COMPARISON OF TWO ARTILLERY WEAPON SYSTEM BY USING LIFE CYCLE COST TECHNIQUE

by

OLCAY KUÇUKTEPE

A THESIS
SUBMITTED TO THE DEPARTMENT OF BUSINESS
ADMINISTRATION OF BİLKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

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

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Abstract

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by

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Department of Business Administration

This thesis presents the use of life cycle cost technique. By using this technique, two different artillery weapon systems is compared on cost base. One of the systems is called SP2000 or Modern Self - Propelled Gun and design, and will be produced in Turkey; and the other system is called M109 Paladin, main artillery system in the U.S army.

Main purpose of the study is to show the disadvantages of the selection system that depends on the initial cost only. The main cost items occur after some period of the life of the system. Maintenance or the operation cost of the systems will be the major cost item in the life of the system. Therefore the life cycle cost technique is one of the tools for estimating the true cost of the system before the costs occur. In this thesis, the definition and the history and the

improvement of the technique are given, and a model is presented for life cycle cost calculation. By using this model the life cycle cost of two systems are calculated; and based on this calculation a comparison of the system is done on the cost base.

ÖZET

Topçu Silah Sistemlerinin Ömür Devir Maliyet Yöntemi Kullanılarak Karşılaştırılması

A.Olcay KÜÇÜKTEPE

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Temmuz 2000, 77 Sayfa

Yapılan bu çalışma ile iki topçu silah sisteminin ömür devir maliyet yöntemi kullanılarak karşılaştırılması esas alınmıştır. Karşılaştırmada sadece maliyetler dikkate alınmış olup silah etkinliklerinin benzer olduğu kabul edilmiştir.

Bu sistemlerden ilki SP2000 veya Modern Kundağı Motorlu Top olarak tanımlanan ve ülkemizde tasarlanıp üretimi planlanan bir sistemdir. Diğer sistem ise Amerika Birleşik Devletlerinin ana topçu silahı olan M109 Paladin'dir.

Bu çalışmanın esas amacı halen kullanılan ve satın alma maliyetleri dikkate alınarak yapılan seçim yönteminin dezavantajlarını ortaya koymaktır. Çünkü yapılan incelemelerde esas maliyet faktörlerinin sistemlerin bir süre kullanımı sonucunda ortaya çıktığı belirlenmiştir. Bunlardan bazıları işletme ve bakım

maliyetleridir. Bundan dolayı ömür devir maliyet yöntemi, maliyetler ortaya çıkmadan gerçek maliyetleri tahmin etmede kullanılan yöntemlerden bir tanesi olarak kullanılmaktadır. Bu çalışmada ömür devir maliyetinin tanımı, tarihi ve gelişimi anlatılmakta ve ömür devir maliyetinin hesaplanmasında kullanılan bir model ortaya konulmaktadır. Bu model kullanılarak topçu silah sistemlerinin maliyetleri hesaplanarak mukayeseleri maliyetler esas alınarak yapılmıştır.

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Chapter I

PURPOSE OF THE STUDY

The aim of this study is first to apply " Life Cycle Cost" Methodology into a newly designed artillery weapon system in Turkish Land Forces and M109 Paladin, a U.S made artillery weapon system and secondly to make a comparison between them. The reason of using such a methodology mainly depends on the current acquisition or production decision method. In this method the initial cost of the weapon system and general operation costs are considered as the real cost of the weapon system, but with the Life Cycle Costing methodology which is especially used in the United States Department of Defense(DoD) since the mid 1970s, the department should consider the cost of weapon system from the beginning of the acquisition process or the research and development phase of production until the disposal phase of the weapon system from the inventory. By the help of this methodology main aim is to minimize the total cost of ownership of the weapon system. On the other hand today's new weapon systems have very high initial costs and also high operating and maintenance cost in their lifetime. So LCC analysis tries to estimate the future costs of the system for minimizing these cost before occurring for the department.

In this study, the total cost of the artillery weapon systems was calculated by using the Life Cycle Cost technique. In the calculation of one of the systems called SP2000 or Modern Self - Propelled Gun, the cost of research and development and cost of production was calculated by using the original data taken from the factory and the operation, maintenance and logistical support cost was estimated by using the model that is presented in this study for a period of 30 years. Also in the M109 Paladin system instead of the research and development and production cost, acquisition cost will be used in the calculations. By using this approach it is planned to generate a model that will be used in the Turkish Land Forces for finding the Total Ownership cost of a new weapon system.

In the acquisition of a new weapon system that has a high cost. The Armed forces should consider not only the cost of acquisition but also the cost of whole life of the system since it has a limited budget. In selection of the weapon system that will be purchased or developed, the decision will be more accurate in use of Life Cycle Costing techniques, than considering the initial cost only.

Chapter II

REVIEW OF LITERATURE

a) Introduction Of Life Cycle Costing

The definition of Life Cycle Cost given by Dale:

"Life Cycle Costing is a mathematical method used to form or support a decision and is usually employed when deliberating on a selection of options. It is an auditable financial ranking system for mutually exclusive alternatives which can be used to promote the desirable and eliminate the undesirable in financial environment." (Dale, 1993, pp.1)

Another definition is given by Dhillon:

"The sum of all costs incurred during the life time of an item, i.e., The total procurement and ownership costs." (Dhillion, 1989, pp.3)

Also procurement cost defined as "the total of investment or acquisition costs (recurring and non-recurring)" and ownership cost is defined as;" The sum of all the costs other than the procurement cost during the life time of an item". (Dhillion, 1989, pp.3)

So that Life Cycle Costing is a methodology for calculating all the costs for an item not only in the acquisition phase but also for the whole life of the item. These costs consist of Research and Development cost, production, acquisition, operation and maintenance costs, support and disposal costs of the item.

The main idea of using the Life Cycle Cost was created in the 1960s. This depends on the rapid improvement of the weapon system and continuous innovations in technology and depending on these two, the cost of operation; maintenance and support costs increase up-to very high level at the same time the acquisition cost of a weapon system increase up-to high amount.

As Kinch stated:

"There are three main reasons of using Life Cycle Costing in the defense industry. First of all acquisition cost of the system is too high. Such that today one of the weapon systems that are used in the air forces, has an average cost of hundreds of million dollars. The second reason is the life of system increased to more than 25 years. In the 1940 and 1950s a new type of an aircraft began to fly every three years or so. But today the planned life of a new weapon system is at least 25 years, so that the producer should make the system more durable against the years and also they should use more complicated sub-system in the weapons. And all of these made the initial cost of acquisition very high. The third reason mostly depends on the first two. Using highly complicated sub-system and having long life, the cost of operation, maintenance and support have a big proportion in the total cost of a system. In the year 1989-1990 it was estimated that the maintenance costs of the defense system in the United Kingdom exceeded £1 billion." (Kinch, 1993, pp.87)

Depending on the these reasons DoD in the United States wanted the Logistics Management Institute(LMI) in Washington to prepare a report in 1965 which has a title of Life Cycle Costing in Equipment Procurement. This is the first study on the subject of Life Cycle Costing. In the year 1969, several studies were published on the use of Life Cycle Costing in the military as well as in the civilian sector. (Chakour,1969; Kaufmann,1969)

Also in the same year U.S Department of Defense wanted the LMI to prepare another report about the Life Cycle Costing in System Acquisition. After this report three guidelines were published by the U.S Department of Defense. These were:

1-Life Cycle Costing Procurement Guide (1970),

2-Life Cycle Costing in Equipment Procurement (1970), 3-Life Cycle Costing Guide for System Acquisition (1973).

These guides were important in the history of the Life Cycle Costing, because after this guide released DoD established the requirement for the Life Cycle Cost procurement for weapon system acquisition.

According to B.S.Dhillon

"Since 1974, many states in the United States have passed legislation making Life Cycle Cost analysis mandatory in the planning, design, and construction of state buildings" (Dhillion, 1989, pp.1).

Also in 1978 U.S Congress established the National Energy Conservation Policy Act. According to this act every new federal construction should use Life Cycle Cost effectively in the United States, and this legislation made the concept of Life Cycle Costing very popular. After 1969 there are many publications made in the subject of Life Cycle Costing.

Today, most of the construction firms, defense contractors, companies that produces costly products use Life Cycle Cost analysis methods in their business. As mentioned before, some of them use this method because of the legislation and requirements and some of them use this method for reducing the cost of their firm.

The need of Life Cycle Costing depends on several factors, these factors;

"Rising Inflation, Budget Limitations, Increased cost effectiveness awareness among users, Competition, Costly products(e.g., Commercial aircrafts, military systems), Increasing maintenance cost" (Dhillion,1989,pp.30)

The main idea in LCC is to calculate the all the estimable cost for a product, not only acquisition cost of it. Fabrycky and Blanchard explain this problem as:

"Total system cost is often not visible, particularly those costs associated with system operation and support. The cost visibility problem can be related to the iceberg effect . One must address not only system acquisition cost , but other costs as well." (Fabrycky and Blanchard,1991,pp.123)

Life Cycle Cost can be used for different purposes, such as, comparing competing projects, long-range planning and budgeting, selecting among competing bidders, controlling and ongoing projects, comparing logistics concepts, and deciding the replacement of aging equipment. Fabrycky and Blanchard give some LCC application areas,

"Alternative system/product operational scenarios and utilization approaches; alternative system maintenance concepts and logistic support policies; alternative system/product design configurations involving technology applications, equipment packaging schemes, diagnostic routines, built-in test versus external test, manual functions versus automatic functions . .; Alternative supplier sources for a given item; alternative production approaches, such as continuous versus discontinuous production, quantity of production lines,. . ; alternative product distribution channels, transportation and handling methods, warehouse locations ; alternative logistic support plans, such as customer service levels, sustaining supply support levels,. ; alternative product disposal and recycling methods; alternative management policies and their impact on the system", (Fabrycky and Blanchard,1991,pp.130)

There are several areas for LCC concepts and there are many advantages of using LCC in these areas. Ashworth defines the advantages of using Life Cycle Costing as,"

- Life Cycle Costing is a whole or total cost approach undertaken in the acquisition of any capital-cost project or asset, rather than merely concentrating on the initial capital cost alone.

- Life Cycle Costing allows for an effective choice to be made between competing proposals of a stated objective. The method will take into account the capital, repairs, running and replacement costs, and expresses these in consistent and comparable terms. It can allow for different solutions and different variables involved and set up hypotheses to test the confidence of the results achieved.

- Life Cycle Costing is an asset management tool that will allow the operating costs of premises to evaluated at frequent intervals

- Life Cycle Costing will enable those areas of buildings to be identified as a result of changes in working practices, such as hours of operation, introduction of new plant or machinery, use of maintenance analysis" (Ashworth,1993,pp.122)

Most of the time the analysts use LCC methodology in different systems. These systems or products have a long life and high production and operation costs. The main problem in this methodology is to define the parts of the cost. In a big project most of the variables are not visible. Thus the main problem is to find relevant data for the system. Most of the time the system is a new one that has no past data for the calculation of LCC. So finding relevant data for the calculation is the main problem in this concept. Also there are some other problems in this methodology. Ashworth tries to explain these problems in his study, "

- Life expectancy; defining the life of a system is mainly a problem, no one can predict the future innovations in that area.

- Data difficulties; the lack of appropriate, relevant and reliable historical cost information and data for the system.

- Technological change; it is difficult to forecast with any degree of accuracy the possible changes in technology, materials and needs

- Fashion changes; same as the technology this forecasting this changes is very difficult so Life Cycle Cost analysis considers on the status quo

- Cost and value changes; the effect of inflation on the analysis

- Policy and decision making changes; one of the most important Life Cycle Costing variables is the future use and maintenance policy of the project by the owner.

- Accuracy; on of the main criteria in any estimate is its accuracy or reliability" (Ashworth,1993,pp.127-130)

The question in the LCC is what type of cost should be considered in the calculations. This always changes but generally the analyst group should consider the cost depending on the phase of the project. In one of the books S.J.Kirk and A.J .Dell'isola mention these cost:

"During its economic life an item is subject to purchase, use, repair, maintenance, perhaps modification, and finally disposal. These process comprise the life cycle of the item, and the cost of these processes make up Life Cycle Cost, or total cost of ownership, of the item." (Kirk and Dell'isola, 1995, pp.27)

b) Methods

The methods or techniques for finding the LCC of an item mostly depends on the analyst but main idea in these methods to find the most available alternatives for the system. Griffin distinguishes these methods into two groups.

"There are two broad methods that can be adopted for this modeling and calculation process which can be summarized as top-down or bottom-up. The bottom-up models use explicit engineering, program and support elements and activities to create a high fidelity model of the life cycle and then phasing and all interrelationships of the elements with one another. These models tend to concentrate in most detail on the operation and support of the system. Top-down or parametric LCCA models take a different approach and are particularly useful in earlier phase of the projects." (Griffin,1993,pp.145)

There are several methods for finding the LCC.

i) One is simple payback period method, however this one is not so common and the result of this method is not well suited for the analysis. Because of the nature of the method, the analyst considers only the number of years that the project covers the investment. So the analyst take care of projects that tend to cover themselves quickly. But this method requires some revenues in order to cover its investment. So that it is not available for non-profit projects such as government projects, weapon systems, some utility projects, etc. Of course the method is well understood by the managers of the projects because calculations are simple and the result of this method gives the number of the investment covering years. One of the formulation about simple payback is given in the book of Capital Investment Analysis For Engineering And Management as,

$$\frac{\text{Investments}}{\text{Net Cash Flow(Revenues - Disbursements)}}$$

(Canada, Sullivan and White,1996,pp.102)

Fabrycky and Blanchard give another formulation in their book. In this formulation they applied an interest rate in finding the pay back period. And the result is given as,

$$0 \leq \sum_{t=0}^{N} F(1+i)^{-t}$$

Where the smallest value of n that satisfies the expression above is the payback period. In this calculation analyst calculates the period by using interpolation, and finally finds the payback period of the project. (Fabrycky and Blanchard, 1991, pp.59-60)

ii) The second method and most preferred one is net present value method and its derivations such as annuity and uniform series payment. In this method all the costs that will occur in the future should be calculated and then the present value of this cost should be found by using the net present value formulations. Main idea in this method is calculating all the cost of the system in its full life and converting the value into today's amount by using the interest rate that analyst decides. This is the most applicable way of calculating the LCC. There are several formulas for this method and the basic present value formula is given below:

$$PV = \sum_{t=0}^{N} \left(\frac{C_t}{(1 + rt)^t} \right)$$

Where Σ refers to the sum of series and C_t refers to the net cash flow of the system for the whole life at time t. There are several derivations of this formula and the analyst should use the one most properly fit for the calculation of the LCC.

iii) The third method is internal or external rate of return method. By using this method the rate of the system return could be calculated. And by comparing with the interest rate the efficiency of the system can be found. Basic concept in this method is to find the rate that makes the net present value of the total cost of the system to the zero. After finding the rater of the return the analyst should compare the result with the opportunity cost of capital in order to decide whether the project is acceptable or not.

Also the analyst can use different methods that depend on the system specifications but the general rule is to convert the cost into today's value by using net present value methods, and then decide whether the system is applicable or not.

c) Models

For calculating the LCC of the system, one of the methods can be used, but methods are not the only requirement of LCC. The analyst should construct a model for LCC. To build a structure of a model is very critical point for the analyst because every calculation and estimation depends on this model. Dhillon gives several different models in his book. In this study the author summarizes twenty-three models in different areas. An example of the models that is given by Dhillon;

" This model was developed by the United States Navy for major weapon systems. The Life Cycle Cost is made up of five major components: research and development cost (RDC), operating and support cost (OSC), associated systems cost (ASC), investment cost (IC), and termination cost (TC). Mathematically the Life Cycle Cost is expressed as follows:

$$L_{cc} = RDC + OSC + ASC + IC + TC$$ "

(Dhillion,1989,pp.48)

In this model every item has some sub components so that the total Life Cycle Cost can be calculated by using such models. But in every model the components and the sub components differ from system to system. In every calculation of the Life Cycle Cost of a system the analyst should consider the every sub components of the major component. And this mainly depends on the work and cost break down structure of the system. For every system the work breakdown structure shows different types. Also some modifications of the same system can have different work breakdown structures. Because type of the works or the elements of the works have different specifications, and depending on this situation the cost elements have different patterns. So the steps in calculation of Life Cycle Cost can be summarized like this;

- Construct a cost structure that reflects every part of the life cycle of a system,

- Find relevant data for the cost structure,

- Make relationships between the past data and the requirement for the new system,

- Formulate a model depending on the cost structure,

- Calculate the Life Cycle Cost of a system,

- Make validation and analysis of the model

In this approach the model should consist of every separate item of the cost structure.

U.S Army uses LCC analysis procedure in every phase of acquisition of weapon systems. In their methodology they use six steps for making cost analysis These are mentioned in the manual prepared by the Army Cost And Economic Analysis Center. The steps are

"Set up definitions, ground rules and assumptions/constraints, select the cost structure, compile the data base, prepare the cost estimate, test the total cost estimate, and prepare documentation" (US Army C&E Analysis Center, 1997, pp.32)

The work flow of cost calculation is described in the manual and shown in Figure 1:

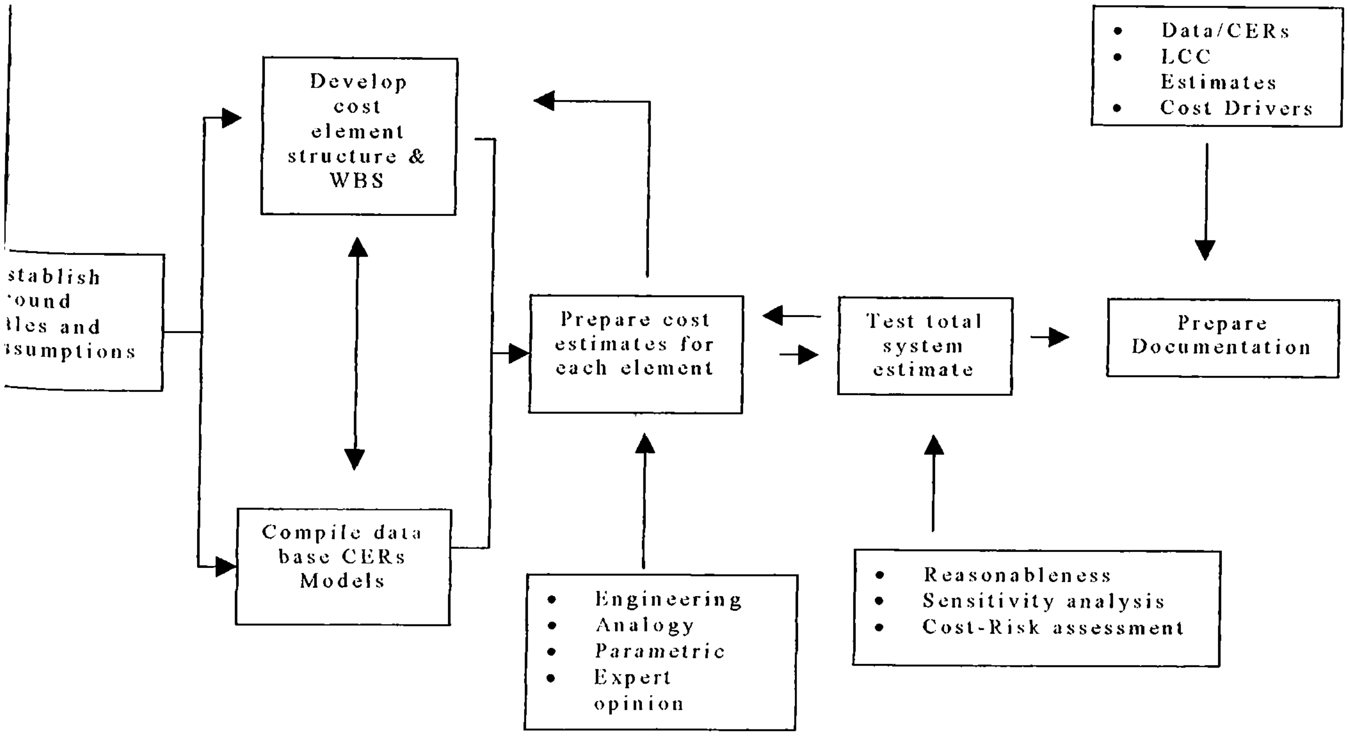


Figure 1:Cost calculation workflow

After constructing a cost breakdown structure of a system the second step should be estimating or calculating the costs of every part of the structure. N.M de Vasconcellos Jr. And M Yoshimura state this situation in their study:

"In general, there are two categories of cost estimating: the top-down approach (parametric) and the bottom-up approach (engineering approach). The top-down approach uses historical data from previous system and forecasts the cost of a new system based on cost determining variables,. The bottoms-up approach requires estimation of material needed for the system, labor hour, support equipment, maintenance, etc. These two approaches are usually used in different stages of the purchasing planning system, where top-down approach is used in early stage and the bottoms-up approach is used in the later stage." (Vasconcellos and Yoshimura, 1999)

Also in every sub level of the breakdown structure the analyst should define the way of calculating the cost of sub elements, so in the LCC concept every activity that takes parts in the life of the system should be considered as a separate problem and should be calculated accordingly. So the analyst should be familiar with the system and should define the specific cost elements of the system in every phase. As a result the important issue turns to be defining the cost breakdown

Structure of the system in LCC calculation: In that part of the subject, there are some general guidelines that are published by several authorities. In their book Fabrycky and Blanchard give a general cost breakdown structure format,

"Total system cost

1.Research and development

A. Program Management

B. Advanced R&D

C. Engineering Design

- System engineering
- Electrical engineering
- Mechanical design
- Reliability
- Maintainability
- Human factors
- Producibilty
- Logistic support analysis

D. Equipment Development and test

- Engineering models
- Test and evaluation

E. Engineering Data

2. Investment

A. Production

- Production engineering
- Tools and test equipment
- Fabrication

- Assembly
- Inspection and test
- Quality control
- Inventory
- Packing and shipping

B. Construction

- Production facilities
- Test facilities
- Operational facilities
- Maintenance facilities

C. Initial Logistic Support

- Program management
- Provisioning
- Initial spare/repair parts
- Initial inventory management
- Technical data preparation
- Initial training and training equipment

- Test and support equipment acquisition
- First destination transportation

3. Operations and Maintenance

A. Operations

- Operating personnel
- Operator training
- Operational facilities
- Support and handling equipment

B. Maintenance

- Maintenance personnel and support
- Spare/repair parts
- Test and support equipment maintenance
- Transportation and handling
- Maintenance training
- Maintenance facilities
- Technical data

C. System/Equipment Modification

4. System Phase-out and Disposal " (Fabrycky and Blanchard, 1991, pp. 333)

There are different cost structures in the literature but this one is the most general cost breakdown structure. But every system or equipment has different cost structure. So the analyst should construct his own structure depending on the system specifications. Also in every part of the cost structure the analyst can find some difficulties in the calculation of the cost. One of them occurs in the maintenance cost of the system. In both approaches, top-down and bottoms-up, the analyst can find relevant data for the scheduled maintenance of the system, or make some estimation depending on the past data for the system maintenance cost. The labor hour of maintenance personnel or the spare/repair parts or maintenance equipment cost can be found in the past data or can be estimated by using these data, but unexpected maintenance costs are not a part of the past data. So the analyst should consider these circumstances.

a) Implementation Of Life Cycle Costing In Different Areas

G.G Hegde, in his study, concentrates on the failure cost of systems and depending on failure cost definition he made, he tried to find Life Cycle Cost of a durable goods in different approaches.

He states that by using some density function the failure cost of a system can be estimated. Also these circumstances change according to the type of the product. And he explains this situation in four different cases. In one case, the system has non-linear failure cost structure and by using exponential density function he estimates the cost of failure. Also, in this study the author takes into consideration of opportunity cost of not using the system. So in this approach calculation of LCC of a system mostly depends on the failure rate of the system(Hedge, 1994)

James V. Carnahan and Charles Marsh use such concepts in their study of underground heat distribution systems Life Cycle Cost analysis. In this study they stated that initial cost and operating costs could be easily calculated by the help of past data. But finding failure rates of the systems is much more complex than the others are. They used a survey that is conducted by the US Army Construction Engineering Research Laboratory, and Poisson distribution in their model and use Life Cycle Cost analysis to compare the different underground heat distribution systems. (Carnahan and Marsh, 1998)

Afif Hasan also used this concept in order to optimize insulation thickness for buildings in his study and compared the effect of different thickness for building in heating and initial cost aspects by using LCC. (Hasan, 1999)

Dan Kralsson and his colleagues use Life Cycle Cost estimates in the 400 kV substation Layouts and they compare the two different systems. After finding all the elements of the systems they use LCC of different systems and then compare the results of the efficiency of the systems. In their study they emphasized that not only the investment and operation cost is important but also the maintenance and outage costs for the whole life of the system should be calculated in order to reach a relevant result. (Kralsson, 1997)

N.M de Vasconcellos and M.Yoshimura set a Life Cycle Cost model for acquisition of automated systems. In that study they define an active life cycle activities of automated systems and then they formulate the Life Cycle Cost of automated systems in their study. Their cost structure consists of every minor cost elements of these systems. As a result, their approach is more valid than today's cost calculation methods as they use the comparison of cost calculation of different systems. (Vasconcellos and Yosimura, 1999)

Chapter III

THE MODEL

In this study, two different type of self-propelled gun Life Cycle Cost will be calculated and after than a comparison will be made depending on the Life Cycle Costs. So that the model should be same for both of the guns in order to make comparison in the same base. But in the first sample, SP2000, all the research and development and production cost will be calculated in the model but in the second sample, M109 A6 Paladin, instead of research and development and production cost, the acquisition cost of the sample will be used in the model. In this study the model mainly based on the Fabrycky and Blanchard sample Life Cycle Cost model in their book Life Cycle Cost and economic analysis. (pp.334-349)

The model follows,

Total system Life Cycle Cost (C)

$$(C) = \sum_{i=1}^{N}[Cr_i + Cp_i + Co_i + Cop_i] \tag{3.1}$$

Cr= research and development cost

Cp= production cost

Co= cost of operation and maintenance

Cop= cost of disposal

a) Research and Development Cost (Cr)

$$Cr = Crpm + Crrd + Cred + Crdt \qquad (3.2)$$

This cost item consists of feasibility studies, research and development activities, engineering design, test of engineering prototype models and all other associated documentation, also covers all related program management functions. These kind of costs are non-recurring costs for the system.

Crpm= Program Management Cost

This cost oriented activity applicable to conceptual studies, research, engineering design, equipment development and test and related documentation. These costs cover the program manager and staff, marketing, contracts, procurement, logistics management, visits of related factory and research centers and etc

$$Crpm = \sum_{i=1}^{N} Crpmi \qquad (3.3)$$

Where $Crpm_i$ *refers to the specific activity i and N refers to the number of the activities.*

Crrd= Advanced research and development cost

The cost of advanced research and development includes conceptual studies conducted to determine and justify a need for a specific requirement.

$$Crrd = \sum_{i=1}^{N} Crrdi \tag{3.4}$$

Where $Crrd_i$ *refers to the specific activity i and N refers to the number of the activities*

Cred = Engineering design cost

All initial design facilities associated with system definition and equipment are calculated in this cost item. Some specific areas such as system engineering, design engineering, reliability and maintainability-engineering etc are included in this cost.

$$Cred = \sum_{i=1}^{N} Credi \tag{3.5}$$

Where $Cred_i$ *refers to the specific design activity i and N refers to the number of the activities*

Crdt = Equipment development and test cost

The cost of fabrication assembly, test and evaluation of engineering prototype models are included in this item.

$$Crdt = [Crdwi + Crdmi + \sum_{k=1}^{N} Crdtk \qquad (3.6)$$

Where i refers to the number of prototypes and k refers to the test activities and N refers to the number of tests.

Crdw= cost of prototype or model production and assembly labor.

Crdm= cost of material that is used in the prototype

Crdt= cost of test facilities and support actions in the prototype

b) Production cost

All costs associated with the acquisition of new systems / equipment that is needed for the production of the system. The acquisition cost of the systems/equipment that is purchased before is not considered as a cost of the new system. The cost of operation of the older system can take as a cost for the new system.

$$Cp = [Cpm + Cpc + Cpl] \qquad (3.7)$$

Cpm = System production cost

This cost covers all recurring and nonrecurring cost that related to the production and test of systems

$$Cpm = [Cpn + Cpr] \qquad (3.8)$$

Cpn =Nonrecurring costs

Nonrecurring costs include all fixed nonrecurring cost associated with the production and test of operational system.

$$Cpn = [Cpnp + Cpnt + Cpnq + Cpnm + Cpnqa] \qquad (3.9)$$

Cpnp =Production engineering cost

Cpnt =Tools and factory test equipment costs

Cpnq =quality assurance cost

Cpnm =production management cost

Cpnqa =cost of qualification tests

Cpr =Recurring cost

This item covers all recurring production costs that include fabrication, subassembly and assembly, material and inventory control, inspection and test, packing and shipping.

$$Cpr = [\ Cprm + Cprl + Cprp + Cpri + Cprt\ ] \qquad (3.10)$$

Cprm =production engineering support cost

Cprl=Production and assembly labor cost

Cprp=Production material and inventory cost

Cpri=inspection and test cost

Cprt=initial transportation cost

Cpc =Construction cost

This costs cover all initial acquisition costs associated with production, test, operational and maintenance facilities and utilities.

$$Cpc = [Cpcm + Cpct + Cpca + Cpcma + [Cpcl+Cpcb+Cpcu+Cpcc]] \quad (3.11)$$

Cpcm =Production facilities cost

Cpct =Test facilities cost

Cpca =Operational facilities acquisition cost

Cpcma =Maintenance facilities acquisition cost

Cpcl =Construction labor cost

Cpcb =Construction material cost

Cpcu =Cost of utilities

Cpcc =Capital equipment cost

Cpl =Initial logistic support cost

All integrated logistic support planning and control functions are related to the development of system support requirements and transition of such requirements from the suppliers to the applicable operational site.

$$Cpl = [\ Cplm + Cplp + Cpls + Cpli + Cpld + Cplt + Cpla + Cplh\ ] \quad (3.12)$$

Cplm =Logistic program management cost

Cplp =Cost of provisioning

Cpls =Initial spare/ repair part material cost

Cpli =Initial inventory management cost

Cpld =Cost of technical data preparation

Cplt =Cost of initial training and training equipment

Cpla =Acquisition cost of operational test and support equipment

Cplh =Initial transportation and handling

c) Operations and maintenance cost

This cost includes all costs associated with the operation and maintenance support of the system throughout its life cycle.

$$Co = [\ Coo + Com\ ] \qquad (3.13)$$

Coo =Operations cost

All cost related to the operation of the system throughout its life cycle. In this cost item every cost except maintenance cost can be used as operational.

$$Coo = [Coop + Coof + Cooe] \quad (3.14)$$

Coop =Operating personnel cost

This item covers the cost of operating personnel that allocated for the system. In this cost item every payment to the operating personnel should be covered such as fringe benefits, salaries, clothing allowance etc.

Coof =Operational facilities cost

This item cover the annual recurring cost that is related to the occupancy and maintenance of the facilities. The maintenance cost of facilities covers the repair, paint, of operational facilities throughout the life cycle of the system.

Cooe =Support and handling equipment cost

In this item all annual recurring usage and maintenance cost for these items that are required to support system operations throughout the life cycle of the system.

$$Cooe = [Cooo + Cooc + Coop] \quad (3.15)$$

Cooo =Cost of operation

Cooc =Cost of equipment corrective maintenance

Coop =Cost of equipment preventive maintenance

Com =Maintenance cost

The maintenance cost of the system can be divided into two parts; one is the scheduled maintenance and that can be also divided into two preventive and corrective maintenance, and unexpected or failure maintenance cost.

For scheduled maintenance the data can be obtained from the related department and the cost can be estimated accordingly and the model for the scheduled maintenance cost is written below. But for unexpected maintenance cost there are no relevant data. Because no one has such an information that how many vehicles or system will fail in specific time period, so that in this model a probabilistic approach is used in order to specify the number of the system failed in a period of time. And then the maintenance cost estimated depend on the number of fail that is found by the probabilistically.

There are some distributions that are used to find the failure rate of a system. One of them and widely used is exponential distribution. And the other is Weibull distribution. The main difference is the time of failure. Leland Blank describes the difference of two distributions in his book as:

> " The exponential is commonly applied in reliability problems where it is hypothesized that the failure rate λ is constant over the entire life of an item. The pdf gives the instantaneous probability of failure at any given time $t>0$. Then the cdf $F(t) = 1- e^{-\lambda t}$ is used to compute the probability of failure prior to t" (Blank, 1980, pp.291).

> And " Weibull distribution is often used for reliability analysis where the time to failure is not constant." (Blank, 1980, pp.296)

According to this definitions in this model the Weibull distribution will be used for calculating the failure rate of the weapon systems. Because the failure time is not known and not constant. If the exponential distribution is used in the model then an arbitrary failure time should be used, and this is not a desired situation in the model.

Weibull distribution has a probability density function (pdf) of ;

$$f(x,\alpha,\beta) = \alpha / \beta^{\alpha} x^{\alpha-1} e^{-(x/\beta)^{\alpha}}$$

(3.16)

And cumulative distribution function (cdf) ;

$$F(x,\alpha,\beta) = 1 - e^{-(x/\beta)^{\alpha}}$$

(3.17)

In these formula α is scale parameter and β is shape parameter. And these parameters define the distribution.

In this study the cost of unexpected maintenance will be estimated by using Weibull distribution. By using Weibull Distribution the failure rate of the system was estimated depending on the past data of the similar weapon system. In this study 160 different artillery weapon system were examined and their failure rates were calculated in yearly base. And according to this calculations, the failure rate of the new systems were estimated by using Weibull distribution. Due to these failure rates the unexpected maintenance cost will be calculated in the study. There are some articles in the literature review that used Weibull distribution in estimating the failure rates. One of them is the study of Bai, Chun and

Cha, in their study they use Weibull distribution in order to test the time censored Ramp. (Bai, Chun and Cha, 1997)

Another study is made by H. Shore. In this study he tried to define a specific failure rate function and after constructing it he checked his function by using several distributions. One of the distributions is Weibull distribution and after this comparison he explain that the best fit function is the Weibull distribution for estimating the failure rate of a system. (Shore, 1997)

After defining how to find the unexpected maintenance rate, the model for the maintenance cost of the system is shown below.

Maintenance cost of the system

$$(Com)=[(Coms)+(Comu)]+ (Comx +Comt+Comf) \quad (3.18)$$

Coms= cost of scheduled maintenance

Comu= cost of unexpected maintenance

Comx= cost of spare / repair parts

Comt= transportation and handling cost

$$Coms = [(Qps)(Mhp)(Copp)+(Qps)(Cmhp)+(Qps)(Cdp)(Nms)] \quad (3.19)$$

Qps= quantity of scheduled maintenance actions

Mhp= scheduled maintenance labor hours

Copp= labor cost

Cmhp= cost of material handling

Cdp= cost of documentation

Nms= number of maintenance areas

$$Comu= [(Qca)(Mmhc)(Cocu)+(Qca)(Cmhu)+(Qca)(Cdu)(Nmu)] \quad (3.20)$$

Qua= quantity of unexpected maintenance actions

Mhmu= unexpected maintenance labor hours

Cocu= cost of labor($/Mhmu)

Cmhu= cost of material handling

Cdu= cost of documentation

Nmu= number of maintenance areas

$$Comx = (Cso+Csi+Csd+Css+Csc) \qquad (3.21)$$

Cso= Cost of organizational spare/repair parts

Csi= Cost of intermediate spare/repair parts

Csd= Cost of depot spare/repair parts

Css=Cost of supplier spare/repair parts

Csc= Cost of consumables

$$Cso = \sum_{i=1}^{N}[(Cai)(Qai) + \sum(Cmi)(Qmi) + \sum(Chi)(Qhi)] \qquad (3.22)$$

Where i refers to the maintenance sites and N refers to the number of maintenance sites

Ca= average cost of material purchase order

Qa= quantity of purchase order

Cm= cost of spare item

Qm= quantity of items required or demand

Ch= cost of maintaining spare item in the inventory

Qh= quantity of items in the inventory

Cost of Csi, Csd and Css are calculated with similar approach

$$Comt = [(Ct)(QT)+(Cp)(Qt)] \qquad (3.23)$$

Ct= cost of transportation

Cp= cost of packing

Qt= quantity of one way shipments

d) System phase out and disposal cost

This category covers the liability or assets incurred when an item is disposed. This category represents the only element of cost that may turn out to have a negative value when the reclamation value of the item is larger than the disposal cost.

$$Cop = (Cdis - Crec) \qquad (3.24)$$

$Cdis$= cost of system disposal

$Crec$= reclamation value

Chapter IV

APPLICATION OF THE MODEL

For finding the Life Cycle Cost of the two alternatives SP2000 and M109 Paladin, an EXCEL^{TM} spread sheet was used.

1. Modern Self- Propelled Gun (SP 2000)

a. Data collection

In the Research and development, and production phase of the calculation, the data does not reflect the original situation. The data that was used in these calculations were distorted but the relation between the items were remained the same as the original. The rest of the data was the original data taken from the related sources. The operational data was taken from the artillery battery and the repair and spare part cost collected from the repair sites.

b. Research and Development

In order to calculate the R&D cost of the system, first of all the personnel of this phase is constructed. In this project one lieutenant colonel is working as a project manager in the headquarter, and also a captain is responsible as an executive project manager for the research and production in the factory project team. This team was established by the factory for this system, and the team has 6 engineers and 8 labors. In calculation of R&D, cost program management part was constructed by using these human resources and the cost was estimated by using equation 3.3. Their wages were calculated by using January salary and converted into US dollar by using January currency rates that were taken from the web site of the Central Bank of Turkey, www.tcmb.gov.tr. After that, annual wages were calculated and the result of this calculation was $157,114.58. And the R&D phase planned to go 6 more months until the mass production begins. So the 6 months wages are also calculated and used in the NPV calculation.

Two prototypes were produced until now and it is planned to produce two more prototypes in the project. And the cost of producing these prototypes was estimated by using equation 3.6 and the result was $ 1,955,370.9 for the produced ones and the same amount was expected to spend for the other two.

For this project factory did not make any investment, so that no special machine or equipment were bought for the project except computers and special software. The cost of this investment was estimated as $ 200,000. Also the project team manager and some of the engineers paid official visits to the countries that some components of the system will be imported from. In these trips, 6 person paid 4 trips until now and one trip costs approximately $ 3500 for one person and the cost of these visits was also estimated as $84,000.

In every prototype 15,000 km test-driving was made and 150 ammunition were used for the test of weapon system. And cumulative cost of this test was $695,655.

For allocation of the R&D cost the total cost of research and development was divided into plan number of total production of 80. So that in the first year of R&D the cost of research and development for one system is $ 36,267.9 and for the second year $ 30,753.97.

c. Production

The production cost was estimated because in the current project the R&D phase is still continuing. So the cost of production is estimated by using the old data of the similar system that is modified in the same factory. In calculation of production costs, direct material, direct labor and overheads are taken into account as a cost factor. The overhead costs were calculated as the function of direct labor. And for the simplicity of the calculation the proportion of the direct labor is used for overheads. Because in some part of the production it is not a good way to use direct labor as a cost driver. So the cumulative overheads and the direct labor are used to find the proportion of the overheads in the old system, and this proportion was used in the estimation of production overheads in this system. The proportion was calculated approximately 40% of the direct labor cost in the old system.

The total production cost of the SP2000 was estimated as $ 724,211.25 by using the equations 3.9, 3.10, and 3.11.

d. Operation

The operation cost was also estimated by using operating personnel costs and operational facilities costs. In this calculation equations 3.14 and 3.15 were used. In one battery the related personnel for one system were listed and then the cost of these personnel were calculated in annual base. The calculation is shown in Appendix 3. In this calculation the total cost of battery commander was divided into 6. Because in one battery there are 6-weapon systems so the cost of battery commander should be divided into the number of the weapon systems. Also the cost of platoon commander was divided into three for the same reason.

4 personnels are needed to operate the system. These are squad or gun commander, driver, operator, gunner and one crew for the rest of the operation. In the calculation of the cost of crew feeding cost, clothing costs, and payments were taken into account, and calculated annually. For operating the system fire control personnel should also be considered as a cost factor. This crew consists of five personnel: fire control officer, operator, calculator, major calculator, signal operator. And these crew cost was calculated as it was in the gun crew.

Training cost for the operator was calculated in this way. Every personnel except the officer and NCO train in the training troops for a period of three months. So the trainer was the cost factor for the system. In every training center there are several companies that the crew as being trained. And in this calculation one of the company personnel and facilities cost is used for the system training cost.

In operational facilities cost section usual practice and fire practice cost were estimated. While the crew cost was calculated, in this section only the fuel and ammunition cost was estimated. For finding the fuel cost of the system the amount of fuel consumption in one kilometer was multiplied by the constant amount of practice kilometer and the days of practice. After then the result was multiplied by the fuel price. In fire practice, cost the ammunition cost was multiplied with the cost of one shell.

In preventive maintenance cost estimation, the aging factor was also considered and the estimation depends on this factor. In preventive maintenance the material or preventive oil cost is estimated. The rest of the maintenance cost was calculated separately.

So, after all this calculation in the first year the operating cost of the system was calculated as $87.350,98.

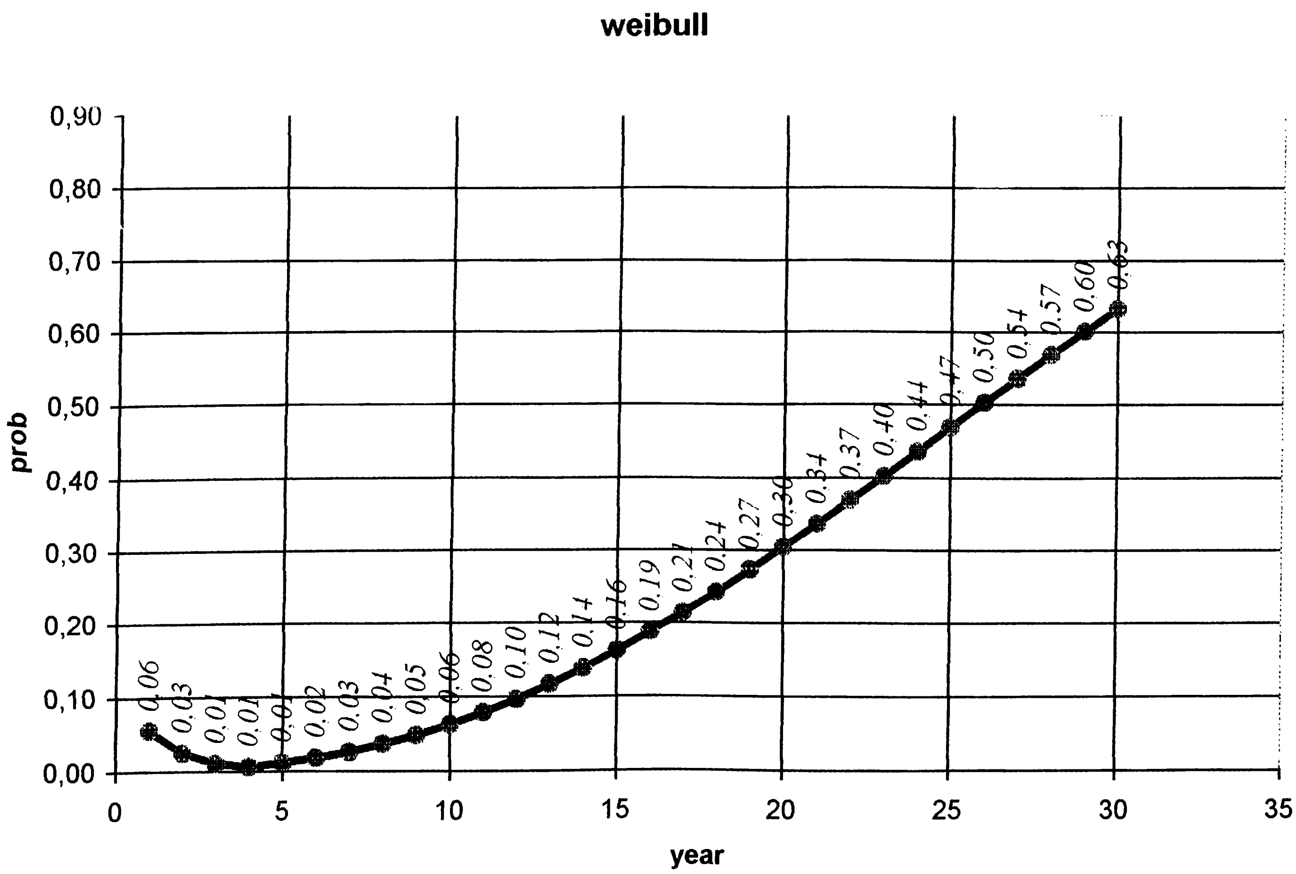
e. Maintenance

In the maintenance part of the system the cost of maintenance divided into two parts. One is Scheduled Maintenance, the second is unexpected maintenance or failure cost. In estimating of maintenance cost of the system the equation 3.18, 3.19 and 3.20 were used.

In scheduled maintenance part system's maintenance expenditure is known. Some of the parts are changed annually and some of them are changed semi annually. So that the cost of known part was calculated by using January 2000 prices and then these prices were converted into US dollar. This cost was same for all the year for the system.

But in unexpected maintenance part the Weibull distribution was used for finding the failure rate. In this distribution α is the shape parameter and β is the scale parameter. For finding the probability of failure 160 different artillery weapon systems were examined. Their failure rates were calculated for every year of service and by using a special software BestFit 4.0 the α and β of Weibull distribution was found depending on these past data. But this information was also classified as secret. So the α and β were distorted in this study. But the shape of the distribution was tried to remain same as the past data. Also the assumption was the failure rate of the new system have the similar pattern with the old ones. Depending on this circumstances the α was taken 2.5 and β was taken 30 for SP2000. In the first three years the failure rate of the new systems have different pattern. Depending on the past experience the probability of failure of these three years had a greater values than expected so in this study this situation was taken into account and the failure rate of these there years calculated greater then the Weibull distribution. For 30 years the failure rate was calculated and shown in Appendix A. The graph of this failure rate is shown in Figure 2.

Figure 2: Graph of failure rates for the SP2000



And this figure shows that it is an acceptable situation that the rates are increasing in the following years.

By using these rates the time that is needed for the repair was calculated and depending of this repair time the labor cost and the material cost was estimated. For the labor part of this calculation, labor hour cost was found firstly, and then by multiplying the number of maintenance hour and the hourly labor cost and number of labor that is worked for repair the total labor cost was estimated. In the material cost part of the estimation the cost of main working part of the system was considered. The engine, transmission and torque converter were the main parts that create the malfunction of the system, so the failure rate of that year was used to find the material cost also. By using the rate of failure and the cost of these three components the material cost was estimated. Such as at the year 5, the failure rate is 0,011276 and the total cost of these three part is $214.000 so the material cost of that year is 0,011276*214.000= $2,413.06. At the result of this calculation in the first year the total maintenance cost of the system was estimated as $16,700.58

f. System Disposal Cost

System disposal cost assumed zero in both of the systems. The reason is that both systems have the same amount of disposal cost. So the effect of this item on the total cost is zero.

g. Net Present Value

After finding all the components of the Life Cycle Cost for all the years, the values were converted into present cost by using net present value formula. This gives the opportunity for making reasonable analysis. Because a raw value in the end of life of system is not so meaningful for the analyst. So that all the values that is found in the early step of the calculation were converted into present value. In present value calculation the critical point is defining of interest rate. In this calculation the interest rate estimated 3% depending on the Central Bank of Turkey and Department of Treasury estimate for the next 5 year. Also the effect of interest rate on the calculations was examined in the analysis section in detail. The result of NPV for the modern self - propelled gun at 3% is $3,555,306.25

NPV calculations are shown on Appendix B, and the data that was used in the calculations are shown on Appendix C,and D

2. M109 Paladin

a. Pre-acquisition cost

In this item all the costs were considered before the acquisition occurred. Such as declaration of acquisition, trips for learning the system condition, documentation, but these costs were an estimation that does not have enough confidence. Because there is no relevant data for this item. The estimation simply depends on the experience of the officers that worked for acquisitions. And for this system the estimation is $50.000

b. Acquisition

The acquisition cost of M109 Paladin self-propelled gun system is taken from the articles in the magazines Jane's Defense Weekly, and International Defense Review. These articles were about to acquisition of Paladin artillery system for the Kuwait Armed Forces. In these article the total budget of the acquisition was given and also the number of the system was given, from that knowledge the acquisition cost of one system was found and this cost was $645,000

c. Operation

The operation cost was estimated as same as the modern self - propelled gun. And the total operation cost in the first year for the M109 Paladin is $90,163.28

d. Maintenance

Also this calculation is the same as SP2000 except the failure rate.

While this system is not new, that was produced five years before the failure rates should be equal to the fifth year failure rate of the SP2000. In this calculation the α and β taken same as SP200 and $\alpha = 2$ and $\beta = 28$ for 30 years, but x was began with 5 due to the age of the system. The failure rate calculation is shown in Appendix E. The failure rates graph is shown in the Figure 3.

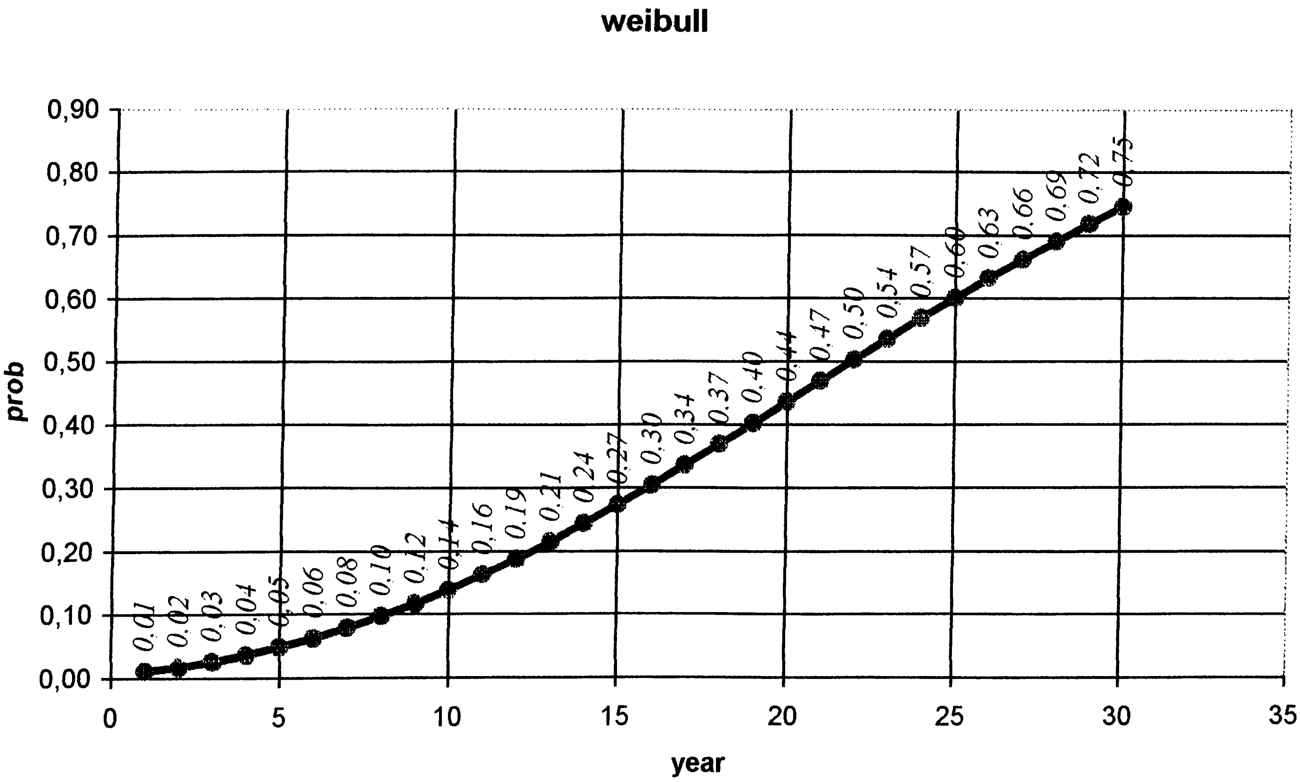


Figure 3: Graph of failure rates for M109

Due to this failure rate and calculations the total maintenance cost of M109 paladin for the first year of operation is \$ 4,365.19

e. Net Present Value

The net present value of M109 Paladin after all the calculations at the rate of 3% is \$ 3,943,997.8

The summary of cost allocation of both systems is shown on Figure 4.

Activity/ Year		R&D	Production	Pre-Acquisition	Acquisition	Operation	Maintenance	Total	Cumulative Total
0	**SP2000**	**36.268**	**0**	**0**	**0**	**0**	**0**	**36.268**	**36.268**
	M109	0	0	50.000	0	0	0	50.000	50.000
1-5	**SP2000**	**30.764**	**724.211**	**0**	**0**	**437.426**	**36.290**	**1.228.681**	**1.264.949**
	M109	0	0	0	645.000	451.633	33.583	1.130.216	1.180.216
6-10	**SP2000**	**0**	**0**	**0**	**0**	**439.301**	**59.226**	**498.526**	**1.763.476**
	M109	0	0	0	0	454.180	142.745	596.925	1.777.141
11-15	**SP2000**	**0**	**0**	**0**	**0**	**442.573**	**172.374**	**614.947**	**2.378.422**
	M109	0	0	0	0	458.011	306.837	764.848	2.541.989
16-20	**SP2000**	**0**	**0**	**0**	**0**	**447.217**	**350.791**	**798.008**	**3.176.430**
	M109	0	0	0	0	463.071	520.164	983.235	3.525.223
21-25	**SP2000**	**0**	**0**	**0**	**0**	**456.276**	**573.638**	**1.029.914**	**4.206.344**
	M109	0	0	0	0	469.081	751.297	1.220.378	4.745.601
26-30	**SP2000**	**0**	**0**	**0**	**0**	**459.860**	**807.376**	**1.267.236**	**5.473.580**
	M109	0	0	0	0	475.722	965.757	1.441.479	6.187.080

Figure 4: Summary of cost allocation of both systems(\$)

NPV calculations are shown on Appendix F, and the data is shown on Appendix G. And cost allocation table through the project life is shown in Appendix H.

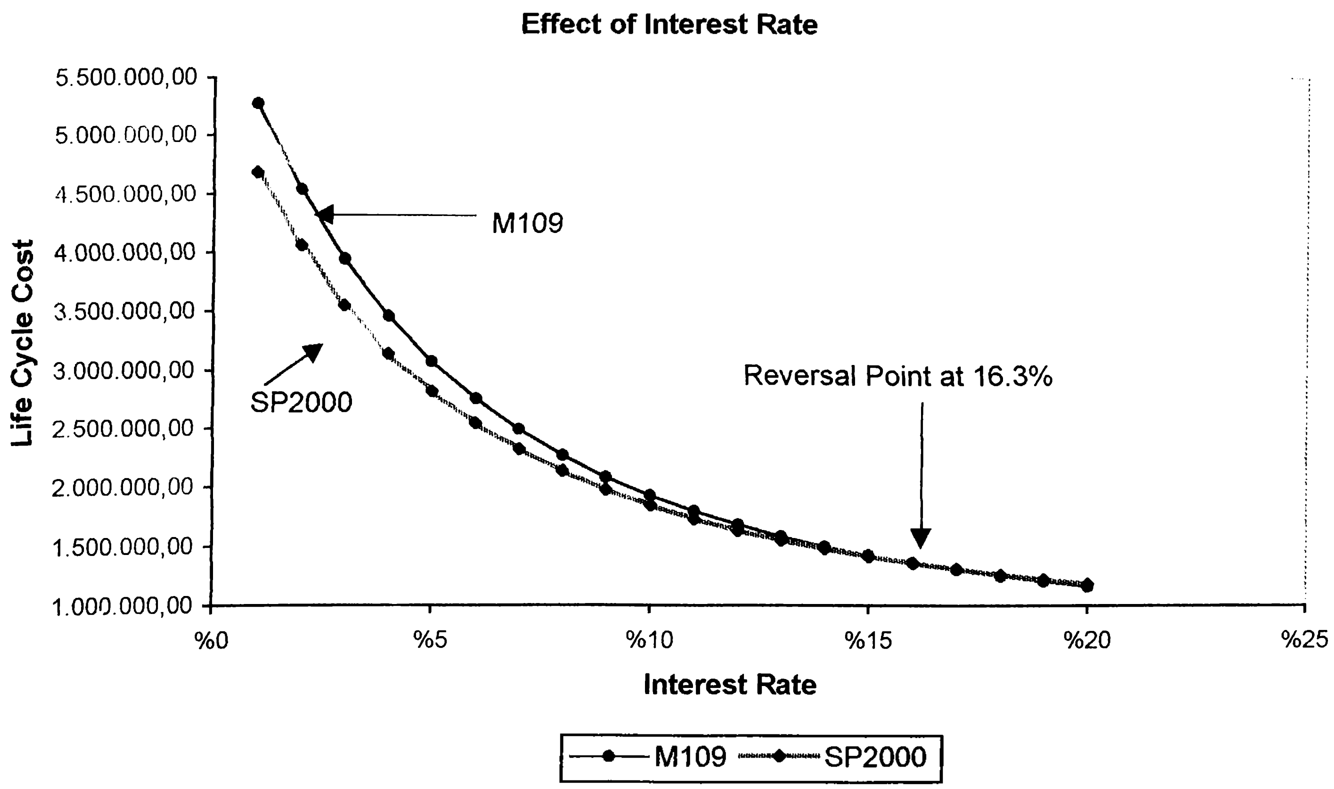
Chapter V

SENSITIVITY ANALYSIS

In this chapter the effect of variations in the model was examined. It was obvious that in the model some variables used depending on the assumptions or expectations. And they can be change in the future so the results of the study could be different due to these changes. Therefore the result should be sustained by some other tools. Also the decision of selecting a system, should not depend on one criterion, the differences between the net present value of Life Cycle Costs. The difference of NPV is not the only criterion for giving a good decision in such a big project. So some other analysis should be made, because there can be some variations in the data that is used in the study. Such as interest rates, if the interest rate changes, NPV would change and then the decision may be different. Therefore before taking the final decision the results should be checked by making sensitivity analysis.

In NPV calculations the first alternative SP2000 has $3,555,306.25 and the second alternative M109 Paladin has $3,943,997.8 and the difference between these NPV values is $388,689.55 According to this calculations SP2000 has a cost advantage of $388,689.55 only 10.9% of its NPV so there is no big difference between the costs of two alternatives. Also depending on the NPV formula the interest rate directly effects the results. And the time period is 30 years. And this means that there can be variations in the interest rate. Figure 5 shows the results of variations in the interest rates. In this analysis at the interest rate of 16.3% or greater the NPV of M109 Paladin is smaller than the first alternative. But until this rate SP2000 has a cost advantage among the Paladin. However there is a great difference between the reversal rate and the rate that is used in the calculation. And due to the economic conditions and projections reversal rate is not an acceptable rate for the calculations. So that SP2000 has cost advantage more or less than the M109 if the economic conditions continue through the end of the life cycle of the project. The changes on NPV depending on the interest rates are shown on Appendix I.

Figure 5: Effect of interest rate change on the LCC calculation



The other analysis is called "break-even analysis". In this analysis the aim is to determine a point in time that selected alternative becomes more economical than the others. If this point is early enough in the life cycle of the project then the selected alternative or the decision is accepted otherwise the decision should be rechecked under the given information.

In this study the result of break-even analysis is 8 years 4 months. This is approximately one third of the project life and it is early enough to support the selection. This means that after 8 years 4 months the first alternative SP2000 is more economical than the M109. At the early year of the project, M109 seems to be the less costly depending on the cumulative present value of two systems, but after 8 years 4 months, the cost of M109 is increasing more rapidly according to increasing maintenance cost of the system. The graph of break-even analysis is shown in Figure 6.

According to this analysis, SP2000 is the favorable system for the selection if the interest rate smaller than 16.3% and the project life bigger than 8 years 4 months otherwise M109 should be chosen. The results of the analysis are shown in the Figure 7.

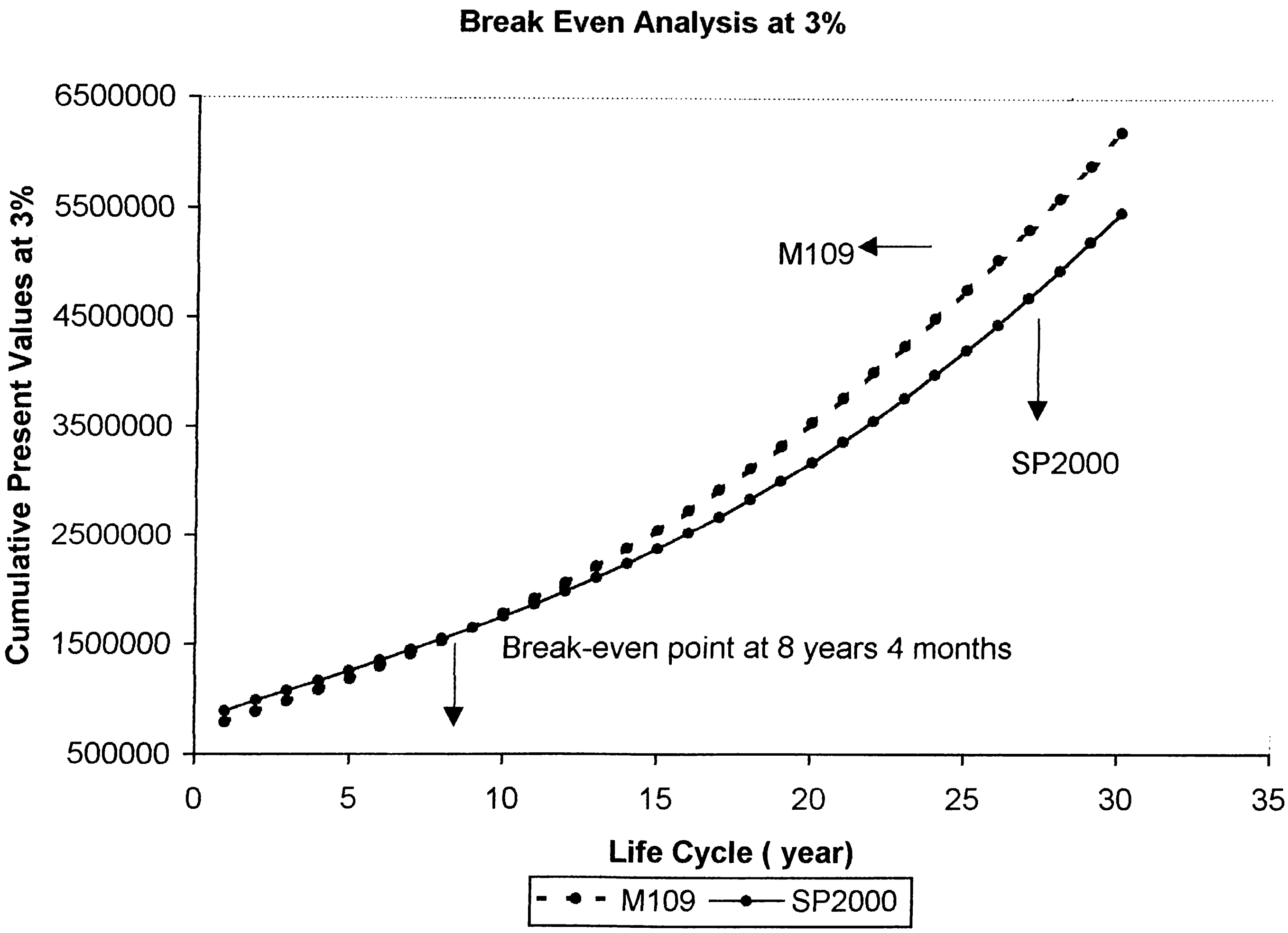


Figure 6: Break-even analysis of SP2000 and M109 at 3% interest rate

ITEMS	SP2000	M109
Initial cost	\$894.682,57	\$645.000
NPV	\$3,555,306.25	\$3,943,997.8
Interest Rate	< 16.3%	16.3% <
Break - Even Point	8years 4 months<	<8 years 4 months

Figure 7: Results of sensitivity analysis

Chapter VI

CONCLUSION

The aim of this study is to compare the cost of two or more artillery weapon systems in corparating the Life Cycle Costs. In order to achieve this purpose, we first defined the Life Cycle Cost of weapon system. Then, a model for the artillery weapon systems which covers all the costs, i.e., from research and development to disposal phase of the system, was developed.

The artillery systems that were compared in this study are SP2000, Modern Self - Propelled Gun of Turkish Army, and M109 Paladin, U.S Army main artillery weapon system. SP2000 is originally designed in Turkey and design and R&D phase is still continuing. M109 Paladin is produced in the 1990 to 1997 for the U.S Army, and after using in several combat situations it proved its effectiveness in the U.S Army.

To make comparison between these two systems in the cost base, the assumption is their effectiveness and other features are the same. So there is no superiority between them except the cost.

The model is simply designed for covering all the related costs for the system. Every differential cost item is taken into consideration in computations. For example the cost of crew, maintenance, cost of practice is considered as differ, but buildings, occupancy of exercise areas, overheads such as cost of electricity, water, or the cost that does not depend on the system or changeable are not considered as cost for the systems. The life of the systems is assumed as 30 years, and all the calculations are done for thirty years.

For SP2000, the total R&D cost was estimated as $5,361,748.99 and this cost is divided into planning production number, that is 80 for finding one system R&D cost. The result is for the first year $36,267.9 and second year $30,753.97. One weapon system production cost was estimated as $724,211.25. The cumulative operational cost and maintenance cost of the system is respectively $2,659,332.71 and $1,999,693.12. In the maintenance cost part for estimating the failure cost of the system, a failure rate is used and this rate is a probabilistic value that is found by using Weibull Distribution. And after all the calculations the values shifted to the base year by using Net Present Value formula. And the final result for SP2000 is $3,555,306.25

For M109 Paladin pre-acquisition and acquisition cost was used instead of R&D and Production cost. The costs are respectively $50,000 and $645,000. The operation cost of M109 is $2,771,697.09 and the maintenance cost is $2,731,641.11 The NPV result for the M109 Paladin is $3,943,997.8

Depending on the model results and the given data SP2000 has a $388,689.55 cost advantage. And after making sensitivity analysis at the beginning SP2000 has more expenditure than the M109. First of all, its R&D and production cost is more than the competitor. But after 8 years and 4 months of service the cumulative cost of M109 exceed the cumulative cost of SP2000, so that as a result of these calculations Life Cycle Cost of SP2000 is $3,555,306.25 and M109 is $3,943,997.8 According to these numbers the SP2000 is the one that should be preferred for the new artillery weapon system in Turkish Armed Forces.

Also this study shows that the initial cost of a system is not an accurate value for the selection of a system. The total Life Cycle Cost of the system can give different results, as in this study. So in acquisition or production decision the Life Cycle Cost concept should be considered and the decision should be made depending on this concept.

REFERENCES

A.Ashworth, "How Life Cycle Costing Could Have Improved Existing Costing", edited by, J.W.Bull "Life Cycle Costing For Construction", Blackie Academic & Professional, London, 1993

D.S.Bai, Y.R.Chun, M.S.Cha, "Time-Censored Ramp Test With Stress Bound For Weibull Life Distribution", IEEE Transactions On Reliability, Vol. 4 ,No.1, 1997, March

L.Blank, PE, "Statistical Procedures For Engineering, Management, and Science" McGraw-Hill, Inc. New York, 1980

J.R. Canada, William G. Sullivan, John A. White, "Capital Investment Analysis For Engineering And Management" Prentice Hall, International, Inc., second edition, New Jersey, 1996

J.V. Carnahan and Charles Marsh, "Comparative Life-Cycle Cost Analysis Of Underground Heat Distribution Systems", Journal of Transportation Engineering, November/December 1998,pp. 594-603

F.M. Chakour, "Automated Life Cycle Cost Models for Army Weapon Systems", US Army Weapon Command, Rock Island, May 1969

S.J Dale, "Introduction To Life Cycle Costing" edited by, J.W.Bull "Life Cycle Costing For Construction", Blackie Academic & Professional, London, 1993

B.S.Dhillion, "Life Cycle Costing: Techniques, Models and Applications", Gordon and Breach, Science Publishers ,New York, 1989,

W.J. Fabrycky, B.S.Blanchard, "Life Cycle Cost and Economic Analysis", Prentice- Hall, Inc., New Jersey, 1991,

R.Flanagan, G.Norman, J.Meadows, G.Robinson, "Life Cycle Costing; Theory And Practice", Blackwell Scientific Publications Professional Books, Oxford, 1989

J.J.Griffin, "Life Cycle Cost Analysis: A Decision Aid" edited by, J.W.Bull "Life Cycle Costing For Construction", Blackie Academic & Professional, London, 1993

A.Hasan, "Optimizing Insulation Thickness For Buildings Using Life Cycle Cost", Applied Energy, vol. 63, pp. 115-124, 1999

G.G Hedge, "Life Cycle Cost: A Model And Application" IIE Transactions, Vol. 26, Number 6, pp. 56-61, November 1994,

M.J.Kinch," Life Cycle Costing In The Defense Industry", edited by, J.W.Bull "Life Cycle Costing For Construction", Blackie Academic & Professional, London, 1993

R. J .Kaufmann, "Life Cycle Costing for Capital Equipment Decisions", Automation, March 1969, pp. 75-80

S.J.Kirk, A.J.dell'isola, "Life cycle costing for design professionals", McGraw-Hill Inc, New York, 1995

D.Kralsson, L. Wallin, H.Olovsson,C. Sölver, "Reliability And Life Cycle Cost Estimates Of 400 kV Substation Layouts" IEEE transactions on Power Delivery, vol. 12, No.4,pp.1486-1492, October 1997

H.Shore, " A General Formula For The Failure-Rate Function When Distribution Information Is Partially Specified", IEEE Transactions On Reliability, Vol. 46, No. 1, 1997 March.

U.S Army Cost and Economic Analysis Center, "Cost Analysis Manual", Columbia Pike, July 1997

N.M. de Vasconcellos Jr. And M.Yoshimura ,"Life Cycle Cost Model For Acquisition Of Automated Systems", International Journal of Production Research, vol. 37, no. 9 , pp. 2059-2076, 1999

APPENDICES

Appendix A

FAILURE RATE CALCULATIONS of SP2000 BY USING WEIBULL DISTRIBUTION

alpha	***2,5***
beta	***30***

Year in Project	Year in Service	Failure Rate
1	1	0,055203
2	2	0,025147
3	3	0,010600
4	4	0,006471
5	5	0,011276
6	6	0,017729
7	7	0,025956
8	8	0,036056
9	9	0,048100
10	10	0,062136
11	11	0,078184
12	12	0,096241
13	13	0,116276
14	14	0,138233
15	15	0,162033
16	16	0,187573
17	17	0,214727
18	18	0,243350
19	19	0,273279
20	20	0,304335
21	21	0,336325
22	22	0,369048
23	23	0,402293
24	24	0,435849
25	25	0,469501
26	26	0,503040
27	27	0,536261
28	28	0,568968
29	29	0,600978
30	30	0,632121

Appendix B

Net Present Value Calculations of SP2000

Intrest Rate	%3,00					
YEAR/ ITEM	**R&D**	**Production**	**Operation**	**Maintenance**	**TOTAL**	**NPV**
0	36.267,90				36.267,90	$3.555.306,25
1	30.753,97	724.211,25	87.350,98	16.700,58	859.017,79	833.997,85
2			87.492,58	8.219,59	95.714,18	90.219,79
3			87.482,44	4.114,83	91.600,27	83.827,22
4			87.515,01	2.949,60	90.468,61	80.380,19
5			87.584,67	4.305,62	91.895,29	79.269,69
6			87.663,27	6.126,58	93.795,84	78.552,54
7			87.751,42	8.447,97	96.206,39	78.224,60
8			87.849,65	11.297,69	99.155,34	78.274,14
9			87.958,37	14.696,24	102.663,61	78.683,11
10			88.077,92	18.656,81	106.744,72	79.428,10
11			88.208,53	23.185,33	111.404,86	80.481,24
12			88.350,35	28.280,47	116.642,82	81.810,93
13			88.503,42	33.933,72	122.450,14	83.382,59
14			88.667,72	40.129,44	128.811,16	85.159,35
15			88.843,13	46.845,13	135.703,26	87.102,76
16			89.029,44	54.051,71	143.097,15	89.173,41
17			89.226,37	61.713,87	150.957,24	91.331,61
18			89.433,58	69.790,61	159.242,20	93.538,01
19			89.650,67	78.235,81	167.905,48	95.754,15
20			89.877,17	86.998,92	176.896,09	97.943,08
21			90.112,61	96.025,70	186.159,30	100.069,80
22			90.356,45	105.259,08	195.637,53	102.101,76
23			90.608,16	114.640,06	205.271,22	104.009,23
24			90.867,22	124.108,54	214.999,76	105.765,64
25			91.133,10	133.604,35	224.762,45	107.347,80
26			91.405,31	143.068,09	234.499,40	108.736,14
27			91.683,39	152.442,08	244.152,46	109.914,77
28			91.966,94	161.671,13	253.666,07	110.871,54
29			92.255,62	170.703,40	262.988,02	111.598,01
30			92.549,16	179.491,03	272.070,19	112.089,32

Appendix C

PRODUCTION COST OF SP2000

MATERIALS	$	Labor Hour	$	Overheads ($) (40% of DL)
POWER PACKAGE				
Engine	85.000,00	96	504,98	201,99
Transmission	75.000,00	144	757,48	302,99
Transmission shaft	15.000,00	16	84,16	33,67
Torque converter	54.000,00	96	504,98	201,99
Exhaust system	7.500,00	32	168,33	67,33
Driving System	28.500,00	72	378,74	151,50
Torque assembler	35.000,00	96	504,98	201,99
Cooling System	17.550,00	64	336,66	134,66
Auxiliary engine	26.500,00	64	336,66	134,66
Hydrolic system	22.600,00	192	1.009,97	403,99
Steering System	12.500,00	144	757,48	302,99
WEAPON				
Barrel	43.000,00	64	336,66	134,66
Suspension	25.000,00	144	757,48	302,99
Secondary Weapon	22.000,00	32	168,33	67,33
Automated loading System	15.000,00	96	504,98	201,99
Firing System	15.000,00	96	504,98	201,99
Fire control system	16.400,00	144	757,48	302,99
Positioning System	25.000,00	144	757,48	302,99
Turret System	15.600,00	144	757,48	302,99
FRAME				
Armor	48.000,00	320	1.683,28	673,31
Fire extinguisher system	12.500,00	64	336,66	134,66
Vehicle electrical system	18.000,00	160	841,64	336,66
NBC system	22.000,00	144	757,48	302,99
Night Vision system	22.000,00	64	336,66	134,66
Communication system	25.000,00	160	841,64	336,66
Total	703.650,00	2792	14.686,61	5.874,64
Grand Total	724.211,25			

Appendix D

DATA USED IN CALCULATIONS

R&D	TL	$
Project Manager	450.000.000,00	826,34
Executive Project Officer	360.000.000,00	661,07
Engineer (engine design)	320.000.000,00	587,62
Engineer (engine design)	320.000.000,00	587,62
Engineer (frame design)	320.000.000,00	587,62
Engineer (frame design)	320.000.000,00	587,62
Engineer (Electronics)	320.000.000,00	587,62
Engineer (Electronics)	320.000.000,00	587,62
Engineer (System)	320.000.000,00	587,62
Labor	550.000.000,00	1.009,97

OPERATION	TL		TL
Battery Commander Salary	350.000.000,00	Feeding Cost(daily)	3.500.000,00
Platoon Commander(1st Liet.)Salary	340.000.000,00	Dressing Cost	20.000.000,00
Squad Commander (Nco) Salary	320.000.000,00	Shoes Cost	35.000.000,00
Sergant Salary	18.000.000,00	Fuel (TL/lt)	360.000,00
Private Salary	12.000.000,00	Currency($)	544.572,00
Ammunution cost	543.400.000,00	# of fire in practice	16
# of km in practice	10,00	# days in practice	240
amount of fuel per km	2,00		

MAINTENANCE		
Lucricant (grease lt)	1.900.000,00	3,49
Lubricant 20W50 (lt)	1.500.000,00	2,75
Lubricant 10W50 (lt)	3.500.000,00	6,43
Lubricant OE50 (lt)	1.000.000,00	1,84
Engine Oil Filter	15.000.000,00	27,54
Fuel Filter	17.000.000,00	31,22
Air Filter	18.000.000,00	33,05
Labor Salary		
NCO	340.000.000,00	624,34
Sergant	18.000.000,00	33,05
Private	12.000.000,00	22,04
Labor	550.000.000,00	1.009,97
fuel	440.000,00	0,81
Currency ($)	544.572,00	
# of labor	6	

Appendix E

FAILURE RATE CALCULATIONS OF M109 BY USING WEIBULL DISTRIBUTION

alpha	***2,5***
beta	***30***

Year in Project	Year in Service	Failure Rate
1	5	0,011276
2	6	0,017729
3	7	0,025956
4	8	0,036056
5	9	0,048100
6	10	0,062136
7	11	0,078184
8	12	0,096241
9	13	0,116276
10	14	0,138233
11	15	0,162033
12	16	0,187573
13	17	0,214727
14	18	0,243350
15	19	0,273279
16	20	0,304335
17	21	0,336325
18	22	0,369048
19	23	0,402293
20	24	0,435849
21	25	0,469501
22	26	0,503040
23	27	0,536261
24	28	0,568968
25	29	0,600978
26	30	0,632121
27	31	0,662243
28	32	0,691209
29	33	0,718904
30	34	0,745230

Appendix F

Net Present Value Calculations for M109 Paladin

Intrest Rate %3,00

YEAR/ ITEM	Contract & Acquisition Cost	Operation	Maintenance	TOTAL	NPV
0	50.000,00			50.000,00	$3.943.997,80
1	645.000,00	90.163,28	4.365,19	739.529,47	717.989,78
2		90.251,09	6.160,33	96.413,42	90.878,89
3		90.322,39	8.448,82	98.774,21	90.392,39
4		90.402,88	11.258,14	101.665,03	90.328,06
5		90.493,07	14.608,51	105.106,58	90.665,86
6		90.593,35	18.512,93	109.112,28	91.379,82
7		90.704,03	22.977,26	113.688,29	92.438,98
8		90.825,33	28.000,18	118.833,51	93.808,27
9		90.957,38	33.573,28	124.539,66	95.449,28
10		91.100,19	39.681,17	130.791,36	97.321,06
11		91.253,71	46.301,67	137.566,39	99.380,88
12		91.417,80	53.406,09	144.835,89	101.584,98
13		91.592,23	60.959,64	152.564,87	103.889,25
14		91.776,69	68.921,88	160.712,57	106.249,94
15		91.970,80	77.247,37	169.233,17	108.624,33
16		92.174,13	85.886,25	178.076,38	110.971,31
17		92.386,20	94.785,06	187.188,26	113.251,98
18		92.606,47	103.887,56	196.512,03	115.430,11
19		92.834,38	113.135,55	205.988,94	117.472,61
20		93.069,38	122.469,81	215.559,20	119.349,90
21		93.310,89	131.831,01	225.162,90	121.036,15
22		93.558,33	141.160,60	234.740,94	122.509,53
23		93.811,19	150.401,70	244.235,89	123.752,31
24		94.068,95	159.499,93	253.592,88	124.750,89
25		94.331,16	168.404,16	262.760,32	125.495,79
26		94.597,44	177.067,21	271.690,65	125.981,52
27		94.867,46	185.446,42	280.340,88	126.206,40
28		95.140,98	193.504,12	288.673,10	126.172,30
29		95.417,86	201.207,98	296.654,84	125.884,40
30		95.698,03	208.531,28	304.259,32	125.350,81

Appendix G

Data Used in Calculations of M109 Paladin

Pre - Acquisition cost	50.000,00
Acquisition Cost	645.000,00

OPERATION	$		$
Battery Commander Salary	642,71	Feeding Cost(daily)	6,43
Platoon Commander(1st Liet.)Salary	624,34	Dressing Cost	36,73
Squad Commander (Nco) Salary	587,62	Shoes Cost	64,27
Sergant Salary	33,05	Currency($)	544.572,00
Private Salary	22,04	# of fire in practice	16
Ammunution cost	997,85	# days in practice	240
# of km in practice	10,00	amount of fuel per k	2,00

MAINTENANCE	$
Lucricant (grease lt)	3,49
Lubricant 20W50 (lt)	2,75
Lubricant 10W50 (lt)	6,43
Lubricant OE50 (lt)	1,84
Engine Oil Filter	27,54
Gasoline Filter	31,22
Air Filter	33,05
NCO	624,34
Sergant	33,05
Private	22,04
Labor	1.009,97
fuel	0,81
# of labor	6
Engine	85.000,00
Torque Converter	57.000,00
Transmission	68.000,00

Appendix H

Cost Allocation By Project Year ($)

Activity/ Year	0	1	2	3	4	5	6	7	8	9	10
SP2000											
R&D	36.267,90	30.753,97									
Manufacturing		724.211,25									
Operation		87.350,98	87.492,58	87.482,44	87.515,01	87.584,67	87.663,27	87.751,42	87.849,65	87.958,37	88.077,92
Maintenance		16.700,58	8.219,59	4.114,83	2.949,60	4.305,62	6.126,58	8.447,97	11.297,69	14.696,24	18.656,81
Total	*36.267,90*	*859.016,79*	*95.712,18*	*91.597,27*	*90.464,61*	*91.890,29*	*93.789,84*	*96.199,39*	*99.147,34*	*102.654,61*	*106.734,72*
M109											
Pre-Acquisition	50.000,00										
Acquisition		645.000,00									
Operation		90.163,28	90.251,09	90.322,39	90.402,88	90.493,07	90.593,35	90.704,03	90.825,33	90.957,38	91.100,19
Maintenance		4.365,19	6.160,33	8.448,82	11.258,14	14.608,51	18.512,93	22.977,26	28.000,18	33.573,28	39.681,17
Total	*50.000,00*	*739.528,47*	*96.411,42*	*98.771,21*	*101.661,03*	*105.101,58*	*109.106,28*	*113.681,29*	*118.825,51*	*124.530,66*	*130.781,36*

Activity/ Year	11	12	13	14	15	16	17	18	19	20	21
SP2000											
R&D											
Manufacturing											
Operation	88.208,53	88.350,35	88.503,42	88.667,72	88.843,13	89.029,44	89.226,37	89.433,58	89.650,67	89.877,17	90.112,61
Maintenance	23.185,33	28.280,47	33.933,72	40.129,44	46.845,13	54.051,71	61.713,87	69.790,61	78.235,81	86.998,92	96.025,70
Total	*111.393,86*	*116.630,82*	*122.437,14*	*128.797,16*	*135.688,26*	*143.081,15*	*150.940,24*	*159.224,20*	*167.886,48*	*176.876,09*	*186.138,30*
M109											
Pre-Acquisition											
Acquisition											
Operation	91.253,71	91.417,80	91.592,23	91.776,69	91.970,80	92.174,13	92.386,20	92.606,47	92.834,38	93.069,38	93.310,89
Maintenance	46.301,67	53.406,09	60.959,64	68.921,88	77.247,37	85.886,25	94.785,06	103.887,56	113.135,55	122.469,81	131.831,01
Total	*137.555,39*	*144.823,89*	*152.551,87*	*160.698,57*	*169.218,17*	*178.060,38*	*187.171,26*	*196.494,03*	*205.969,94*	*215.539,20*	*225.141,90*

Activity/ Year	22	23	24	25	26	27	28	29	30
SP2000									
R&D									
Manufacturing									
Operation	90.356,45	90.608,16	90.867,22	91.133,10	91.405,31	91.683,39	91.966,94	92.255,62	92.549,16
Maintenance	105.259,08	114.640,06	124.108,54	133.604,35	143.068,09	152.442,08	161.671,13	170.703,40	179.491,03
Total	*195.615,53*	*205.248,22*	*214.975,76*	*224.737,45*	*234.473,40*	*244.125,46*	*253.638,07*	*262.959,02*	*272.040,19*
M109									
Pre-Acquisition									
Acquisition									
Operation	93.558,33	93.811,19	94.068,95	94.331,16	94.597,44	94.867,46	95.140,98	95.417,86	95.698,03
Maintenance	141.160,60	150.401,70	159.499,93	168.404,16	177.067,21	185.446,42	193.504,12	201.207,98	208.531,28
Total	*234.718,94*	*244.212,89*	*253.568,88*	*262.735,32*	*271.664,65*	*280.313,88*	*288.645,10*	*296.625,84*	*304.229,32*

Appendix I

Effect of Interest Rates on NPVs

Intrest Rate	NPV of SP2000	NPV of M109
%1	4.685.234,63	5.274.735,64
%2	4.058.611,65	4.536.992,51
%3	3.555.306,25	3.943.997,80
%4	3.148.175,57	3.464.069,69
%5	2.816.466,06	3.072.948,04
%6	2.544.232,27	2.751.964,96
%7	2.319.163,28	2.486.685,48
%8	2.131.707,85	2.265.893,10
%9	1.974.419,58	2.080.829,47
%10	1.841.464,60	1.924.622,14
%11	1.728.249,92	1.791.852,00
%12	1.631.141,70	1.678.224,96
%13	1.547.250,82	1.580.321,70
%14	1.474.268,85	1.495.406,10
%15	1.410.342,30	1.421.278,02
%16	1.353.975,60	1.356.159,66
%17	1.303.956,03	1.298.607,48
%18	1.259.295,40	1.247.443,68
%19	1.219.184,52	1.201.702,66
%20	1.182.957,57	1.160.588,97