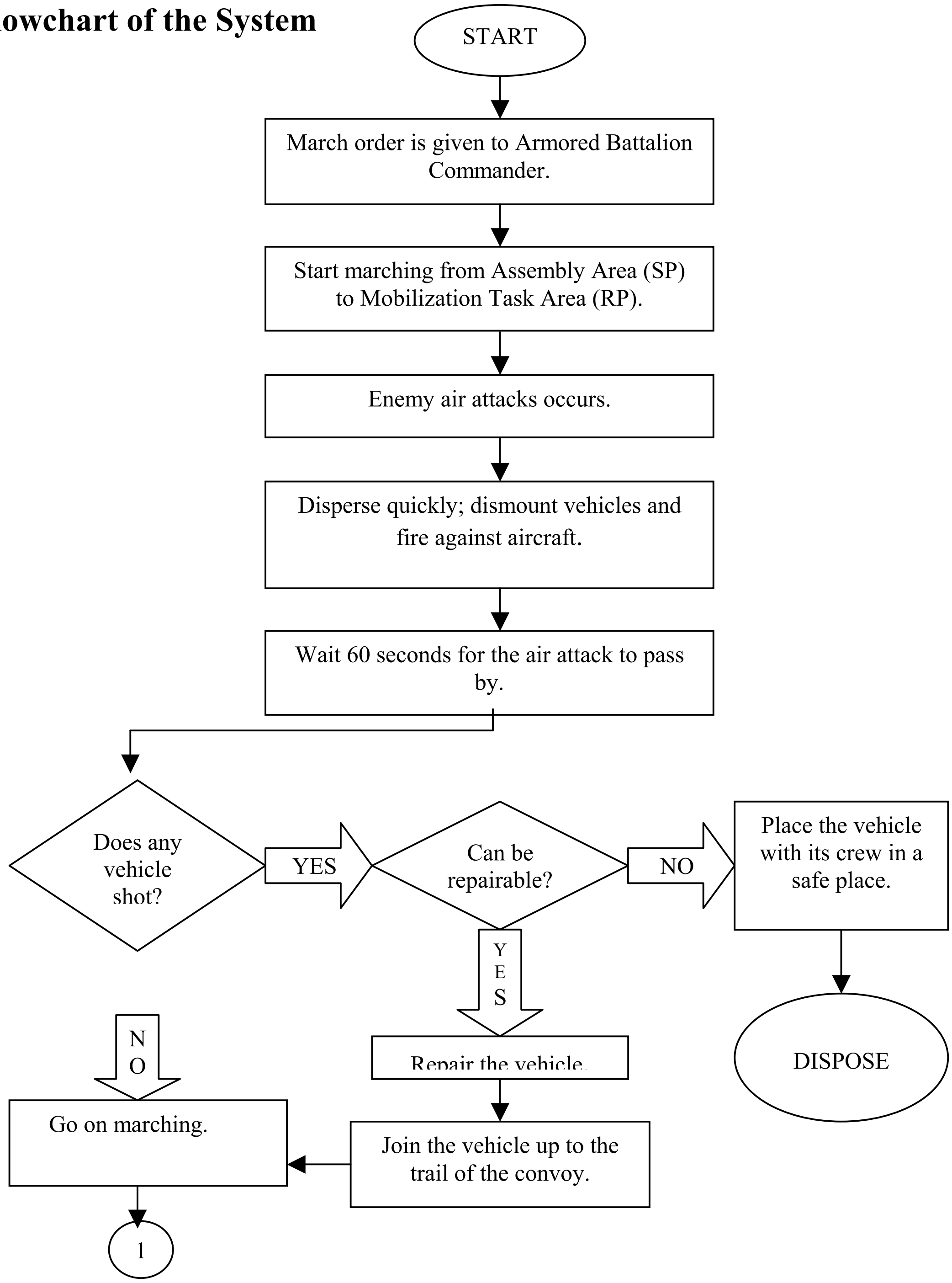


Figure 3.5 Flowchart of the System.

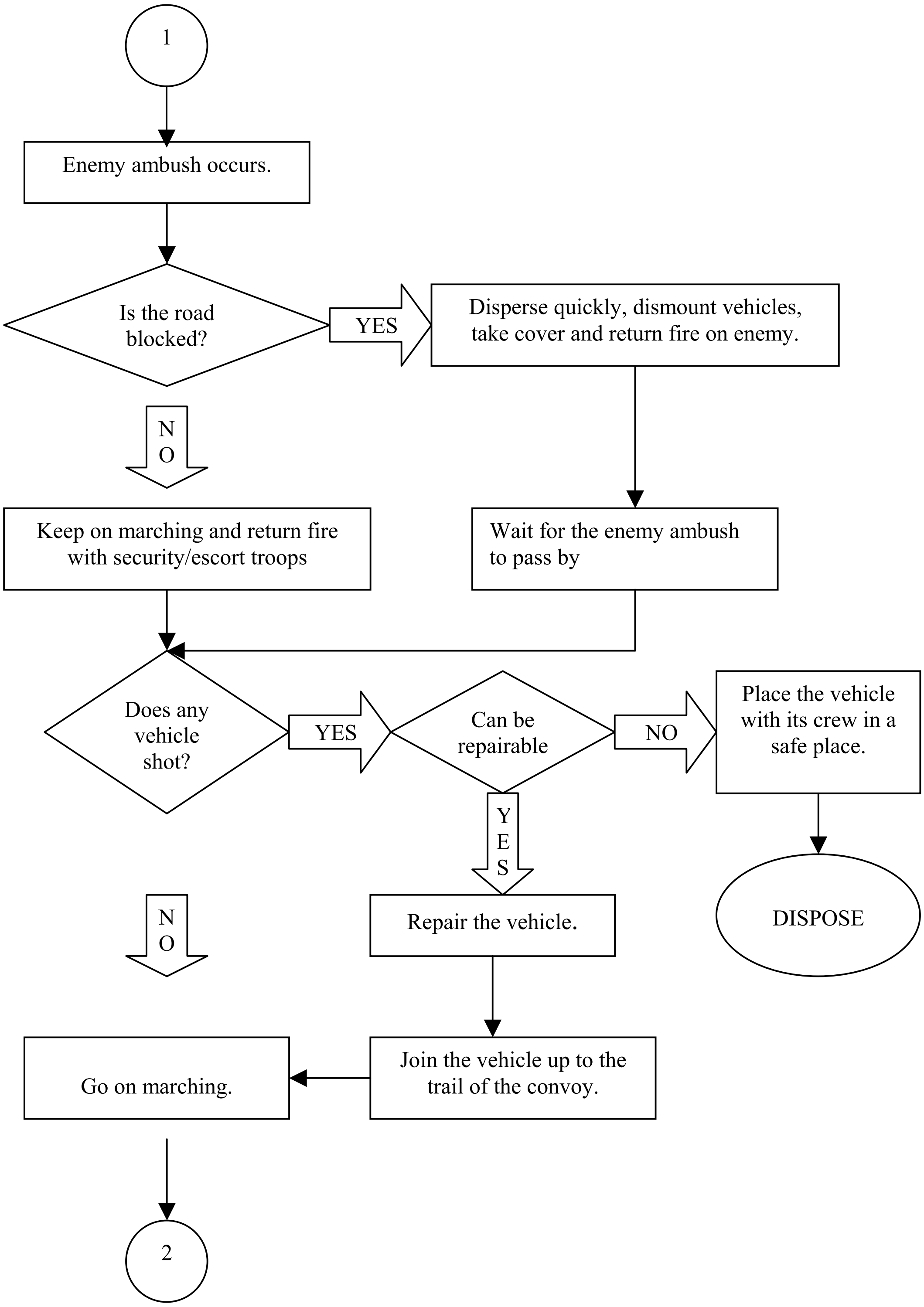


Figure 3.5 Flowchart of the System (cont'd).

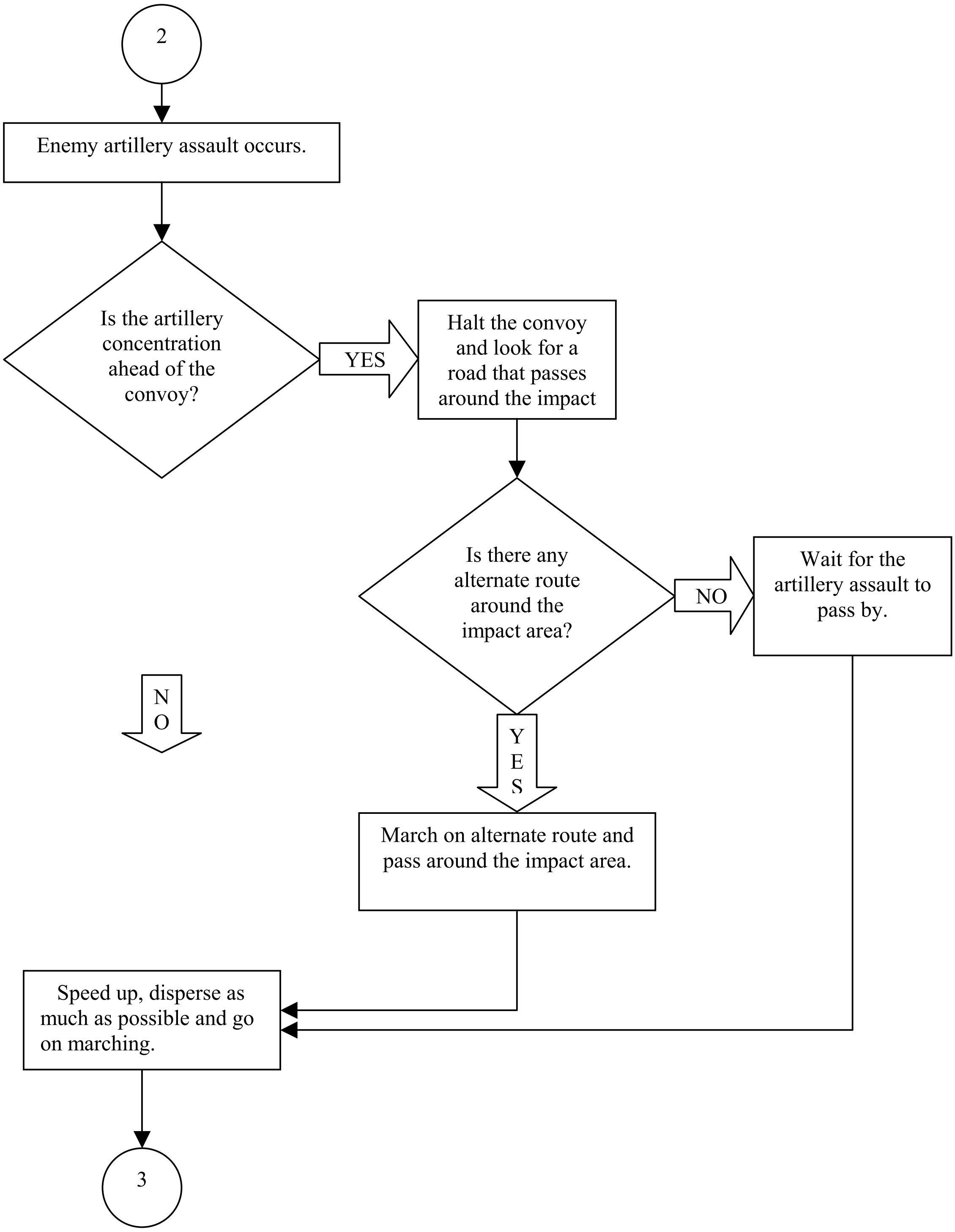


Figure 3.5 Flowchart of the System (cont'd).

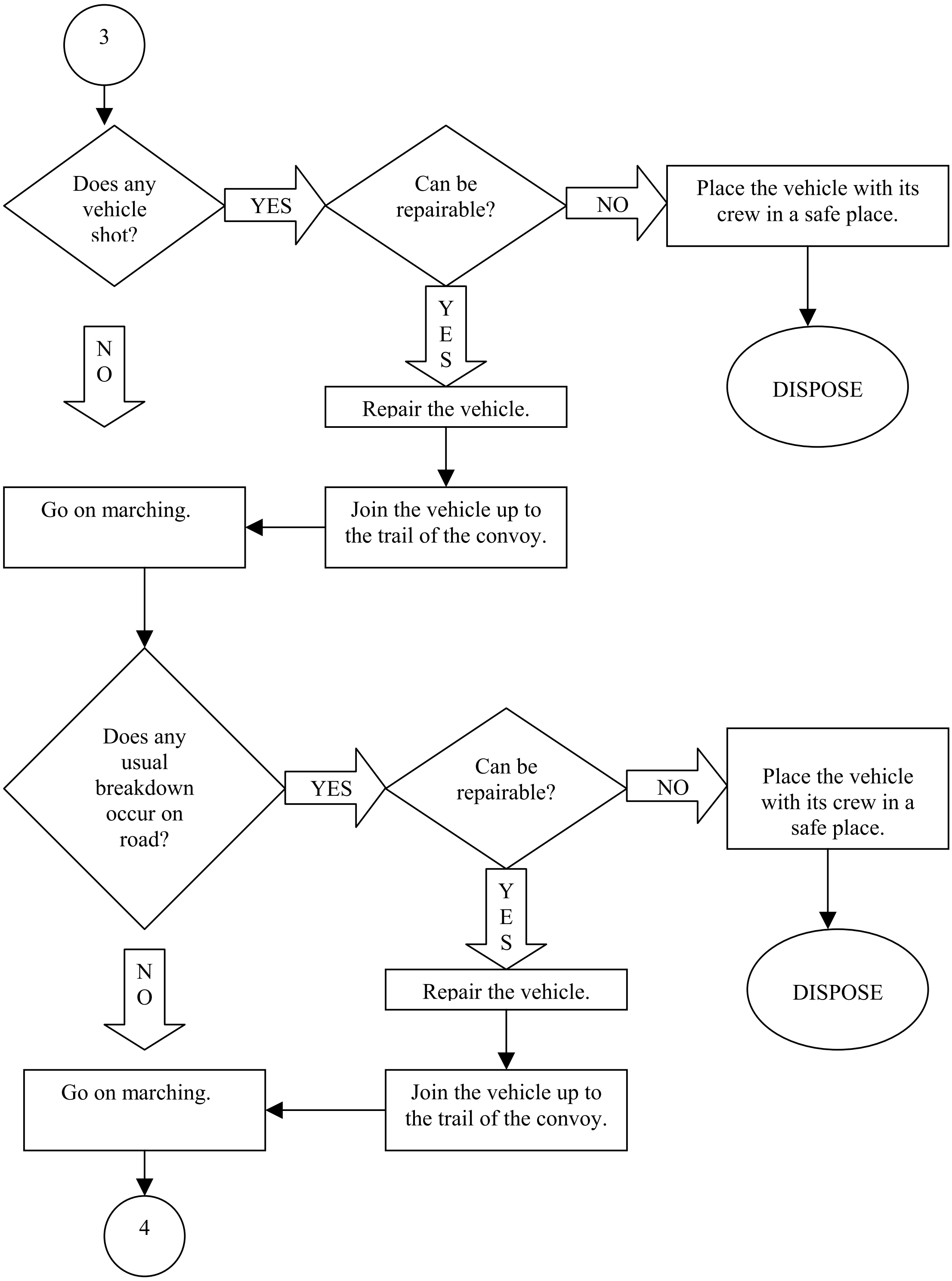


Figure 3.5 Flowchart of the System (cont'd).

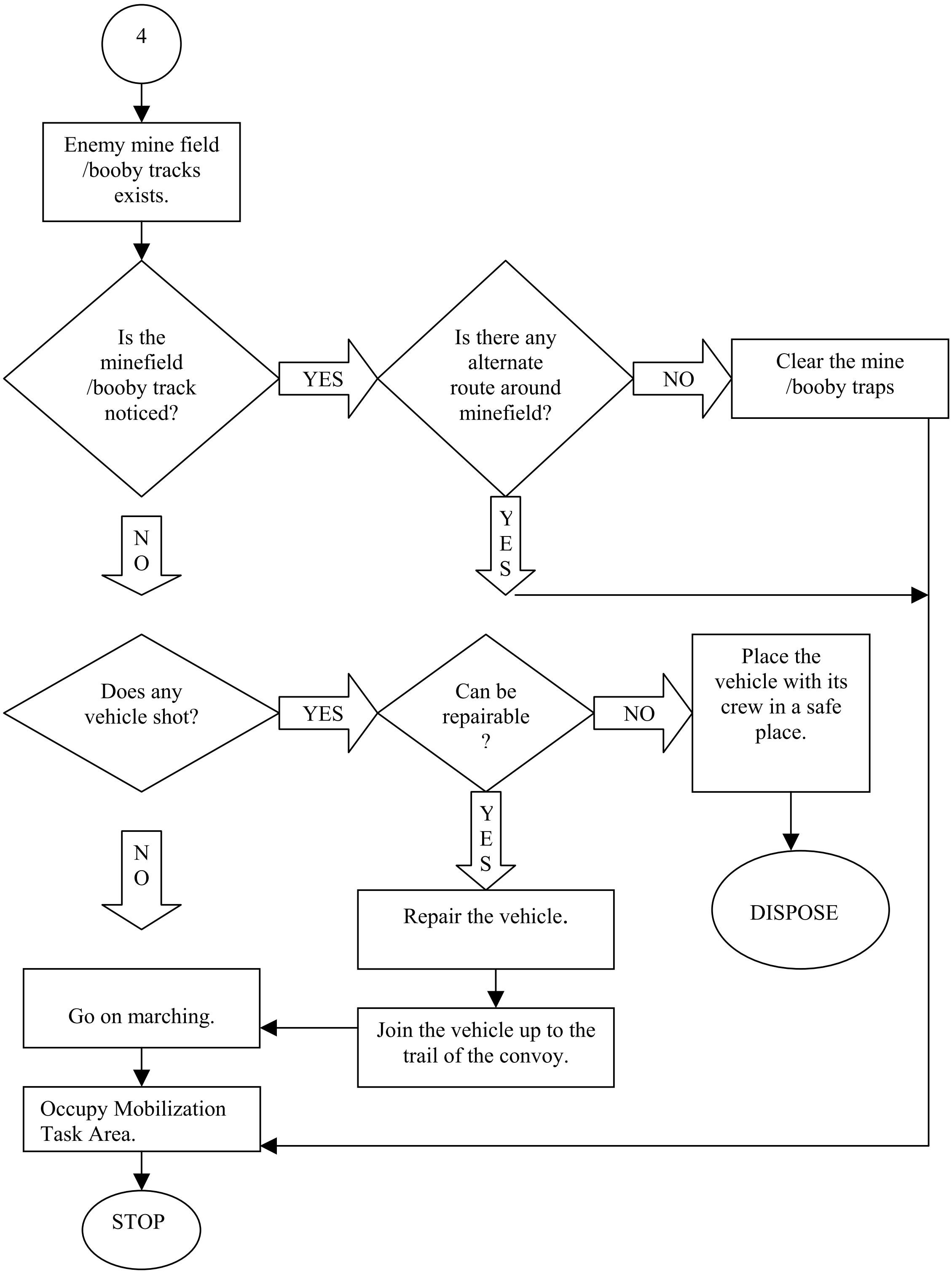


Figure 3.5 Flowchart of the System (cont'd).

Appendix D

Input Data

It is convenient to define the input data that we used in our simulation model separately for each random event.

A. Air Attack:

- Time delay of an enemy air attack: TRIA (15,20,25) minutes.

We interview with the armored battalion and tank company commanders who are the executors of this operation to determine the time delay of an enemy air attack. This delay includes the time to disperse to terrain to decrease the loss and the time to return back to movement road. We decide on the parameters of the triangular distribution as TRIA (15,20,25) minutes for minimum, mode and maximum values, correspondingly.

- The probability to be shot and to have a breakdown given an air attack occurs:

  For armored vehicles: 0.05

  For wheeled vehicles: 0.30

- Types of breakdown caused by air attack:

We categorize the breakdowns into 4 types and determine the repair times of vehicles by interviewing with the technicians of armored and wheeled vehicles who work in the armored battalions and are the experts on breakdowns. The first three types of breakdowns are repairable types but the fourth type is the irreparable type.

The type of breakdown for armored vehicles when an air attack occurs is 1, 2, 3, or 4, with frequency of occurrence 0.45, 0.35, 0.15, and 0.05, respectively. The random variable X, which represents the type of breakdown for armored vehicles when an air attack occurs, has a probability mass function (pmf), p(x), as follows:

$$p(1) = P(X = 1) = 0.45$$
$$p(2) = P(X = 2) = 0.35$$
$$p(3) = P(X = 3) = 0.15$$
$$p(4) = P(X = 4) = 0.05$$

The type of breakdown for wheeled vehicles when an air attack occurs is 1, 2, 3, or 4, with frequency of occurrence 0.40, 0.30, 0.10, and 0.20, respectively. The random variable X, which represents the type of breakdown for wheeled vehicles when an air attack occurs, has a probability mass function (pmf), p(x), as follows:

$$p(1) = P(X = 1) = 0.40$$
$$p(2) = P(X = 2) = 0.30$$
$$p(3) = P(X = 3) = 0.10$$
$$p(4) = P(X = 4) = 0.20$$

We decide parameters of discrete probability distribution of type of breakdown when an air attack occurs for armored and wheeled vehicles as follows:

For armored vehicles: DISC (0,45,1,0,80,2,0,95,3,1,4),

For wheeled vehicles: DISC (0.4,1,0,7,2,0,8,3,1,4).

- The repair times of breakdowns for each type when an air attack occurs are the following:

  1st Type: TRIA (25,30,35) minutes,

  2nd Type: TRIA (40,45,50) minutes and

  3rd Type: TRIA (55,60,65) minutes.

The probability of being shot and having a breakdown and the limits of number of damaged and destroyed vehicles are determined by KKT 190-1 (A) Manevra ve Tatbikatların Sevk ve İdaresi (July 1998) Appendix E, Table19 and Table 17, respectively.

B. Natural Breakdowns:

- The probability having a natural breakdown during movement: 0,08

- Types of breakdown caused by air attack:

The type of breakdown for armored vehicles when a natural breakdown occurs is 1, 2, 3, or 4, with frequency of occurrence 0.55, 0.30, 0.14, and 0.01, respectively. The random variable X, which represents the type of breakdown for armored vehicles when a natural breakdown occurs, has a probability mass function (pmf), p(x), as follows:

$$
\begin{aligned}
p(1) &= P(X=1) = 0.55 \\
p(2) &= P(X=2) = 0.30 \\
p(3) &= P(X=3) = 0.14 \\
p(4) &= P(X=4) = 0.01
\end{aligned}
$$

The type of breakdown for wheeled vehicles when a natural breakdown occurs is 1, 2, 3, or 4, with frequency of occurrence 0.45, 0.35, 0.19, and 0.01, respectively. The random variable X, which represents the type of breakdown for wheeled vehicles when a natural breakdown occurs, has a probability mass function (pmf), p(x), as follows:

$$
\begin{aligned}
p(1) &= P(X = 1) = 0.45 \\
p(2) &= P(X = 2) = 0.35 \\
p(3) &= P(X = 3) = 0.19 \\
p(4) &= P(X = 4) = 0.01
\end{aligned}
$$

We decide parameters of discrete probability distribution of type of breakdown when a natural breakdown occurs for armored and wheeled vehicles as follows:

For armored vehicles: DISC (0,55,1,0,85,2,0,99,3,1,4),

For wheeled vehicles: DISC (0.45,1,0,8,2,0,99,3,1,4).

- The repair times of natural breakdowns for each type are the following:

1st Type: TRIA (15,20,25) minutes,

2nd Type: TRIA (30,35,40) minutes and

3rd Type: TRIA (40,50,55) minutes.

C. Ambush:

- Time delay of an enemy ambush: TRIA (8,10,12) minutes.

  This delay includes the time to dismount vehicles, return fire and the time to return back to movement road.

- The probability to be shot and to have a breakdown given an ambush occurs:

  For armored vehicles: 0,55

  For wheeled vehicles: 0.80

- Types of breakdowns caused by ambush:

The type of breakdown for armored vehicles when an ambush occurs is 1, 2, 3, or 4, with frequency of occurrence 0.40, 0.30, 0.29, and 0.01, respectively. The random variable X, which represents the type of breakdown for armored vehicles when an ambush occurs, has a probability mass function (pmf), p(x), as follows:

$$
\begin{aligned}
p(1) &= P(X = 1) = 0.40 \\
p(2) &= P(X = 2) = 0.30 \\
p(3) &= P(X = 3) = 0.29 \\
p(4) &= P(X = 4) = 0.01
\end{aligned}
$$

The type of breakdown for wheeled vehicles when an ambush occurs is 1, 2, 3, or 4, with frequency of occurrence 0.45, 0.25, 0.10, and 0.20, respectively. The random variable X, which represents the type of breakdown for wheeled vehicles when an ambush occurs, has a probability mass function (pmf), p(x), as follows:

$$p(1) = P(X = 1) = 0.45$$
$$p(2) = P(X = 2) = 0.25$$
$$p(3) = P(X = 3) = 0.10$$
$$p(4) = P(X = 4) = 0.20$$

We decide parameters of discrete probability distribution of type of breakdown when an ambush occurs for armored and wheeled vehicles as follows:

For armored vehicles: DISC (0,4,1,0,7,2,0,99,3,1,4),

For wheeled vehicles: DISC (0.45,1,0,7,2,0,8,3,1,4).

- The repair times of breakdowns for each type when an ambush occurs are the following:

  1st Type: TRIA (25,30,35) minutes,

  2nd Type: TRIA (40,45,50) minutes and

  3rd Type: TRIA (55,60,65) minutes.

The limits of number of damaged and destroyed vehicles are determined by KKT 190-1 (A) Manevra ve Tatbikatların Sevk ve İdaresi (July 1998) Appendix E, Direct Fire, Table1.

D. Mine:

- The probability to notice the mine or booby trap during movement: 0,05.

- Time to react to mine or booby trap when noticed: TRIA (5,7,9) minutes.

- Time to react to mine or booby trap when not noticed: TRIA (9,10,11) minutes. (This time includes the time to dismount vehicles, to take cover, to take all around security, and to pull the damaged/destroyed vehicles out of road).
- The probability having an alternate road around the mine or booby trap: 0,75.
- Time to clear the mine or booby trap when there is no alternate road to pass around: TRIA (9,10,11) minutes.
- The probability to have a breakdown caused by mine:

  For armored vehicles: 0.27

  For wheeled vehicles: 0.72
- Types of breakdown caused by mine:

The type of breakdown for armored vehicles caused by mine is 1, 2, 3, or 4, with frequency of occurrence 0.15, 0.20, 0.30, and 0.35, respectively. The random variable X, which represents the type of breakdown for armored vehicles caused by mine, has a probability mass function (pmf), p(x), as follows:

$$p(1) = P(X = 1) = 0.15$$
$$p(2) = P(X = 2) = 0.20$$
$$p(3) = P(X = 3) = 0.30$$
$$p(4) = P(X = 4) = 0.35$$

The type of breakdown for wheeled vehicles caused by mine is 1, 2, 3, or 4, with frequency of occurrence 0.10, 0.20, 0.20, and 0.50, respectively. The random variable X, which represents the type of breakdown for wheeled vehicles caused by mine, has a probability mass function (pmf), p(x), as follows:

$$
\begin{aligned}
p(1) &= P(X = 1) = 0.10 \\
p(2) &= P(X = 2) = 0.20 \\
p(3) &= P(X = 3) = 0.20 \\
p(4) &= P(X = 4) = 0.50
\end{aligned}
$$

We decide parameters of discrete probability distribution of type of breakdown caused by mine for armored and wheeled vehicles as follows:

For armored vehicles: DISC (0,15,1,0,35,2,0,65,3,1,4),

For wheeled vehicles: DISC (0.1,1,0,3,2,0,5,3,1,4).

- The repair times of breakdowns for each type are the following:

1st Type: TRIA (25,30,35) minutes,

2nd Type: TRIA (40,60,75) minutes and

3rd Type: TRIA (70,80,90) minutes.

D. Artillery Attack:

- The probability having an alternate road around the impact area: 0,75.
- Time to disperse and to wait for the artillery attack to pass by when there is no alternate road around the impact area: TRIA (15,20,25) minutes.

- Type of concentration: DISC (0,2,1,0,8,2,1,3)

  When an enemy artillery attack occurs the artillery concentration can be:

  1. Ahead of the convoy,
  2. On the flanks or behind of the convoy or,
  3. On the center of the convoy.

The type of concentration when an artillery attack occurs is 1, 2, or 3, with frequency of occurrence 0.20, 0.60, and 0.20, respectively. The random variable X, which represents the type of concentration when an artillery attack occurs, has a probability mass function (pmf), p(x), as follows:

$$p(1) = P(X = 1) = 0.20$$
$$p(2) = P(X = 2) = 0.60$$
$$p(3) = P(X = 3) = 0.20$$

So, the discrete probability distribution of type of concentration is

DISC (0,2,1,0,8,2,1,3).

- The probability to have a breakdown caused by artillery attack when the artillery concentration is on the convoy:

  For armored vehicles: 0.40

  For wheeled vehicles: 0.90

- Types of breakdowns caused by artillery attack:

The type of breakdown for armored vehicles when an artillery attack occurs is 1, 2, 3, or 4, with frequency of occurrence 0.40, 0.35, 0.20, and 0.05, respectively. The random variable X, which represents the type of breakdown for armored vehicles when an artillery attack occurs, has a probability mass function (pmf), p(x), as follows:

$$\begin{aligned} p(1) &= P(X = 1) = 0.40 \\ p(2) &= P(X = 2) = 0.35 \\ p(3) &= P(X = 3) = 0.20 \\ p(4) &= P(X = 4) = 0.05 \end{aligned}$$

The type of breakdown for wheeled vehicles when an artillery attack occurs is 1, 2, 3, or 4, with frequency of occurrence 0.25, 0.25, 0.30, and 0.20, respectively. The random variable X, which represents the type of breakdown for wheeled vehicles when an artillery attack occurs, has a probability mass function (pmf), p(x), as follows:

$$\begin{aligned} p(1) &= P(X = 1) = 0.25 \\ p(2) &= P(X = 2) = 0.25 \\ p(3) &= P(X = 3) = 0.30 \\ p(4) &= P(X = 4) = 0.20 \end{aligned}$$

We decide parameters of discrete probability distribution of type of breakdown when an artillery attack occurs for armored and wheeled vehicles as follows:

For armored vehicles: DISC (0,4,1,0,75,2,0,95,3,1,4),

For wheeled vehicles: DISC (0.25,1,0,5,2,0,8,3,1,4).

- The repair times of breakdowns for each type are the following:

  1st Type: TRIA (25,30,35) minutes,

  2nd Type: TRIA (40,45,50) minutes and

- 3rd Type: TRIA (55,60,65) minutes.

The limits of number of damaged and destroyed vehicles are determined by KKT 190-1 (A) Manevra ve Tatbikatların Sevk ve İdaresi (July 1998) Appendix E, Indirect Fire, Table 6. and Table 7.

Appendix E

Sample Sizes

1. Sample Sizes for Scenario1:

- **Sample Sizes for MTIS**

Table 4.10 Summary Table of Sample Sizes for MTIS in Scenario-1.

CASE1			
SAMPLE SIZE	AVERAGE	VARIANCE	$\delta(n,\alpha)$
n = 5	193.58	66.344	**10.126**
CASE2			
SAMPLE SIZE	AVERAGE	VARIANCE	$\delta(n,\alpha)$
n = 5	261.97	311.844	21.954
n = 6	260.608	260.6	16.937
n = 7	261.943	229.633	**14.032**
CASE3			
SAMPLE SIZE	AVERAGE	VARIANCE	$\delta(n,\alpha)$
n = 5	311.982	1200.978	43.085
n = 6	308.455	1035.421	33.76105
n = 7	309.773	875.007	27.39194
n = 8	309.718	750.03	22.85106
n = 9	305.802	794.329	21.70156
n = 10	305.763	706.085	18.99052
n = 11	303.491	692.263	17.69066
n = 12	304.632	644.969	16.12878
n = 13	303.283	614.867	**14.99255**

- **Sample Sizes for NODV**

Table 4.11 Summary Table of Sample Sizes for NODV in Scenario-1.

CASE1			
SAMPLE SIZE	AVERAGE	VARIANCE	$\delta(n,\alpha)$
n = 5	0	0	**0**
CASE2			
SAMPLE SIZE	AVERAGE	VARIANCE	$\delta(n,\alpha)$
n = 5	4.4	2.3	**1.885**
CASE3			
SAMPLE SIZE	AVERAGE	VARIANCE	$\delta(n,\alpha)$
n = 5	7.8	1.7	**1.885**

2. Sample Sizes for Scenario2:

- **Sample Sizes for MTIS**

Table 4.12 Summary Table of Sample Sizes for MTIS in Scenario-2.

CASE1			
SAMPLE SIZE	**AVERAGE**	**VARIANCE**	$\delta(n,\alpha)$
n = 5	149.138	42.717	**8.125**
CASE2			
SAMPLE SIZE	**AVERAGE**	**VARIANCE**	$\delta(n,\alpha)$
n = 5	201.506	63.701	**9.922**
CASE3			
SAMPLE SIZE	**AVERAGE**	**VARIANCE**	$\delta(n,\alpha)$
n = 5	241.372	50.156	**8.804**

- **Sample Sizes for Number of Destroyed Vehicles**

Table 4.13 Summary Table of Sample Sizes for NODV in Scenario-2.

CASE1			
SAMPLE SIZE	**AVERAGE**	**VARIANCE**	$\delta(n,\alpha)$
n = 5	0	0	**0**
CASE2			
SAMPLE SIZE	**AVERAGE**	**VARIANCE**	$\delta(n,\alpha)$
n = 5	5.6	9.8	**3.892**
CASE3			
SAMPLE SIZE	**AVERAGE**	**VARIANCE**	$\delta(n,\alpha)$
n = 5	7	10	**3.931**

Appendix F

Data Lists of Paired-t Test

1. Data List for MTIS

Table 4.14 Data List for MTIS.

	CASE1			CASE2			CASE3		
REP. #	**Xi**	**Yi**	**Zi**	**Xi**	**Yi**	**Zi**	**Xi**	**Yi**	**Zi**
1	187.28	153.45	**33.83**	257	193.81	**63.19**	309.31	237.55	**71.76**
2	207.45	158.53	**48.92**	282.23	212.82	**69.41**	308.16	231.65	**76.51**
3	194.13	144.25	**49.88**	276.14	200.14	**76**	362.11	245.2	**116.91**
4	189.38	145.54	**43.84**	256.66	194.76	**61.9**	315.83	242.38	**73.45**
5	189.66	143.92	**45.74**	237.82	206	**31.82**	264.5	250.08	**14.42**
6	194.6	162.19	**32.41**	253.8	186.1	**67.7**	290.82	299.29	**-8.47**
7	187.84	144.54	**43.3**	269.95	222.13	**47.82**	317.68	236.61	**81.07**
8	190.94	142.49	**48.45**	251.78	254.22	**-2.44**	309.34	240.13	**69.21**
9	192.15	147.69	**44.46**	267.39	235.13	**32.26**	274.47	317.53	**-43.06**
10	194.28	155.19	**39.09**	238.39	194.39	**44**	305.41	268.41	**37**
11	192	145.05	**46.95**	300.74	173.63	**127.11**	280.77	217.08	**63.69**
12	221.07	144.09	**76.98**	251.88	172.86	**79.02**	317.19	232.13	**85.06**
13	180.23	135.33	**44.9**	229.21	195.16	**34.05**	287.1	224.79	**62.31**
14	193.36	164.15	**29.21**	234.84	188.66	**46.18**	333.38	215.01	**118.37**
15	208.92	141.54	**67.38**	219.18	191.94	**27.24**	306.15	270.92	**35.23**

2. Data List for Number of Destroyed Vehicles

Table 4.15 Data List for Number of Destroyed Vehicles.

	CASE1			CASE2			CASE3		
REP. #	**Xi**	**Yi**	**Zi**	**Xi**	**Yi**	**Zi**	**Xi**	**Yi**	**Zi**
1	0	0	**0**	4	9	**-5**	7	2	**5**
2	0	0	**0**	3	1	**2**	7	6	**1**
3	0	0	**0**	4	5	**-1**	7	9	**-2**
4	0	0	**0**	4	5	**-1**	10	10	**0**
5	0	0	**0**	7	8	**-1**	8	8	**0**
6	0	0	**0**	5	5	**0**	9	9	**0**
7	0	0	**0**	2	7	**-5**	10	8	**2**
8	0	0	**0**	4	7	**-3**	5	5	**0**
9	0	0	**0**	8	8	**0**	10	7	**3**
10	0	0	**0**	6	5	**1**	5	7	**-2**
11	1	0	**1**	7	6	**1**	10	7	**3**
12	0	0	**0**	4	9	**-5**	8	10	**-2**
13	0	0	**0**	4	10	**-6**	10	10	**0**
14	0	0	**0**	9	4	**5**	10	3	**7**
15	0	0	**0**	7	3	**4**	5	7	**-2**

Appendix G

The Design Matrix for 2^5 Factorial Design

Table 4.16 Design Matrix for 2^5 Factorial Design

	A	B	C	D	E
DP1	-	-	-	-	-
DP2	+	-	-	-	-
DP3	-	+	-	-	-
DP4	-	-	+	-	-
DP5	-	-	-	+	-
DP6	-	-	-	-	+
DP7	+	+	-	-	-
DP8	+	-	+	-	-
DP9	+	-	-	+	-
DP10	+	-	-	-	+
DP11	-	+	+	-	-
DP12	-	+	-	+	-
DP13	-	+	-	-	+
DP14	-	-	+	+	-
DP15	-	-	+	-	+
DP16	-	-	-	+	+
DP17	+	+	+	-	-
DP18	+	+	-	+	-
DP19	+	+	-	-	+
DP20	+	-	+	+	-
DP21	+	-	+	-	+
DP22	+	-	-	+	+
DP23	-	+	+	+	-
DP24	-	+	+	-	+
DP25	-	+	-	+	+
DP26	-	-	+	+	+
DP27	+	+	+	+	-
DP28	+	+	+	-	+
DP29	+	+	-	+	+
DP30	+	-	+	+	+
DP31	-	+	+	+	+
DP32	+	+	+	+	+

The Outputs of Design Points for Performance Measures

Table 4.17 The Outputs of 32 Design Points for MTIS.

REP. #	DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8
1	130.19	178.08	146.87	152.82	130.82	163.57	185.32	187.85
2	140.13	174.23	142.97	184.83	143.95	167.78	172.71	170.32
3	144.76	185.86	149.60	146.48	155.36	150.05	207.88	187.36
4	145.23	168.18	156.04	152.68	155.12	143.54	188.97	74.81
5	127.39	159.44	166.74	174.45	112.99	156.37	182.54	183.85
6	130.80	200.74	151.58	153.09	143.33	146.10	181.31	172.96
7	183.22	155.23	158.01	164.04	155.05	176.03	178.96	175.11
8	129.49	178.26	160.90	141.36	117.03	177.86	188.78	192.22
9	146.59	165.76	156.47	151.36	144.88	145.64	184.31	191.64
10	112.87	179.53	163.10	146.04	156.82	145.35	204.26	210.86
11	143.21	201.96	143.21	149.32	146.09	148.68	187.64	185.53
12	132.55	214.34	162.51	143.67	133.98	146.90	184.51	215.79
13	130.21	169.20	165.46	155.14	134.24	147.61	204.05	175.58
14	145.05	175.58	138.40	163.08	131.97	147.57	170.13	204.89
15	142.93	174.47	150.08	145.01	150.41	148.49	165.77	173.86
MEAN	**138.97**	**178.72**	**154.13**	**154.89**	**140.80**	**154.10**	**185.81**	**186.84**
VARIANCE	**237.65**	**263.38**	**78.23**	**145.80**	**188.26**	**133.22**	**148.79**	**203.42**

REP. #	DP9	DP10	DP11	DP12	DP13	DP14	DP15	DP16
1	178.08	231.72	163.61	147.49	188.50	153.44	142.11	173.44
2	185.52	210.57	157.03	165.05	185.37	164.84	152.83	170.28
3	183.64	224.32	167.02	166.21	194.09	154.76	165.89	175.16
4	195.98	199.36	159.53	164.67	177.77	148.31	177.08	165.57
5	202.45	208.26	192.17	153.22	152.35	166.61	199.23	172.56
6	165.53	241.46	166.63	181.45	161.81	176.74	195.82	186.65
7	177.94	230.89	167.92	198.12	208.85	168.31	181.31	157.24
8	202.29	236.36	168.67	151.24	165.39	143.31	167.19	163.28
9	174.75	210.24	167.31	166.11	170.30	165.22	158.38	144.90
10	183.25	226.76	164.95	140.82	167.68	168.54	186.55	178.48
11	196.53	212.30	178.41	162.60	161.14	185.89	155.38	147.38
12	173.09	202.82	151.18	153.05	189.23	153.21	147.08	145.47
13	176.79	168.49	177.09	167.37	166.76	156.59	160.44	148.02
14	183.03	196.92	161.32	146.59	148.56	156.99	149.06	147.28
15	207.72	301.28	167.90	154.22	189.99	157.96	191.81	151.04
MEAN	**185.77**	**220.12**	**167.38**	**161.21**	**175.19**	**161.38**	**168.68**	**161.78**
VARIANCE	**154.58**	**853.11**	**94.3911**	**213.197**	**289.172**	**122.489**	**351.721**	**193.68**

Table 4.17 The Outputs of 32 Design Points for MTIS (cont'd).

REP. #	DP17	DP18	DP19	DP20	DP21	DP22	DP23	DP24
1	177.01	185.94	203.34	188.48	209.40	197.90	147.30	163.55
2	183.46	187.54	183.66	199.08	186.08	239.43	175.58	184.11
3	190.41	202.91	202.34	219.17	203.87	235.63	178.44	212.16
4	193.35	198.44	237.93	185.98	212.95	225.82	154.92	168.84
5	207.12	175.67	238.24	183.49	224.56	184.57	167.41	165.46
6	183.70	180.37	218.81	174.15	233.80	193.10	178.94	168.68
7	191.55	180.94	203.41	187.67	205.20	279.87	168.06	160.16
8	212.99	207.23	194.83	190.26	213.83	213.12	165.81	198.93
9	215.24	179.44	206.88	177.57	203.05	224.97	192.82	175.08
10	184.34	188.81	196.60	211.93	189.82	197.48	166.23	196.18
11	174.23	192.81	223.20	188.12	235.17	205.65	163.36	174.98
12	194.84	177.42	208.64	186.27	186.29	192.93	171.89	183.07
13	186.68	185.11	207.85	194.24	203.42	245.52	163.27	166.90
14	212.84	199.16	211.51	186.09	215.45	190.49	167.37	168.41
15	184.75	171.25	178.07	185.49	173.44	211.01	175.20	187.61
MEAN	**192.84**	**187.54**	**207.69**	**190.53**	**206.42**	**215.83**	**169.11**	**178.27**
VARIANCE	**176.26**	**113.21**	**288.37**	**139.48**	**307.40**	**683.38**	**114.48**	**227.00**
REP. #	**DP25**	**DP26**	**DP27**	**DP28**	**DP29**	**DP30**	**DP31**	**DP32**
1	181.48	167.01	178.70	211.36	225.34	230.10	178.60	206.96
2	155.31	164.80	203.59	194.12	217.36	197.83	190.49	229.16
3	212.86	185.95	221.80	236.65	235.74	221.96	208.93	209.06
4	181.78	156.84	182.73	212.35	224.10	228.57	209.20	251.39
5	173.81	163.73	184.35	238.51	197.55	277.52	167.28	249.55
6	179.73	178.49	196.56	208.56	253.28	206.17	181.29	224.03
7	167.10	174.00	209.17	183.56	248.51	207.72	200.45	198.23
8	170.39	181.50	188.25	218.16	189.71	205.37	163.08	192.22
9	179.26	176.75	184.11	221.53	203.82	253.83	173.74	242.30
10	163.33	189.54	185.06	184.66	216.14	231.46	182.70	236.45
11	177.05	164.18	201.72	223.48	220.09	190.75	166.49	197.62
12	153.15	183.26	189.60	200.24	266.72	209.62	173.14	211.22
13	180.67	157.61	190.82	244.15	214.03	209.91	175.53	210.90
14	183.36	172.57	186.31	176.91	197.15	206.76	174.81	218.31
15	162.95	184.53	185.97	183.28	195.30	232.51	164.40	233.11
MEAN	**174.82**	**173.38**	**192.58**	**209.17**	**220.32**	**220.67**	**180.68**	**220.70**
VARIANCE	**207.048**	**111.386**	**139.203**	**469.11**	**519.06**	**514.397**	**230.637**	**363.571**

Table 4.18 The Outputs of 32 Design Points for NODV.

REP. #	DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8
1	0.00	2.00	0.00	0.00	0.00	0.00	2.00	2.00
2	0.00	5.00	0.00	0.00	0.00	1.00	4.00	5.00
3	0.00	6.00	0.00	0.00	0.00	0.00	6.00	6.00
4	0.00	3.00	0.00	0.00	2.00	0.00	3.00	1.00
5	0.00	3.00	0.00	0.00	0.00	0.00	5.00	3.00
6	0.00	4.00	0.00	1.00	0.00	1.00	8.00	4.00
7	0.00	5.00	1.00	0.00	0.00	0.00	4.00	7.00
8	0.00	4.00	0.00	0.00	0.00	0.00	7.00	4.00
9	0.00	1.00	0.00	0.00	0.00	1.00	2.00	5.00
10	0.00	3.00	0.00	0.00	2.00	0.00	3.00	4.00
11	0.00	3.00	0.00	0.00	0.00	0.00	4.00	8.00
12	0.00	3.00	0.00	1.00	0.00	0.00	2.00	4.00
13	0.00	4.00	0.00	0.00	0.00	0.00	8.00	5.00
14	0.00	2.00	0.00	0.00	0.00	0.00	5.00	5.00
15	0.00	2.00	0.00	0.00	2.00	0.00	5.00	3.00
MEAN	**0.00**	**3.33**	**0.07**	**0.13**	**0.40**	**0.20**	**4.53**	**4.40**
VARIANCE	**0.00**	**1.81**	**0.07**	**0.12**	**0.69**	**0.17**	**4.12**	**3.26**
REP. #	**DP9**	**DP10**	**DP11**	**DP12**	**DP13**	**DP14**	**DP15**	**DP16**
1	2.00	2.00	1.00	0.00	0.00	0.00	1.00	0.00
2	6.00	4.00	2.00	1.00	1.00	1.00	0.00	1.00
3	7.00	5.00	1.00	1.00	0.00	2.00	0.00	1.00
4	1.00	4.00	1.00	1.00	1.00	0.00	0.00	1.00
5	4.00	5.00	0.00	1.00	0.00	1.00	0.00	1.00
6	3.00	5.00	0.00	0.00	1.00	0.00	1.00	2.00
7	7.00	5.00	0.00	0.00	0.00	2.00	0.00	0.00
8	11.00	3.00	0.00	0.00	2.00	0.00	0.00	0.00
9	5.00	5.00	0.00	0.00	1.00	1.00	0.00	0.00
10	3.00	6.00	1.00	0.00	0.00	2.00	0.00	1.00
11	7.00	2.00	0.00	2.00	0.00	0.00	1.00	0.00
12	9.00	4.00	0.00	0.00	0.00	0.00	1.00	0.00
13	7.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00
14	4.00	4.00	1.00	0.00	0.00	0.00	0.00	0.00
15	2.00	4.00	0.00	0.00	0.00	2.00	1.00	0.00
MEAN	**5.20**	**4.20**	**0.47**	**0.40**	**0.40**	**0.73**	**0.33**	**0.47**
VARIANCE	**8.02857**	**1.31429**	**0.40952**	**0.4**	**0.4**	**0.78095**	**0.2381**	**0.40952**

Table 4.18 The Outputs of 32 Design Points for NODV (cont'd).

REP. #	DP17	DP18	DP19	DP20	DP21	DP22	DP23	DP24
1	3.00	2.00	2.00	2.00	2.00	2.00	1.00	0.00
2	4.00	4.00	3.00	2.00	5.00	4.00	3.00	0.00
3	5.00	4.00	4.00	5.00	11.00	4.00	0.00	1.00
4	2.00	1.00	4.00	7.00	5.00	6.00	0.00	0.00
5	4.00	3.00	2.00	5.00	4.00	6.00	2.00	2.00
6	4.00	4.00	6.00	4.00	6.00	5.00	3.00	1.00
7	7.00	5.00	8.00	7.00	1.00	2.00	0.00	0.00
8	3.00	4.00	6.00	5.00	5.00	6.00	0.00	1.00
9	3.00	8.00	6.00	2.00	8.00	4.00	3.00	3.00
10	4.00	5.00	1.00	3.00	6.00	5.00	0.00	0.00
11	4.00	9.00	6.00	3.00	5.00	6.00	1.00	0.00
12	4.00	6.00	9.00	7.00	6.00	9.00	2.00	0.00
13	1.00	2.00	4.00	3.00	8.00	5.00	2.00	1.00
14	10.00	7.00	5.00	7.00	5.00	7.00	0.00	1.00
15	1.00	2.00	4.00	4.00	8.00	6.00	1.00	1.00
MEAN	**3.93**	**4.40**	**4.67**	**4.40**	**5.67**	**5.13**	**1.20**	**0.73**
VARIANCE	**5.07**	**5.40**	**4.95**	**3.69**	**6.10**	**3.27**	**1.46**	**0.78**
REP. #	**DP25**	**DP26**	**DP27**	**DP28**	**DP29**	**DP30**	**DP31**	**DP32**
1	2.00	1.00	5.00	2.00	4.00	3.00	0.00	4.00
2	0.00	0.00	1.00	6.00	3.00	2.00	1.00	2.00
3	2.00	1.00	6.00	9.00	4.00	7.00	4.00	9.00
4	0.00	0.00	5.00	3.00	5.00	6.00	0.00	3.00
5	1.00	3.00	2.00	3.00	6.00	6.00	2.00	5.00
6	0.00	2.00	6.00	3.00	5.00	6.00	1.00	5.00
7	0.00	0.00	3.00	5.00	5.00	7.00	0.00	5.00
8	0.00	1.00	4.00	6.00	9.00	4.00	0.00	10.00
9	2.00	0.00	7.00	4.00	8.00	5.00	1.00	5.00
10	0.00	0.00	0.00	7.00	4.00	5.00	5.00	8.00
11	0.00	2.00	5.00	5.00	6.00	4.00	5.00	6.00
12	0.00	0.00	5.00	5.00	7.00	7.00	1.00	6.00
13	0.00	0.00	5.00	11.00	4.00	6.00	2.00	3.00
14	2.00	2.00	6.00	1.00	3.00	4.00	1.00	8.00
15	0.00	0.00	2.00	7.00	7.00	5.00	1.00	5.00
MEAN	**0.60**	**0.80**	**4.13**	**5.13**	**5.33**	**5.13**	**1.60**	**5.60**
VARIANCE	**0.82857**	**1.02857**	**4.26667**	**7.12381**	**3.2381**	**2.26667**	**2.97143**	**5.25714**

Appendix H

Regression Models for Performance Measures

Table 4.19 Regression Model of Response for Performance Measures

Performance Measure	Regression Model
MTIS	$\hat{y} = 182.385 + 18.962 * X_A + 3.703X_B + 3.459X_C + 2.434X_D + 10.603X_E - 2.971X_{AB} - 2.338X_{AC} - 7.405X_{AE} + 8.867X_{CE}$
Number of Destroyed Vehicles	$\hat{y} = 2.617 + 2.084X_A + 0.158X_C + 0.229X_D + 0.259X_E + 0.15X_{AE}$

Table 4.20 Residuals for MTIS Performance Measure.

DESIGN POINT	y	$\hat{y}$	E
1	138.975	139.378	-0.403
2	178.724	202.727	-24.003
3	154.129	152.726	1.402
4	154.891	133.239	21.652
5	140.803	144.246	-3.443
6	154.102	157.659	-3.557
7	185.809	204.193	-18.384
8	186.842	187.237	-0.395
9	185.773	207.595	-21.822
10	220.116	191.390	28.725
11	167.383	146.587	20.796
12	161.215	157.594	3.621
13	175.187	171.007	4.179
14	161.381	138.107	23.273
15	168.677	186.988	-18.311
16	161.784	162.527	-0.743
17	192.835	188.703	4.132
18	187.536	209.061	-21.525
19	207.689	192.857	14.832
20	190.532	192.105	-1.573
21	206.423	211.369	-4.946
22	215.833	196.258	19.574
23	169.105	183.998	-14.893
24	178.274	200.336	-22.063
25	174.815	175.875	-1.060
26	173.384	191.856	-18.473
27	192.583	193.571	-0.988
28	209.168	212.835	-3.666
29	220.323	197.725	22.598
30	220.671	216.237	4.434
31	180.676	205.204	-24.529
32	220.699	217.703	2.997

Table 4.21 Residuals for NODV Performance Measure.

DESIGN POINT	y	$\hat{y}$	E
1	0.000	2.620	-2.620
2	3.333	2.620	0.713
3	0.067	2.620	-2.553
4	0.133	2.620	-2.487
5	0.400	2.620	-2.220
6	0.200	2.620	-2.420
7	4.533	2.620	1.913
8	4.400	2.620	1.780
9	5.200	2.620	2.580
10	4.200	2.620	1.580
11	0.467	2.620	-2.153
12	0.400	2.620	-2.220
13	0.400	2.620	-2.220
14	0.733	2.620	-1.887
15	0.333	2.620	-2.287
16	0.467	2.620	-2.153
17	3.933	2.620	1.313
18	4.400	2.620	1.780
19	4.667	2.620	2.047
20	4.400	2.620	1.780
21	5.667	2.620	3.047
22	5.133	2.620	2.513
23	1.200	2.620	-1.420
24	0.733	2.620	-1.887
25	0.600	2.620	-2.020
26	0.800	2.620	-1.820
27	4.133	2.620	1.513
28	5.133	2.620	2.513
29	5.333	2.620	2.713
30	5.133	2.620	2.513
31	1.600	2.620	-1.020
32	5.600	2.620	2.980

Appendix I

ANOVA Results for Performance Measures (SPSS 11.0)

Table 4.22 ANOVA Results for MTIS.

Tests of Between-Subjects Effects
Dependent Variable: RESPONSE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	259653.592	31	8375.922	32.308	.000
Intercept	15964378.008	1	15964378.008	61578.874	.000
A	172824.300	1	172824.300	666.630	.000
B	6571.200	1	6571.200	25.347	.000
C	5754.675	1	5754.675	22.197	.000
D	2832.408	1	2832.408	10.925	.001
E	54017.633	1	54017.633	208.360	.000
A * B	4212.675	1	4212.675	16.249	.000
A * C	2632.033	1	2632.033	10.152	.002
B * C	246.533	1	246.533	.951	.330
A * B * C	848.008	1	848.008	3.271	.071
A * D	108.300	1	108.300	.418	.518
B * D	16.133	1	16.133	.062	.803
A * B * D	102.675	1	102.675	.396	.529
C * D	63.075	1	63.075	.243	.622
A * C * D	70.533	1	70.533	.272	.602
B * C * D	240.833	1	240.833	.929	.336
A * B * C * D	78.408	1	78.408	.302	.583
A * E	4775.408	1	4775.408	18.420	.000
B * E	343.408	1	343.408	1.325	.250
A * B * E	136.533	1	136.533	.527	.468
C * E	1387.200	1	1387.200	5.351	.021
A * C * E	42.008	1	42.008	.162	.687
B * C * E	39.675	1	39.675	.153	.696
A * B * C * E	80.033	1	80.033	.309	.579
D * E	177.633	1	177.633	.685	.408
A * D * E	291.408	1	291.408	1.124	.290
B * D * E	69.008	1	69.008	.266	.606
A * B * D * E	529.200	1	529.200	2.041	.154
C * D * E	264.033	1	264.033	1.018	.313
A * C * D * E	226.875	1	226.875	.875	.350
B * C * D * E	18.408	1	18.408	.071	.790
A * B * C * D * E	653.333	1	653.333	2.520	.113
Error	116144.400	448	259.251		
Total	16340176.000	480			
Corrected Total	375797.992	479			

a R Squared = .691 (Adjusted R Squared = .670)

Table 4.23 ANOVA Results for NODV.

Tests of Between-Subjects Effects
Dependent Variable: RESPONSE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2211.631	31	71.343	28.547	.000
Intercept	3291.769	1	3291.769	1317.17	.000
A	2079.169	1	2079.169	831.965	.000
B	3.169	1	3.169	1.268	.261
C	11.719	1	11.719	4.689	.031
D	24.752	1	24.752	9.904	.002
E	31.519	1	31.519	12.612	.000
A * B	2.002	1	2.002	.801	.371
A * C	1.519	1	1.519	.608	.436
B * C	1.875E-02	1	1.875E-02	.008	.931
A * B * C	5.852	1	5.852	2.342	.127
A * D	5.208E-02	1	5.208E-02	.021	.885
B * D	.169	1	.169	.068	.795
A * B * D	1.102	1	1.102	.441	.507
C * D	1.302	1	1.302	.521	.471
A * C * D	10.502	1	10.502	4.202	.057
B * C * D	7.752	1	7.752	3.102	.079
A * B * C * D	3.852	1	3.852	1.541	.215
A * E	11.102	1	11.102	4.442	.036
B * E	1.302	1	1.302	.521	.471
A * B * E	1.875E-02	1	1.875E-02	.008	.931
C * E	4.219	1	4.219	1.688	.195
A * C * E	3.169	1	3.169	1.268	.261
B * C * E	.102	1	.102	.041	.840
A * B * C * E	5.208E-02	1	5.208E-02	.021	.885
D * E	.169	1	.169	.068	.795
A * D * E	1.875E-02	1	1.875E-02	.008	.931
B * D * E	3.502	1	3.502	1.401	.237
A * B * D * E	2.552	1	2.552	1.021	.313
C * D * E	2.083E-03	1	2.083E-03	.001	.977
A * C * D * E	5.208E-02	1	5.208E-02	.021	.885
B * C * D * E	.169	1	.169	.068	.795
A * B * C * D * E	.752	1	.752	.301	.584
Error	1119.600	448	2.499		
Total	6623.000	480			
Corrected Total	3331.231	479			

a R Squared = .664 (Adjusted R Squared = .641)

Table 4.24 ANOVA Results of Transformed Data for MTIS.

Tests of Between-Subjects Effects
Dependent Variable: RESPONSE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.100E-02	31	3.548E-04	36.795	.000
Intercept	2.678	1	2.678	277658.167	.000
A	7.264E-03	1	7.264E-03	753.300	.000
B	4.125E-04	1	4.125E-04	42.779	.000
C	3.622E-04	1	3.622E-04	37.557	.000
D	1.211E-04	1	1.211E-04	12.562	.000
E	2.076E-03	1	2.076E-03	215.329	.000
A * B	2.656E-04	1	2.656E-04	27.537	.000
A * C	1.810E-04	1	1.810E-04	18.773	.000
B * C	3.221E-05	1	3.221E-05	3.340	.068
A * B * C	5.088E-05	1	5.088E-05	5.277	.072
A * D	1.079E-08	1	1.079E-08	.001	.973
B * D	3.150E-06	1	3.150E-06	.327	.568
A * B * D	4.683E-06	1	4.683E-06	.486	.486
C * D	8.582E-07	1	8.582E-07	.089	.766
A * C * D	1.839E-06	1	1.839E-06	.191	.663
B * C * D	6.570E-06	1	6.570E-06	.681	.410
A * B * C * D	6.915E-07	1	6.915E-07	.072	.789
A * E	3.517E-05	1	3.517E-05	3.647	.047
B * E	2.613E-05	1	2.613E-05	2.709	.100
A * B * E	1.576E-07	1	1.576E-07	.016	.898
C * E	8.306E-05	1	8.306E-05	8.613	.004
A * C * E	1.310E-06	1	1.310E-06	.136	.713
B * C * E	3.495E-06	1	3.495E-06	.362	.547
A * B * C * E	3.105E-07	1	3.105E-07	.032	.858
D * E	2.279E-06	1	2.279E-06	.236	.627
A * D * E	5.682E-06	1	5.682E-06	.589	.443
B * D * E	1.376E-06	1	1.376E-06	.143	.706
A * B * D * E	2.058E-05	1	2.058E-05	2.134	.145
C * D * E	7.864E-06	1	7.864E-06	.816	.367
A * C * D * E	6.911E-06	1	6.911E-06	.717	.398
B * C * D * E	2.854E-08	1	2.854E-08	.003	.957
A * B * C * D * E	2.110E-05	1	2.110E-05	2.188	.140
Error	4.320E-03	448	9.643E-06		
Total	2.693	480			
Corrected Total	1.532E-02	479			

a R Squared = .718 (Adjusted R Squared = .698)

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