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ENHANCING READINESS OF THE UNMANNED AERIAL VEHICLE (UAV) SYSTEM VIA USE OF SIMULATION MODELING AND CONTRACT INCENTIVES

by

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The two most important reasons for the inefficiency in the Unmanned Aerial Vehicle (UAV) test system of the Turkish Army Command are the failure to address life-cycle cost (LCC) considerations during financial resource allocations and the absence of contract reliability incentives. These problems are not uncommon to newly developed major weapon systems. The objective of this thesis is to develop a life-cycle cost based decision support tool and a performance incentive fee contracting model to improve the operational availability of the UAV system.

This thesis integrates the spare parts, and repair and replacement cost considerations into life-cycle cost calculation of the UAV system and establishes a methodology to determine these costs by exploring the relationship among spare level, service and failure rate in terms of readiness. An increase in the stock level does not improve the UAV system's efficiency in the long run. This thesis also provides a tool for the computation of a performance incentive fee by using modeling and simulation. This study presents a computer aided decision support tool for more efficient and effective allocation of scarce resources.

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ENHANCING READINESS OF THE UNMANNED AERIAL VEHICLE (UAV) SYSTEM VIA USE OF SIMULATION MODELING AND CONTRACT INCENTIVES

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I. INTRODUCTION

A. BACKGROUND

Turkey, with the largest army in Western Europe, accounts for over one quarter of Western Europe's armed forces. [Ref. 1:p. 7] In an instable environment, with an increasing geopolitical and strategic importance as a peacekeeper, Turkey becomes the most important ally for NATO countries including the United States. In his article in the *Disam Journal*, Walter B. Slocombe stated that:

> It is strongly in the United States interest to continue to assist Turkey. ...Turkey remains a close ally. It is enduring substantial economic losses and political burdens to maintain the embargo upon Iraq and the enforcement of the no-fly zone over the northern portion of that country. It is an important, pro-Western bulwark at the juncture of several unstable regions, and it supports interests vital to the United States. [Ref. 2:p. 58]

The crisis in Bosnia and recently in Kosovo reemphasizes the importance of Turkey's role within NATO and their influence and support in resolving regional conflicts.

The Turkish military enhances its capabilities through modernization of old systems and acquisition of new technological developments in the defense industry. The Turkish Government initiates massive defense procurement programs to bolster its Army, Navy and Air Force and intends to spend $31 billion for reinvestment and modernization through 2005. The Unmanned Aerial Vehicle (UAV) system is one of the first 20 programs of the Turkish military that has embraced a procurement strategy of *"local production with foreign partners."* [Ref. 3:p. 8] The new Unmanned Aerial Vehicle (UAV) system will provide the Turkish military with a better reconnaissance capability in the 21st century.

B. OBJECTIVES

The objective of this thesis is to provide a life-cycle cost based decision support tool and Fixed-Price Incentive (FPI) contract methodology to improve the operational availability of a Turkish Army UAV system. This thesis also provides a tool for performance criteria and incentive fee computation of a FPI contract. These objectives will be accomplished by integrating economics, contracting and logistics engineering theories and will rely heavily upon modeling and simulation. One of the most important goals in this thesis is to integrate the spare part, and repair and replacement cost considerations in calculating life-cycle costs for the UAV system and establish a methodology to determine those costs by exploring the relationship among spare level, service and failure rate in terms of readiness.

C. THE RESEARCH QUESTIONS

1. Primary Research Question

How can the Turkish Army Command allocate enough resources for the UAV system and incentivize the contractor to achieve a certain level of operational availability with FPI contract in a budget constrained environment?

2. Secondary Research Question

a. How can we build a flexible model and apply simulation for the analysis of the UAV system to allocate enough resources to the UAV program?

b. What is the relationship among spare level, service and failure rate in terms of readiness for the UAV system? Is it possible to increase operational availability in the long run by increasing UAV system spare parts inventory?

c. In which conditions should we use the fixed-price incentive contract and what are the applicable performance incentives?

d. How can we calculate the target cost and incentive fee for the UAV program by using modeling and simulation?

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

Even though the model is built for the UAV system based on the problem definition (Chapter II), it offers a wide range of implementation for different systems, conditions, and organizations. This thesis focuses on building the model, applying simulation, and interpreting simulation results to facilitate the calculation of life-cycle costs and FPI contract performance incentives. The contractual techniques for enhancing Turkish domestic production capacity of the American manufactured UAV system is outside the scope of this thesis.

In the problem definition, we use hypothetical scenarios, places, and values since the actual information is classified. We also use Microsoft Excel and Crystal Ball software in building the model and applying simulation. The learning curve is not considered in the UAV model.

E. ORGANIZATION OF THE STUDY

This thesis is divided into six chapters. Chapter I provides the objective and scope of the thesis. Chapter II presents a brief background on the Unmanned Aerial Vehicle (UAV) system and describes the problem on which the model is built. Chapter III explains the UAV model, the methodology used, and places emphasis on the spare part, and repair and replacement cost calculation by showing the relation among spare level, service and failure rate in terms of readiness in the light of logistic engineering concepts. This chapter ends with the application of the simulation to the UAV model. Chapter IV provides a brief discussion on Fixed-Price Incentive (FPI) contracts and performance incentives. Chapter V calculates the contract cost and incentive fee for the UAV project by applying simulation to the model. Finally, Chapter VI presents conclusions and recommendations.

II. PROBLEM DEFINITION

A. BACKGROUND HISTORY

The Unmanned Air Vehicle (UAV) system is a newly developed system, which can provide very important strategic benefits in the battlefield. Lately, the United States military effectively has used the UAV systems in the Desert Storm Operation in the Gulf and in Bosnia. Today, many countries try to develop their own UAV systems. The UAV system basically performs its missions by a UAV with one of different types of payload placed on it. A UAV system can be used for many different purposes by simply replacing the payload with another one. However, the primary mission for the UAV systems is reconnaissance of an operational area. The following are some aspects of the UAV systems, which encourage the military forces all over the world to use them:

- Low operating costs,
- Long endurance,
- Long range,
- Autonomous capability.

Recently, the Turkish military expressed its interest in this new weapon system. In 1995, Turkish Army procured one GNAT-750 UAV system as a test system (hereafter test UAV system) and explore its efficiency in operational missions, especially in reconnaissance of the operational area. When the GNAT-750 UAV system is further investigated, some flexible mission options are encountered. These are:

- Highly reliable conventional launch and recovery,
- Built-in test for flight and maintenance diagnostics,
- Endurance provides flexible basing and recovery options,

- Retractable landing gear provides unobstructed payload view,
- Unique operating altitude flexibility.

The GNAT-750 UAV System basically has five different subsystems:

- Unmanned Aerial Vehicle (UAV):
  - Dimensions: Span 35.3ft – Length 16.3ft,
  - Weights: Empty 255kg(560lb) - Payload 64kg(140lb) – Fuel 194kg(426lb) – Gross take off 513kg (1126lb),
  - Fuel: Diesel fuel (for 1.44gal of fuel, on the average 0.5gal oil and lubricants),
  - Powerplant: 65 HP,
  - Structure: Carbon Epoxy composite,
  - Avionics: Digital – Built-in test – 3kW power supply,
  - Navigation: Autonomous – GPS/INS options,
  - Datalink: Frequency selectable – Digital video option.
- Payload,
- Ground Control Station (GCS): One UAV and one payload control,
- Ground Data Terminal (GDT): Tracking antenna,
- Ground Support Unit.

One UAV system consists of four GNAT-750 UAVs, four payloads, one GCS, one GDT, and one Ground Support Unit. Last three of them is also known as Ground Support System. Among these subsystems *payload* determines the type of operational mission for the UAV system. Turkey planned to procure Stabilized Infra Red (IR), Spotter, and Day TV Payload for reconnaissance purposes. This payload has the capability to provide the real time video of the field. The real time video is transmitted to the GCS by the antenna system on the UAV. Although Turkey needs to use these UAV systems for reconnaissance purposes, the system presents an application-range for possible missions with different payloads. Below are the different types of payload systems.

- Stabilized Infrared (IR), Spotter, and Day TV,
- Infrared (IR) Linescanner,
- Direction Finding,
- Radio Relay,
- Datalink Relay,
- Nuclear Biological and Chemical (NBC) Detection,
- Radar Systems,
- Air Delivered Sensors.

These different missions are executed by a specially trained group of personnel. Every operational mission conducted by a mission group. The mission group of GNAT-750 UAV system consists of two teams, UAV flight team and UAV maintenance team. The flight team includes UAV pilot, payload operator, and mission commander. The maintenance team also includes electronic and mechanic technicians. One mission group is fully capable of conducting an operational mission from a Ground Control Station (GCS). The communication between the UAV and the GCS is provided by Ground Data Terminal (GDT) (Figure 2.1).

In executing a mission, the UAV pilot remotely takes off the UAV from the GCS. After the UAV climbs over a certain altitude, auto-control function can control the UAV.

Navigation is conducted by GPS. Prior to take off, the mission would be programmed to the UAV navigation computer from the GCS by using the digital maps on the main

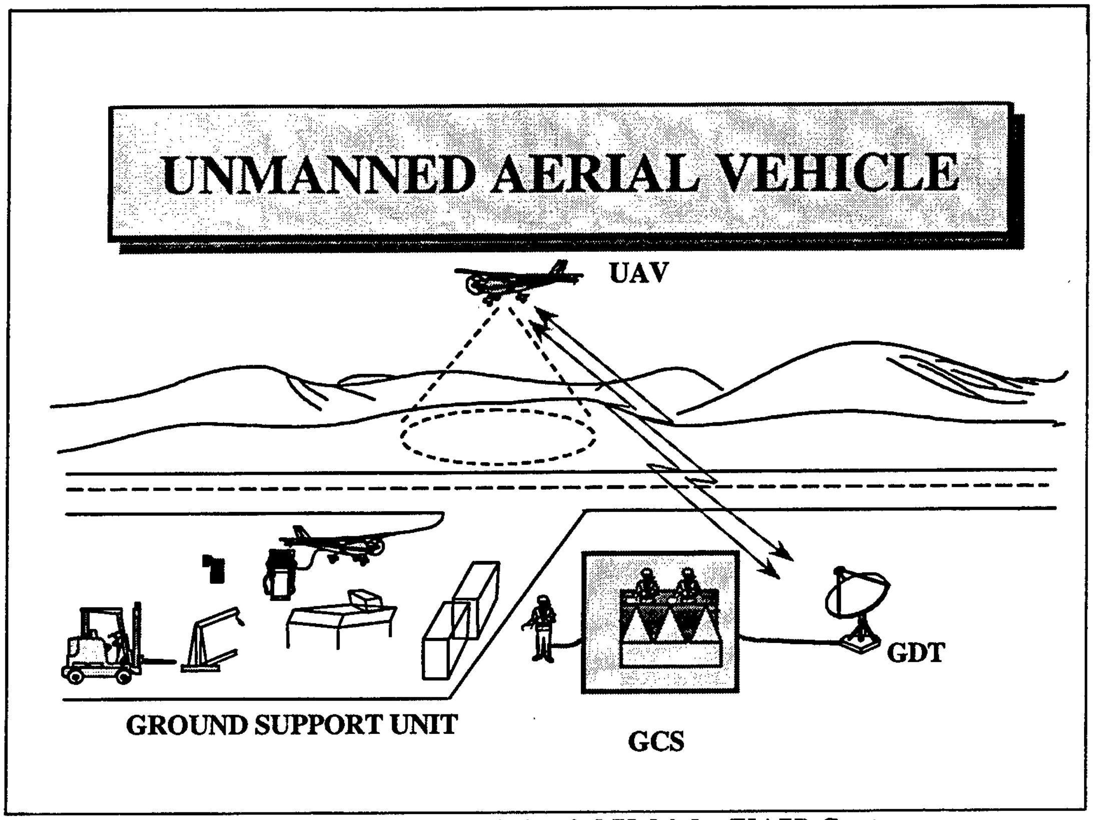


FIGURE 2.1:Unmanned Aerial Vehicle (UAV) System

display unit of GCS. The mission plan can be changed any time during the flight. The UAV pilot can take the control of the UAV and enter a new mission plan. This feature gives flexibility to the system. Over the target area the UAV executes the mission with its payload. The payload is remotely controlled by payload operator to identify the targets and their locations in the field. After the mission is completed the UAV turns back to the base and is remotely landed by a UAV pilot. UAV can not take off or land by itself. Only one UAV can be controlled from the GCS at a time.

B. PROBLEM

We will use hypothetical scenarios, places and values since the actual information is classified.

The Turkish Army Command has decided to acquire more UAV systems. The test UAV system's performance in reconnaissance missions is satisfactory. However, frequent failures in the system and supply support deficiencies diminish the operational availability of this critical weapon system.

A need determination is made for air reconnaissance intelligence throughout the country. To fulfil this need, the Turkish Army will purchase 10 GNAT-750 UAV Systems and deploy over five regions: South Anatolia, Southeast Anatolia, East Anatolia, Northwest Anatolia, and West Anatolia. Each region will have one operational base and each operational base will have a maximum force level of two GNAT-750 UAV Systems, with the bases being activated in series. The deployment plan is in Table 2.1.

Operational Bases/Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
South Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
Southeast Anatolia	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
East Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
Northwest Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
West Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
Total number of UAV Sys.	3	6	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	7	2

TABLE 2.1 Deployment Plan of the UAV Systems

The Army Command is planning to use the UAV System on the average of 12 hours per day, 365 days per year. To provide 12 hours of reconnaissance, surveillance, and target acquisition in real time, the operating hours average is expected to be five hours per day per UAV (there are four UAVs in a UAV system), and 14 hours per day for ground support systems. The excess UAV and ground support systems operating hours are planned for test and evaluation facilities.

Operator Training: The operators are required to have a knowledge of the UAV systems, its operational conditions, limits, capabilities, and operational use of the UAV. The UAV flight team members will attend a basic operator course for three weeks. In the advance operator course the UAV flight team will study different subjects according to their positions. The UAV Pilot will be trained in operation of flight control, launch, and recovery. The UAV payload operator will be trained in operation of payload control, area searching, targeting and infrared vision. The UAV mission commander will be trained in UAV tactics where he will get a good understanding of its operational missions, mission planning, command, control, and communication. After five weeks of advance operator course, there will be an operation mission training course for two weeks in which every member of the mission group, both UAV flight team and UAV maintenance team, gains experience for various operational uses of the UAV system. The UAV unit commander will attend the courses as a mission commander.

Maintenance Training: There are three layers of maintenance for UAV system, O-level, I-level, and D-level maintenance. O-level maintenance is done by UAV maintenance team members, mechanical technician and electronic technician. All the maintenance personnel in the O-level will attend basic maintenance course for two weeks regardless of his special expertise. In advance maintenance course for six weeks, according to their specific services, they will be trained in periodic checks of the UAV system, visual inspection, verification of software, some servicing, external adjustments, removal and replacement of some components, and preparing the UAV system for the operational mission. The O-level maintenance personnel will also attend operational mission team training as a UAV maintenance team with assigned UAV flight team simultaneously for two weeks.

All the I-level technicians are electronic technicians; there are no mechanical technicians at this level of maintenance. I-level technicians and the maintenance supervisor will attend advance electronic maintenance course for ten weeks in addition to basic maintenance course. They will be responsible for more detailed maintenance like GDT static checks, payload computerized checks, main board and main display unit electronic controls with additional test and support equipment. The maintenance supervisor will attend an additional two-week course of maintenance and support planning, and maintenance facilities' recording and reporting. The training costs consist of the salaries of the personnel getting trained and training overhead cost such as instructor salaries, training material, and travel costs.

The maintainability factors associated with the test UAV system are shown in Table 2.2. The UAV system component failures occur randomly and are exponentially distributed.

Unmanned Aerial Vehicle (UAV)	**MTBF (hours)**
Antenna System	1500
Navigation Computer	500
Sensors (Probe Tube, Tempr.)	350
Landing Gears	750
Engine	700
Propeller	3500
Payload	**MTBF (hours)**
IR Scanner	450
Targeting	800
Video Scanner	2500
Ground Control Station (GCS)	**MTBF (hours)**
Main Display Unit	1000

TABLE 2.2 UAV System Mean Time Between Failures (MTBF) Values

Power Supply	4000
Power Generator	3500
Air Conditioner	6000
Control Panel	500
Ground Data Terminal (GDT)	**MTBF (hours)**
Rotation Engine	1700
Receiver	800
Transmitter	650

TABLE 2.2 UAV System Mean Time Between Failures (MTBF) Values (Continued)

The test UAV system personnel stated that the operational capability of the UAV system would be lost as a result of the following critical component failures:

- Main Display Unit (GCS),
- Power Supply (GCS),
- Control Panel (GCS),
- Air Conditioner (GCS),
- Power Generator (GCS),
- Rotation Engine (GDT),
- Transmitter (GDT),
- Receiver (GDT).

The test UAV system personnel also pointed out that the operational capability of the UAV system would be reduced significantly due to a failure in any of the following components:

- Antenna System (UAV),
- Navigation Computer (UAV),
- Sensors (Probe Tube, Temperature) (UAV),
- Landing gears (UAV),
- Engine (UAV),

- Propeller (UAV),
- IR Scanner (Payload),
- Targeting (Payload),
- Video Scanner (Payload).

The GCS and GDT failures cause a total loss of operational capability until repaired as there are only one GCS and one GDT in a UAV unit. Nevertheless, UAV and payload failures cause degradation in operational capability since there are four from each of them in a UAV unit.

There is no corrective maintenance in the O-level. The UAV system incorporates a built-in self-test capability that enables rapid system checkout and fault isolation to the units listed above. In the O-level, after the fault isolation the unit is removed, replaced with a spare, and the defective component is sent to the I-level maintenance center for corrective maintenance. At the O-level, maintenance personnel do some servicing, external adjustments, removal and replacement of some components, and prepare the UAV system for the operational mission with a material cost of $200 per flight hour on the average. For all maintenance actions at the O-level, personnel use the equipment at the ground support unit which is provided with the UAV system. The preventive maintenance is done in the O-level with a cost of $500 per preventive maintenance action. Table 2.3 illustrates the subsystems and their schedule ($MTBM_S$: Mean Time Between Preventive (scheduled) Maintenance, Mpt: Mean Preventive Maintenance Time) for preventive maintenance.

Subsystem	$MTBM_S$	Mpt
UAV	25 flight hours	3 hours
Payload	50 flight hours	2 hours

TABLE 2.3 Preventive Maintenance in the UAV System

The I-level maintenance centers are equipped with special support equipment. Special support equipment is produced and delivered at a cost of $45,000. The I-level maintenance center can repair 60% of the failures with a TAT (turnaround time) of seven days, and 40% of them are sent to the United States for D-level maintenance with a TAT of 75 days.

I-level maintenance material costs are $150 per UAV operating hour for corrective maintenance. There is no I-level maintenance material cost for the failures sent to the D-level maintenance. For the GNAT-750 UAV system, D-level is the manufacturer in the United States. D-level maintenance center repairs or replaces the material. As a result of high repair and replacement costs, on average, all the corrective actions cost 80% of a new spare part.

Manning: Each of the UAV units has one UAV system, which contains one GCS, one GDT, four UAVs, and four payloads. There are three mission groups assigned in a UAV unit. A mission group consists of three officers as mission commander, UAV pilot, and payload operator, and two noncommissioned officers (NCO) as mechanical technician and electronic technician. The unit commander (officer) and a power generator technician (NCO) are in the headquarters of the UAV unit. In each operational base there is one I-level maintenance center which consists of one maintenance supervisor, an electronic engineer officer, and four electronic technicians all of which are NCOs. One officer's and one NCO's salaries are $10,000/year and $7,000/year, respectively. 50% of the assigned personnel will be rotated every three years.

There is no design and development cost for the UAV system as it had been developed for the United States military. However, the Turkish Armed Forces policy places heavy emphasis on local production. Therefore, the design and technology of the UAV system are planned to be procured from the contractor, the American manufacturing company, and given to a domestic company or companies in the future. After this transition, the Turkish Military Forces will acquire its future needs from local producers. Table 2.4 depicts some of the costs associated with the UAV system.

UNIT	COST	UNIT	COST
Unmanned Aerial Vehicle (UAV)	$ 1,500,000	**Ground Data Terminal (GDT)**	$1,200,000
Antenna System	$ 75,000	Rotation Engine	$ 450,000
Navigation Computer	$ 300,000	Receiver	$ 250,000
Sensors (Probe Tube, Tempr.)	$ 50,000	Transmitter	$ 500,000
Landing Gears	$ 100,000	**Ground Support Unit**	$ 400,000
Engine	$ 400,000	**UAV System**	$ 14,200,000
Propeller	$ 40,000		
		Cost of Diesel Fuel ($/gal)	$1
Payload	$ 650,000	Cost of Oil and Lubricants ($/gal)	$2
IR Scanner	$ 240,000	Officer Salary ($/year)	$10,000
Targeting	$ 150,000	NCO Salary ($/year)	$7,000
Video Scanner	$ 200,000	Operator Tr. O/H Cost ($/year)	$100,000
		Maintenance Tr. O/H Cost ($/year)	$140,000
Ground Control Station (GCS)	$ 4,000,000	O-level Maint. Material($/flight hour)	$200
Main Display Unit	$ 400,000	O-level Maint. Material (Preventive) ($/preventive action)	$500
Power Supply	$ 250,000	I-level Maint. Material (Corrective) ($/flight hour)	$400
Power Generator	$ 500,000	I-level special support equipment	$45,000
Air Conditioner	$ 1,000,000	Design and Technology Transfer Cost	$50,000,000
Control Panel	$ 2,000,000	Disposal Cost ($/UAV System)	$350,000

TABLE 2.4 Some of the Costs Associated with the UAV System

Different inflation rates will be used, as assumptions, for different price increases in the markets.

- 3% for personnel salary,
- 6% for the UAV system, subsystems, and training overhead costs,
- 2% for diesel fuel, oil, and lubricants,

- 2.4% as discount rate.

The Turkish Army Command policy requires that in the event a UAV and payload were lost (both of them lost together since payload is installed in UAV) during an operational mission, a new UAV and payload would be procured and delivered to the UAV unit the next year. Risk of UAV and payload loss during peace time is 10% per year, where risk of loss during a contingency is 25% per year. For the life cycle of the UAV program the chance of a contingency takes place is 40% per year due to instability in the region.

The Army command requires a UAV system to operate satisfactorily with at least 0.85 operational availability when used in an operational environment. However, the Army command's objective is to accomplish an operational availability of 0.95 for the UAV system.

In this chapter, we provide brief background information about UAV systems and define the problem. In the next chapter, we will describe the essence of the problem encountered in the Turkish Military associated with test UAV system procured in 1995. Then we will focus on the solution of these problematic areas.

III. PROBLEM SOLUTION

A. INTRODUCTION

The basic problem with the UAV systems encountered in the test UAV unit is frequent system failures and supply support deficiencies, which diminish the operational availability of this critical weapon system. Two of the most important reasons for this inefficiency are:

1. Inadequate financial resource allocation due to deficiencies in the life-cycle cost (LCC) consideration of the UAV program.
2. Absence of incentivizing tools for the contractor to supply the UAV system with better products since they profit from each part they provide.

In this chapter, we will focus on the solution of the first problem which is closely related to the Turkish Army Command's objective to achieve a certain level of operational availability for the UAV systems. The second problem will be addressed in Chapters IV and V. However, we will present a brief discussion on the second reason in this section since we need to address both of them to solve the inefficiency of the UAV system.

In this chapter, to improve the life-cycle cost considerations of the UAV program, we build a model for the UAV project of the Turkish Armed Forces based on the problem defined in Chapter II. This model will provide a base to allocate adequate financial resources for each year of the UAV project to reach a certain level of operational availability throughout the project life from a life-cycle cost perspective.

> The life-cycle cost analysis needs to be based on a definition of system operational requirements, a definition of the maintenance concept, and a program plan and profile illustrating major life-cycle activities and the projected operational horizon for the system. ...In any event,

> regardless of the type of problem, the configuration(s) being evaluated must be projected in terms of system-level requirements. These requirements may change as the program evolves from phase to phase. However, an initial baseline must be established. From this point on, changes to this baseline may be evaluated systematically and in a controlled manner. [Ref. 4:pp. 477, 478]

The absence of incentivizing tools for the contractor to supply the UAV system with better products is another important reason for the diminishing operational availability problem. Once the Turkish Armed Forces procures a system from a foreign country, interdependency with this country continues by means of D-level maintenance, logistic delay time (the maintenance downtime as a result of waiting for a spare part to become available, waiting for transportation, etc. [Ref. 4:p. 57]), and spare part management considerations. Since the contractor profits from each part of the UAV system they sell to the Turkish Armed Forces, they gain more with increasing number of failures in the system, essentially after the initial procurement of the system.

This scenario results in inefficient use of resources, and very high costs to achieve a certain level of operational availability. If the system procured is vital for the military operations like UAV system, the operational requirements necessitate a responsive stock level, and shorter maintenance downtime (total time required to repair and restore a system to full operational status and/or retain a system in that condition. [Ref. 4:p. 58]). Even the procurement of additional spare parts does not solve the problem totally. Kang, in his "Spreadsheet Decision Support Model for Aviation Logistics" article, states that "(Without improving the average repair time) *It is interesting to note that the operational availability remains constant even with additional spare parts."* [Ref. 5:p. 10] We will discus this issue later in more detail.

The Turkish Military should take actions to achieve better readiness for the UAV system. The operational availability should be improved by acquiring quality products (with higher MTBF values), reducing the maintenance down time, and having a reasonable stock level of spare parts. The test UAV system had faced some shortfalls in inventory during its operational usage, essentially due to long logistic lead time. In his "DoD Inventory Management Cultural Changes and Training in Commercial Practices" report, Kang recommends that *"Excess (inventory) caused by poor estimates of support required for initial procurement can be alleviated with some of the initiatives such as making the contractor responsible for all parts support for the first several years of a weapon system."* [Ref. 6:p. 21]. The same logic might be used for shortfalls in inventory.

We will discuss the option of giving the contractor all support responsibility for a limited time and incentivize it to reach a certain level of operational availability of the UAV system with a Fixed- Price Incentive (FPI) type contract. Under this scenario the contractor should improve the quality of the products (higher MTBF values) and shorten the maintenance down time (cycle time reduction) to earn the incentive fee. This will also help the Turkish Military Forces to determine a more responsive stock level for the life-cycle of the UAV systems. We will address FPI type contracts and implementation of the model to the FPI type contract in Chapter IV and Chapter V, respectively.

In this chapter we will first build a model and then use simulation tool to assess adequate resource allocation for the UAV program. The purpose of the model is not only to solve a specific problem of the UAV systems, but also to provide a decision support tool and methodology for a large family of multi-year weapon system projects. The model will be structured so that the user can change easily the parameters and data in the problem definition. We will also explain the construction of the model in detail to give insight to the reader about the methodology and logic employed. This gives an opportunity to apply the same techniques and logic to a large family of multi-year weapon system programs. In the next section, we will explain how we construct the model (hereafter UAV model) with Microsoft Excel Spreadsheet.

The spreadsheet has several important features, which make it an effective tool for decision and policy analysis. First and foremost, it is used by millions of managers in both government and private sector. Models presented on a spreadsheet are easier for managers to see and understand. Second, spreadsheet cells can be clearly labeled to represent the different variables involved in a decision model, thus making it easier to visualize the model. We will use this feature occasionally in the UAV model. Third, the relationship among the cells is represented by numerical relationships, closely matching how the mathematical models are used to analyze problems. Fourth, the spreadsheet affords the user with interactive and user-friendly implementation of complex models. [Ref. 7:p. 3] With these unique capacities, a spreadsheet facilitates the construction of the UAV model.

B. THE UNMANNED AERIAL VEHICLE (UAV) MODEL

When we develop the life-cycle cost for the UAV program, it is important to establish a top-down framework that will allow for the initial allocation and subsequent collection, accumulation, organization, and computation of costs. For establishing this top-down framework, one of the useful tools in the life cycle cost analysis is a Cost Breakdown Structure (CBS). The cost breakdown structure should be tailored to the aspects of project analyzed. [Ref. 4:p. 478]. We will use six major cost categories as our cost breakdown structure for UAV project to cover all future activities and associated costs.

1. Design and Technology Transfer Cost,
2. Investment Costs,
3. Operation and Maintenance Costs,
4. Training Costs,
5. Manning Costs,
6. Disposal Costs.

Each major cost category will be divided into sub cost categories, identified with functions, significant levels of activity, or some major items of hardware or software. In the model we will estimate the cost for each year of twenty-year-life-cycle by considering the effects of inflation, and other factors that are likely to cause changes in cost, either increasing or decreasing. [Ref. 4:p. 479]

Before explaining each cost category, we want to draw the big picture of UAV model. We built two different types of worksheets in the model, Reference Worksheet (RW) and Decision Support Worksheet (DSW). The data used in the model are put in three different RWs, these are "COSTS," "DATA," and "DEPLOYMENT" worksheets. In addition to that, there are also four DSWs in the model. One of them is "LCC" worksheet, which is basically used for life-cycle cost calculation. The other three of the DSWs are "SPARES," "POISSON," and "A_o" worksheets, which are used for readiness analysis of the UAV system. Figure 3.1 illustrates the UAV model worksheet structure.

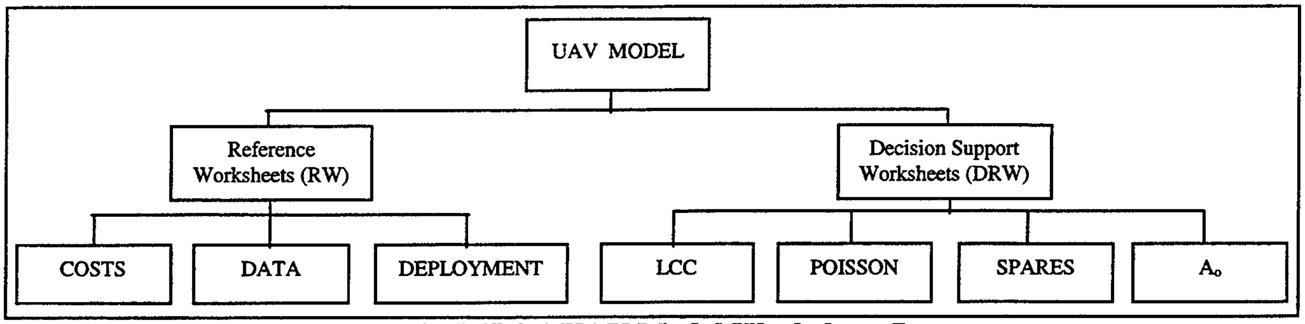


FIGURE 3.1 UAV Model Worksheet Structure

The construction of the DSW is based on formulas and expressions using RW data. This aspect makes all DSWs interrelated with each other and with RWs and gives flexibility to the user to change or update the data given in the problem definition. We assigned a name for most of the data in RWs in the "Name Box" of spreadsheet. These names make it easier for the user to understand the formulas and expressions in the DSWs. Appendix A includes a list of all assigned names used in the model.

In the UAV model, we will also interject some aspects of the problem definition like uncertainty, probability, and randomness by using specific tools of the Crystal Ball software. Forecasting capability of a spreadsheet model can be extended via use of Crystal Ball. Crystal Ball can provide information for more accurate, efficient, and confident decision making. [Ref. 8:p. 19] We will use the Crystal Ball in the simulation of UAV model to acquire a more broad and realistic information on the project.

In the next section, we will explain how we build the model for the UAV project for each cost category. These cost categories are in the "LCC" DSW of the UAV model. Appendix B consists of all the worksheets used in the UAV model. The reader can reference Appendix A and B whenever it is necessary to do so.

1. Design and Technology Transfer Cost

In a developmental weapon system, we incur research and development costs. These costs are one of the major cost drivers in the life-cycle cost of a weapon system during concept exploration, program definition and risk reduction, and engineering and manufacturing development phases. However, this is not the case in the UAV system for the Turkish Armed Forces. The GNAT-750 UAV system was already developed and used in the United States Military. Although research and development costs are not seen as a separate cost category these are in the procurement cost of the system. Instead of research and development costs, we establish design and technology transfer (D&TT) costs in the UAV model. Our program is required to transfer the design and the technology from the contractor to a local enterprise, as the Turkish Armed Forces policy place heavy emphasis on local production.

Transfer of design and technology gives both sides, Turkey and manufacturing company, some advantages. For the original manufacturing company, after the initial procurement of the systems, a decrease in the demand for this particular UAV system will increase the costs of all goods and services throughout the company as they allocate overhead costs to less production units. The company needs to develop new designs to stay in the competitive edge, which requires new assets. The company can liquidate its old assets with this transfer. From Turkey's perspective, by transferring design and technology, the UAV system could be supported domestically. This will not only create a new technological industrial base in Turkey but also shorten the Logistic Lead Time (LLT) dramatically, which means lower stock level requirements for the system.

We require $50,000,000 for design and technology transfer cost in the sixth year. In the present value calculation of the life-cycle cost, we will discount that amount to the present value. To give flexibility to the program manager or contracting officer in changing the transfer year and amount, we defined each cell of the design and technology transfer cost of the UAV model with following expression. The formula for design and technology transfer cost for the first year (B21) is below. Note that we take D&TT year data from "DATA" reference worksheet and D&TT cost from "COSTS" reference worksheet (Appendix A).

B21=IF(DTTYear=B19,DTTCost,0)

In that expression D&TT year data in "DATA" reference worksheet is compared to the year data in "LCC" DSW. If they match, the cell takes D&TT cost data, for all other options it takes zero (0). We do not consider inflation for this cost category, as D&TT cost will be negotiated on nominal values. Nominal amounts are valued according to the level of the prices that exist in the year that amount occurs. [Ref. 8:p. 226]

In the UAV model, we only need to construct the formula once and then copy it to the desired location for each year of life cycle. This nice feature of the spreadsheet for modeling provides the user with flexibility to change the life cycle time of a system easily, by just copying the cells. However, because of the *relative position method* used by spreadsheet programs, we must use *absolutes* in the construction of the formulas. [Ref. 7:p. 4] There are two ways to make the values absolute in spreadsheet. We use both of them in appropriate places throughout UAV model. One of them is using ($) sign in front of column letter and row number of the cell location. One can tailor the formula just fixing one or both of column or row depending on how the formula is to be copied. The second way to make a value absolute is to give a name to the cell in the *Name Box* of spreadsheet. This feature makes both column and row of the cell absolute and formula more explicit and easy to understand as the names represent the characteristics of the cell. For example, in the above formula for the first year of the D&TT cost, "DTTYear" name is assigned for D&TT year value in the "DATA" RW.

2. Investment Costs

For the UAV project, we divide investment major category into three different sub cost categories. These are

a. Initial Procurement Cost of UAV Systems,

b. Subsequent Procurement Cost of UAV and Payload,

c. I-level Special Support Equipment Cost.

As a program manager or a contracting officer, one should consider not only initial procurement costs but also subsequent procurement costs based on risk assessment of the operational arena. We will explain how to contrive these costs into the UAV model in an Excel worksheet.

a. Initial Procurement Cost of UAV Systems

The initial procurement cost of UAV system is based on the deployment plan in the problem definition. According to the plan, 10 Gnat-750 UAV systems will be purchased and deployed in first three years. To give flexibility to the model, the deployment plan constructed in "DEPLOYMENT" RW (Table 3.1), then related life-cycle cost model cells formulated to get the correct initial procurement cost for that year.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	**Operational Bases/Year**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
2	South Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
3	Southeast Anatolia	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
4	East Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
5	Northwest Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
6	West Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
7	**Total number of UAV Sys**	**3**	**6**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**6**	**3**
8	New Operational Base	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 3.1 DEPLOYMENT Reference Worksheet

In the calculation of each cell of initial procurement costs of UAV systems we use the following expression given as an example for the first year (cell B22) and the second year (cell C22) of "LCC" DSW.

B22=DEPLOYMENT!B7*UAVSystemCost*((1+UAVsystem)^B19)

C22=IF(DEPLOYMENT!C7>DEPLOYMENT!B7,(DEPLOYMENT!C7-DEPLOYMENT!B7)*UAVSystemCost*((1+UAVsystem)^C19),0)

Although the first year expression is unique, we may use the second year expression for all of the other life-cycle years of the project by just copying it. For the second year, the total number of UAV systems is compared to prior year's number. If it is bigger than the prior year's value (there is a new procurement of UAV system), then additional systems number is multiplied by UAV system cost ("UAVSystemCost" is the name assigned in "Name Box" attributed to that cell in "COST" RW) and that year's inflation to get a realistic estimate of initial procurement cost of UAV system for that specific year. If there is no new procurement, the cell takes no value. This expression gives user flexibility so that when he/she changes the deployment plan or UAV system's cost from the RWs (namely "DEPLOYMNET" and "COSTS" worksheet respectively), the UAV model automatically updates the initial procurement costs.

Throughout the construction of the model, sometimes we are not able to use one formula in calculation of a cost category for each year of life-cycle due to special conditions in the problem definition or working principles of worksheet. However, we try to minimize multiple formula usage. For the first year's initial procurement cost calculation, in cell B22, the new procurement number is different from the other years. The change is basically imposed by written format of cell A22.

It is possible to create only one expression for all of the cells. In fact, we use that expression for every year in the model but we find useful to explain it with an easier version. One can easily understand the expression below as we only add one more check for year one.

B22=IF(B19=1,(DEPLOYMENT!B7)*UAVSystemCost*((1+UAVsystem)^ B19),IF(DEPLOYMENT!B7>DEPLOYMENT!A7,(DEPLOYMENT! B7-DEPLOYMENT!A7)*UAVSystemCost*((1+UAVsystem)^B19),0))

When constructing the expression, one must be very careful about the appropriateness of the formula in each cell. This one is a combination of the first two expressions. Although the expression looks complex, one expression for every year provides flexibility to change production or deployment plan, and the system cost.

b. Subsequent Procurement Cost of UAV Systems

The subsequent procurement cost is based on the risk assessment of the operational arena. Depending on the peace time or contingency period, there is always a risk of operational loss. We need to allocate adequate resources to satisfy the mission needs over the life-cycle of the system. As a program manager or a contracting officer, one will not have the luxury to not to plan and allocate resources due to potential difficulty for predicting the future risks in the operational arena. In the model, we use Monte Carlo Simulation in the Crystal Ball software to determinate the subsequent procurement cost of the UAVs and payloads. There are four steps to calculate the subsequent procurement cost of a UAV and payload.

We first define a contingency assumption for each year. We give (1) for contingency and (0) for peacetime and assign appropriate probability of having a contingency in each year by using Crystal Ball. We want to explain how we define contingency assumption to help the user in case of a need to change the assumption contingency due to a difference in contingency assumption. Unfortunately it is not possible for the user to change the contingency assumptions just by changing the contingency possibility value in the "DATA" RW. Just as all the assumption definitions, contingency assumption definition should be changed from the *Cell* menu. Because of that, understanding the procedure is important. Below is the procedure for defining the first year's contingency assumption.

In the problem definition we stated that for the life-cycle of the UAV program the chance of a contingency is 40% per year due to instability in the region. To implement this expression into the model, first, we choose *Define Assumption* from the *Cell* menu (a menu added in Excel menu with the opening of Crystal Ball program). Second, we choose *Custom Distribution* from the *Distribution Gallery* since the defined probability distribution can not be represented with given distribution options. Third, we type (1) in the *Value* box and 40% in the *Probability* box. This represents 40% chance of contingency in that year. Fourth, by clicking enter, we type (0) in the *Value* box and 60%

in the *Probability* box. This represents 60% chance of peacetime. Finally, we select *OK* to return to the spreadsheet. One can copy the same assumption to the other years of life cycle by using *Copy Assumption* and *Paste Assumption* in the *Cell* menu. The contingency assumption for the first year (B12) is in Figure 3.2. We use same assumption for all the years in life cycle of UAV program.

LCC - Cell: B12

Assumption: Contingency

Custom distribution with parameters:		Relative Prob.
Single point	0.00	0.600000
Single point	1.00	0.400000
Total Relative Probability		1.000000

Mean value in simulation was 0.41

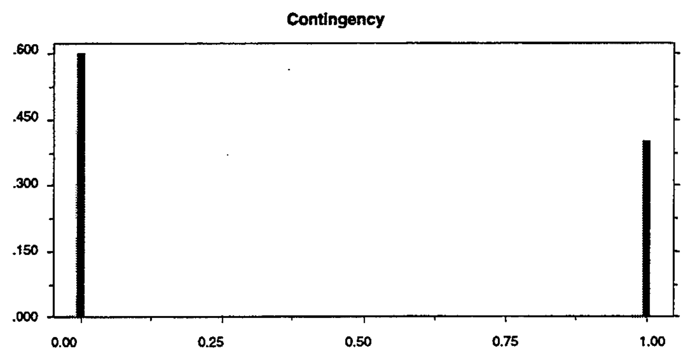


FIGURE 3.2 Contingency Assumption for the First Year

Second step in the calculation of subsequent procurement cost is to find the attrition rate for each year. In the problem definition, we set forth that the risk of UAV and payload loss during peacetime is 10% per year, where risk of loss during contingency is 25% per year. We use the binary variable (1 or 0) assigned by the simulation for contingency in the first step to find the correct attrition rate for that year.

Below is the attrition rate formula for the first year. We just copy this formula along the life cycle of the system.

B13 =Peace*(1-B12)+Contingency*B12

In the first year's attrition rate formula, "Peace" and "Contingency" are the assigned names for the risk of UAV and payload loss during peacetime and contingency in "DATA" RW. As we explained, the user can change these values in "DATA" RW and the model will automatically update the information with this formula. Note that the attrition rate takes "Contingency" value (25%) in contingency year (B12=1), however, it takes "Peace" value (10%) in peacetime (B12=0).

The third step is the calculation of subsequent purchase number of UAVs and payloads for each year by using the attrition rate of that year. By multiplying the number of UAVs in operation and attrition rate for that year, we can find the subsequent purchase number of UAVs and payloads. However, the result must be an integer since we can not buy a fraction of UAV or payload. We use the ROUNDUP function of Excel spreadsheet to round the number calculated to the next largest integer number. As stated in the problem definition, the Army Command policy requires that in the case of UAV and payload loss during operational mission, a new one will be procured and delivered to the UAV unit next year. The subsequent purchase number of UAVs and payloads formula for the second year is below. The formula calculates the number for the first year and places in the second year (C15) in LCC DSW.

C15=IF(C19=1,0,IF(C19=19,0,IF(C19=20,0,ROUNDUP(B13*B14,0))))

The fourth and the last step is the calculation of subsequent procurement cost, by multiplying the number of UAVs and payloads with their costs. Just as the other cost calculation, we add the appropriate inflation rate represented with "UAVSystem" assigned name. The subsequent procurement cost of UAV and payload formula for the first year (B23) is below.

B23=B15*(UAVCost+PayloadCost)*((1+UAVsystem)^(B19))

c. I-level Special Support Equipment Cost

Each operational base has an I-level maintenance center, which supports two UAV systems in the region. The I-level maintenance centers are activated as the UAV systems are deployed to the region. The 8th row in the "DEPLOYMENT" RW (TABLE 3.1) shows new operational base numbers for each year. These numbers also indicate the number of activated I-level maintenance centers.

Each I-level maintenance center is equipped with special support equipment which is essential for performing more detailed maintenance than those of the O-level. Because of that, we need to allocate enough resources to acquire special support equipment for each I-level maintenance center as they are activated. Below is the formula for the first year's (B24) I-level special support equipment cost.

B22=DEPLOYMENT!B8*SportEquipment*((1+UAVsystem)^(B19))

The user can change the activation year of the operational bases in "DEPLOYMENT" RW or cost of the I-level special support equipment ("SupportEquipment" is the assigned name for this cost) in the "COST" RW and the model automatically calculate new I-level special support equipment cost for appropriate years. We also adjust the cost with the specific inflation rate for UAV system which is denoted with "UAVSystem" in the formula.

3. Operation and Maintenance Costs

Although initial procurement cost looks like the major driver in the procurement decision of a major weapon system, operation and especially maintenance costs prove their importance from a life-cycle cost perspective. Careful planning and allocation of resources for operation and maintenance costs is vital for effective use of UAV systems in the operational arena. We divide major operation and maintenance cost of UAV system into seven sub categories. These are

a. Fuel Cost,

b. Oil and Lubricants Cost,

c. O-level Maintenance Material Cost,

d. O-level Preventive Maintenance Material Cost,

e. I-level Corrective Maintenance Material Cost,

f. Spare Part Cost,

g. Repair and Replacement Cost.

We will explain how we construct these costs into the model. In the spares, and repair and replacement cost categories, we will make a readiness analyses with the objective of reaching certain level of operational availability for UAV system as required by Turkish Military Forces in the problem definition. In that part of the thesis, we will also discuss the other two of our decision support worksheet; "SPARES" and "POISSON" DSWs.

a. Fuel Cost

GNAT-750 UAV consumes diesel fuel with a fuel burn rate of 1.26 gallon per operating hour. As we stated in the problem definition, the Army Command is planning to use the UAV System on the average of 12 hours per day, 365 days per year. To provide 12 hours of reconnaissance, surveillance, and target acquisition in real time, the operating hours on the average are expected as five hours per day per UAV (there are four UAVs in a UAV system). To calculate fuel cost, we first multiply UAV operating hours with fuel burn rate which gives the total annual diesel fuel consumption for a UAV. Then we multiply this number with the number of UAVs in operation to find the total annual diesel fuel consumption for active UAV systems. Finally, we multiply that amount with the cost of diesel fuel and the appropriate inflation factor for fuel. The fuel cost formula for the first year (B29) is below.

B29=UAVhours*FuelBurnRate*FuelCost*B$14*((1+(Fuel))^(B$19))

Note that in the formula, assigned names are used for each item described above (for a list of all assigned names used in the model, look Appendix A). The user has the flexibility to change every item in the calculation of fuel cost from appropriate data worksheets and the model automatically adjust the fuel cost for that year.

b. Oil and Lubricant Cost

Oil and lubricant cost is calculated just like the fuel cost (B.3.a). The only difference in the calculation is using oil and lubricant consumption rate of 0.25 gallon per operation hour and cost of oil and lubricants, instead of the fuel burn rate and the cost of diesel fuel. Below is the formula for the first year (B30) oil and lubricant cost.

B30=UAVhours*OLConsumptionRate*OilLubCost*B$14*((1+(Fuel))^(B$19))

c. O-level Maintenance Material Cost

At the O-level, maintenance personnel do some servicing, external adjustments, removal and replacement of some components, and prepare the UAV system for the operational mission with a material cost of $200 per flight hour on average. To calculate the O-level maintenance material cost, first, we multiply UAV operating hours with the O-level maintenance material cost per operating hour per UAV. Second, we find the cost for all UAV systems by multiplying the number of UAVs in operation for that year. Then we multiply this amount with the appropriate inflation rate to reach a realistic O-level maintenance material cost for each year. Below is the formula for the first year (B31) O-level maintenance material cost.

B31=UAVhours*OlevelMM*B$14*((1+UAVsystem)^(B$19))

d. O-level Preventive Maintenance Material Cost

In the problem definition we pointed out that the preventive maintenance is done in the O-level for only two subsystems, UAV and payload, and the O-level maintenance material cost for preventive maintenance is $500 per preventive maintenance action. *"Preventive maintenance consists of the actions required to retain a system at a specified level of performance and may include such functions as periodic* *inspection, servicing, scheduled replacement of critical items, calibration, overhaul and so on."* [Ref. 4:p. 55] From the definition we can conclude that the basic characteristics of preventive maintenance is its periodic and scheduled maintenance action structure. For UAV system the preventive maintenance schedule is based on operating hours of UAV. Table 2.3 shows mean time between preventive maintenance ($MTBM_s$- (s) denotes scheduled) values in operating hours for UAV and payload as 25 and 50, respectively.

We now explain the O-level preventive maintenance in four steps. First of all, we need to find the frequency of preventive maintenance (fpt) in actions per system operating hour. Since we had mean time between preventive maintenance actions, we use ($fpt=1/ MTBM_s$) formula to calculate fpt. Second, by multiplying the frequency of preventive maintenance (fpt) with the total operating hours (t), we get the total number of preventive maintenance action (TMA_p) ($TMA_p=fpt*t$). Third, the product of the total number of preventive maintenance action and the material cost per preventive maintenance action gives the total O-level preventive maintenance material cost for one UAV. Fourth, we need to multiply this product with number of UAVs in operation and add appropriate inflation rate to the calculation to reach each year's cost. The O-level preventive maintenance material cost for the first year (B32) is below.

B32=((UAVhrs/MTBFsUAV)+(UAVhours/MTBFsPayload))*B$14*

OlevelMMprv*((1+UAVsystem)^(B$19))

As we define two sub systems for preventive maintenance in the formula (UAV and payload), we need to add two of these numbers of preventive maintenance actions together to get the total number of preventive maintenance actions. The user has a flexibility to change mean time between preventive maintenance as the product or process necessitates a higher or lower value. The model automatically adjusts the O-level preventive maintenance material cost. As a matter of fact, all of the assigned names represent values that can be changed from the reference worksheets.

e. I-level Corrective Maintenance Material Cost

In the problem definition, we stated that the I-level maintenance material cost for corrective maintenance is $400 per UAV operating hour. The calculation of the I-level corrective maintenance material cost is similar to the O-level maintenance material cost since both of them is based on the UAV operating hours. The only difference in formulation is the use of I-level corrective maintenance material cost per UAV operating hour instead of O-level maintenance material cost per UAV operating hours. Below is the formula for the first year (B33) I-level corrective maintenance cost.

B33=UAVhrs*IlevelMMcorr*B$14*((1+UAVsystem)^(B$19))

f. Spare Part Cost

(1) Background: Spare part consideration is based on readiness requirements of Turkish Army Command and failure vulnerability assessment of the UAV system. Inadequate spare stock level can put the whole UAV system in non-mission capable state while excess spare stock levels (beyond what is needed to support current operating requirements) cause inefficient allocation of scarce resources. We need to determine our stock level very carefully.

In the problem definition, we addressed both, readiness requirement and failure vulnerability assessment of the UAV system. First, for the readiness requirement, we contended that the Army Command requires a UAV system to operate satisfactorily with at least 0.85 operational availability when used in an operational environment. However, the Army Command's objective is to accomplish an operational availability of 0.95 for the UAV system. Second, for the failure vulnerability assessment, we listed component failures which stimulate a complete loss or a significant reduction of the operational availability of the UAV system.

In the model, we determine spare part level using the Poisson distribution to reach a certain level of operational availability of the UAV system. To do that we build two decision support spreadsheets, "SPARES" and "POISSON" DSW. We use "SPARES" decision support worksheet in finding the appropriate spare part level for each component of UAV system and in calculating the spare part costs. The second decision support worksheet, "POISSON" DSW, is used to transform readiness requirement into spare part quantity determination which in eventually used by "SPARE" DSW to calculate the spare part costs.

Before explaining the construction of the decision support worksheets, we want to scrutinize the relation between spare part consideration and the Poisson distribution with an example. This discussion will help the user to gain insight into the logic of the model. We first state assumptions used in the model.

(a) Random Occurrence of Failures: There have been a number of studies done which shows the fitness of the Poisson distribution to the random process, e.g., accidents. "*The number of wrong telephone numbers that are dialed in a day*," and "*the number of misprints on a page of a book*" are some examples of random variables which shows the fitness of Poisson probability. [Ref. 10:p. 102]Another study shows that the number of flying-bomb hits recorded in south of London during World War II is well fitted to a Poisson probability distribution. [Ref. 11:p. 48]

In the problem definition, we stated that the UAV system component failure occur randomly and are exponentially distributed. There is a strong relation between exponential distribution and Poisson distribution. We will highlight this relationship since it gives broader understanding to the process applied in the problem solution.

(b) Relation between Exponential Distribution and Poisson Distribution: For the distribution of times between the occurrence of successive events, the exponential distribution is frequently used as a model. Customers arriving at a service facility or calls coming in to a switchboard are examples. The reason for this is that the exponential distribution is the mirror image of the Poisson process. [Ref. 12:p. 171]

> If T_1, T_2, ...are independent and identically distributed exponential() random variables denoting the inter event times for a point process, then the *number* of events in the interval (0,t] has the Poisson distribution with parameter λt.
>
> This property is related to the memoryless property and can be applied to a component that is subjected to shocks occurring randomly over time. It states that if the time between shocks is exponential (λ) then the number of shocks occurring by time *t* has the Poisson distribution with parameter λt. ...The probability of fewer than *n* failures by time *t* (the system reliability) is $\sum_{k=0}^{n-1} \frac{(\lambda t)^k}{k!} \cdot e^{-\lambda \cdot t}$. [Ref. 13:p. 87]

For the exponential distribution, the random variable is the time to failure, whereas for the Poisson distribution, it is the number of failures per a given time period. Given the above, the exponential variable is continuous and the Poisson variable is discrete. [Ref. 4:p. 64]

(c) Spare Part Consideration and the Poisson Distribution: After reviewing the Poisson process, we examine the relation between spare part consideration and the Poisson distribution with UAV antenna system example. The test UAV system personnel determine UAV antenna system as one of the components causing significant reduction in the operational capability of the UAV system. We require 0.85 operational availability for this type of component and 0.95 operational availability for the components whose failure cause a loss of operational capability of the UAV system.

When we use a single component with certain reliability for time t in a unique system application and purchase one spare component, we can determine the probability of system success having a spare available in time t with the following formula.

$$P = e^{-\lambda t} + (\lambda t) * e^{-\lambda t}$$ (λ is the instantaneous failure rate) [Ref. 4:p. 63]

For the antenna system of one UAV with a MTBF of 1500 hours (TABLE 2.4), we can calculate the probability of its success having a spare available in 1825 hours (UAV operating hours in a year). The calculation below indicates that there is 65.66% probability that the antenna system will survive within one year with one spare part.

$$P = e^{-(1/1500)*1825} + ((1/1500)*1825) * e^{-(1/1500)*1825} = 0.6566$$

If we want to find out the probability of system success having a spare available in time t for a system backed up with two spare component, we can use the below formula.

$$P= e^{-\lambda t} + (\lambda t) * e^{-\lambda t} + ((\lambda t)^2 * e^{-\lambda t})/2\ )$$ [Ref. 4:p. 63]

As we increase the spare part quantity of the component, we add one additional term to the Poisson expression. For only one item having n spares, we can represent the probability of system success having a spare available in time t, with a general Poisson expression below.

$$P= \sum_{x=0}^{x=n} ((\lambda t)^x * e^{-\lambda t}) / x!\ )$$ [Ref. 4:p. 64]

Spare part quantity determination is a function of a probability of having a spare part available when required, the reliability of the item in question, the quantity of items used in the system, and so on. An expression, derived from the Poisson distribution, useful for spare part quantity determination is

$$P = \sum_{n=0}^{n=s} \left[\frac{R(-\ln R)^n}{n!} \right]$$

Where

P = probability of having a spare of a particular item available when required

S = number of spare parts carried in stock

R = composite reliability (probability of survival); $R = e^{-K\lambda t}$

K =quantity of parts used of a particular type

ln R = natural logarithm of R

In determining spare part quantities, one should consider the level of protection desired (safety factor). The protection level is the P value in the above equation. This is the probability of having a spare available when required. The higher the protection level, the greater the quantity of spares required. This results in a higher cost for item procurement and inventory maintenance. The protection level, or safety factor, is a hedge against the risk of stock-out. [Ref. 4:pp. 66,67]

(2) Spare Part Cost Calculation: After these backgrounds on the subject, we now explain how we determine spare part level and associated cost of it with regard to operational availability determination made by the Turkish Army Command. In the "SPARES" decision support worksheet (DSW), we divide the process of spare part cost calculation into three steps. First, we calculate composite factor (K λ t) of spare part determination. Second, we transform composite factor (K λ t) to the number of spare part. Third, we find the spare part cost for each component.

(a) Step One - Calculation of Composite Factor (K λ t) of Spare Part Determination: In the first step we calculate composite factor (K λ t) of spare part determination of each component for the first three years. This calculation is constructed in the first part of the "SPARES" DSW (Table 3.2). We will explain how we determine each element of composite factor (K), (λ), and (t).

The deployment plan (Table 3.1) requires a three-year-period for the activation of all the UAV systems. As we mentioned, (K) is the quantity of parts used of a particular type. In the model, (K) is the total number of UAVs for that year. The determination of this variable is closely related to selection of time period (t).

In the problem definition, we stated that the I-level maintenance center can repair 60% of the failures with a TAT of seven days, and 40% of them are sent to the United States for D-level maintenance with a TAT of 75 days. We calculate the required UAV operating hours for average TAT of UAV system with the formula below.

t = (UAVhours*((IlevelRR*IlevelTAT+DlevelRR*DlevelTAT)/365))

t = (1825*((0.60*7+0.40*75)/365)) = 171 hours

We use TAT for spare part determination because within that period the component is fixed or repaired by I-level or D-level. With this formula we find how many UAV operating hours pass until that component failure is fixed. This is the (t) in our composite factor (K λ t) calculation.

Finally, (λ) is the 1 / MTBF (mean time between failures) for that component. Below is the formula we used for the calculation of composite factor (K λ t) of spare part determination for UAV Antenna system in first year (D14) in "SPARES" DSW.

D14=B$9*(1/$B14)*(UAVhours*((IlevelRR*IlevelTAT+DlevelRR*DlevelTAT)/365))

- **D14 = K λ t** (Composite factor for UAV Antenna system in first year)
- **B$9 = K** (Quantity of UAV Antenna system)
- **1/$B14 = 1/MTBF = λ** (Instantaneous failure rate of UAV Antenna sys.)

We copy the formula for three years and for UAV and payload components. Note that the formula gives flexibility to change the (K) and (λ) values. We reference each cell in [A1: U7] portion of "SPARES" DSW (Table 3.2) to the "DEPLOYMENT" reference worksheet (RW). The user can change the deployment plan and the model automatically adjust the (K) in the formula. In the same manner MTBF values [B14: B33] (Table 3.2) are referenced to the "DATA" RW.

Although the above formula can be used for UAV and payload components, we need to adjust the formula for GCS and GDT. The components of GCS and GDT have different quantity and operating hours than the components of UAV and payload. We change the UAV operating hours to the UAV support equipment operating hours for appropriate components in (t) calculation. We also change the (K) quantity of parts used of particular type since there is only one GDT and GCS versus four UAVs and payloads within a UAV system.

The formula for calculation of the composite factor (K λ t) of spare part for GCS main display unit in the first year (D25) is below. Table 3.2 shows the first step (composite factor (K λ t) calculation) of the spare part determination. This table is given as a reference to enhance the understanding of the formula constructed in the module.

D25=B$7*(1/$B25)*(SupportHours*((IlevelRR*IlevelTAT+DlevelRR*DlevelTAT)/365))

	A	B	C	D	E	F	G	H	I
1		A	B	C	D	E	F	G	H
2	1	**Operational Bases/Year**	1	2	3	4	5	6	7
3	2	South Anatolia	1	1	2	2	2	2	2
4	3	Southeast Anatolia	1	2	2	2	2	2	2
5	4	East Anatolia	1	1	2	2	2	2	2
6	5	Northwest Anatolia	0	1	2	2	2	2	2
7	6	West Anatolia	0	1	2	2	2	2	2
8	7	Total number of system	3	6	10	10	10	10	10
9	8	New UAV System	3	3	4	0	0	0	0
10	9	Total number of UAV	12	24	40	40	40	40	40
11	10	New UAV	12	12	16	0	0	0	0
12	11								
13	12								
14	13	**UAV k*lambda*t**	**MTBF**		**Year1**	**Year2**	**Year3**		**Operational Availability**
15	14	Antenna System	1500		1.37	2.74	4.56		[illegible]
16	15	Navigation Computer	500		4.10	8.21	13.68		[illegible]
17	16	Sensors (Probe Tube, Tempr.)	350		5.86	11.73	19.54		[illegible]
18	17	Landing Gears	750		2.74	5.47	9.12		[illegible]
19	18	Engine	700		2.93	5.86	9.77		[illegible]
20	19	Propeller	3500		0.59	1.17	1.95		[illegible]
21	20	**PAYLOAD**							
22	21	IR Scanner	450		4.56	9.12	15.20		[illegible]
23	22	Targeting	800		2.57	5.13	8.55		[illegible]
24	23	Video Scanner	2500		0.82	1.64	2.74		[illegible]
25	24	**GCS**							
26	25	Main Display Unit	1000		0.72	1.44	2.39		[illegible]
27	26	Power Supply	4000		0.18	0.36	0.60		[illegible]
28	27	Power Generator	3500		0.21	0.41	0.68		0.97
29	28	Air Conditioner	6000		0.12	0.24	0.40		0.97
30	29	Control Panel	500		1.44	2.87	4.79		0.97
31	30	**GDT**	-						
32	31	Rotation Engine	1700		0.42	0.84	1.41		0.97
33	32	Receiver	800		0.90	1.80	2.99		0.97
34	33	Transmitter	650		1.10	2.21	3.68		0.97

TABLE 3.2 Step One of Spare Part Determination (First Part of "SPARES" DSW)

(b) Step Two - Transformation of Composite Factor to the Number of Spare Part: In the second step, we transform composite factor (K λ t) to the number of spare part for each component for the first three years. This transformation is done by "POISSON" decision support worksheet (DSW) and applied by second part of "SPARES" DSW. The "POISSON" DSW consists of tables for each component listed in the problem definition as causing a loss or a reduction of operational capability of UAV system. The functional and logical structure of each table is identical, so we will explain just one of them (UAV antenna system).

In the "POISSON" DSW, each component has a scale from one to thirty for three years. This scale is used by one of Microsoft Excel program's statistical function category, POISSON (notation for Poisson probability calculation) in calculation of cumulative Poisson probabilities. Table 3.3 shows a part of "POISSON" DSW constructed for the computation of cumulative Poisson probabilities for the UAV antenna system. The Excel spreadsheet expression used in the calculation of antenna system's cumulative Poisson probability for the first year is depicted below.

B3=POISSON(C3,SPARES!D$14,1)

	A	B	C	D	E	F	G
1		1X Antena System					
2		P(X <=x)	x1	P(X <=x)	x2	P(X <=x)	x3
3	0	0.2546	0	0.0648	0	0.0105	0
4	1	0.6029	1	0.2422	1	0.0582	1
5	2	0.8412	2	0.4848	2	0.1669	2
6	3	0.9498	3	0.7061	3	0.3323	3
7	4	0.9870	4	0.8575	4	0.5208	4
8	5	0.9971	5	0.9403	5	0.6926	5
9	6	0.9995	6	0.9781	6	0.8233	6
10	7	0.9999	7	0.9929	7	0.9084	7
11	8	1.0000	8	0.9979	8	0.9569	8
12	9	1.0000	9	0.9994	9	0.9815	9
13	10	1.0000	10	0.9999	10	0.9927	10
14	11	1.0000	11	1.0000	11	0.9973	11
15	12	1.0000	12	1.0000	12	0.9991	12
16	13	1.0000	13	1.0000	13	0.9997	13
17	14	1.0000	14	1.0000	14	0.9999	14
18	15	1.0000	15	1.0000	15	1.0000	15
19	16	1.0000	16	1.0000	16	1.0000	16
20	17	1.0000	17	1.0000	17	1.0000	17
21	18	1.0000	18	1.0000	18	1.0000	18
22	19	1.0000	19	1.0000	19	1.0000	19
23	20	1.0000	20	1.0000	20	1.0000	20
24	21	1.0000	21	1.0000	21	1.0000	21
25	22	1.0000	22	1.0000	22	1.0000	22
26	23	1.0000	23	1.0000	23	1.0000	23
27	24	1.0000	24	1.0000	24	1.0000	24
28	25	1.0000	25	1.0000	25	1.0000	25
29	26	1.0000	26	1.0000	26	1.0000	26
30	27	1.0000	27	1.0000	27	1.0000	27
31	28	1.0000	28	1.0000	28	1.0000	28
32	29	1.0000	29	1.0000	29	1.0000	29
33	30	1.0000	30	1.0000	30	1.0000	30

TABLE 3.3 Cumulative Poisson Probability Table for UAV Antenna System (From "POISSON" DSW)

The generic formula, which calculates the cumulative Poisson probability, is given above. We can rewrite the formula more explicitly by replacing composite reliability (R) term with ($e^{-K \lambda t}$) (see (B.3.f.(1).(c)) for the explanation of formula). The Excel spreadsheet's Poisson statistical function basically uses the same formula.

$$P = \sum_{n=0}^{n=s} \left[\frac{(K\lambda t)^n \cdot e^{-K \cdot \lambda \cdot t}}{n!} \right]$$

We now explain how the Poisson statistical function uses the formula briefly. There are three parameters in the Excel spreadsheet's Poisson statistical function. The first parameter represents the number of spare parts carried in stock (denoted by (S) in the formula). The second parameter in the expression represents composite factor of the component (K λ t). The last parameter in the expression shows whether it calculates cumulative Poisson probability. It takes (1) (true) for cumulative and (0) (false) for individual Poisson probability. The generic expression of Poisson statistical function is below. The UAV antenna system's cumulative Poisson probability for the first year is also jotted down for comparison of two in the light of given explanation.

POISSON (x, mean, cumulative) **(Original parameters)**

POISSON (S, K λ t, 1) **(Model parameters)**

POISSON (number of spare part, composite factor, cumulative)

B3=POISSON(C3,SPARES!D$14,1) **(in "POISSON" DSW)**

The formula above computes the probability of having one UAV antenna system available (A3 = 0.2546 = 25.46%) when required, in the first year if there is no spare part (B3 = 0). We copy the formula down to spare number thirty. Then we implement the same procedure for the second and third year. Table 3.3 is constructed with the same way for the UAV antenna system. After that we follow the same process for each component listed in the "SPARES" DSW and create "POISSON" DSW. "POISSON" DSW is used for in essence the transformation of composite factor (K λ t) to the cumulative Poisson probabilities (having one component available) in a quantity (spare part) range of zero to thirty for each component for the first three years.

We determine the number of spares needed for each component in the second part of "SPARES" DSW. As we mentioned, in the "POISSON" DSW we calculated the probability of having one component available for each spare part quantity from zero (or no spare) to thirty. However, we need to find out spare part quantity for a certain probability for every one component of a UAV system. The operational availability of the component is the certain probability we use in this determination. We will discuss structure of UAV system operational availability later. The UAV Antenna system operational availability is determined as 0.90 (90%). To find out the spare part quantity for a certain probability we use another function of Microsoft Excel Spreadsheet, VLOOKUP (notation for Vertical Look-up).

VLOOKUP function reaches for a value in the leftmost of a defined table and then returns a value in the same row from a column we specified in the table. There are four parameters in the VLOOKUP function. A generic formula for the function and the formula we use for UAV antenna system in the first year (D36) is below.

VLOOKUP (lookup value, table array, column index number, range lookup)

D36 =VLOOKUP($H14,POISSON!$B$3:$C$23,2)+1

We find the appropriate spare part quantity for a predefined certain operational availability for each component by using VLOOKUP function in the second part of "SPARES" DSW (Table 3.4). We now explain four parameters of VLOOKUP function (seen in the generic formula). In the above formula for UAV antenna system *lookup value* is the operation availability of UAV antenna system ($H14 = 0.90 (Table 3.2)). VLOOKUP function finds this value in the first column of the given table array. The *table array* is the cumulative Poisson probabilities (table of information) calculated in the "POISSON" DSW for the UAV antenna system in the first year (POISSON! $B$3: $C$33 (Table 3.3)), in which specified operational availability data ($H14 = 0.90) is looked up. In the first column of table array [B3: B33] the matching number is found by the function. The *range lookup* is a logical value which specifies whether to find an approximate match (True or omitted) or an exact match (False). We just omitted the range lookup parameter to find an approximate match. In that case, the table array must be placed in ascending order like we did in "POISSON" DSW beginning from zero to thirty (Table 3.3). In finding an approximate match if an exact match is not found, it locates the next largest value, which is less than the lookup value. It then returns a value in the same row from the *column number* (2) specified in the function. In UAV antenna system example, the model search for a value of 0.90 ($H14 = Operational availability of the component) in the leftmost column of a defined table (POISSON! $B$3: $C$33) that is column B. It takes 0.8412 (next largest value which is less than the lookup value)(Table 3.3). This value is on the 5th row (Table 3.3). The model returns the value of 2 which is the 5th row (same row) from the column C (The column we specified in the column index number. First column of table array is column B whereas the second column of it is column C).

As we explain above, for the first year of UAV antenna system, the model returns (2) as the number of spare part for 0.90 operational availability. But in reality two (2) spare parts corresponds to 0.8412 operational availability. As the VLOOKUP function gives most of the time less than 0.90 operational availability (with an exception of mostly unlikely situation of exact match between operational availability and cumulative Poisson probability) we add one more spare part (denoted with +1 in the formula for D36 cell above) to this calculation. Three (3) spare parts provide a certainty that we can reach at least 0.90 operational availability for the first year of UAV antenna system. The second part of "SPARES" DSW is built up by using the same logic for the first three years of all the components (Table 3.4).

	A	B	C	D	E	F	G	H
35	UAV	MTBF		1	2	3		Cost
36	Antenna System	1500		3	5	7		75000
37	Navigation Computer	500		7	12	19		300000
38	Sensors (Probe Tube, Tempr.)	350		9	16	25		50000
39	Landing Gears	750		5	9	13		100000
40	Engine	700		5	9	14		400000
41	Propeller	3500		2	3	4		40000
42	PAYLOAD							
43	IR Scanner	450		7	13	20		240000
44	Targeting	800		5	8	12		150000
45	Video Scanner	2500		2	3	5		200000
46	GCS							
47	Main Display Unit	1000		3	4	6		400,000
48	Power Supply	4000		1	2	2		250,000
49	Power Generator	3500		1	2	3		500,000
50	Air Conditioner	6000		1	1	2		1,000,000
51	Control Panel	500		4	6	9		2,000,000
52	GDT							
53	Rotation Engine	1700		2	3	4		450000
54	Receiver	800		3	5	7		250000
55	Transmitter	650		3	5	8		500000

Table 3.4 Step Two - Transformation of Composite Factor to the Number of Spare Part (Second Part of "SPARES" DSW)

(c) Step Three - Spare Part Cost Calculation: In the third part of "SPARES" DSW, we finally find the cost figures for spare parts of each component. After the first two steps, spare part cost calculation is a pretty straight forward process. We simply multiply the spare part quantities with appropriate spare part costs. The important thing is to remember that we need to find out how many additional spare parts we should buy with increasing UAV units in the field. Because of that we subtract spare part quantity of previous year's quantity. We also add appropriate inflation factor. The spare part cost formula for the UAV antenna system and Table 3.5, which shows the spare part costs of UAV system are below.

D58=(D36-C36)*$H36*((1+UAVsystem)^(D$35-1))

54	A	D	E	F	G	H	I
55	UAV	1	2	3	4	19	20
56	Antenna System	225000	159000	168540	525000	375000	225000
57	Navigation Computer	2100000	1590000	2359560	5700000	3600000	2100000
58	Sensors (Probe Tube, Tempr.)	450000	371000	505620	1250000	800000	450000
59	Landing Gears	500000	424000	449440	1300000	900000	500000
60	Engine	2000000	1696000	2247200	5600000	3600000	2000000
61	Propeller	80000	42400	44944	160000	120000	80000
62	PAYLOAD					0	0
63	IR Scanner	1680000	1526400	1887648	4800000	3120000	1680000
64	Targeting	750000	477000	674160	1800000	1200000	750000
65	Video Scanner	400000	212000	449440	1000000	600000	400000
66	GCS					0	0
67	Main Display Unit	1200000	424000	898880	2400000	1600000	1200000
68	Power Supply	250000	265000	0	500000	500000	250000
69	Power Generator	500000	530000	561800	1500000	1000000	500000
70	Air Conditioner	1000000	0	1123600	2000000	1000000	1000000
71	Control Panel	8000000	4240000	6741600	18000000	12000000	8000000
72	GDT					0	0
73	Rotation Engine	900000	477000	505620	1800000	1350000	900000
74	Receiver	750000	530000	561800	1750000	1250000	750000
75	Transmitter	1500000	1060000	1685400	4000000	2500000	1500000
76	TOTAL STOCK COST	22,285,000	14,023,800	20,865,252			
77	REPAIR&REPLACEMENT COS	17,828,000	29,047,040	39,929,834	43,268,000	28,412,000	17,828,000
78	NOT: Total Spare Cost of 4th, 19th, and 20th year is calculated to be used in the "Repair and Replacement Cost"						
79	G58=F36*$H36 (Total UAV antenna system spare part cost without inflation effect)						
80	G79=0.8*SUM(G58:G77)						

Table 3.5 Step Three - Spare Part Costs (Third Part of "SPARES" DSW)

The deployment plan requires completion of UAV units in three years. After the initiation of UAV systems with appropriate spare stock levels we do not need to allocate money for these spare parts again. Along the life-cycle of the system, repair and replacement costs are encountered instead of spare part costs after the third year. In Table 3.5, $4^{th,}$ 19^{th}, and 20^{th} year cost values are used in repair and replacement cost calculation. We will explain this sub cost category in the next section.

The spare part cost is one of the seven sub cost categories of operational and maintenance costs of the UAV system. We placed a formula in "LCC" DSW which takes the result of the spare part cost calculations from "SPARES" DSW. The spare part cost formula in the "LCC" DSW for the first year (B35) is below.

B34=SPARES!D78

g. *Repair and Replacement Cost*

In the problem definition, we contended that the I-level maintenance center can repair 60% of the failures with a TAT of seven days, and 40% of them is sent to the United States for D-level maintenance with a TAT of 75 days. The spare part quantity determination is based on the average TAT of the UAV system components (Look B.3.f.(2).(a)). In that time interval, due to encountered failures, these spare parts are repaired or replaced with new ones. We need to calculate how many times those spare parts are processed.

Average TAT = 0.6*7+0.4*75 = 34.2 days

Average Number of Repairs/year = 365/34.2 = 10.673

NumberofRepairs=365/(IlevelRR*IlevelTAT+DlevelRR*DlevelTAT)

To maintain the operational availability, we should allocate enough resources to the repair and replacement of the UAV system components. In the problem definition, we stated that the average repair and replacement process costs 80% of a new spare part. We already calculated the spare part quantities (Table 3.4) and related spare part costs for the first three years (Table 3.5). As a result, we can use spare part costs in the calculation of repair and replacement cost. The formula we used for the repair and replacement cost in the first year (B36) is presented below. This formula is used for the first 18 years.

B35=IF(DEPLOYMENT!B7>=DEPLOYMENT!C7,SPARES!$G$79*

NumberofRepairs*((1+UAVsystem)^(B19)),

SPARES!D79*NumberofRepairs)

We need to clarify the above formula. The cell SPARES!$G$79 (4^{th} year's total in Table 3.5) is calculated by adding the total spare part cost for each component for a fully deployed UAV systems without inflation effect (Look "NOT" in Table 3.5). The above formula first tests whether the deployment of the UAV systems continue or not from the "DEPLOYMENT" RW. If there is a new deployment (first three years) then it takes directly 80% of total spare part cost which is calculated with appropriate inflation rate. On the other hand if there is no new deployment then the formula takes 80% of total spare part cost (denoted by SPARES!$G$79) and the result is multiplied with appropriate inflation rate. This formula uses SPARES!$G$79 value after the third year in repair and replacement cost calculation.

Since the deployment plan requires the disposal of UAV systems, we need to use different formulas for the 19^{th} and 20^{th} year. We use the first and second year's total spare part costs without inflation for the 19^{th} and 20^{th} year's repair and replacement cost, respectively, since the quantities of UAV systems in operation match with these years. Below are the formulas for repair and replacement cost in the 19^{th} and 20^{th} year.

T35=SPARES!H$79*NumberofRepairs*((1+UAVsystem)^(T19))

U35=SPARES!I$79*NumberofRepairs*((1+UAVsystem)^(U19))

4. Training Costs

Training cost is another major cost category in our cost breakdown structure for UAV project. Personnel training must be planned very carefully to supply necessary expertise for the system on a timely manner. We first identify the training requirements then calculate associated training costs.

In the problem definition we stated a detailed training requirement for each position. Based on this definition, we divide the UAV personnel training into two; operator training and maintenance training. The operator training is received by the UAV flight team; UAV pilot (officer), payload operator (officer), and mission commander (officer). Every UAV unit has three UAV flight teams. The UAV unit commander also attends the operator training as a mission commander. Operator training consists of three different types of training with different requirements and durations (Table 3.6).

The maintenance training provides O-level and I-level maintenance training. The O-level maintenance training is given to mechanical technicians (NCO) and electronic technicians (NCO). There are three mechanical technicians and three electronic technicians in support of three UAV flight teams in one UAV unit. The O-level maintenance training consists of three different types of training with different requirements and durations (Table 3.6).

The I-level maintenance training is received by one maintenance supervisor (officer) and four electronic technicians (NCO) per operational base. Their training differentiates from the O-level due to higher level expertise requirements. We organize all of these data in "DATA" RW. Table 3.6 demonstrates that structure.

	A	B	C	D
28	**TRAINING (3 UAV Mission Goups/UAV System)**	For Each UAV System		Duration
29	**Operator Training**	Officer	NCO	(Weeks)
30	Basic Operator Course	10		3
31	Advance Operator Course	10		5
32	Operation Mission Team Training	10		2
33	**Total Operator Training**	**10**		**10**
34				
35	**Maintenance Training**			
36	**O-level**			
37	Basic Maintenance Course		6	2
38	Advance Maintenance Course		6	6
39	Operation Mission Team Training		6	2
40	**Total O-level Maintenance**		**6**	**10**
41				
42		For Each Operational Base		Duration
43	**I-level**	Officer	NCO	(Weeks)
44	Basic Maintenance Course		4	2
45	Advance Electronic Maintenance Course	1	4	10
46	Maintenance and Support Planning, Reporing	1		2
47	**Total O-level Maintenance**	**1**	**4**	**12**

TABLE 3.6 UAV System Training Structure (From "DATA" RW)

After the identification of training requirements, we can calculate the associated training costs. We use the same diversification of training types in the cost calculation. Each training cost has two categories; personnel costs and overhead costs. Personnel costs are computed for each separate course by allocating personnel salary associated with the duration of the training. The formula for the computation of the basic operator course cost in the first year (B41) in "LCC" DSW is below.

B41=DATA!$B$30*(DATA!$D$30/52)*Officer*$B$16*((1+Salary)^B$39)

The above formula multiplies the personnel number which attend to basic operator course for all the UAV system in operation (DATA!$B$30*$B$16 where $B$16=DEPLOYMENT!B7) with the salary associated with the duration of the training (DATA!$D$30/52*Officer) and appropriate inflation rate ((1+Salary)^B$39). We use the same logic for other personnel costs in each training.

The second training cost category is the overhead costs. This cost category includes instructors' salaries, training material, and travel costs. We assume that operator training overhead costs and maintenance training overhead costs are $100,000 and $140,000 per year respectively (Table 2.4). We calculate the operator training overhead cost by multiplying the duration of the training with operator training cost and the appropriate inflation rate. The formula for the computation of operator training overhead cost in the first year (B44) is below.

B44=(DATA!$D$33/52)*OprTrOH*((1+UAVsystem)^B$39)

In the problem definition, we assume that 50% of the assigned personnel will be rotated every three years. The assigned personnel will be trained in their assignment year to the UAV unit and plans will be developed to finish the training by June every year. In that scenario, one out of two UAV pilots joins the UAV unit in the first year will be assigned to another job in the fourth year. The UAV system training program will continue as a rotation in every fourth year, since second year attendees will be assigned to another job on fifth year, third year attendees will be assigned to another job on sixth year and so on. The formula for the computation of the basic operator course cost in the fourth year (E41) in "LCC" DSW is below. We did not allocate any resource for training in the 19^{th} and 20^{th} years since we reduce the number of UAV systems in the field.

E41=(DATA!$B$30*Rotation)*(DATA!$D$30/52)*Officer*$B$16*((1+Salary)^E$39)

5. Manning Costs

Life-cycle cost determination should include manning costs as a major cost category. Just as the other resources, human resources are scarce. We need to consider the opportunity cost of assigning the personnel in a particular position. Although personnel will be paid the same salary independent of the assignment, we need to find ways to make more efficient use of the human resources in the military. This objective can be achieved by allocating the appropriate manning cost to the programs.

In the model, we divide the manning costs into four by their functions in the UAV system. These are flight team, maintenance team, headquarter, and I-level maintenance center. From the problem definition we find the personnel number for each operational base and for each UAV systems (Table 3.7). After that we find the total personnel number for each year and multiply them with the associated salaries to calculate manning costs in each year. The formulas we used in the calculation of manning costs in "LCC" DSW for the first year are depicted below.

B67=B$16*DATA!$D$53*Officer*((1+Salary)^(B$66)) (Flight Team)

B68=B$16*DATA!$E$54*NCO*((1+Salary)^(B$66)) (Maintenance Team)

B69=B$16*(DATA!$D$55*Officer+DATA!$E$55*NCO)*

((1+Salary)^(B$66)) (UAV Unit Headquarter)

B70=B$17*(DATA!$B$56*Officer+DATA!$C$56*NCO)*

((1+Salary)^(B$66)) (I-Level Maintenance Center)

	A	B	C	D	E
51		For Each Operational Base		For Each UAV System	
52	**Manning:**	Officer	NCO	Officer	NCO
53	UAV Unit Flight Team	18	----	9	----
54	UAV Unit Maintainance Team	----	12	----	6
55	UAV Unit Headquarter	2	2	1	1
56	I-Level Maintainance Center	1	4	----	----

TABLE 3.7 UAV System Personnel Numbers (From "DATA" RW)

6. Disposal Costs

The last major cost category in the life cycle cost calculation of any system should be the disposal costs. We need to allocate enough resources for recycling or disposing hazardous materials without causing any degradation to the environment. The increasing concerns for the environment, political interest, and publicity of environmental issues force military programs to allocate resources for material recycling and disposal.

The deployment plan requires the UAV system reduction in the last three years of the life-cycle (Table 2.1). Since the disposal cost per UAV system is determined as $350,000 in the problem definition (Table 2.4), the calculation of the disposal cost is straightforward. The disposal cost formula in "LCC" DSW for the 18th year is below. Note that we do not allocate any resource until the 18th year and we add appropriate inflation rate to get a more realistic value.

S75=IF(C16<B16,(B16-C16)*Disposal*((1+UAVsystem)^(B19)),0)

7. Total Costs

We explained how we calculate the costs for each of six major cost categories above. To reach the total annual costs we simply add individual major cost categories for each year. These values are calculated with different inflation rates for different products or services. We should discount them into present values to understand the costs associated with each year of the UAV project life cycle. In the problem definition we assume that the discount rate is 2.4%. We use this rate for the calculation of discounted total annual costs. Below are the formulas we used for the total annual costs and discounted total annual costs for the first year (B84&B85).

B84 =SUM(B79:B83)

B85 =B84*(1/((1+DiscountRate)^(B77-1)))

The total life-cycle cost for the UAV system is calculated just by adding all of the total annual costs in the life cycle of the system. To find the present value of total life cycle cost, we add all of the discounted total annual costs. Table 3.8 shows the total costs for the UAV program.

76	A	B	C	D	E	F
77	**Year**	1	2	3	4	5
78	**TOTAL COSTS**					
79	Investment Costs	$45,299,100	$52,797,964	$75,331,762	$27,143,255	$11,508,740
80	Operation&Maintenance Costs	$227,218,726	$355,113,580	$625,761,840	$641,184,930	$679,650,463
81	Training Costs	$194,647	$202,981	$251,138	$159,963	$167,734
82	Manning Costs	$577,830	$1,150,016	$1,835,781	$1,890,855	$1,947,580
83	Disposal Costs	$0	$0	$0	$0	$0
84	Total Annual Costs	$273,290,302	$409,264,541	$703,180,521	$670,379,002	$693,274,517
85	Discounted total Annual Costs	$273,290,302	$399,672,403	$670,605,203	$624,339,098	$630,529,500
86	**NOTE:** Discount rate is 2.4%.					
87	TOTAL LIFE CYCLE COST:	$18,419,097,750				
88	PV OF TOTAL LIFE CYCLE COST:	$14,304,928,740				

TABLE 3.8 UAV Program Total Costs for the First Five Years ("LIFE-CYCLE COST" DSW)

C. SIMULATION OF THE UAV MODEL

There are some uncertainties in the problem definition. One of them is the contingency risk that Turkey encounters in its unstable region. We already addressed this issue in the calculation of subsequent procurement cost of the UAV systems (B.2.b). The model takes into account this uncertainty in its life-cycle cost calculation. The other uncertainty is the magnitude of operational availability of the UAV system. Just as changing threat in the region, varying operational availability of the UAV system requires different resource allocation for the UAV program. In this section, we will calculate life-cycle cost of the UAV program for changing operational availability. At the end of this section, we will be able to give life-cycle cost limits of the UAV program which can be encountered due to changing risk and operational availability of the systems. First we will explain operational availability determination of the UAV system. Then we will simulate the model by using Crystal Ball software and Monte Carlo simulation for changing operational availability.

1. Operational Availability "A_o" Decision Support Worksheet

In the second step of spare part cost calculation, the transformation of composite factor to the number of spare part, we calculated spare UAV antenna system quantity. In that spare part quantity determination even though the model returns two (2), we took three (3) spare UAV antenna systems for 0.90 operational availability. We also noticed that this increase provides us a certainty that we can reach at least 0.90 operational availability for the first year of the UAV antenna system. (B.3.f.(2).(b)).

In that calculation we take three (3) spares for the first year, because to divide the spare part quantity into decimal values is not a realistic approach (i.e. a fraction of UAV antenna systems can not be procured for the sake of achieving exactly the desired operational availability). However, it is also unrealistic to state that we achieve 0.90 operational availability with three (3) spare UAV antenna system (actually this stock level provides 0.9498 operational availability (Table 3.3)). In this case, we need to take into consideration the actual operational availability achieved with three (3) spare UAV antenna systems in our calculations. This determination is very critical, since we will pay an incentive fee to the contractor based on achieved operational availability. We need to find out exactly how much operational availability can be achieved with this spare part level. We will explain incentive fee determination with operational availability in Chapter V.

We create "A_o" decision support worksheet to calculate the achieved operational availability with different levels of spare parts for the components. Before explaining the "A_o" DSW, we first describe the operational availability structure of UAV system. As we stated in the problem definition, there are four UAVs, four payloads, one GDT, and one GCS in a UAV system. For any operational mission, we use only one UAV and one payload in addition to GDT and GCS at a time. Besides, the Army Command requires a UAV system to operate satisfactorily with at least 0.85 operational availability when used in an operational environment. This objective can be satisfied with one UAV, one payload, one GDT and one GCS subsystems working properly (Figure 3.2.(a) and (b)). That also requires proper working of all the components of each subsystem (Figure 3.2.(c)). The operational availability structure of UAV system is shown in Figure 3.2.

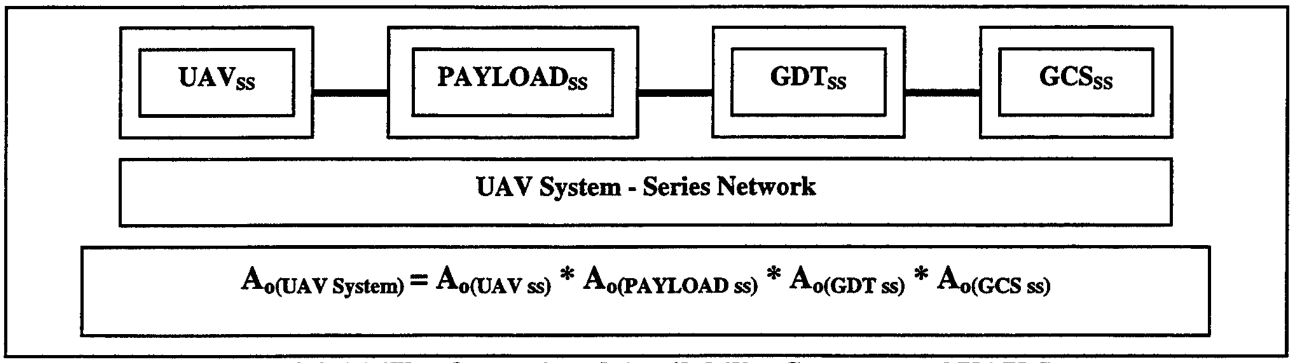


FIGURE 3.2.(a) The Operational Availability Structure of UAV System

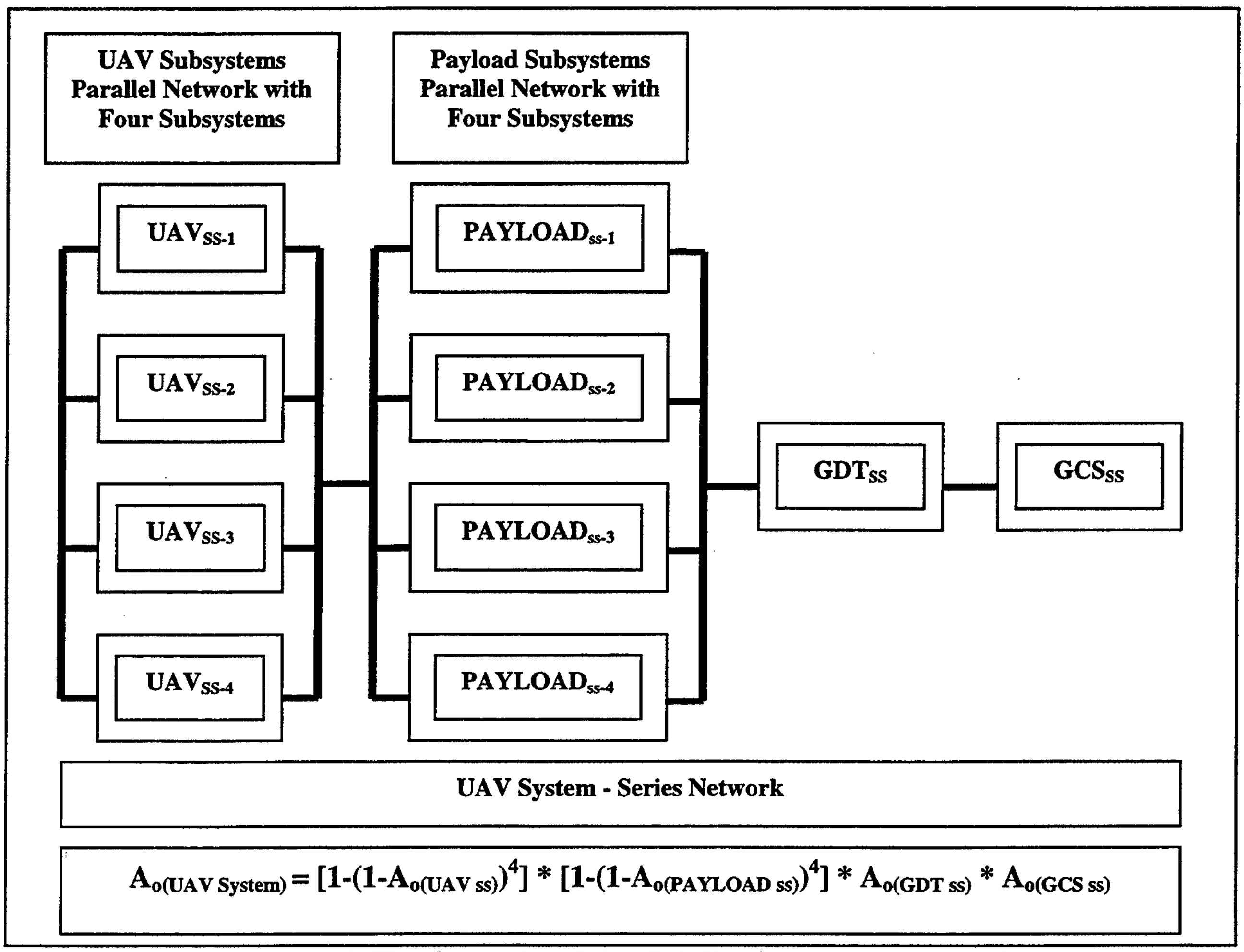
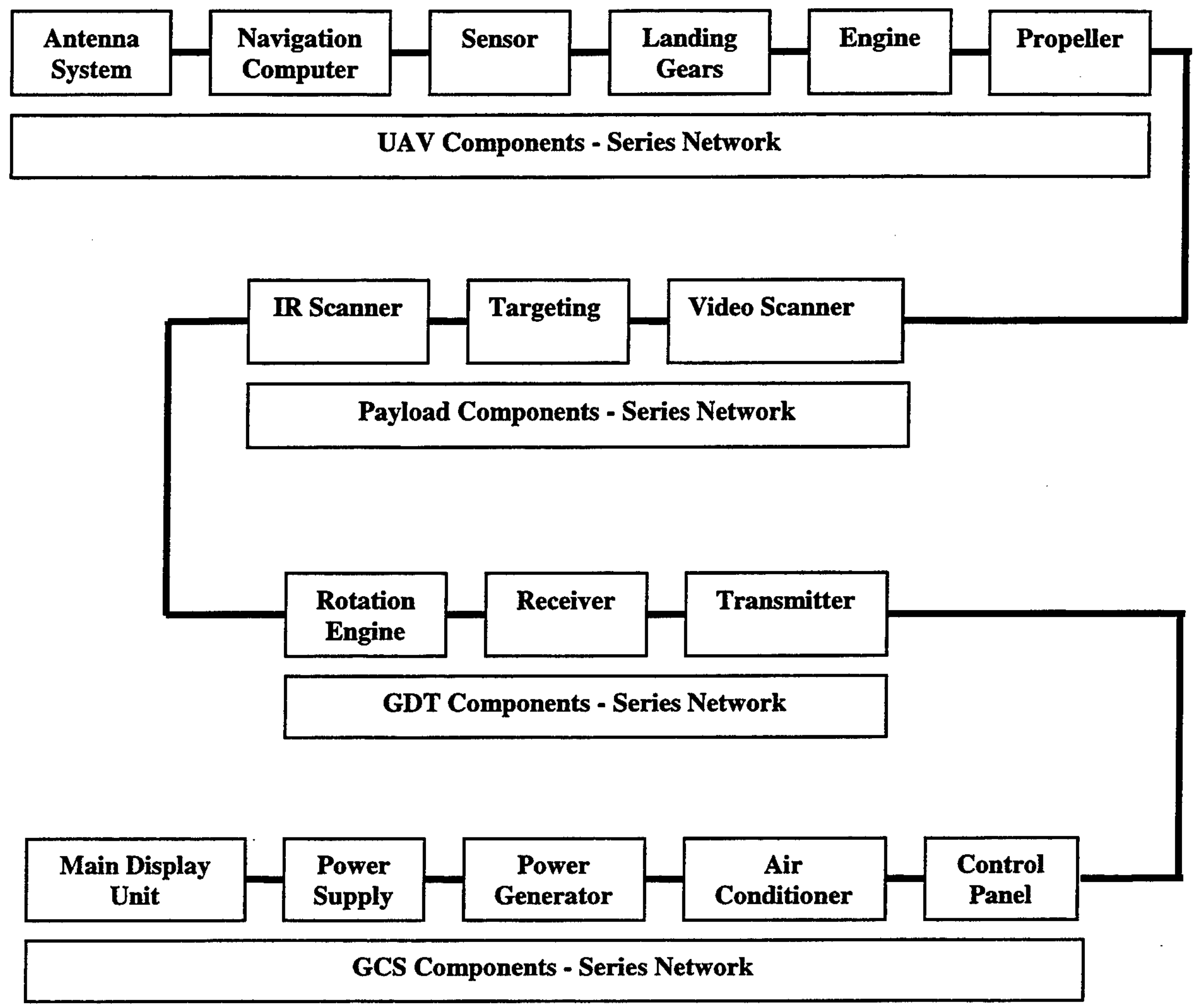


FIGURE 3.2.(b) The Operational Availability Structure of UAV System



$$A_{o(\text{UAV System})} = [1-(1-(A_{o(\text{UAV comp})})^6)^4]*[1-(1-(A_{o(\text{PAYLOAD comp})})^3)^4]*(A_{o(\text{GDT comp})})^3*(A_{o(\text{GCS comp})})^5$$

Assumption for planning purposes: Each component in a subsystem has the same operational availability.

FIGURE 3.2.(c) The Operational Availability Structure of UAV System

We employ this structure into our model in the "A_o" DSW. There are three parts in the "A_o" DSW. First part calculates the desired operational availability of the UAV system with an assumption that each component in a subsytem has the same operational availability for planning purposes. Table 3.9 shows the first part of "A_o" DSW. Note that the values represent the desired operational availability of components. We use target values in the construction of the model. The UAV system operational availability is calculated by using the structure we employ in Figure 3.2. We multiply the operational availability with 365 days to get how many days the UAV system operationally available under this scenario according to our plans. We use ROUND function to get an integer value. The formula used in Table 3.9 are below.

C3 =DATA!B$26

C7 =(1-(1-(C3^$F$3))^4)*(1-(1-(C4^$F$4))^4)*(C5^$F$5)*(C6^$F$6)

C9 =ROUND(365*C7,0)

	A	B	C	D	E	F	G	H
1	Operational Availability of the UAV System (Desired)							
2			MIN	TARGET	MAX	Number of Component		
3	1	UAV	0.85	0.9	0.95	6		
4	2	Payload	0.85	0.9	0.95	3		
5	3	GCS	0.95	0.97	0.99	5		
6	4	GDT	0.95	0.97	0.99	3		
7		UAV System	0.551081	0.741943	0.91782			
8								
9		Ao (day/year)	201	271	335			

TABLE 3.9 Desired Operational Availability of UAV System (First Part of "A_o" DSW)

The second part of the "A_o" DSW is created for obtaining the achieved operational availability of the components with provided spare part quantities for each of them. Since we explain the logic behind the VLOOKUP function, we just write down the formula we use for the achieved operational availability of UAV antenna system in the first year. Table 3.10 shows the second part of the "A_o" DSW.

J5=VLOOKUP(SPARES!$D$36,POISSON!$A$3:$B$23,2)

	I	J	K	L
4	**UAV**	**1**	**2**	**3**
5	Antenna System	0.949817	0.940331	0.908390
6	Navigation Computer	0.942431	0.925668	0.935828
7	Sensors (Probe Tube, Tempr.)	0.925193	0.912921	0.907035
8	Landing Gears	0.940331	0.947662	0.919942
9	Engine	0.922837	0.925193	0.927903
10	Propeller	0.978218	0.968561	0.951377
11	**PAYLOAD**			
12	IR Scanner	0.908390	0.919942	0.908387
13	Targeting	0.953495	0.923088	0.906031
14	Video Scanner	0.949540	0.915349	0.940331
15	**GCS**			
16	Main Display Unit	0.993714	0.984261	0.988550
17	Power Supply	0.985686	0.994090	0.977033
18	Power Generator	0.981617	0.991504	0.994689
19	Air Conditioner	0.993383	0.975532	0.992127
20	Control Panel	0.984261	0.972502	0.975225
21	**GDT**			
22	Rotation Engine	0.990814	0.989089	0.985419
23	Receiver	0.986652	0.989739	0.988257
24	Transmitter	0.973893	0.974619	0.986658

TABLE 3.10 Achieved Operational Availability of Components (Second Part of "A_o" DSW)

The third part of the " A_o" DSW is constructed to calculate the achieved operational availability of the UAV system. In reality, each component provides different operational availability (Table 3.10). Although we use the same structure employed in Figure 3.2, this time we need to calculate the subsystem achieved operational availability. In the desired operational availability calculation (Table 3.9), we skip this step as we assume they provide the same operational availability. Out of that the structure of the calculation is similar. Table 3.11 shows the achieved operational availability of the UAV system for the first three years. Note that although we calculate spare part quantity based on our desired operational availability, the achieved operational availability is higher than the desired one (A_o(desired) = 271 days vs. A_o(achieved)=316 - 324 days).

12	A	B	C	D	E	F	G	H
13	Operational Availability of the UAV System (Achieved)							
14		Year	1	2	3	Number of Component		
15	1	UAV comp	0.992221	0.988817	0.980475	6		
16	2	Payload comp	0.999006	0.99754	0.997387	3		
17	3	GCS comp	0.940089	0.92037	0.929538	5		
18	4	GDT comp	0.952067	0.954093	0.960854	3		
19		UAV System	0.887183	0.866163	0.873424			
20								
21		Ao (day/year)	324	316	319			

TABLE 3.11 Achieved Operational Availability of UAV System (Third Part of "A_o" DSW)

2. Simulation of the UAV Model

Before explaining which tools we use in the construction of the UAV model for simulation, we now discuss briefly why we employ a simulation in our model. Our objective is to get a realistic life-cycle cost for the UAV program. In an uncertain situation, it is better to get a range of outcomes then getting one unanimous outcome. We can make more accurate, efficient and confident decisions if we can get a range of possible outcomes for different situations. Crystal Ball software enhances this capacity.

We use Crystal Ball for its two unique characteristics. First, by using Crystal Ball we can describe the range of possible values for each uncertainty represented with a cell in the spreadsheet. Everything we know about assumptions is expressed at once. This gives a capability to realistically determine the amount of risk that impacts our bottom line. Second, Crystal Ball displays results in a forecast chart, which shows the entire range of possible outcomes and the likelihood of achieving each of them by using Monte Carlo Simulation. In essence, Crystal Ball provides a statistical picture of the range of possibilities inherent in our assumptions. [Ref. 8:p. 9]

In the construction of the UAV model, we use two tools for simulation; *define assumption* and *define forecast.* For the representation of uncertainty of the data we define assumption by choosing or customizing a probability distribution. We explained how we define assumption for contingency in the calculation of subsequent procurement cost of UAV systems (B.2.b). We are not going to repeat the same technical explanations in this section. In the UAV model we also define assumptions for operational availability of the critical components and secondary components. Table 3.12 shows operational availability values for different components of UAV system.

	A	B	C	D
24		Minimum	Target	Maximum
25	Operational Availability of Critical Components	95.0%	97.0%	99.0%
26	Operational Availability of Secondary Components	85.0%	90.0%	95.0%

TABLE 3.12 Operational Availability Requirement of Turkish Army Command ("DATA" RW)

We define assumptions for each component of the UAV systems. We employ uniform distribution as there is no specific information about the type of probability distribution. As we contended in the problem definition, GCS and GDT failures cause a total loss of operational capability until repaired as there are only one GCS and one GDT in a UAV system. Nevertheless, UAV and payload failures cause degradation in operational capability since there are four from each of them in a UAV system. Figures 3.3 and 3.4 demonstrate the operational availability assumption for the UAV antenna system and the GCS main display unit, respectively. We use the same assumption in the UAV antenna system for all component of UAV and payload subsystems. Similarly, the

GCS main display unit operational availability assumption is used for all components of GCS and GDT.

SPARES - Cell: H14

Assumption: Operational Availability (UAV Antenna System)

Uniform distribution with parameters:

Minimum	0.85
Maximum	0.95

Mean value in simulation was 0.90

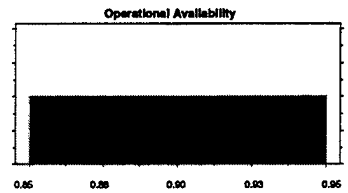


FIGURE 3.3 Operational Availability Assumption of UAV Antenna System

SPARES - Cell: H25

Assumption: Operational Availability (GCS Main Dispaly Unit)

Uniform distribution with parameters:

Minimum	0.95
Maximum	0.99

Mean value in simulation was 0.97

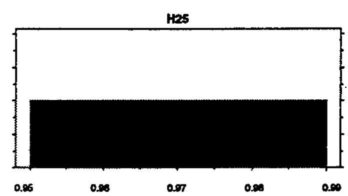


FIGURE 3.4 Operational Availability Assumption of GCS Main Display Unit

The second tool we use for simulation is *define forecast* function of Crystal Ball. The command, *define forecast*, identifies the cell we want to forecast. Our purpose is to find how those uncertainties affect the UAV system life-cycle cost. At the same time we need to know the achieved operational availability range which we calculate in "A_o" DSW (Table 3.11). In Crystal Ball, before we use define forecast function, we need to be sure that forecast cells contain the formulas that refer to one or more assumption cells. To define a forecast one needs to choose the appropriate cell then choose *Define Forecast* from the *Cell* menu.

We run the simulation for 10,000 iterations and collect data for forecast cells. The results derived from simulation are below (Figure 3.5 - Figure 3.11). We also calculate the total LCC (undiscounted) and present value of LCC (discounted) for various operational availability values from the simulation results. Table 3.13 demonstrates these results.

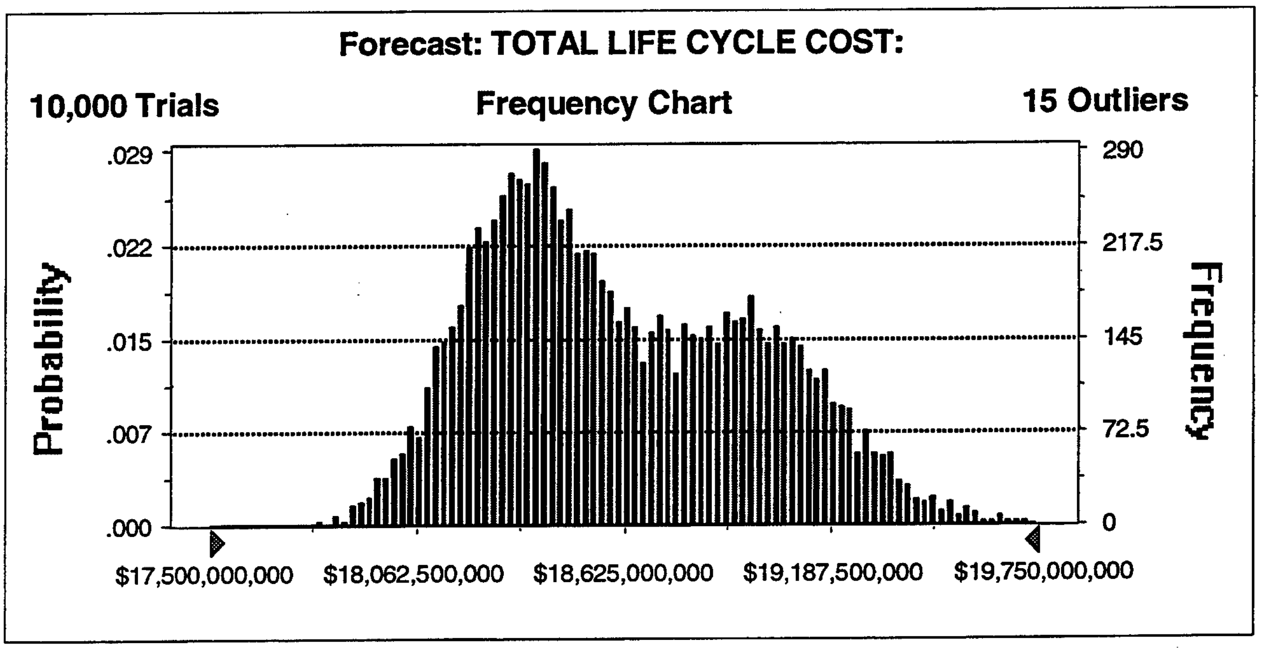


FIGURE 3.5 Simulation Results for UAV Program Total Life Cycle Cost (Undiscounted) (Range: $17,722,086,842 - $20,047,249,995)

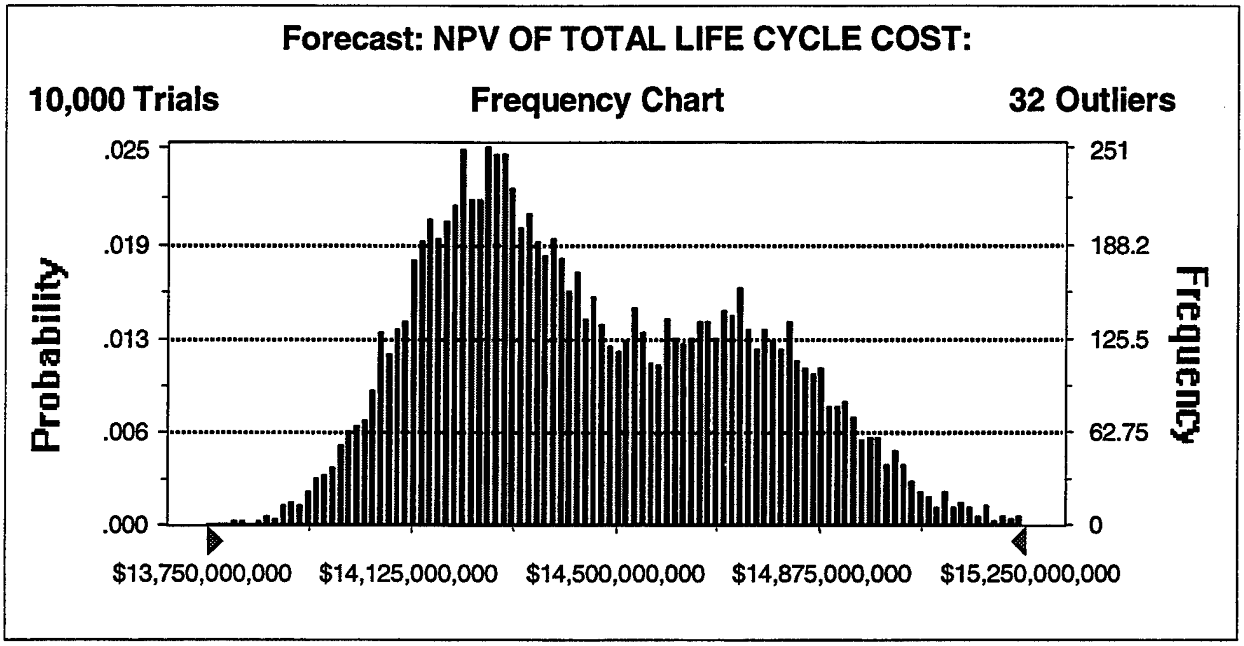


FIGURE 3.6 Simulation Results for Net Present Value of UAV Program Total Life Cycle Cost (Discounted) (Range: $13,762,086,988 - 15,566,508,368)

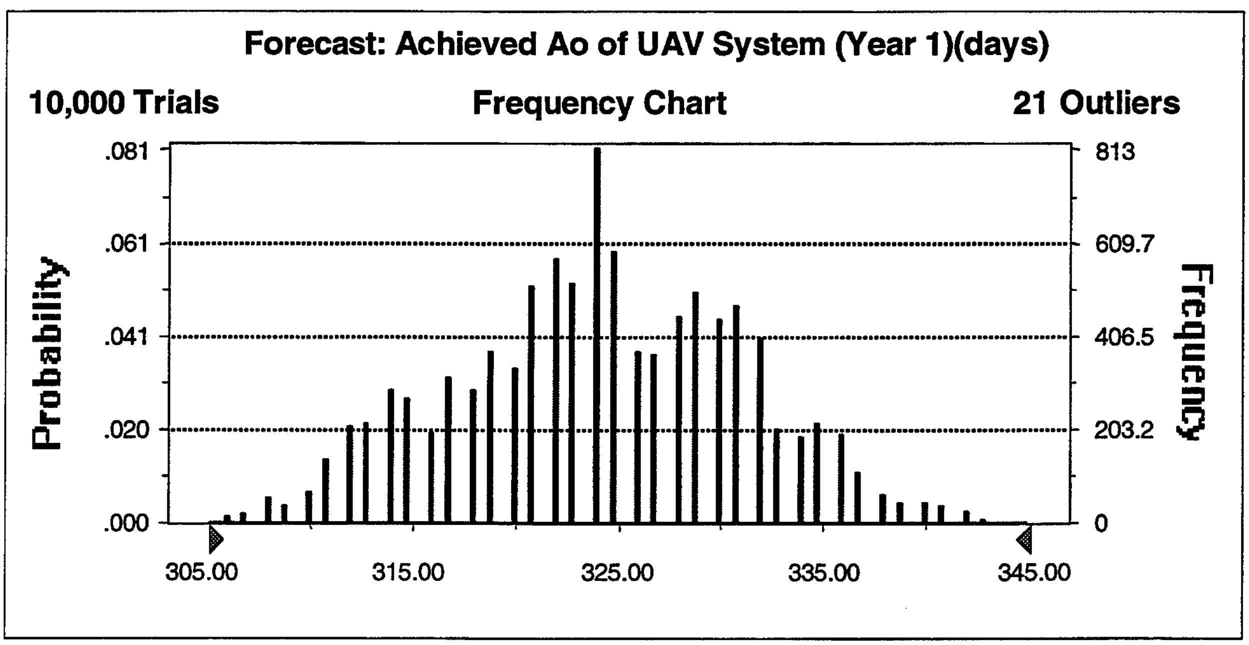


FIGURE 3.7 Simulation Results for Achieved Operational Availability of UAV System in Year 1 (Range: 297 days - 346 days)

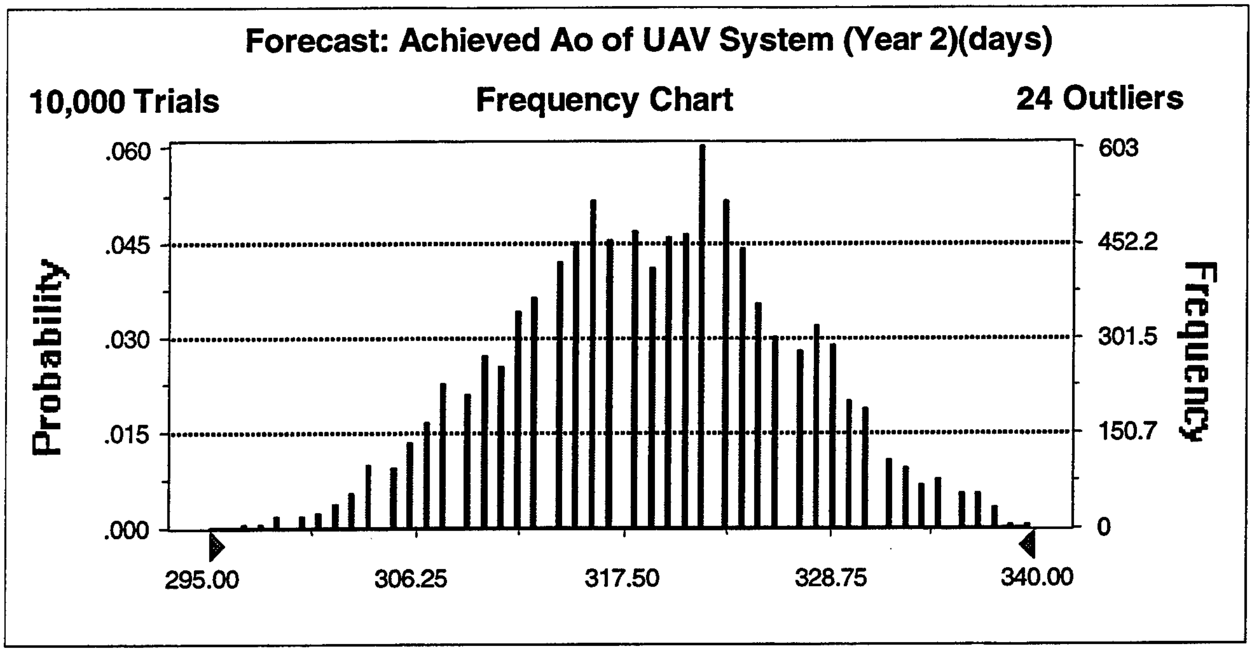


FIGURE 3.8 Simulation Results for Achieved Operational Availability of UAV System in Year 2 (Range: 290 days - 342 days)

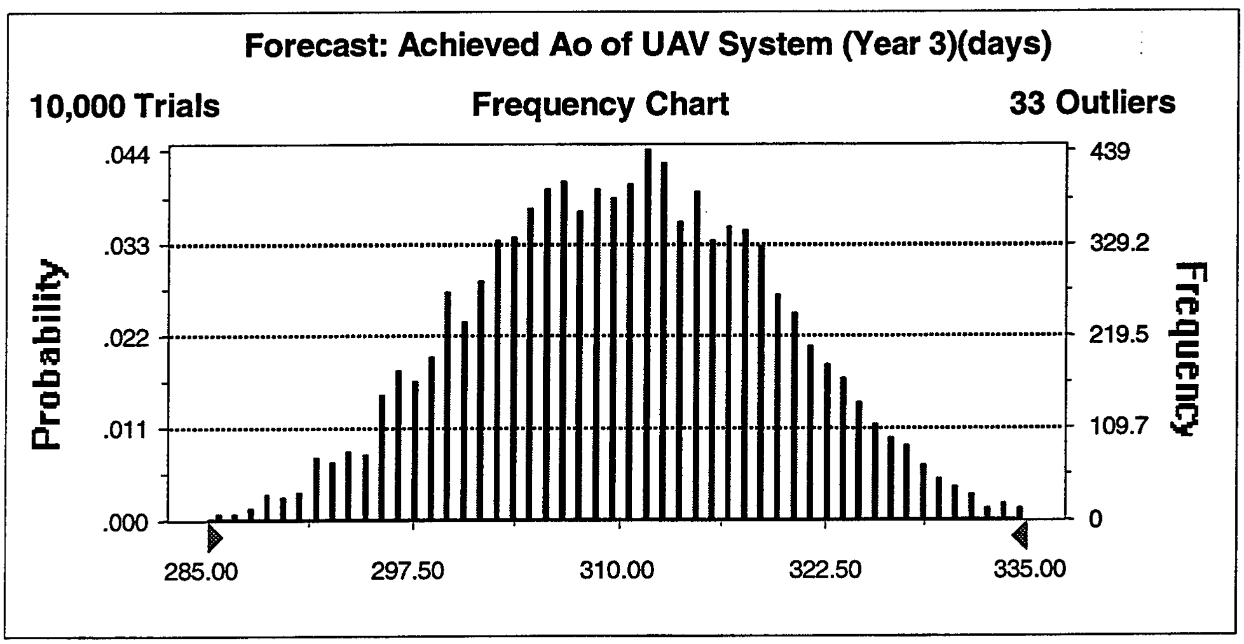


FIGURE 3.9 Simulation Results for Achieved Operational Availability of UAV System in Year 3 (Range: 279 days - 341 days)

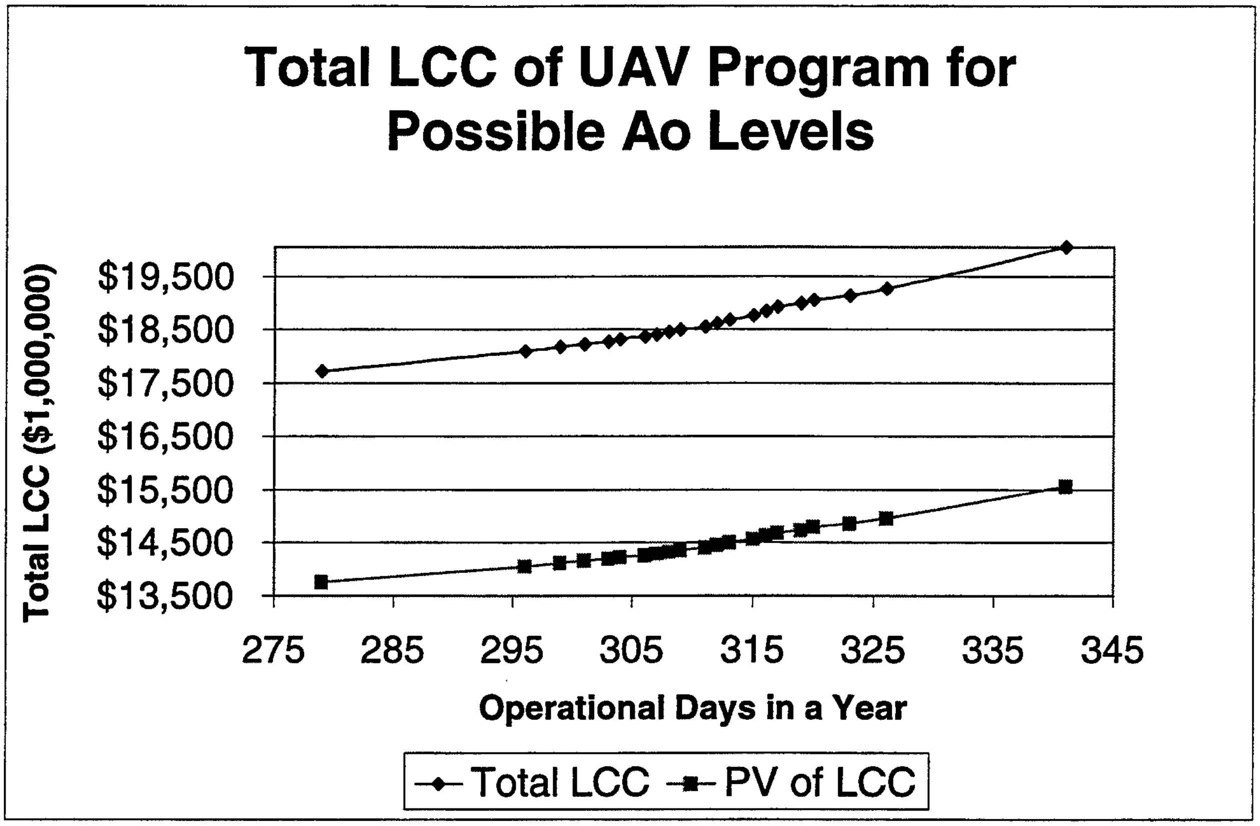


FIGURE 3.10 Simulation Results for Total Life Cycle Cost of UAV Program for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Total LCC	PV of Total LCC
0%	279	$17,722,086,842	$13,762,086,988
5%	296	$18,103,604,047	$14,059,663,703
10%	299	$18,182,664,564	$14,119,211,234
15%	301	$18,236,679,914	$14,161,611,560
20%	303	$18,285,370,002	$14,199,247,459
25%	304	$18,327,399,452	$14,232,489,157
30%	306	$18,372,730,233	$14,266,983,314
35%	307	$18,410,968,919	$14,296,420,435
40%	308	$18,453,265,020	$14,329,251,485
45%	309	$18,501,476,643	$14,367,338,003
50%	311	$18,555,036,469	$14,407,723,709
55%	312	$18,617,470,797	$14,456,552,500
60%	313	$18,692,420,796	$14,514,031,572
65%	315	$18,767,080,476	$14,572,335,794
70%	316	$18,846,914,001	$14,633,513,310
75%	317	$18,920,713,085	$14,690,472,240
80%	319	$18,986,310,096	$14,741,769,373
85%	320	$19,063,561,256	$14,801,845,851
90%	323	$19,147,280,066	$14,865,816,396
95%	326	$19,264,688,128	$14,955,938,993
100%	341	$20,047,249,995	$15,566,508,368

TABLE 3.13 Simulation Results for Total Life Cycle Cost of UAV Program for Possible Operational Availability Levels

The simulation results demonstrate that under the given scenario, we might expect a total life-cycle cost of $17,722,086,842 to $20,047,249,995 for UAV program. This is the amount of money the Turkish Army Command needs to allocate to acquire 10 UAV systems and to achieve desired performance level with these systems during the 20-year life cycle. The present value of total life-cycle cost might vary between $13,762,086,988 to $15,566,508,369. This amount of resource allocation gives us 279 days to 341 days operationally available UAV systems. The most probable outcomes of simulation are $18,623,292,236 total life-cycle cost and 310 days/year operational availability.

With that simulation, we can determine the total life-cycle cost of the UAV program with changing number of days in which UAV system can actually execute operational mission in a year. In the introduction of this chapter we addressed two of the most important reasons for the inefficiencies in the test UAV system. In this chapter, we address the first reason, deficiencies in the life-cycle cost considerations of the UAV program. The UAV model and applied simulation present how much resource the Turkish Army should allocate for UAV program to achieve a certain operational availability.

The second important reason for inefficiency emphasized in the introduction of this chapter, which is absence of incentivizing tools for the contractor to supply the UAV system with better products, will be addressed in the subsequent chapters. In Chapter IV, we will explain the incentive concept in Fixed-Price Incentive (FPI) type contracts and discuss performance incentives. In Chapter V, we will build another model to determine the incentive fee amount for various levels of operational availability.

IV. FIXED-PRICE INCENTIVE CONTRACT

A. INTRODUCTION

In Chapter III, we pointed out two of the most important reasons for inefficiency of UAV systems: (1) Failure to address life cycle cost considerations during financial resource allocations and (2) the absence of incentives for the contractor to build a more reliable system. We addressed the first issue by building a UAV model, which incorporates life-cycle considerations. The second issue of system reliability will be addressed in Chapter V.

In Chapter III, we discussed the option of giving the contractor logistic support responsibility of the UAV system for a limited time and incentivize them to reach a certain level of operational availability with a Fixed-Price Incentive (FPI) type contract. Before the discussion on how we can incentivize the contractor to provide UAV system with better reliability, we will give some background information in this chapter. First, we will give a brief explanation of Fixed-Price Incentive (FPI) type contracts. Then we will discuss some of the issues associated with performance incentives.

B. FIXED PRICE INCENTIVE TYPE CONTRACT

Successful acquisition managers recognize that the type of contract and associated pricing arrangements can influence contract performance. The type of contract is the method for compensating the contractor for the goods and/or services acquired. Using appropriate type of contract is very important since the type of contract should reflect the degree of risk to both the government and the contractor. The primary objective should be to make use of the type of contract that includes reasonable contractor risk and provides the contractor with the greatest incentive for efficient and economical performance. Although, there are a range of different types of contracts, the Cost-Reimbursement type and the Fixed-Price type are two basic types of contracts. (Ref. 14:p. 73)

For contracts with relatively high uncertainty as to the cost, performance, and schedule of completing the contracts, Cost-Reimbursement is best suited. In that type of contract, the government agrees to pay the contractor all allowable and allocable costs incurred on the contract. On the other hand, the contractor guarantees best efforts to meet the terms and conditions of the contract. Since the government agrees to pay for all allowable and allocable costs, the government bears the burden of risk. (Ref. 15:pp. 1-11) In this arrangement the government pays basically for "best effort" of the contractor regardless of the end result of that effort.

For contracts with high certainty as to the cost, performance, and schedule of completing the contracts, Fixed-Price arrangements are best suited. In these types of contracts, the contractor agrees to deliver the goods and/or services on time according to the terms and conditions of the contract regardless of the actual costs. Since the contractor agrees to deliver the goods and/or services according to the terms and conditions of the contract, the contractor bears the burden of risk. (Ref. 15:pp. 1-11) In this arrangement the government pays basically for the "end result" regardless of the complexity of the process or unpredictability of the situation for the contractor.

As discussed above, contract type selection is influenced by the core issues of cost, schedule, performance risks and probabilities. In reality it is not easy to identify the risk areas as certain or uncertain in a clear-cut way. Because of that, within these two basic categories, there is a family of contracts, which differs according to how the risk for costs of performance is shared. "*The contract type determines how cost risk is passed to the contractor. In a move from cost-reimbursement toward fixed-price contracts, the contractor assumes most of the cost risk.*" (Ref. 16:p. 5-7)

A certain degree of cost uncertainty is expected in incentive contracting. When a firm-fixed-price contract is not appropriate and the required goods and services can be acquired at lower costs and in certain instances, with improved delivery or technical performance by connecting the amount of profit or fee payable under the contract to the contractor's performance, incentive contracts are appropriate. (Ref. 17)

There are two basic categories of incentive contracts; fixed-price incentive contracts and cost-reimbursement incentive contracts. Because the contractor assumes substantial cost responsibility and an appropriate share of the cost risk, fixed price incentives are more preferable from the government's point of view whenever contract costs and performance requirements are reasonably certain. (Ref. 17)

In an incentive contract the objective is to motivate the contractor to earn more compensation by achieving better performance and by controlling costs. (Ref. 18:p. 254) Incentive contracting is based on the profit motive of the contractor. The implied assumption in incentive contracting is that the contractor will have more motivation in performing the contract, as it perceives a chance to increase the profits. Because of that, the objective is to motivate the contractor to earn more profit with an incentive contract. The contractor gains more by achieving better performance and controlling contract costs. The ultimate results are in the best interest of both the government and the contractor. The contractor's profit is adjusted by comparing the achieved performance goals set in the contract. After this assessment, the contractor's profit adjustments may be positive (i.e., reward), negative (i.e., penalty) or a combination of the two (Ref. 14:p. 84,85)

Although there are different types of incentive contracts, some arrangements are common in all of them. There are three elements in a simplified incentive contract

1. Target cost,
2. Target profit or fee,
3. The buyer/seller sharing arrangement.

Target cost is the most likely cost outcome for the effort involved according to the judgment of both the government and the contractor. The target cost should be based on the most likely outcome under normal conditions. The cost point where both parties agree that there is an equal chance of going above or below should be the target cost. Other than the target cost, there must be a target profit. *Target profit* is the profit amount which is considered fair and reasonable, based on all reward facts. Finally, the *sharing arrangement* is a method which reflects the sharing of the cost responsibility between the government and the contractor. Since cost overruns and underruns are possible options in incentive contracting, sharing arrangements prospectively define profit/fee adjustments. Because of that aspect, sharing arrangements should reflect the cost risk involved as evidenced by the magnitude of potential increases and decreases for the specific effort. (Ref. 19:p. 346,347)

The Fixed-Price Incentive (FPI) contract is preferred over a Cost Plus Incentive Fee (CPIF) contract when certain prerequisite conditions exist. First, the degree of technical uncertainty should be the primary criterion in selecting between FPI and CPIF contract. Second, the mutual confidence the parties have in the cost and pricing information shall be taken into consideration. When the available cost or pricing information and performance specifications prevent negotiation of firm targets and firm ceiling prices, FPI contracts should not be used. When there is a reasonable expectation of technical success within stated measurable limits, FPI contracts are appropriate. (Ref. 14:p. 86) In FPI contracts, the contractor's share of cost is typically higher than under a CPIF contract. In addition to that, under a FPI contract, the contractor's requirement to deliver the goods and/or services is more firm. (Ref. 20:p. 225)

We propose that a fixed-price incentive contract be used in the UAV program for the acquisition of the UAV systems and their logistics support facilities for a limited time. The UAV program satisfies the criteria for a fixed-price incentive contract. First, GNAT-750 UAV system is produced by the contractor for a certain period of time. The technical uncertainty is low since the manufacturing company has experience and enough expertise to satisfy the need of the Turkish Military Forces for GNAT-750 UAV systems. Second, the Turkish Army Command has used the test UAV system operationally for more than three years. In addition to cost and pricing information, there is enough performance metrics in hand. This system is not a new production with high technical uncertainty. Moreover, there is a reasonable expectation of technical success within stated measurable limits. These facts lead us to a fixed-price incentive contract rather than a cost-plus incentive fee contract for the UAV program.

Applying incentives to contracts is an attempt to motivate the contractor to improve performance in cost, schedule, and other stated parameters. The cost control is the most frequent application of incentives. Nevertheless, this is not the only type of incentive. The type of the incentive may vary depending on the desired outcome. (Ref. 19:p. 346) The Turkish Army Command's primary interest is in the operational availability of the UAV system. "*Performance incentives reward the contractor for developing a system that achieves the objectives of the government.*" (Ref. 20:p. 229) We propose to use performance incentives in the fixed-price incentive contract for the UAV program.

C. PERFORMANCE INCENTIVES

The government's values with respect to enhancements in the value of performance are represented by performance incentives. In the acquisition process this is a government's primary expertise area. On the other hand, the performance incentives also guide the contractor to achieve this objective by permitting the contractor to make cost effective tradeoff decisions. This is the contractor's primary expertise area. (Ref. 20:p. 218)

In general, performance incentives could be considered in connection with specific characteristics such as engine thrust, UAV endurance, or a missile range or other specific elements of the contractor's performance. The profit or fee must be determined by comparing these specified targets with achieved results. The performance incentives should be designed in such a way that positive and negative performance incentives shall be considered in connection with service contracts for performance of objectively measurable tasks to the maximum extend practicable. There are two major issues in this consideration. The performance incentives should be employed when quality of performance is critical and incentives are likely to motivate the contractor. (Ref. 17)

Another important consideration is to see if there are opportunities for tradeoffs to be made during the contract. Performance incentives are practicable only if there is space for tradeoffs which can be achieved by performance specifications combined with an Operational Requirements Document (ORD) that identifies both threshold and objective performance levels. However, detailed design specifications may prevent many tradeoffs possibilities. (Ref. 20:p. 219) For the UAV system performance incentives, we provide a large tradeoff space for the contractor by giving broad performance criteria.

The measurement of the performance criteria is essential. The degree of attainment of performance targets should be determined with performance tests and/or assessment of work performed. The contract should reflect these issues and be specific in establishing test criteria (such as testing conditions and data interpretation) and performance standards (such as the quality levels of services to be provided). (Ref. 17)

"*The use of award fees based on a subjective assessment of effort was suggested as a way of coming to grips with factors that are difficult to define at the time the contract is specified.*" (Ref. 20:p. 221) One of the biggest problems with award fees is the determination of the contractor's performance. The award fee can be based on quantifiable data such as attained range, weight, speed, etc. However, most of the time the decision process that determines the amount of the award fees might have a subjective nature. (Ref. 18:p. 255) To solve this problem we develop specific, measurable performance objectives, such as the number of UAV operational flight days. As a result of this, we use performance measures in the assessment of the contractor's effort, at the same time we use objective incentive arrangements instead of subjective award fee arrangements. However, the incentives should not be narrowly focused to the extent that they do not necessarily contribute to program goals. (Ref. 21:p. 5) This attribute is specific enough to use as an incentive fee criterion instead of subjective award fee criterion. Moreover, we can satisfy following three rules of thumb for writing specification/requirements. (Ref. 22:p. 17)

1. *Does the requirement clearly state "What we need"?*
2. *Does the requirement directly relate to the user's need?*
3. *Does the requirement allow for different solutions?*

Based on the problem definition in Chapter II, we propose to put performance incentives in the contract. The performance criterion is the number of operational UAV system flight days per year. The profit of the contractor will be determined by this criterion. Other issues that can impact system availability and subsequent profit determinations are O-level maintenance, I-level maintenance, and personnel training. These issues will be addressed in Chapter V.

Although we stated that the Turkish Army Command's primary interest is in the operational availability of the UAV system, resources are limited. Because of that, another important issue is the target cost. The target cost should be determined very carefully, should include all the costs associated with the contract, and should reflect realistic objectives. To control costs, we need to use a very precise target cost in our contract. We will explain how we calculate the target cost and performance incentive fee for UAV system in the next chapter.

V. INCENTIVIZE THE CONTRACTOR

A. INTRODUCTION

In this chapter we will first explain how we calculate the contract cost for the UAV project and how we determine the incentive fee for various performance levels. Then we will use simulation to find the contract cost and incentive fee based on the problem definition.

First of all we need to determine the scope of the contract, i.e., which cost categories should be included and the reason for including that specific cost category. In this determination we use another decision support worksheet. In Chapter III, we built the UAV model and we calculated the life-cycle cost of the UAV program. In this chapter, we derive a decision support worksheet, "CONTRACT COST" DSW, from "LCC" DSW to calculate the contract cost. Figure 5.1 illustrates the derivation of "CONTRACT COST" DSW. The "CONTRACT COST" DSW, just referred to as the "LCC" DSW, is interactive with other DSWs and RWs (Appendix B).

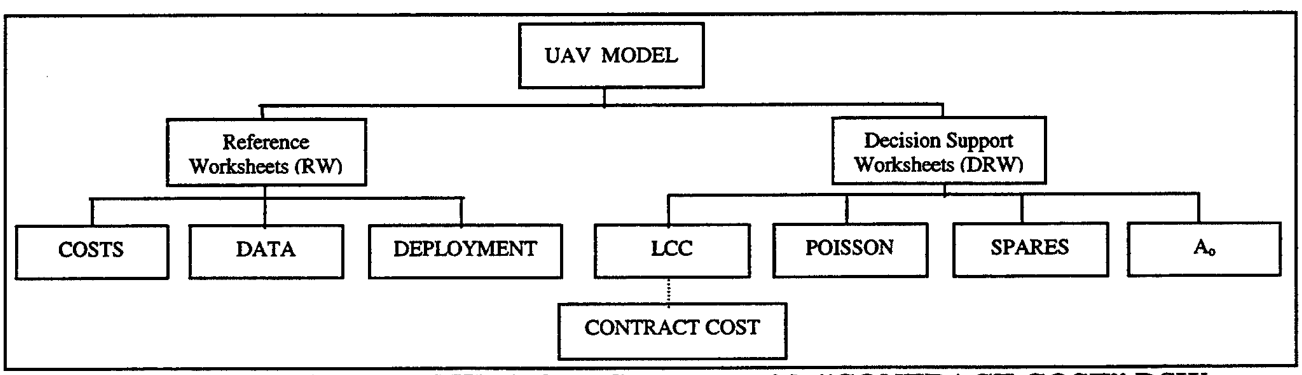


FIGURE 5.1 UAV Model Worksheet Structure with "CONTRACT COST" DSW

B. CONTRACT COST DSW

The UAV program objective is to acquire 10 UAV systems according to the deployment plan (Table 2.1), provide the logistics support of the UAV program for the first six years with on time quality products, and transfer of the design and technology of UAV system to a domestic company in the sixth year.

Based on this objective, the contract should include the costs associated with the UAV program for the first six years. The following cost categories are included in "CONTRACT COST" DSW:

1. Design and technology transfer cost.
2. Investment cost:
    a. Initial procurement cost of UAV systems,
    b. I-level special support equipment cost.
3. Operation and maintenance cost:
    a. O-level maintenance material cost,
    b. O-level preventive maintenance material cost,
    c. I-level corrective maintenance material cost,
    d. Spare part cost,
    e. Repair and replacement cost.
4. Training cost:
    a. Operator training O/H cost,
    b. O-level maintenance training O/H cost,
    c. I-level maintenance training O/H cost.

The following cost categories in the life-cycle cost calculation are excluded from contract:

1. Investment cost:
    a. Subsequent procurement cost of UAV systems.

2. Operation and maintenance cost:

    a. Fuel cost,

    b. Oil and lubricants cost.

3. Training cost:

    a. Operator training (except operator training O/H cost),

    b. O-level maintenance training (except O-level mnt. training O/H cost),

    c. I-level maintenance training (except I-level mnt. training O/H cost).

4. Manning cost.

5. Disposal cost.

Although the logic behind this separation of most of the cost categories is easy to understand, we now explain the basis for inclusion of some of the costs in the contract, which we find necessary. These are basically costs incurred due to given logistics support responsibility to the contractor for the first six years with an objective of achieving a certain level of operational availability.

Since we require the contractor to provide logistics support, which gives a certain level of readiness for the UAV system, we need to determine which factors are associated with this effort. Kang stated that the level of readiness or operational availability can be expressed with the following formula.

$$A_o = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}}$$

Kang also contended that "*Clearly, operational availability can be improved by increasing MTBM* [Mean Time Between Maintenance] *(i.e., increasing reliability) or decreasing MDT* [Maintenance Downtime] *(i.e., reducing repair time). Thus the two key issues to improve weapon systems readiness are reliability improvement and cycle time* *reduction*." (Ref. 23:p. 1) To achieve a certain level of operational availability, the Turkish Army Command should focus on these two key issues, reliability improvement and cycle time reduction.

Increasing the stock for the components of UAV system could be seen as a solution to the readiness problem. Can the Turkish Army Command increase the operational availability of the UAV system by having a higher stock level? To a limited extent, increasing stock level might be a highly expensive and tentative solution to the problem in the short run. However, the operational availability required by the Turkish Army Command for the UAV system is not an easy target which can be achieved with temporary solutions like increasing the stock level. Kang pointed out that if a system does not have a repair facility quick enough to support it and if there is no improvement in the reliability of its critical items, increasing the stock level of the critical items does not necessarily increase the operational availability of the system in the long run. Therefore, the Turkish Army Command cannot improve the operational availability of the UAV systems without increasing the reliability of the critical item or reducing the repair time. The increase in the stock level will not improve the UAV system's efficiency in the long run. (Ref. 5:p. 10)

Only the contractor, the manufacturing company, has the capability of improving the reliability of the critical items in the UAV system since it has the expertiese to make appropiate production process and design changes. In addition to that, the 87.72% ((0.4*75)/34.2) of the avarage TAT is under the control of the contractor via D-level maintainance (Chapter III B.3.f.(2).(a)). As a result two key issues of readiness, reliability improvement and cycle time reduction, can be improved by incentivizing the contractor toward those goals.

If we can find out a realistic target price and incentive fee amount for our performance measure, operational flying days in a year, then we can incentivize the contrator toward the Turkish Army Command's objective. In a FPI contract arrangement this performance incentive motivates the contractor to earn more compeansation by achieving better performance and by controlling costs. Hence the incentive fee is calculated by operational availability of the UAV systems. The contractor should increase reliability (e.g., bigger MTBF values), reduce repair time (e.g., dicrease TAT) and also control costs to earn more profit. In a short term one or two-year contract, the contractor might have chosen not to make necessary investments especially the ones essential for increasing reliability. However, in a long term contractual relationship, the contractor is more likely to invest as the potential return on investment is higher. On the other hand, with increased reliability and reduced repair time, Turkey will be able to transfer an improved technology and design at the end of the sixth year.

To implement this strategy, we need to give necessary tools to the contractor. The repair and replacement cost, O-level maintainance material cost, and I-level maintainance material cost should be included in the contract. As the contractor improves the reliability of the components, the system gives less failures and needs less maintenance actions. Eventually, the contractor gains more profit since the contract is the fixed-price incentive type.

The training costs should also be included in the contract. To reduce the maintenance down time, the contractor could shorten repair time, and administrative and logistics delay time. By giving the responsibility of UAV personnel training, we provide the contractor another effective tool to improve operational availability of the UAV systems. The contractor could improve the processes and procedures of operational, maintenance, and support functions of the UAV system. The contractor should have training responsibility to instruct and implement the new processes and procedures improved via system engineering processes. At the same time, the Turkish Army Command should include the contractor representative in the UAV personnel selection process or provide excess personnel for training to make the contractor able to select the best personnel for the UAV system.

The subsequent procurement cost of UAV systems is excluded from the contract cost calculation. With the exclusion of this cost category, we eliminate the effects of contingency assumption variations over the contract cost. After that only operational availability factors can stimulate the differences in the contract cost during the simulation.

"CONTRACT COST" DSW is derived from "LCC" DSW by including relevant costs and excluding irrelevant costs according to the scope of the UAV FPI contract for the specified time period. The program manager or contracting officer can tailor the "CONTRACT COST" DSW for different systems and for different scnerios. After the life-cycle cost calculation from the total ownership cost perspective, a better judgement might be made on the scope of the contract according to tasks, environmental conditions, organizational structures and system requirements for the scope of the contract. Now, we use simulation to find the contract cost and incentive fee for the different performance levels under the scnerio given in the problem definition.

C. CONTRACT COST AND INCENTIVE FEE DETERMINATION BY USING SIMULATION

In this section, we calculate the contract cost of the UAV program for changing operational availability. At the end of this section, we will be able to determine the target price and incentive fee structure for different performance levels in the UAV FPI contract. We simulate the model and achieve these results by using Crystal Ball software and Monte Carlo simulation for changing operational availability. "CONTRACT COST" DSW exploits "A_o" DSW in the determination of performance levels.

The target price is calculated directly in the "CONTRACT COST" DSW during the simulation. This value includes the contractor's profit margin of 8%. We use the minimum and maximum range of contract cost for each year to calculate the minimum and maximum fee. The minimum fee percentage is the ratio of the difference between minimum contract cost found in the simulation and target cost to the target cost for that year. The maximum fee percentage is calculated with the same method. Since the changes in the contract cost stem from the changes in the operational availability factors, we figure out the relation between them with regression analysis. The incentive fee determination formulas are derived from this relation. We use the trend analysis in Microsoft Excel program to find out the incentive fee determination formula.

We run the simulation for 10,000 iterations and collect data for forecast cells. The results derived from simulation are presented in the Appendix C. In this chapter, we presented the simulation results for the third year below (Figure 5.2 – Figure 5.4) since it represents most of the similar results in the simulation. We also calculate the target price and write down the formula for incentive fee determination for each of the six years in the UAV FPI contract.

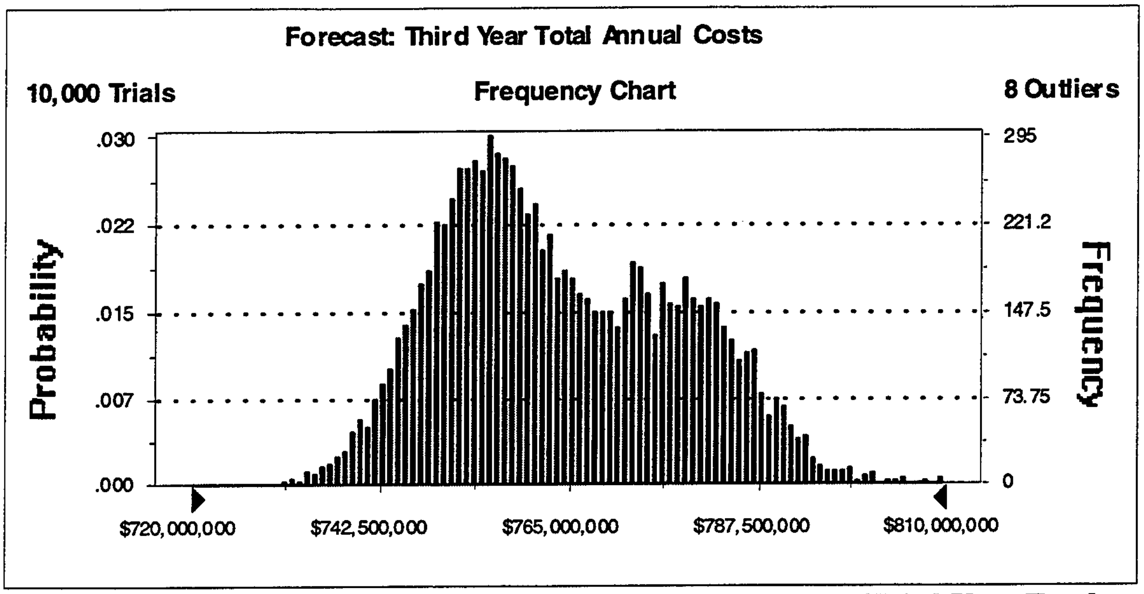


FIGURE 5.2 Simulation Results for the UAV FPI Contract Third Year Total Annual Costs (Range:$729,356,927 - $820,037,433)

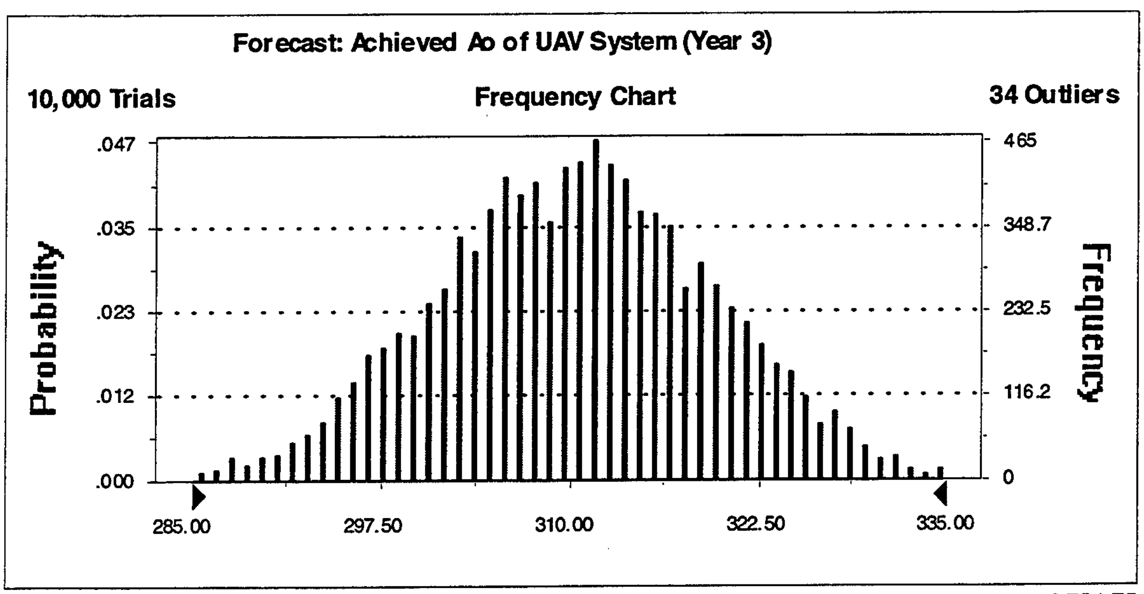


FIGURE 5.3 Simulation Results for the Achieved Operational Availability of UAV System in Year 3 (Range: 279 days – 341 days)

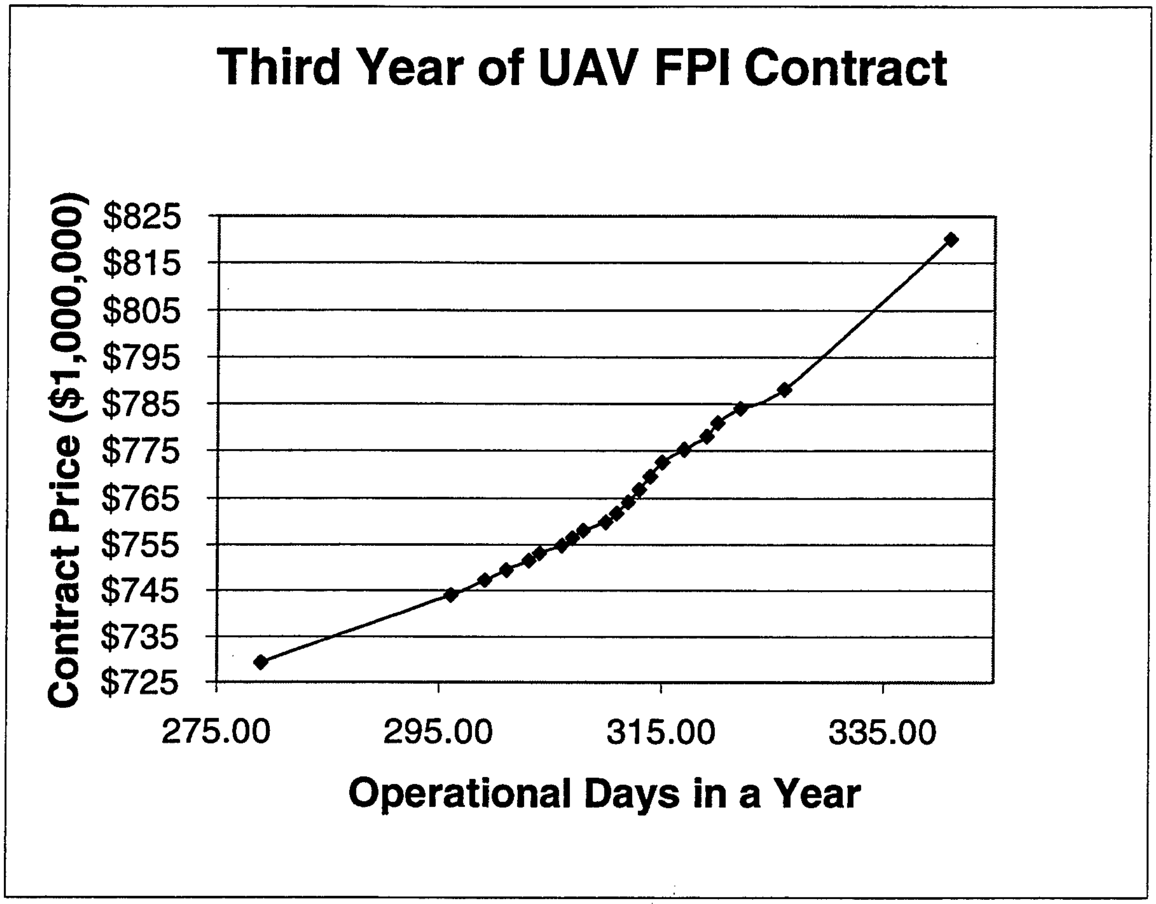


FIGURE 5.4 Simulation Results for the Third Year of the UAV FPI Contract Price for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Contract Cost
0%	279.00	$729,356,927
5%	296.00	$743,971,495
10%	299.00	$747,224,426
15%	301.00	$749,595,373
20%	303.00	$751,552,939
25%	304.00	$753,178,515
30%	306.00	$754,825,571
35%	307.00	$756,433,344
40%	308.00	$758,055,577
45%	310.00	$759,841,950
50%	311.00	$761,784,333
55%	312.00	$764,118,230
60%	313.00	$766,693,054
65%	314.00	$769,656,889
70%	315.00	$772,634,463
75%	317.00	$775,258,749
80%	319.00	$778,183,560
85%	320.00	$780,941,503
90%	322.00	$783,969,336
95%	326.00	$788,066,487
100%	341.00	$820,037,433

TABLE 5.1 Simulation Results for the Third Year of the UAV FPI Contract Price for Possible Operational Availability Levels

The simulation results demonstrate that under the given scenario, the target price, the incentive fee, and the formula for incentive fee determination for each of the six years in the UAV FPI contract should be as follow.

Year	Target Price	UAV sys.	Formula for Incentive Fee Determination	
1	$272,561,680	3	$y=(0.0148x^2-8.6214x+1516.1)*10^6$	$R^2=0.9636$
2	$403,088,021	6	$y=(0.0096x^2-4.7784x+961.97)*10^6$	$R^2=0.9742$
3	$761,346,852	10	$y=(0.0133x^2-6.7522x+1575.6)*10^6$	$R^2=0.9938$
4	$676,123,987	10	$y=(0.0117x^2-5.7984x+1352.4)*10^6$	$R^2=0.9913$
5	$679,613,610	10	$y=(0.0117x^2-5.7984x+1355.9)*10^6$	$R^2=0.9913$
6	$733,312,609	10	$y=(0.0117x^2-5.7984x+1409.6)*10^6$	$R^2=0.9913$

Year	Target Price	Target Cost	Target Fee	Min Fee	Target Fee	Max Fee
1	$272,561,680	$252,371,926	$20,189,754	4.41%	8%	22.97%
2	$403,088,021	$373,229,649	$29,858,372	4.39%	8%	20.34%
3	$761,346,852	$704,950,788	$56,396,063	3.46%	8%	16.33%
4	$676,123,987	$626,040,729	$50,083,258	3.18%	8%	17.02%
5	$679,613,610	$629,271,861	$50,341,749	3.21%	8%	16.97%
6	$733,312,609	$678,993,157	$54,319,453	3.56%	8%	16.31%

The increases in the target prices for the first three years is due to the increasing number of UAV systems purchased in accordance with the deployment plan (Table 2.1). The spare part costs are incurred in the first three years. Beginning from the forth year there is no initial procurement costs or spare part costs since there is no new UAV systems deployed. This is the reason for the difference of the third and forth years' target prices. The increase in the sixth year target price is due to design and technology transfer cost incurred in that year.

The calculation of the amount of fee should be paid to the contractor under the UAV FPI contract is explained with an example. We assume that in the first year UAV systems execute 306 days reconnaissance flight mission. Since this operational availability level is lower than the Turkish Army Command's objective for the first year (324 days (Table 3.11)), we expect a lower incentive fee than the target incentive fee. If we place the achieved operational availability (306 days) into the first year's formula for incentive fee determination (x=306), we find out $263,764,400 as the contract price (y). This is $8,797,280 lower than target price of $272,561,680. The $11,392,474 ($263,764,400-$252,371,926 or $20,189,754-$8,797,280) is the incentive fee for providing 306 operational days (18 days less than objective flying days).

We assume that in the third year UAV systems execute 332 days reconnaissance flight mission. Since this operational availability level is higher than the Turkish Army Command's objective for the third year (319 days (Table 3.11)), we expect a higher incentive fee than the target incentive fee. If we place the achieved operational availability (332 days) into the third year's formula for incentive fee determination (x=332), we find out $799,848,800 as the contract price (y). This is $38,501,948 higher than target price of $761,346,852. The $94,898,011 ($799,848,800-$704,950,788 or $56,396,063+$38,501,948) is the incentive fee for providing 332 operational days (13 days more than objective flying days).

Although we use these formulas for incentive fee determination, we need to set a minimum acceptable performance levels. For each year, if the achieved performance level is lower than the minimum flight day obtained from the simulation, then it will be considered as poor performance (e.g., for the first year less than 302 days). On this situation the Turkish Army Command might terminate the contract for default. These performance levels should be explicitly written down in the UAV FPI contract.

In this chapter, we address the second reason for the inefficiency in the test UAV system, which is absence of incentivizing tools for the contractor to supply UAV system with better reliability. As the target price and incentive fee become more certain, it is more likely to incentivize the contractor toward our objective, achieving a certain level of operational availability by increasing reliability, reducing repair time, and controlling the costs. In the next chapter we will give some recommendations and present conclusion for this thesis.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The objective of this thesis is to provide a life-cycle cost based decision support tool and a Fixed-Price Incentive (FPI) contract methodology to improve the operational availability of the UAV system. To achieve this objective we examine the UAV system for the Turkish Army Command. To develop a model, we build hypothetical scenarios, including locations, specifications, and performance of the UAV systems since the actual information is classified. The bottom line of the problem definition is that the Turkish Army Command wants to achieve a certain operational availability for the UAV system.

Based on the problem definition, we build a flexible model, which consists of three reference worksheets (RW) and four decision support worksheets (DSW), with the Microsoft Excel software. The information in the RWs can be manipulated with changing conditions, requirements, organizational structures, logistic considerations, etc. The DSWs calculate the new results automatically. We address uncertainties in the problem definition and apply Monte Carlo simulation for the model by using Crystal Ball software. Showing the modeling approach, applying that approach to the problem defined for the UAV system and demonstrating the use of simulation technique in the decision making process are the most important goals in this thesis. By doing that we give a powerful tool to the decision makers which can be tailored to a wide range of needs and systems.

In the first part of this thesis, we address the issue of allocating enough resources to the UAV program from the life-cycle cost perspective. We put emphasis on the spare, repair and replacement cost considerations by showing the relationship among spare level, service and failure rate in terms of readiness.

In the second part of this thesis we address the issue of incentivizing the contractor for the UAV system toward the Turkish Army Command's objective. First, we give a brief discussion on incentive contracting and applicable performance incentives. Then we apply that information to the UAV program with another DSW derived from the UAV model. In a Fixed-Price Incentive (FPI) contract, we use the number of UAV flying days as the performance incentive. To calculate the contract cost and incentive fee for the UAV project we apply simulation to the model. Finally, we identify the relation between the performance criteria and costs with polynomial functions for each year of the contract. These functions are eventually used as the incentive fee determination formula in the UAV FPI contract.

B. CONCLUSIONS

The two most important reasons for the inefficiency in the UAV test system are the failure to address life-cycle cost (LCC) considerations in the resource allocation process and the absence of contract reliability performance incentives. The two major problems addressed in this thesis are not unique to the UAV systems. Any newly developed major weapon system could face similar problems.

In major weapon system acquisition, the program manager and contracting officer should have a life-cycle cost perspective over the program. Allocation of enough resources for each single cost category is vital for the success of the program. This requires a detailed and flexible planning. The model, the method used to build the model, and the simulation technique explained in this thesis give that capacity to the decision makers. After calculating life-cycle costs from a total ownership cost perspective, one can make a better judgement on contract scope, tasks, environmental conditions, organizational structures, and system requirements.

Rather than simply explaining the benefits and use of modeling and simulation techniques in the decision making process, we also show the implementation and explain the methodology and simulation techniques in this process.

We place particular emphasis on spare parts, repair and replacement cost considerations for the UAV system. This thesis shows the implementation of the spare parts, repair and replacement cost considerations and establishes a methodology in determination of these costs.

The repair and replacement costs of the UAV system are much higher than the other cost categories from a life-cycle cost perspective. To achieve a certain level of operational availability the Turkish Army Command should allocate enough resources for the repair and replacement costs.

The Turkish Army Command cannot improve the operational availability of the UAV systems without increasing the reliability of critical components or without reducing the repair time. An increase in the stock level will not improve the UAV system's efficiency in the long run.

To enhance the operational availability of the UAV system, the reliability of the product and repair time, which are under the control of the manufacturing company must be improved. The Turkish Army Command should incentivize the contractor toward this objective.

We can implement a FPI type contract in giving the support responsibility of the UAV systems to the manufacturing company, since we develop objective metrics for performance incentives. Calculation of realistic target prices and fair incentive fee arrangements are crucial elements of a FPI type contract and are necessary to motivate improved contract performance.

Although the performance incentive is perceived most of the time as a subjective measure, which might be used in award fee arrangements, we generate a tool to implement the performance incentive of the UAV system objectively in a FPI type contract to achieve the Turkish Army Command's objective performance level. Instead of using a share ratio, we use an incentive fee determination formula where we can calculate the incentive fee amount according to an achieved UAV system performance level. Since we can objectively measure the monetary value of the performance level achieved, using the calculated amount of fee instead of a share ratio gives a more precise and encouraging fee to the contractor. The incentive fee determination formula employed in the thesis is also fairer for the UAV system, with its second degree polynomial structure. Because the effort to increase the performance will be much bigger at the high performance levels than at the low performance levels. The incentive fee amount calculated with the incentive fee determination formula also follows that pattern. For the same amount of increase in the performance, contractor earns more incentive fee at higher performance levels.

The model and the simulation technique explained in this thesis can be used for different weapon systems, under different scenarios, with minor modifications. In any case, using modeling and simulation provides a valuable tool to the decision-maker.

C. RECOMMENDATIONS

The MTBF values for each component should be monitored very closely by the UAV personnel and the data should be updated continuously. The contract should include a term for the review of the incentive fee determination formula each year based on the actual values of the system. Another clause in the contract should be the minimum acceptable performance levels below which gives the Turkish Army Command the right to terminate the contract for default.

For the UAV system, the Turkish Army Command should take into consideration the option of giving the support responsibility to the manufacturing company for a limited time (not shorter than two years). This could lead to an improvement in the reliability of the system and could potentially shorten logistic lead times.

The acquisition community should place more emphasis on total ownership costs and should base their resource allocation and procurement decisions upon life-cycle cost analysis. The model presented in this thesis provides key decision makers with a flexible planning and budgeting tool from a total ownership perspective. The contract price can then be derived from attained system performance and the contractual FPI pricing structure.

When the effort to improve performance is greater at the higher end of the performance spectrum, it is recommended that the incentive fee determination formula use second degree polynomial function in lieu of a traditional incentive fee share ratio. This type of performance fee arrangement recognizes the additional effort required to attain higher performance levels and provides a more meaningful incentive to the contractor.

The contracting officer should determine a very precise target cost in the Fixed-Price Incentive (FPI) contract to get the benefits of the incentive fee concept. Otherwise, the incentive structure will not serve its purpose, which is to encourage the contractor to achieve program goals. The modeling and simulation approach has the potential to be a very useful tool in this determination.

APPENDIX A: LIST OF ASSIGNED NAMES IN THE MODEL

Assigned Name	Item Represented by Assigned Name	Worksheet
AirConditioner	: GCS air conditioner cost	COST
Antenna	: UAV antenna system cost	COST
Contingency	: Risk of UAV and payload loss during peace time	DATA
ContingencyProb	: Contingency probability	DATA
ControlPanelCost	: GCS control panel cost	COST
DieselCost	: Diesel fuel cost ($/gal)	LCC
DiscountRate	: Discount rate	DATA
Disposal	: Disposal cost ($/UAV System)	COST
DlevelRR	: D-level repair rate	DATA
DlevelTAT	: D-level turnaround time (days)	DATA
DTTCost	: Design and technology transfer cost	COST
DTTYear	: Design and technology transfer time (year)	DATA
Engine	: UAV engine cost	COST
Fuel	: Diesel fuel, oil, and lubricants increase rate	DATA
FuelBurnRate	: Diesel fuel burn rate (gal/h)	DATA
FuelCapacity	: UAV fuel capacity (lb)	LCC
FuelCapacityGal	: UAV fuel capacity (gal)	LCC
FuelCost	: Diesel fuel cost	COSTS
IlevelMMcorr	: I-level corrective maintenance material cost ($/h)	COSTS

Assigned Name	Item Represented by Assigned Name	Worksheet
IlevelRR	: I-level repair rate	DATA
IlevelTAT	: I-level turnaround time (days)	DATA
IRScanner	: Payload IR Scanner cost	COST
LandingGears	: UAV landing gears cost	COST
MainDisplayUnit	: GCS main display unit cost	COST
MntTrOH	: Maintenance training overhead cost ($/month)	COST
MTBFsPayload	: Payload MTBFs (s : scheduled/preventive)	DATA
MTBFsUAV	: UAV MTBFs (s : scheduled/preventive)	DATA
NCO	: NCO salary ($/year)	COST
NevigationComputer	: UAV navigation computer cost	COST
Officer	: Officer salary ($/year)	COST
OilLubCost	: Oil and lubricant cost	COSTS
OLConsumptionRate	: Oil and lubricant consumption rate (gal/h)	DATA
OlevelMM	: O-level maintenance material cost ($/h)	COSTS
OlevelMMprv	: O-level preventive mnt. material cost ($/prv. action)	COST
OprTrOH	: Operator training overhead cost ($/month)	COST
PayloadCost	: Payload cost	COST
Peace	: Risk of UAV and payload loss during peace time	DATA
PowerGenerator	: GCS power generator cost	COST
PowerSupply	: GCS power supply cost	COST

Assigned Name	Item Represented by Assigned Name	Worksheet
Propeller	: UAV propeller cost	COST
ReceiverCost	: GDT receiver cost	COST
Rotation	: Personnel rotation rate in every 3 years	DATA
RotationEngineCost	: GDT rotation engine cost	COST
Salary	: Personnel salary increase rate	DATA
Sensors	: UAV sensors (Probe tube, temperature) cost	COST
SportEquipment	: I-level special support equipment cost	COST
SupportHour	: UAV support equipment operating hours (hrs/yr)	DATA
Targeting	: Payload targeting cost	COST
TransmitterCost	: GDT transmitter cost	COST
UAVCost	: Unmanned Aerial Vehicle cost	COST
UAVhours	: UAV operating hours (hrs/yr)	DATA
UAVsystem	: UAV System, subsystem, and training cost increase	DATA
UAVSystemCost	: UAV System cost	COST
VideoScanner	: Payload video scanner cost	COST

APPENDIX B: REFERENCE WORKSHEETS (RWs) AND DECISION SUPPORT WORKSHEETS (DSWs) OF THE UAV MODEL

COSTS

	A	B	C	D
1	**UNIT**	**COST**	**UNIT**	**COST**
2	**Unmanned Aerial Vehicle (UAV)**	$1,500,000	**Ground Data Terminal (GDT)**	$1,200,000
3	Antenna System	$75,000	Rotation Engine	$450,000
4	Navigation Computer	$300,000	Receiver	$250,000
5	Sensors (Probe Tube, Tempr.)	$50,000	Transmitter	$500,000
6	Landing Gears	$100,000	**Ground Support Unit**	$400,000
7	Engine	$400,000	**UAV System**	$14,200,000
8	Propeller	$40,000		
9			Cost of Diesel Fuel ($/gal)	$1
10	**Payload**	$650,000	Cost of Oil and Lubricants ($/gal)	$2
11	IR Scanner	$240,000	Officer Salary ($/year)	$10,000
12	Targeting	$150,000	NCO Salary ($/year)	$7,000
13	Video Scanner	$200,000	Operator Tr. O/H Cost ($/month)	$100,000
14			Maintenance Tr. O/H Cost ($/month)	$140,000
15	**Ground Control Station (GCS)**	$4,000,000	O-level Maintenance Material($/flight hour)	$200
16	Main Display Unit	$400,000	O-level Preventive Mnt.Material($/prv. action)	$500
17	Power Supply	$250,000	I-level Corrective Mnt.Material($/flight hour)	$400
18	Power Generator	$500,000	I-level special support equipment	$45,000
19	Air Conditioner	$1,000,000	Design and Technology Transfer Cost	$50,000,000
20	Control Panel	$2,000,000	Disposal Cost ($/UAV System)	$350,000

DEPLOYMENT

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	**Operational Bases/Year**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
2	South Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
3	Southeast Anatolia	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
4	East Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
5	Northwest Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
6	West Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
7	**Total number of UAV Sys**	**3**	**6**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**6**	**3**
8	New Operational Base	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DATA

	A	B	C	D	E
1	Design and Technology Transfer Time (year)	6			
2	UAV System Cost	$14,200,000			
3	UAV Support Equipment (hrs/yr)	2555			
4	UAV (hrs/yr)	1825			
5	Fuel Capacity (lb)	426			
6	Diesel Conversion (lb/gal)	7.034			
7	Fuel Capacity (gal)	60.56			
8	UAV fuel burn rate (gal/hr)	1.26			
9	Oil&Lubricant Consumption (gal/hr)	0.25			
10	Number of I-level Maint. Center	5			
11	I-level Repair Rate	60%			
12	I-level TAT (days)	7			
13	D-level Repair Rate	40%			
14	D-level TAT (days)	75			
15	Average Number of Repairs in a Year	10.673			
16	Risk of UAV and payload loss during peace time	10%			
17	Risk of UAV and payload loss during peace time	25%			
18					
19	Personnel Salary Increase	3%			
20	UAV System, subsystem, and training cost increase	6%			
21	Diesel Fuel, Oil, and Lubricants Increase	2%			
22	Discount Rate	2.4%			
23	Contingency Probability	40.0%			
24		Minimum	Target	Maximum	
25	Operational Availability of Critical Components	95.0%	97.0%	99.0%	
26	Operational Availability of Secondary Components	85.0%	90.0%	95.0%	
27					
28	**TRAINING (3 Goups/UAV System)**	For Each UAV System		Duration	
29	**Operator Training**	Officer	NCO	(Weeks)	
30	Basic Operator Course	10		3	
31	Advance Operator Course	10		5	
32	Operation Mission Team Training	10		2	
33	**Total Operator Training**	**10**		**10**	
34					
35	**Maintenance Training**				
36	**O-level**				
37	Basic Maintenance Course		6	2	
38	Advance Maintenance Course		6	6	
39	Operation Mission Team Training		6	2	
40	**Total O-level Maintenance**		**6**	**10**	
41					
42		For Each Operational Base		Duration	
43	**I-level**	Officer	NCO	(Weeks)	
44	Basic Maintenance Course		4	2	
45	Advance Electronic Maintenance Course	1	4	10	
46	Maintenance and Support Planning, Reporing	1		2	
47	**Total O-level Maintenance**	**1**	**4**	**12**	
48					

DATA

	A	B	C	D	E
49	Personnel rotation rate in every 3 years	50%			
50					
51		For Each Operational Base		For Each UAV System	
52	**Manning:**	Officer	NCO	Officer	NCO
53	UAV Unit Flight Team	18	----	9	----
54	UAV Unit Maintainance Team	----	12	----	6
55	UAV Unit Headquarter	2	2	1	1
56	I-Level Maintainance Center	1	4	----	----
57					
58	**I-level Preventive Maintenance**	MTBMs	Preventive		
59		(flight hours)	Action		
60	UAV Preventive Action	25	73		
61	Payload Preventive Action	50	37		
62					
63	**UAV k*lambda*t**	**MTBF**			
64	Antenna System	1500			
65	Navigation Computer	500			
66	Sensors (Probe Tube, Tempr.)	350			
67	Landing Gears	750			
68	Engine	700			
69	Propeller	3500			
70	**PAYLOAD**				
71	IR Scanner	450			
72	Targeting	800			
73	Video Scanner	2500			
74	**GCS**				
75	Main Display Unit	1000			
76	Power Supply	4000			
77	Power Generator	3500			
78	Air Conditioner	6000			
79	Control Panel	500			
80	**GDT**				
81	Rotation Engine	1700			
82	Receiver	800			
83	Transmitter	650			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	UAV System Cost	$14,200,000		Contingency	Probability																
2	UAV Support Equipment (hrs/yr)	2555		1	40%																
3	UAV (hrs/yr)	1825		0	60%																
4	Fuel Capacity (lb)	426																			
5	Diesel Conversion (lb/gal)	7.034																			
6	Fuel Capacity (gal)	60.56																			
7	UAV fuel burn rate (gal/hr)	1.44																			
8	Oil&Lubricant Consumption (gal/hr)	0.25																			
9	cost of diesel fuel ($/gal)	1																			
10	Number of I-level Maint. Center	5																			
11																					
12	Contingency																				
13	Attrition Rate	0.1	0.1	0.25	0.1	0.1	0.25	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.1	0.1	0.25	0.1	0.1	0.1	0.1
14	Number of UAV in Operation	12	24	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	24	12
15	New Purchase of UAV&Payload	0	2	3	10	4	4	10	4	4	4	4	4	4	10	4	4	10	4	0	0
16	UAV System in Operation	3	6	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	6	3
17	UAV Operational Base	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	2
18																					
19	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20	INVESTMENT COST																				
21	Design&Technology Transfer Cost	$0	$0	$0	$0	$0	$50,000,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
22	Initial Procurement UAV System	$45,156,000	$47,865,360	$67,649,709	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
23	Subsequent Purchase UAV&Payload	$0	$4,831,480	$7,682,053	$27,143,255	$11,508,740	$12,199,264	$32,328,051	$13,707,093	$14,529,519	$15,401,290	$16,325,368	$17,304,890	$18,343,183	$48,609,435	$20,610,400	$21,847,024	$57,894,615	$24,547,317	$0	$0
24	I-Level Special Support Equipment	$143,100	$101,124	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25	Total Investment Cost	$45,299,100	$52,797,964	$75,331,762	$27,143,255	$11,508,740	$62,199,264	$32,328,051	$13,707,093	$14,529,519	$15,401,290	$16,325,368	$17,304,890	$18,343,183	$48,609,435	$20,610,400	$21,847,024	$57,894,615	$24,547,317	$0	$0
26																					
27																					
28	OPERATION AND MAINTENAINCE																				
29	Diesel Fuel Cost	$28,146	$57,418	$97,610	$99,562	$101,553	$103,584	$105,656	$107,769	$109,925	$112,123	$114,366	$116,653	$118,986	$121,366	$123,793	$126,269	$128,794	$131,370	$80,398	$41,003
30	Oil and Lubricants Cost	$11,169	$22,785	$38,734	$39,509	$40,299	$41,105	$41,927	$42,766	$43,621	$44,493	$45,383	$46,291	$47,217	$48,161	$49,124	$50,107	$51,109	$52,131	$31,904	$16,271
31	O-level Maintenance Material Cost	$4,642,800	$9,842,736	$17,388,834	$18,432,164	$19,538,093	$20,710,379	$21,953,002	$23,270,182	$24,666,393	$26,146,376	$27,715,159	$29,378,068	$31,140,753	$33,009,198	$34,989,750	$37,089,135	$39,314,483	$41,673,352	$26,504,252	$14,047,253
32	O-level Preventive Mnt.MaterialCost	$696,420	$1,476,410	$2,608,325	$2,764,825	$2,930,714	$3,106,557	$3,292,950	$3,490,527	$3,699,959	$3,921,956	$4,157,274	$4,406,710	$4,671,113	$4,951,380	$5,248,462	$5,563,370	$5,897,172	$6,251,003	$3,975,638	$2,107,088
33	I-level Corrective Mnt.MaterialCost	$9,285,600	$19,685,472	$34,777,667	$36,864,327	$39,076,187	$41,420,758	$43,906,004	$46,540,364	$49,332,786	$52,292,753	$55,430,318	$58,756,137	$62,281,505	$66,018,396	$69,979,499	$74,178,269	$78,628,965	$83,346,703	$53,008,503	$28,094,507
34	Spare Part Cost	$22,285,000	$14,023,800	$20,865,252	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
35	Repair and Replacement Cost	$190,269,591	$310,004,959	$549,985,418	$582,984,543	$617,963,616	$655,041,433	$694,343,919	$736,004,554	$780,164,827	$826,974,717	$876,593,200	$929,188,792	$984,940,119	$1,044,036,527	$1,106,678,718	$1,173,079,441	$1,243,464,206	$1,318,072,060	$917,444,929	$610,220,353
36	Total O&M Cost	$227,218,726	$355,113,580	$625,761,840	$641,184,930	$679,650,463	$720,423,816	$763,643,458	$809,456,162	$858,017,510	$909,492,419	$964,055,699	$1,021,892,651	$1,083,199,693	$1,148,185,026	$1,217,069,347	$1,290,066,591	$1,367,484,731	$1,449,526,619	$1,001,045,624	$654,526,476
37																					
38																					
39	TRAINING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
40	Operator Training																				
41	Basic Operator Course	$17,827	$18,362	$25,217	$9,740	$10,032	$13,778	$10,643	$10,962	$15,055	$11,630	$11,979	$16,451	$12,706	$13,090	$17,977	$13,887	$14,303	$19,643		
42	Advance Operator Course	$29,712	$30,603	$42,028	$16,233	$16,720	$22,963	$17,739	$18,271	$25,092	$19,383	$19,965	$27,418	$21,181	$21,816	$29,961	$23,145	$23,839	$32,739		
43	Operation Mission Team Training	$11,885	$12,241	$16,811	$6,493	$6,688	$9,185	$7,095	$7,308	$10,037	$7,753	$7,986	$10,967	$8,472	$8,726	$11,984	$9,258	$9,536	$13,096		
44	Operator Training O/H Cost	$20,385	$21,608	$22,904	$24,278	$25,735	$27,279	$28,916	$30,651	$32,490	$34,439	$36,506	$38,696	$41,018	$43,479	$46,088	$48,853	$51,784	$54,891		
45	Total Operator Training	$79,808	$82,813	$106,960	$56,745	$59,176	$73,204	$64,393	$67,192	$82,674	$73,206	$76,436	$93,533	$83,379	$87,111	$106,009	$95,143	$99,462	$120,369		
46	Maintenance Training																				
47	O-level																				
48	Basic Maintenance Course	$4,992	$5,141	$7,061	$2,727	$2,809	$3,858	$2,980	$3,069	$4,215	$3,256	$3,354	$4,606	$3,558	$3,665	$5,033	$3,888	$4,005	$5,500		
49	Advance Maintenance Course	$14,975	$15,424	$21,182	$8,182	$8,427	$11,573	$8,940	$9,208	$12,646	$9,769	$10,062	$13,819	$10,675	$10,995	$15,100	$11,665	$12,015	$16,501		
50	Operation Mission Team Training	$4,992	$5,141	$7,061	$2,727	$2,809	$3,858	$2,980	$3,069	$4,215	$3,256	$3,354	$4,606	$3,558	$3,665	$5,033	$3,888	$4,005	$5,500		
51	O-level Maintenance Training O/H	$28,538	$30,251	$32,066	$33,990	$36,029	$38,191	$40,482	$42,911	$45,486	$48,215	$51,108	$54,175	$57,425	$60,870	$64,523	$68,394	$72,498	$76,848		
52	Total O-level Maintenance	$53,496	$55,957	$67,369	$47,626	$50,074	$57,479	$55,383	$58,259	$66,563	$64,497	$67,879	$77,206	$75,217	$79,196	$89,690	$87,836	$92,523	$104,348		
53	I-level																				
54	Basic Maintenance Course	$3,328	$3,428	$4,707	$1,818	$1,873	$2,572	$1,987	$2,046	$2,810	$2,171	$2,236	$3,071	$2,372	$2,443	$3,356	$2,592	$2,670	$3,667		
55	Advance Eltr. Maintenance Course	$22,581	$23,258	$31,941	$12,337	$12,707	$17,452	$13,481	$13,886	$19,070	$14,731	$15,173	$20,838	$16,097	$16,580	$22,770	$17,590	$18,118	$24,882		
56	Maint.&Support Planning, Reporing	$1,188	$1,224	$1,681	$649	$669	$919	$710	$731	$1,004	$775	$799	$1,097	$847	$873	$1,198	$926	$954	$1,310		
57	I-level Maintenance Training O/H	$34,246	$36,301	$38,479	$40,788	$43,235	$45,829	$48,579	$51,494	$54,583	$57,858	$61,330	$65,009	$68,910	$73,045	$77,427	$82,073	$86,997	$92,217		
58	Total I-level Maintenance	$61,343	$64,211	$76,808	$55,592	$58,484	$66,771	$64,756	$68,156	$77,467	$75,536	$79,538	$90,015	$88,227	$92,941	$104,752	$103,181	$108,739	$122,075		
59																					
60	Total Training Cost	$194,647	$202,981	$251,138	$159,963	$167,734	$197,455	$184,532	$193,608	$226,704	$213,239	$223,852	$260,754	$246,823	$259,248	$300,451	$286,159	$300,724	$348,793		
61																					
62	** 50% of personnel will be rotated every 3 years																				
63	NOTE: In year 19, no more groups need to be trained due to reduction in the number of the UAV systems																				
64																					
65																					
66	MANNING	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
67	UAV Unit Flight Team	$278,100	$572,886	$983,454	$1,012,958	$1,043,347	$1,074,647	$1,106,886	$1,140,093	$1,174,296	$1,209,525	$1,245,810	$1,283,185	$1,321,680	$1,361,331	$1,402,171	$1,444,236	$1,487,563	$1,532,190	$946,893	$487,650
68	UAV Unit Maintenance Team	$129,780	$267,347	$458,945	$472,714	$486,895	$501,502	$516,547	$532,043	$548,005	$564,445	$581,378	$598,820	$616,784	$635,288	$654,346	$673,977	$694,196	$715,022	$441,884	$227,570
69	UAV Unit Headquarter	$52,530	$108,212	$185,764	$191,336	$197,077	$202,989	$209,079	$215,351	$221,811	$228,466	$235,320	$242,379	$249,651	$257,140	$264,854	$272,800	$280,984	$289,414	$178,858	$92,112
70	I-Level Maintenance Center	$117,420	$201,571	$207,618	$213,847	$220,262	$226,870	$233,676	$240,686	$247,907	$255,344	$263,004	$270,895	$279,021	$287,392	$296,014	$304,894	$314,041	$323,462	$333,166	$137,264
71	Toatal ManningCost	$577,830	$1,150,016	$1,835,781	$1,890,855	$1,947,580	$2,006,008	$2,066,188	$2,128,174	$2,192,019	$2,257,780	$2,325,513	$2,395,278	$2,467,137	$2,541,151	$2,617,385	$2,695,907	$2,776,784	$2,860,088	$1,900,801	$944,596
72																					
73																					
74	DISPOSAL COSTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
75	UAV System Disposal Cost	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$3,996,075	$3,176,879	$3,367,492
76																					
77	Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
78	TOTAL COSTS																				
79	Investment Costs	$45,299,100	$52,797,964	$75,331,762	$27,143,255	$11,508,740	$62,199,264	$32,328,051	$13,707,093	$14,529,519	$15,401,290	$16,325,368	$17,304,890	$18,343,183	$48,609,435	$20,610,400	$21,847,024	$57,894,615	$24,547,317	$0	$0
80	Operation&Maintenance Costs	$227,218,726	$355,113,580	$625,761,840	$641,184,930	$679,650,463	$720,423,816	$763,643,458	$809,456,162	$858,017,510	$909,492,419	$964,055,699	$1,021,892,651	$1,083,199,693	$1,148,185,026	$1,217,069,347	$1,290,066,591	$1,367,484,731	$1,449,526,619	$1,001,045,624	$654,526,476
81	Training Costs	$194,647	$202,981	$251,138	$159,963	$167,734	$197,455	$184,532	$193,608	$226,704	$213,239	$223,852	$260,754	$246,823	$259,248	$300,451	$286,159	$300,724	$348,793	$0	$0
82	Manning Costs	$577,830	$1,150,016	$1,835,781	$1,890,855	$1,947,580	$2,006,008	$2,066,188	$2,128,174	$2,192,019	$2,257,780	$2,325,513	$2,395,278	$2,467,137	$2,541,151	$2,617,385	$2,695,907	$2,776,784	$2,860,088	$1,900,801	$944,596
83	Disposal Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$3,996,075	$3,176,879	$3,367,492
84	Total Annual Costs	$273,290,302	$409,264,541	$703,180,521	$670,379,002	$693,274,517	$784,826,543	$798,222,229	$825,485,036	$874,965,752	$927,364,728	$982,930,432	$1,041,853,573	$1,104,256,835	$1,199,594,860	$1,240,597,583	$1,314,915,681	$1,428,456,654	$1,481,276,891	$1,006,123,304	$658,838,564
85	Discounted total Annual Costs	$273,290,302	$399,672,403	$670,605,203	$624,339,098	$630,529,500	$697,065,999	$692,347,419	$699,213,023	$723,754,706	$749,119,261	$775,395,390	$802,614,798	$830,750,510	$881,323,114	$890,085,114	$921,294,662	$977,389,842	$989,776,150	$656,528,069	$419,836,155
86	NOTE: Discount rate is 2.4%.																				
87	TOTAL LIFE CYCLE COST:	$18,419,097,750																			
88	PV OF TOTAL LIFE CYCLE COST:	$14,304,928,740																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Operational Bases/Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	South Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
3	Southeast Anatolia	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
4	East Anatolia	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
5	Northwest Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
6	West Anatolia	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0
7	Total number of system	3	6	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	6	3
8	New UAV System	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Total number of UAV	12	24	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	24	12
10	New UAV	12	12	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11																					
12																					
13	[illegible]	MTBF		Year1	Year2	Year3	Operational Availability														
14	Antenna System	1500		1.37	2.74	4.56		[illegible]													
15	Navigation Computer	500		4.10	8.21	13.68		[illegible]													
16	Sensors (Probe Tube, Tempr.	350		5.86	11.73	19.54		[illegible]													
17	Landing Gears	750		2.74	5.47	9.12		[illegible]													
18	Engine	700		2.93	5.86	9.77		[illegible]													
19	Propeller	3500		0.59	1.17	1.95		[illegible]													
20	PAYLOAD																				
21	IR Scanner	450		4.56	9.12	15.20		[illegible]													
22	Targeting	800		2.57	5.13	8.55		[illegible]													
23	Video Scanner	2500		0.82	1.64	2.74		[illegible]													
24	GCS																				
25	Main Display Unit	1000		0.72	1.44	2.39		[illegible]													
26	Power Supply	4000		0.18	0.36	0.60		[illegible]													
27	Power Generator	3500		0.21	0.41	0.68		[illegible]													
28	Air Conditioner	6000		0.12	0.24	0.40		[illegible]													
29	Control Panel	500		1.44	2.87	4.79		[illegible]													
30	GDT																				
31	Rotation Engine	1700		0.42	0.84	1.41		[illegible]													
32	Receiver	800		0.90	1.80	2.99		[illegible]													
33	Transmitter	650		1.10	2.21	3.68		[illegible]													
34																					
35	UAV	MTBF		1	2	3		Cost													
36	Antenna System	1500		3	5	7		75000													
37	Navigation Computer	500		7	12	19		300000													
38	Sensors (Probe Tube, Tempr.	350		9	16	25		50000													
39	Landing Gears	750		5	9	13		100000													
40	Engine	700		5	9	14		400000													
41	Propeller	3500		2	3	4		40000													
42	PAYLOAD																				
43	IR Scanner	450		7	13	20		240000													
44	Targeting	800		5	8	12		150000													
45	Video Scanner	2500		2	3	5		200000													
46	GCS																				
47	Main Display Unit	1000		3	4	6		400,000													
48	Power Supply	4000		1	2	2		250,000													
49	Power Generator	3500		1	2	3		500,000													
50	Air Conditioner	6000		1	1	2		1,000,000													
51	Control Panel	500		4	6	9		2,000,000													
52	GDT																				
53	Rotation Engine	1700		2	3	4		450000													
54	Receiver	800		3	5	7		250000													
55	Transmitter	650		3	5	8		500000													
56																					
57	UAV			1	2	3	4	19	20												
58	Antenna System			225000	159000	168540	525000	375000	225000												
59	Navigation Computer			2100000	1590000	2359560	5700000	3600000	2100000												
60	Sensors (Probe Tube, Tempr.)			450000	371000	505620	1250000	800000	450000												
61	Landing Gears			500000	424000	449440	1300000	900000	500000												
62	Engine			2000000	1696000	2247200	5600000	3600000	2000000												
63	Propeller			80000	42400	44944	160000	120000	80000												
64	PAYLOAD							0	0												
65	IR Scanner			1680000	1526400	1887648	4800000	3120000	1680000												
66	Targeting			750000	477000	674160	1800000	1200000	750000												
67	Video Scanner			400000	212000	449440	1000000	600000	400000												
68	GCS							0	0												
69	Main Display Unit			1200000	424000	898880	2400000	1600000	1200000												
70	Power Supply			250000	265000	0	500000	500000	250000												
71	Power Generator			500000	530000	561800	1500000	1000000	500000												
72	Air Conditioner			1000000	0	1123600	2000000	1000000	1000000												
73	Control Panel			8000000	4240000	6741600	18000000	12000000	8000000												
74	GDT							0	0												
75	Rotation Engine			900000	477000	505620	1800000	1350000	900000												
76	Receiver			750000	530000	561800	1750000	1250000	750000												
77	Transmitter			1500000	1060000	1685400	4000000	2500000	1500000												
78	TOTAL SPARE COST			[illegible]	[illegible]	[illegible]															
79	REPAIR&REPLACEMENT COST			17,828,000	29,047,040	39,929,834	43,268,000	28,412,000	17,828,000												
80	NOT: Total Spare Cost of 4th, 19th, and 20th year is calculated to be used in the "Repair and Replacement Cost"																				
81	G58=F36*$H36 (Total UAV antenna system spare part cost without inflation effect)																				
82	G79=0.8*SUM(G58:G77)																				

A	B	C	D	E	F	G	H	I	J	K	L	M
	Antena System						Navigation Computer					
	P(X <=x)	x1	P(X <=x)	x2	P(X <=x)	x3	P(X <=x)	x25	P(X <=x)	x26	P(X <=x)	x27
0	0.2546	0	0.0648	0	0.0105	0	0.0165	0	0.0003	0	0.0000	0
1	0.6029	1	0.2422	1	0.0582	1	0.0842	1	0.0025	1	0.0000	1
2	0.8412	2	0.4848	2	0.1669	2	0.2233	2	0.0117	2	0.0001	2
3	0.9498	3	0.7061	3	0.3323	3	0.4134	3	0.0368	3	0.0006	3
4	0.9870	4	0.8575	4	0.5208	4	0.6085	4	0.0883	4	0.0023	4
5	0.9971	5	0.9403	5	0.6926	5	0.7687	5	0.1729	5	0.0069	5
6	0.9995	6	0.9781	6	0.8233	6	0.8782	6	0.2866	6	0.0173	6
7	0.9999	7	0.9929	7	0.9084	7	0.9424	7	0.4243	7	0.0377	7
8	1.0000	8	0.9979	8	0.9569	8	0.9754	8	0.5635	8	0.0725	8
9	1.0000	9	0.9994	9	0.9815	9	0.9904	9	0.6905	9	0.1254	9
10	1.0000	10	0.9999	10	0.9927	10	0.9966	10	0.7947	10	0.1979	10
11	1.0000	11	1.0000	11	0.9973	11	0.9989	11	0.8725	11	0.2880	11
12	1.0000	12	1.0000	12	0.9991	12	0.9997	12	0.9257	12	0.3906	12
13	1.0000	13	1.0000	13	0.9997	13	0.9999	13	0.9593	13	0.4987	13
14	1.0000	14	1.0000	14	0.9999	14	1.0000	14	0.9789	14	0.6043	14
15	1.0000	15	1.0000	15	1.0000	15	1.0000	15	0.9897	15	0.7008	15
16	1.0000	16	1.0000	16	1.0000	16	1.0000	16	0.9952	16	0.7830	16
17	1.0000	17	1.0000	17	1.0000	17	1.0000	17	0.9979	17	0.8492	17
18	1.0000	18	1.0000	18	1.0000	18	1.0000	18	0.9991	18	0.8996	18
19	1.0000	19	1.0000	19	1.0000	19	1.0000	19	0.9997	19	0.9358	19
20	1.0000	20	1.0000	20	1.0000	20	1.0000	20	0.9999	20	0.9606	20
21	1.0000	21	1.0000	21	1.0000	21	1.0000	21	1.0000	21	0.9768	21
22	1.0000	22	1.0000	22	1.0000	22	1.0000	22	1.0000	22	0.9868	22
23	1.0000	23	1.0000	23	1.0000	23	1.0000	23	1.0000	23	0.9928	23
24	1.0000	24	1.0000	24	1.0000	24	1.0000	24	1.0000	24	0.9962	24
25	1.0000	25	1.0000	25	1.0000	25	1.0000	25	1.0000	25	0.9981	25
26	1.0000	26	1.0000	26	1.0000	26	1.0000	26	1.0000	26	0.9991	26
27	1.0000	27	1.0000	27	1.0000	27	1.0000	27	1.0000	27	0.9996	27
28	1.0000	28	1.0000	28	1.0000	28	1.0000	28	1.0000	28	0.9998	28
29	1.0000	29	1.0000	29	1.0000	29	1.0000	29	1.0000	29	0.9999	29
30	1.0000	30	1.0000	30	1.0000	30	1.0000	30	1.0000	30	1.0000	30

A	N	O	P	Q	R	S	T	U	V	W	X	Y
	Sensors (Probe Tube, Tempr.)						Landing Gears					
	P(X <=x)	x28	P(X <=x)	x29	P(X <=x)	x30	P(X <=x)	x31	P(X <=x)	x32	P(X <=x)	x33
0	0.0028	0	0.0000	0	0.0000	0	0.0648	0	0.0042	0	0.0001	0
1	0.0195	1	0.0001	1	0.0000	1	0.2422	1	0.0272	1	0.0011	1
2	0.0684	2	0.0007	2	0.0000	2	0.4848	2	0.0901	2	0.0057	2
3	0.1639	3	0.0028	3	0.0000	3	0.7061	3	0.2049	3	0.0195	3
4	0.3038	4	0.0092	4	0.0000	4	0.8575	4	0.3619	4	0.0510	4
5	0.4680	5	0.0241	5	0.0001	5	0.9403	5	0.5337	5	0.1086	5
6	0.6283	6	0.0533	6	0.0004	6	0.9781	6	0.6904	6	0.1961	6
7	0.7626	7	0.1022	7	0.0011	7	0.9929	7	0.8129	7	0.3100	7
8	0.8611	8	0.1738	8	0.0028	8	0.9979	8	0.8967	8	0.4400	8
9	0.9252	9	0.2672	9	0.0065	9	0.9994	9	0.9477	9	0.5716	9
10	0.9628	10	0.3766	10	0.0138	10	0.9999	10	0.9755	10	0.6917	10
11	0.9828	11	0.4933	11	0.0267	11	1.0000	11	0.9894	11	0.7912	11
12	0.9926	12	0.6073	12	0.0478	12	1.0000	12	0.9957	12	0.8669	12
13	0.9970	13	0.7101	13	0.0798	13	1.0000	13	0.9984	13	0.9199	13
14	0.9989	14	0.7963	14	0.1238	14	1.0000	14	0.9994	14	0.9545	14
15	0.9996	15	0.8636	15	0.1815	15	1.0000	15	0.9998	15	0.9755	15
16	0.9999	16	0.9129	16	0.2519	16	1.0000	16	0.9999	16	0.9875	16
17	1.0000	17	0.9470	17	0.3329	17	1.0000	17	1.0000	17	0.9938	17
18	1.0000	18	0.9691	18	0.4208	18	1.0000	18	1.0000	18	0.9972	18
19	1.0000	19	0.9828	19	0.5113	19	1.0000	19	1.0000	19	0.9988	19
20	1.0000	20	0.9908	20	0.5998	20	1.0000	20	1.0000	20	0.9995	20
21	1.0000	21	0.9953	21	0.6819	21	1.0000	21	1.0000	21	0.9998	21
22	1.0000	22	0.9977	22	0.7549	22	1.0000	22	1.0000	22	0.9999	22
23	1.0000	23	0.9989	23	0.8170	23	1.0000	23	1.0000	23	1.0000	23
24	1.0000	24	0.9995	24	0.8675	24	1.0000	24	1.0000	24	1.0000	24
25	1.0000	25	0.9998	25	0.9070	25	1.0000	25	1.0000	25	1.0000	25
26	1.0000	26	0.9999	26	0.9367	26	1.0000	26	1.0000	26	1.0000	26
27	1.0000	27	1.0000	27	0.9582	27	1.0000	27	1.0000	27	1.0000	27
28	1.0000	28	1.0000	28	0.9732	28	1.0000	28	1.0000	28	1.0000	28
29	1.0000	29	1.0000	29	0.9833	29	1.0000	29	1.0000	29	1.0000	29
30	1.0000	30	1.0000	30	0.9899	30	1.0000	30	1.0000	30	1.0000	30

A	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
	Engine						Propeller					
	P(X <=x)	x34	P(X <=x)	x35	P(X <=x)	x36	P(X <=x)	x37	P(X <=x)	x38	P(X <=x)	x39
0	0.0533	0	0.0028	0	0.0001	0	0.5564	0	0.3096	0	0.1417	0
1	0.2096	1	0.0195	1	0.0006	1	0.8826	1	0.6726	1	0.4185	1
2	0.4387	2	0.0684	2	0.0033	2	0.9782	2	0.8854	2	0.6890	2
3	0.6626	3	0.1639	3	0.0122	3	0.9969	3	0.9686	3	0.8653	3
4	0.8267	4	0.3038	4	0.0339	4	0.9996	4	0.9929	4	0.9514	4
5	0.9228	5	0.4680	5	0.0762	5	1.0000	5	0.9987	5	0.9850	5
6	0.9698	6	0.6283	6	0.1452	6	1.0000	6	0.9998	6	0.9960	6
7	0.9895	7	0.7626	7	0.2415	7	1.0000	7	1.0000	7	0.9991	7
8	0.9967	8	0.8611	8	0.3591	8	1.0000	8	1.0000	8	0.9998	8
9	0.9991	9	0.9252	9	0.4868	9	1.0000	9	1.0000	9	1.0000	9
10	0.9998	10	0.9628	10	0.6116	10	1.0000	10	1.0000	10	1.0000	10
11	0.9999	11	0.9828	11	0.7225	11	1.0000	11	1.0000	11	1.0000	11
12	1.0000	12	0.9926	12	0.8127	12	1.0000	12	1.0000	12	1.0000	12
13	1.0000	13	0.9970	13	0.8806	13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	0.9989	14	0.9279	14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	0.9996	15	0.9587	15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	0.9999	16	0.9776	16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	0.9884	17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	0.9943	18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	0.9973	19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	0.9988	20	1.0000	20	1.0000	20	1.0000	20
21	1.0000	21	1.0000	21	0.9995	21	1.0000	21	1.0000	21	1.0000	21
22	1.0000	22	1.0000	22	0.9998	22	1.0000	22	1.0000	22	1.0000	22
23	1.0000	23	1.0000	23	0.9999	23	1.0000	23	1.0000	23	1.0000	23
24	1.0000	24	1.0000	24	1.0000	24	1.0000	24	1.0000	24	1.0000	24
25	1.0000	25	1.0000	25	1.0000	25	1.0000	25	1.0000	25	1.0000	25
26	1.0000	26	1.0000	26	1.0000	26	1.0000	26	1.0000	26	1.0000	26
27	1.0000	27	1.0000	27	1.0000	27	1.0000	27	1.0000	27	1.0000	27
28	1.0000	28	1.0000	28	1.0000	28	1.0000	28	1.0000	28	1.0000	28
29	1.0000	29	1.0000	29	1.0000	29	1.0000	29	1.0000	29	1.0000	29
30	1.0000	30	1.0000	30	1.0000	30	1.0000	30	1.0000	30	1.0000	30

	IR Scanner						Targeting						Video Scanner					
	P(X <=x)	x19	P(X <=x)	x20	P(X <=x)	x21	P(X <=x)	x22	P(X <=x)	x23	P(X <=x)	x24	P(X <=x)	x49	P(X <=x)	x41	P(X <=x)	x42
0	0.0105	0	0.0001	0	0.0000	0	0.0769	0	0.0059	0	0.0002	0	0.4401	0	0.1937	0	0.0648	0
1	0.0582	1	0.0011	1	0.0000	1	0.2742	1	0.0363	1	0.0018	1	0.8013	1	0.5116	1	0.2422	1
2	0.1669	2	0.0057	2	0.0000	2	0.5273	2	0.1141	2	0.0089	2	0.9495	2	0.7728	2	0.4848	2
3	0.3323	3	0.0195	3	0.0002	3	0.7436	3	0.2472	3	0.0291	3	0.9901	3	0.9153	3	0.7061	3
4	0.5208	4	0.0510	4	0.0007	4	0.8823	4	0.4180	4	0.0722	4	0.9984	4	0.9740	4	0.8575	4
5	0.6926	5	0.1086	5	0.0024	5	0.9535	5	0.5932	5	0.1459	5	0.9998	5	0.9932	5	0.9403	5
6	0.8233	6	0.1961	6	0.0067	6	0.9839	6	0.7429	6	0.2509	6	1.0000	6	0.9985	6	0.9781	6
7	0.9084	7	0.3100	7	0.0160	7	0.9951	7	0.8527	7	0.3792	7	1.0000	7	0.9997	7	0.9929	7
8	0.9569	8	0.4400	8	0.0337	8	0.9986	8	0.9231	8	0.5162	8	1.0000	8	0.9999	8	0.9979	8
9	0.9815	9	0.5716	9	0.0636	9	0.9997	9	0.9632	9	0.6465	9	1.0000	9	1.0000	9	0.9994	9
10	0.9927	10	0.6917	10	0.1091	10	0.9999	10	0.9838	10	0.7578	10	1.0000	10	1.0000	10	0.9999	10
11	0.9973	11	0.7912	11	0.1718	11	1.0000	11	0.9934	11	0.8444	11	1.0000	11	1.0000	11	1.0000	11
12	0.9991	12	0.8669	12	0.2514	12	1.0000	12	0.9975	12	0.9060	12	1.0000	12	1.0000	12	1.0000	12
13	0.9997	13	0.9199	13	0.3444	13	1.0000	13	0.9991	13	0.9466	13	1.0000	13	1.0000	13	1.0000	13
14	0.9999	14	0.9545	14	0.4453	14	1.0000	14	0.9997	14	0.9714	14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	0.9755	15	0.5476	15	1.0000	15	0.9999	15	0.9855	15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	0.9875	16	0.6448	16	1.0000	16	1.0000	16	0.9930	16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	0.9939	17	0.7317	17	1.0000	17	1.0000	17	0.9968	17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	0.9972	18	0.8051	18	1.0000	18	1.0000	18	0.9986	18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	0.9988	19	0.8638	19	1.0000	19	1.0000	19	0.9994	19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	0.9995	20	0.9084	20	1.0000	20	1.0000	20	0.9998	20	1.0000	20	1.0000	20	1.0000	20
21	1.0000	21	0.9998	21	0.9407	21	1.0000	21	1.0000	21	0.9999	21	1.0000	21	1.0000	21	1.0000	21
22	1.0000	22	0.9999	22	0.9630	22	1.0000	22	1.0000	22	1.0000	22	1.0000	22	1.0000	22	1.0000	22
23	1.0000	23	1.0000	23	0.9777	23	1.0000	23	1.0000	23	1.0000	23	1.0000	23	1.0000	23	1.0000	23
24	1.0000	24	1.0000	24	0.9871	24	1.0000	24	1.0000	24	1.0000	24	1.0000	24	1.0000	24	1.0000	24
25	1.0000	25	1.0000	25	0.9928	25	1.0000	25	1.0000	25	1.0000	25	1.0000	25	1.0000	25	1.0000	25
26	1.0000	26	1.0000	26	0.9961	26	1.0000	26	1.0000	26	1.0000	26	1.0000	26	1.0000	26	1.0000	26
27	1.0000	27	1.0000	27	0.9979	27	1.0000	27	1.0000	27	1.0000	27	1.0000	27	1.0000	27	1.0000	27
28	1.0000	28	1.0000	28	0.9990	28	1.0000	28	1.0000	28	1.0000	28	1.0000	28	1.0000	28	1.0000	28
29	1.0000	29	1.0000	29	0.9995	29	1.0000	29	1.0000	29	1.0000	29	1.0000	29	1.0000	29	1.0000	29
30	1.0000	30	1.0000	30	0.9998	30	1.0000	30	1.0000	30	1.0000	30	1.0000	30	1.0000	30	1.0000	30

	1 Main Display Unit					
	P(X <=x)	x1	P(X <=x)	x2	P(X <=x)	x3
0	0.4876	0	0.2378	0	0.0913	0
1	0.8378	1	0.5793	1	0.3097	1
2	0.9636	2	0.8246	2	0.5713	2
3	0.9937	3	0.9421	3	0.7800	3
4	0.9991	4	0.9843	4	0.9049	4
5	0.9999	5	0.9964	5	0.9647	5
6	1.0000	6	0.9993	6	0.9885	6
7	1.0000	7	0.9999	7	0.9967	7
8	1.0000	8	1.0000	8	0.9992	8
9	1.0000	9	1.0000	9	0.9998	9
10	1.0000	10	1.0000	10	1.0000	10
11	1.0000	11	1.0000	11	1.0000	11
12	1.0000	12	1.0000	12	1.0000	12
13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

	2 Power Supply					
	P(X <=x)	x4	P(X <=x)	x5	P(X <=x)	x6
0	0.8356	0	0.6983	0	0.5496	0
1	0.9857	1	0.9491	1	0.8786	1
2	0.9992	2	0.9941	2	0.9770	2
3	1.0000	3	0.9995	3	0.9967	3
4	1.0000	4	1.0000	4	0.9996	4
5	1.0000	5	1.0000	5	1.0000	5
6	1.0000	6	1.0000	6	1.0000	6
7	1.0000	7	1.0000	7	1.0000	7
8	1.0000	8	1.0000	8	1.0000	8
9	1.0000	9	1.0000	9	1.0000	9
10	1.0000	10	1.0000	10	1.0000	10
11	1.0000	11	1.0000	11	1.0000	11
12	1.0000	12	1.0000	12	1.0000	12
13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

	3 Power Generator					
	P(X <=x)	x7	P(X <=x)	x8	P(X <=x)	x9
0	0.8145	0	0.6634	0	0.5046	0
1	0.9816	1	0.9356	1	0.8497	1
2	0.9988	2	0.9915	2	0.9678	2
3	0.9999	3	0.9991	3	0.9947	3
4	1.0000	4	0.9999	4	0.9993	4
5	1.0000	5	1.0000	5	0.9999	5
6	1.0000	6	1.0000	6	1.0000	6
7	1.0000	7	1.0000	7	1.0000	7
8	1.0000	8	1.0000	8	1.0000	8
9	1.0000	9	1.0000	9	1.0000	9
10	1.0000	10	1.0000	10	1.0000	10
11	1.0000	11	1.0000	11	1.0000	11
12	1.0000	12	1.0000	12	1.0000	12
13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

	4 Air Conditioner					
	P(X <=x)	x13	P(X <=x)	x14	P(X <=x)	x15
0	0.8872	0	0.7871	0	0.6710	0
1	0.9934	1	0.9755	1	0.9387	1
2	0.9997	2	0.9981	2	0.9921	2
3	1.0000	3	0.9999	3	0.9992	3
4	1.0000	4	1.0000	4	0.9999	4
5	1.0000	5	1.0000	5	1.0000	5
6	1.0000	6	1.0000	6	1.0000	6
7	1.0000	7	1.0000	7	1.0000	7
8	1.0000	8	1.0000	8	1.0000	8
9	1.0000	9	1.0000	9	1.0000	9
10	1.0000	10	1.0000	10	1.0000	10
11	1.0000	11	1.0000	11	1.0000	11
12	1.0000	12	1.0000	12	1.0000	12
13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

	5 Contol Panel					
	P(X <=x)	x16	P(X <=x)	x17	P(X <=x)	x18
0	0.2378	0	0.0565	0	0.0083	0
1	0.5793	1	0.2190	1	0.0482	1
2	0.8246	2	0.4523	2	0.1437	2
3	0.9421	3	0.6757	3	0.2961	3
4	0.9843	4	0.8362	4	0.4784	4
5	0.9964	5	0.9284	5	0.6531	5
6	0.9993	6	0.9725	6	0.7925	6
7	0.9999	7	0.9906	7	0.8878	7
8	1.0000	8	0.9971	8	0.9449	8
9	1.0000	9	0.9992	9	0.9752	9
10	1.0000	10	0.9998	10	0.9898	10
11	1.0000	11	1.0000	11	0.9961	11
12	1.0000	12	1.0000	12	0.9986	12
13	1.0000	13	1.0000	13	0.9995	13
14	1.0000	14	1.0000	14	0.9999	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

	1 Rotation Engine					
	P(X <=x)	x10	P(X <=x)	x11	P(X <=x)	x12
0	0.6554	0	0.4296	0	0.2446	0
1	0.9323	1	0.7926	1	0.5890	1
2	0.9908	2	0.9459	2	0.8315	2
3	0.9991	3	0.9891	3	0.9453	3
4	0.9999	4	0.9982	4	0.9854	4
5	1.0000	5	0.9998	5	0.9967	5
6	1.0000	6	1.0000	6	0.9994	6
7	1.0000	7	1.0000	7	0.9999	7
8	1.0000	8	1.0000	8	1.0000	8
9	1.0000	9	1.0000	9	1.0000	9
10	1.0000	10	1.0000	10	1.0000	10
11	1.0000	11	1.0000	11	1.0000	11
12	1.0000	12	1.0000	12	1.0000	12
13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

	2 Receiver					
	P(X <=x)	x1	P(X <=x)	x2	P(X <=x)	x3
0	0.4075	0	0.1660	0	0.0502	0
1	0.7733	1	0.4642	1	0.2003	1
2	0.9375	2	0.7318	2	0.4249	2
3	0.9867	3	0.8920	3	0.6489	3
4	0.9977	4	0.9639	4	0.8165	4
5	0.9997	5	0.9897	5	0.9168	5
6	1.0000	6	0.9975	6	0.9669	6
7	1.0000	7	0.9994	7	0.9883	7
8	1.0000	8	0.9999	8	0.9963	8
9	1.0000	9	1.0000	9	0.9989	9
10	1.0000	10	1.0000	10	0.9997	10
11	1.0000	11	1.0000	11	0.9999	11
12	1.0000	12	1.0000	12	1.0000	12
13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

	3 Transmiter					
	P(X <=x)	x1	P(X <=x)	x2	P(X <=x)	x3
0	0.3312	0	0.1097	0	0.0251	0
1	0.6972	1	0.3522	1	0.1178	1
2	0.8994	2	0.6201	2	0.2883	2
3	0.9739	3	0.8174	3	0.4977	3
4	0.9945	4	0.9264	4	0.6905	4
5	0.9990	5	0.9746	5	0.8325	5
6	0.9998	6	0.9924	6	0.9197	6
7	1.0000	7	0.9980	7	0.9665	7
8	1.0000	8	0.9995	8	0.9867	8
9	1.0000	9	0.9999	9	0.9953	9
10	1.0000	10	1.0000	10	0.9985	10
11	1.0000	11	1.0000	11	0.9995	11
12	1.0000	12	1.0000	12	0.9999	12
13	1.0000	13	1.0000	13	1.0000	13
14	1.0000	14	1.0000	14	1.0000	14
15	1.0000	15	1.0000	15	1.0000	15
16	1.0000	16	1.0000	16	1.0000	16
17	1.0000	17	1.0000	17	1.0000	17
18	1.0000	18	1.0000	18	1.0000	18
19	1.0000	19	1.0000	19	1.0000	19
20	1.0000	20	1.0000	20	1.0000	20

A_o

	A	B	C	D	E	F	G	H	I	J	K	L
1	Operational Availability of the UAV System (Desired)											
2			MIN	TARGET	MAX	Number of Component						
3	1	UAV	0.85	0.9	0.95	6						
4	2	Payload	0.85	0.9	0.95	3			UAV	1	2	3
5	3	GCS	0.95	0.97	0.99	5			Antenna System	0.949817	0.940331	0.908390
6	4	GDT	0.95	0.97	0.99	3			Navigation Computer	0.942431	0.925668	0.935828
7		UAV System	0.551081	0.741943	0.91782				Sensors (Probe Tube, Tempr.)	0.925193	0.912921	0.907035
8									Landing Gears	0.940331	0.947662	0.919942
9		Ao (day/year)	201	271	335				Engine	0.922837	0.925193	0.927903
10									Propeller	0.978218	0.968561	0.951377
11									PAYLOAD			
12									IR Scanner	0.908390	0.919942	0.908387
13	Operational Availability of the UAV System (Achieved)								Targeting	0.953495	0.923088	0.906031
14		Year	1	2	3	Number of Component			Video Scanner	0.949540	0.915349	0.940331
15	1	UAV comp	0.992221	0.988817	0.980475	6			GCS			
16	2	Payload comp	0.999006	0.99754	0.997387	3			Main Display Unit	0.993714	0.984261	0.988550
17	3	GCS comp	0.940089	0.92037	0.929538	5			Power Supply	0.985686	0.994090	0.977033
18	4	GDT comp	0.952067	0.954093	0.960854	3			Power Generator	0.981617	0.991504	0.994689
19		UAV System	0.887183	0.866163	0.873424				Air Conditioner	0.993383	0.975532	0.992127
20									Control Panel	0.984261	0.972502	0.975225
21		Ao (day/year)	324	316	319				GDT			
22									Rotation Engine	0.990814	0.989089	0.985419
23									Receiver	0.986652	0.989739	0.988257
24									Transmitter	0.973893	0.974619	0.986658

CONTRACT COST

	A	B	C	D	E	F	G
1	UAV System Cost	$14,200,000		Contingency	Probability		
2	UAV Support Equipment (hrs/yr)	2555		1	40%		
3	UAV (hrs/yr)	1825		0	60%		
4	Fuel Capacity (lb)	426					
5	Diesel Conversion (lb/gal)	7.034					
6	Fuel Capacity (gal)	60.56					
7	UAV fuel burn rate (gal/hr)	1.44					
8	Oil&Lubricant Consumption (gal/hr)	0.25					
9	cost of diesel fuel ($/gal)	1					
10	Number of I-level Maint. Center	5					
11							
12	Contingency	[redacted]					
13	Attrition Rate	0.1	0.1	0.25	0.1	0.1	0.25
14	Number of UAV in Operation	12	24	40	40	40	40
15	New Purchase of UAV&Payload	0	2	3	10	4	4
16	UAV System in Operation	3	6	10	10	10	10
17	UAV Operational Base	3	5	5	5	5	5
18							
19	**Year**	1	2	3	4	5	6
20	**INVESTMENT COST**						
21	Design&Technology Transfer Cost	$0	$0	$0	$0	$0	$50,000,000
22	Initial Procurement UAV System	$45,156,000	$47,865,360	$67,649,709	$0	$0	$0
23	I-Level Special Support Equipment	$143,100	$101,124	$0	$0	$0	$0
24	**Total Investment Cost**	$45,299,100	$47,966,484	$67,649,709	$0	$0	$50,000,000
25							
26							
27	**OPERATION AND MAINTENAINCE**						
28	O-level Maintenance Material Cost	$4,642,800	$9,842,736	$17,388,834	$18,432,164	$19,538,093	$20,710,379
29	O-level Preventive Mnt.MaterialCost	$696,420	$1,476,410	$2,608,325	$2,764,825	$2,930,714	$3,106,557
30	I-level Corrective Mnt.MaterialCost	$9,285,600	$19,685,472	$34,777,667	$36,864,327	$39,076,187	$41,420,758
31	Spare Part Cost	$22,285,000	$14,023,800	$20,865,252	$0	$0	$0
32	Repair and Replacement Cost	$190,269,591	$310,004,959	$617,963,616	$617,963,616	$617,963,616	$617,963,616
33	**Total O&M Cost**	$227,179,411	$355,033,377	$693,603,694	$676,024,931	$679,508,610	$683,201,310
34							
35							
36	**TRAINING**	1	2	3	4	5	6
37	**Operator Training**						
38	Operator Training O/H Cost	$20,385	$21,608	$22,904	$24,278	$25,735	$27,279
39	**Maintenance Training**						
40	O-level Maintenance Training O/H	$28,538	$30,251	$32,066	$33,990	$36,029	$38,191
41	I-level Maintenance Training O/H	$34,246	$36,301	$38,479	$40,788	$43,235	$45,829
42	**Total Training Cost**	$83,169	$88,159	$93,449	$99,056	$104,999	$111,299
43							
44							
45	**Year**	1	2	3	4	5	6
46	**TOTAL COSTS**						
47	Investment Costs	$45,299,100	$47,966,484	$67,649,709	$0	$0	$50,000,000
48	Operation&Maintenance Costs	$227,179,411	$355,033,377	$693,603,694	$676,024,931	$679,508,610	$683,201,310
49	Training Costs	$83,169	$88,159	$93,449	$99,056	$104,999	$111,299
50	Total Annual Costs	$272,561,680	$403,088,021	$761,346,852	$676,123,987	$679,613,610	$733,312,609
51	Discounted total Annual Costs	$272,561,680	$393,640,645	$726,076,938	$629,689,533	$618,104,977	$651,312,434
52	**NOTE:** Discount rate is 2.4%.						
53	TOTAL CONTRACT COST	$3,526,046,758					
54	PV OF TOTAL CONTACT COST	$3,291,386,207					
55							
56							
57	Year	1	2	3	4	5	6
58	Target Price	$272,561,680	$403,088,021	$761,346,852	$676,123,987	$679,613,610	$733,312,609
59	Target Fee	8%	8%	8%	8%	8%	8%
60	Target Fee	$20,189,754	$29,858,372	$56,396,063	$50,083,258	$50,341,749	$54,319,453
61	Target Cost	$252,371,926	$373,229,649	$704,950,788	$626,040,729	$629,271,861	$678,993,157
62		$272,561,680					
63	Minimum Price	$263,500,569	$389,625,609	$729,356,927	$645,959,913	$649,449,535	$703,148,535
64	Minimum Fee	4.41%	4.39%	3.46%	3.18%	3.21%	3.56%
65		=(B6-B4)/B4					
66	Maximum Price	$310,332,206	$449,139,793	$820,037,433	$732,567,368	$736,056,991	$789,755,990
67	Maximum Fee	22.97%	20.34%	16.33%	17.02%	16.97%	16.31%
68		=(B10-B4)/B4					

APPENDIX C: UAV MODEL SIMULATION RESULTS FOR FPI CONTRACT

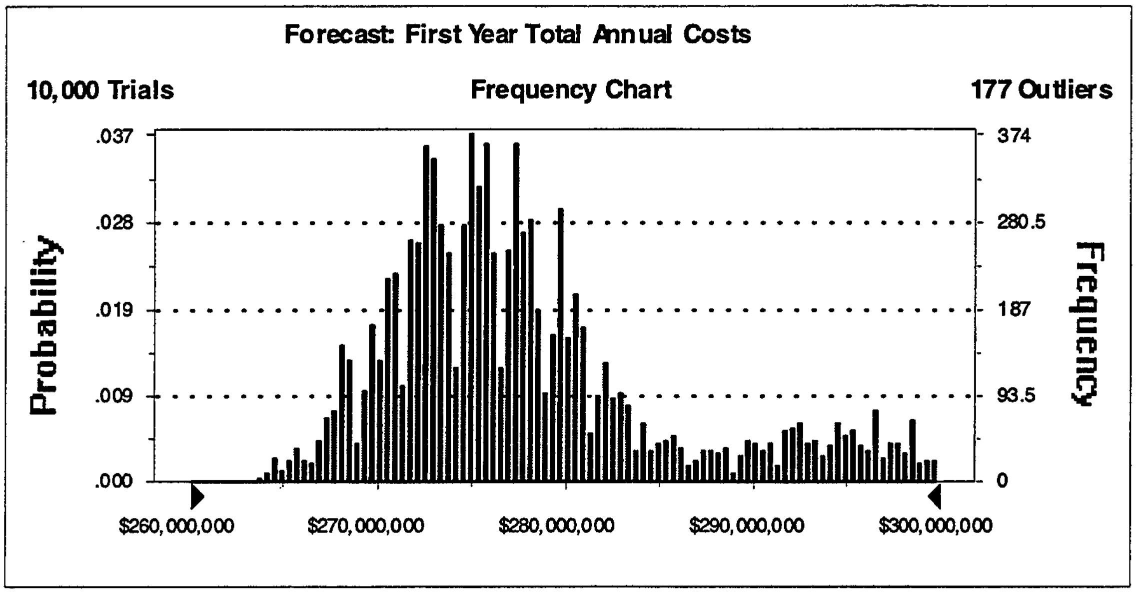


FIGURE 1 Simulation Results for the UAV FPI Contract First Year Total Annual Costs (Range:$263,500,569 - $310,332,206)

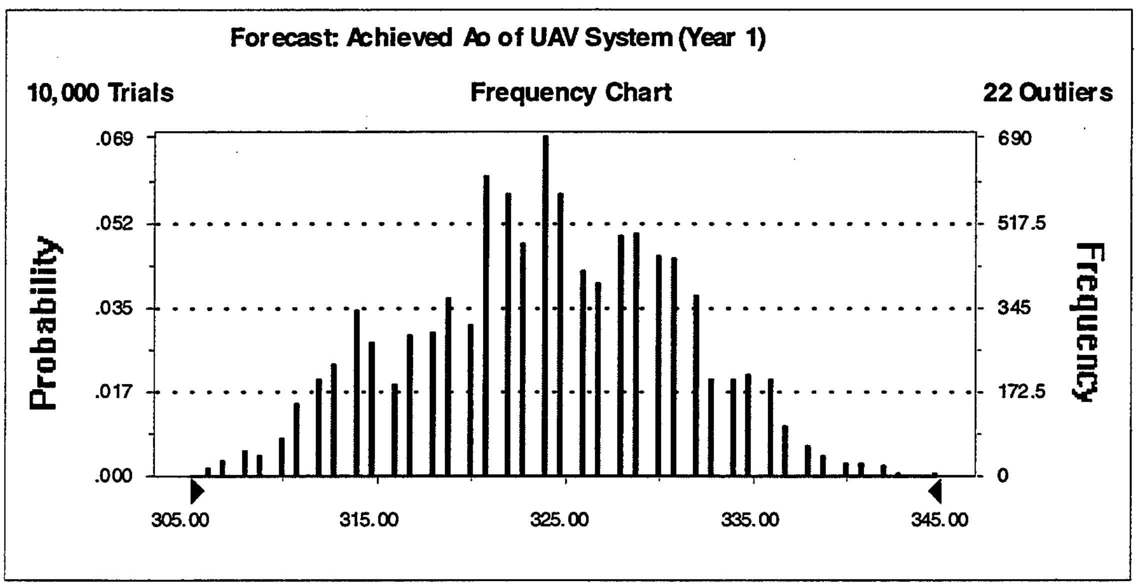


FIGURE 2 Simulation Results for the Achieved Operational Availability of UAV System in Year 1 (Range: 302 days – 350 days)

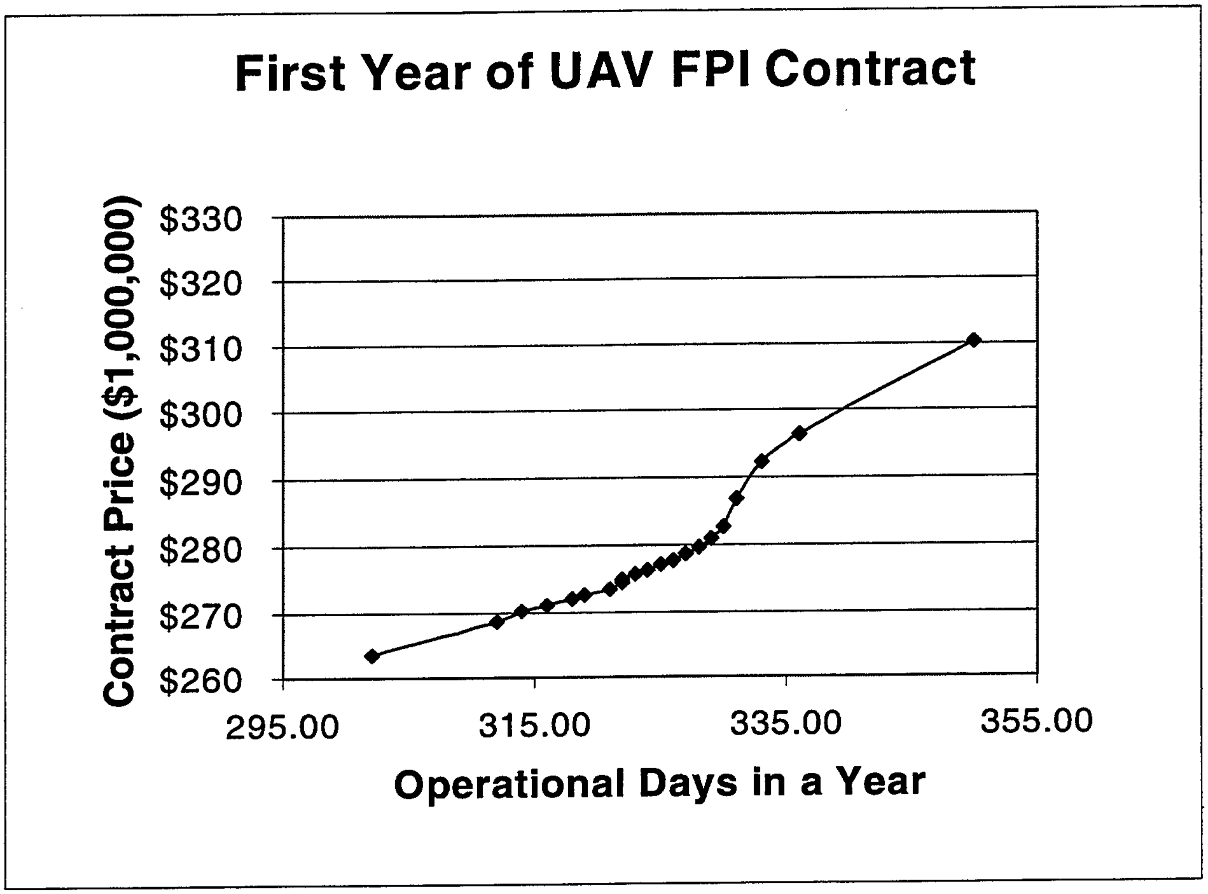


FIGURE 3 Simulation Results for the First Year of the UAV FPI Contract Price for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Contract Price
0%	302.00	$263,500,569
5%	312.00	$268,651,095
10%	314.00	$270,177,177
15%	316.00	$271,130,978
20%	318.00	$272,084,779
25%	319.00	$272,657,060
30%	321.00	$273,515,481
35%	322.00	$274,469,282
40%	322.00	$274,946,183
45%	323.00	$275,804,604
50%	324.00	$276,376,885
55%	325.00	$277,235,306
60%	326.00	$277,807,586
65%	327.00	$278,761,387
70%	328.00	$279,715,189
75%	329.00	$281,050,510
80%	330.00	$282,671,972
85%	331.00	$286,773,317
90%	333.00	$292,209,984
95%	336.00	$296,406,709
100%	350.00	$310,332,206

TABLE 1 Simulation Results for the First Year of the UAV FPI Contract Price for Possible Operational Availability Levels

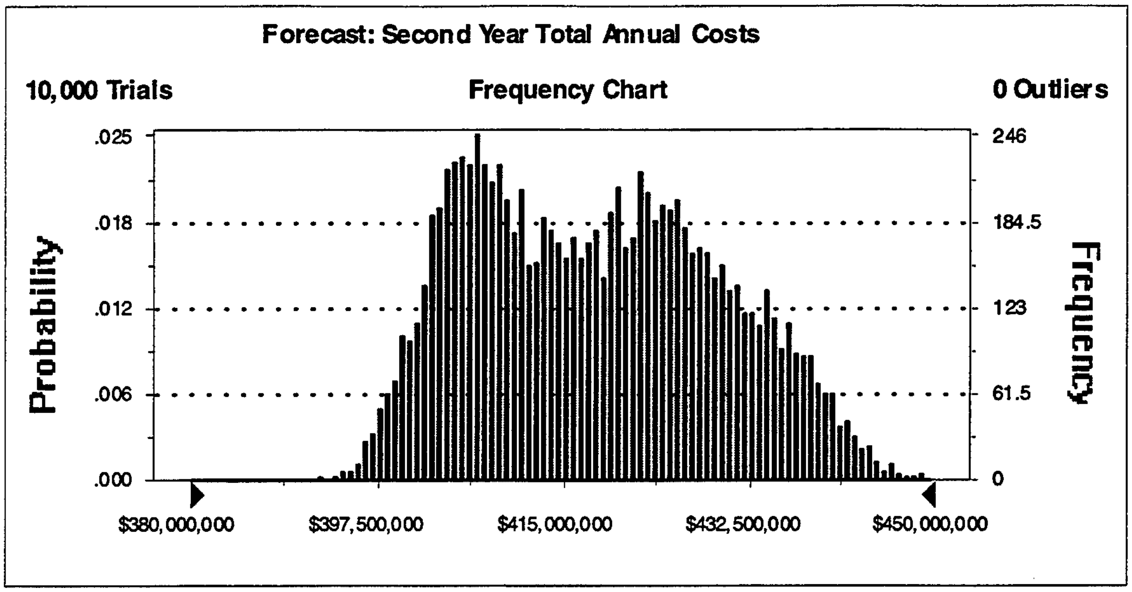


FIGURE 4 Simulation Results for the UAV FPI Contract Second Year Total Annual Costs (Range:$389,635,609 - $449,139,793)

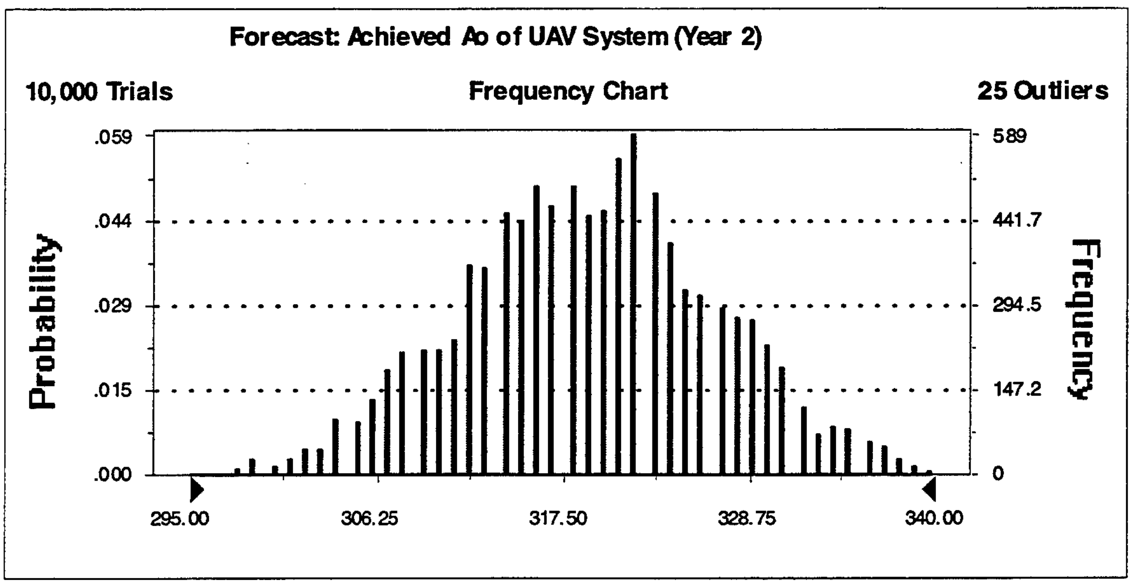


FIGURE 5 Simulation Results for the Achieved Operational Availability of UAV System in Year 2 (Range: 291 days – 342 days)

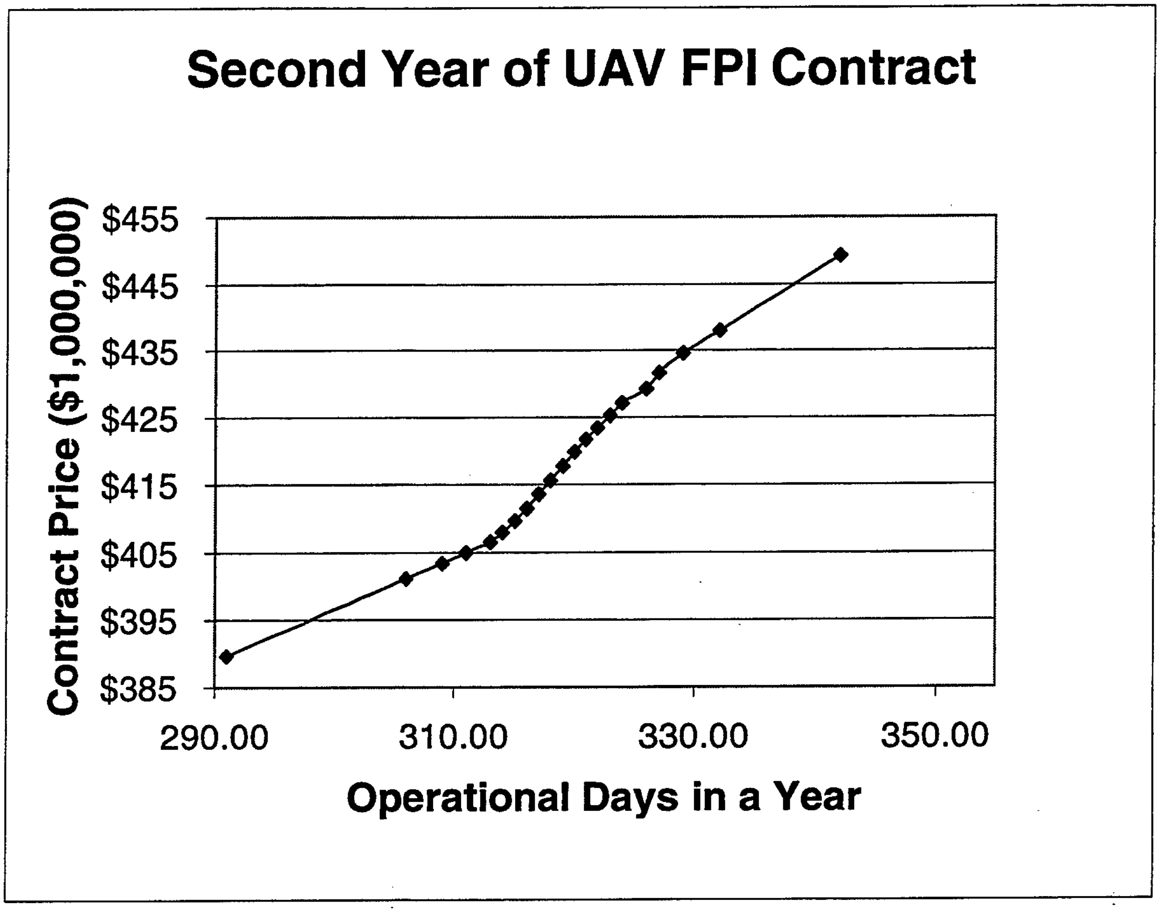


FIGURE 6 Simulation Results for the Second Year of the UAV FPI Contract Price for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Contract Price
0%	291.00	$389,625,609
5%	306.00	$401,151,342
10%	309.00	$403,414,013
15%	311.00	$405,002,404
20%	313.00	$406,537,860
25%	314.00	$408,019,769
30%	315.00	$409,625,880
35%	316.00	$411,428,208
40%	317.00	$413,580,430
45%	318.00	$415,659,612
50%	319.00	$417,720,076
55%	320.00	$419,803,834
60%	321.00	$421,732,138
65%	322.00	$423,388,190
70%	323.00	$425,224,182
75%	324.00	$427,072,901
80%	326.00	$429,244,617
85%	327.00	$431,662,325
90%	329.00	$434,570,240
95%	332.00	$437,961,764
100%	342.00	$449,139,793

TABLE 2 Simulation Results for the Second Year of the UAV FPI Contract Price for Possible Operational Availability Levels

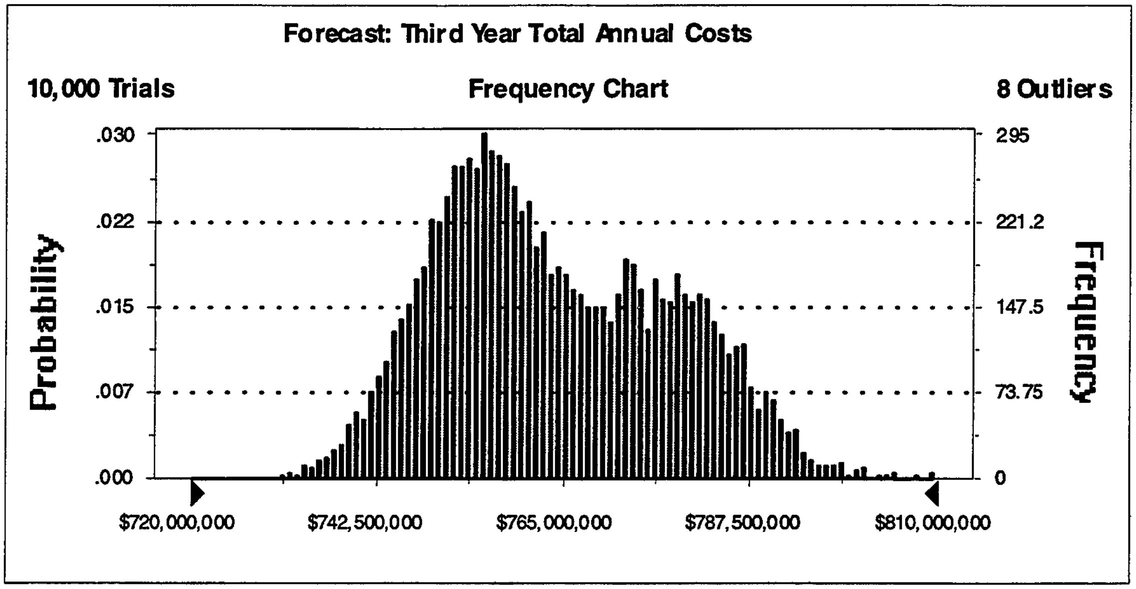


FIGURE 7 Simulation Results for the UAV FPI Contract Third Year Total Annual Costs (Range:$729,356,927 - $820,037,433)

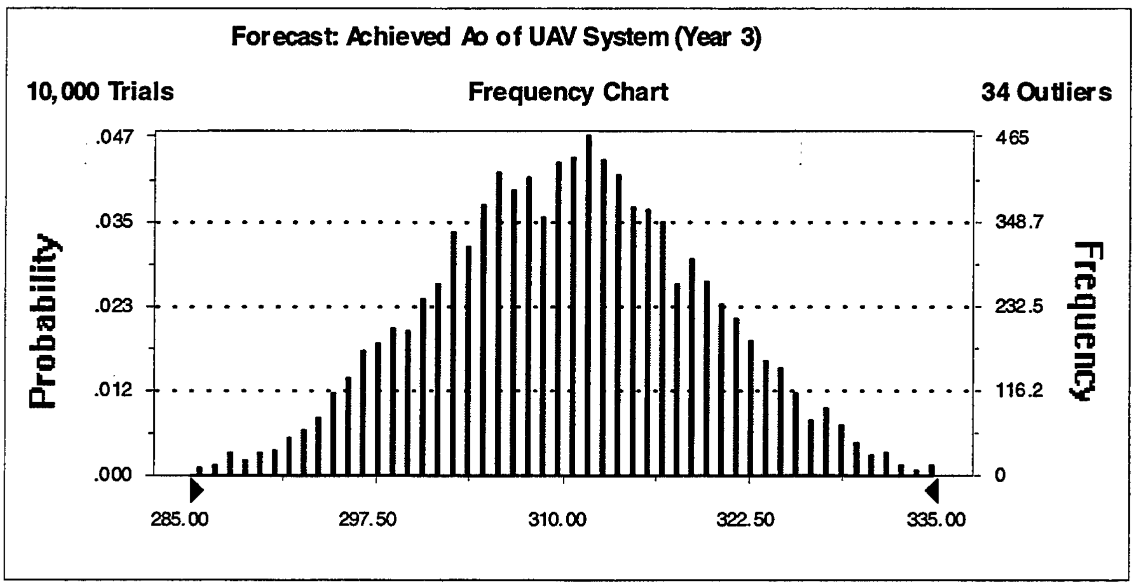


FIGURE 8 Simulation Results for the Achieved Operational Availability of UAV System in Year 3 (Range: 279 days – 341 days)

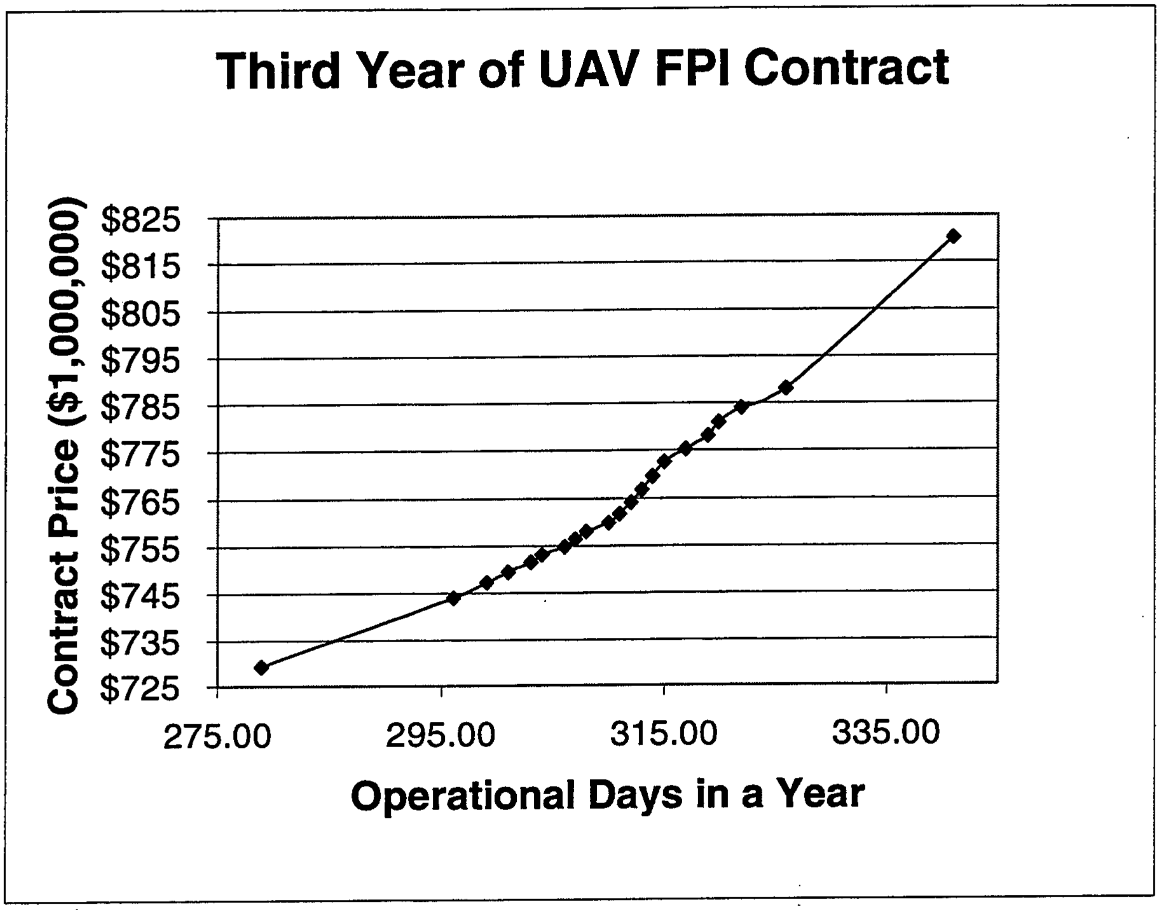


FIGURE 9 Simulation Results for the Third Year of the UAV FPI Contract Price for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Contract Cost
0%	279.00	$729,356,927
5%	296.00	$743,971,495
10%	299.00	$747,224,426
15%	301.00	$749,595,373
20%	303.00	$751,552,939
25%	304.00	$753,178,515
30%	306.00	$754,825,571
35%	307.00	$756,433,344
40%	308.00	$758,055,577
45%	310.00	$759,841,950
50%	311.00	$761,784,333
55%	312.00	$764,118,230
60%	313.00	$766,693,054
65%	314.00	$769,656,889
70%	315.00	$772,634,463
75%	317.00	$775,258,749
80%	319.00	$778,183,560
85%	320.00	$780,941,503
90%	322.00	$783,969,336
95%	326.00	$788,066,487
100%	341.00	$820,037,433

TABLE 3 Simulation Results for the Third Year of the UAV FPI Contract Price for Possible Operational Availability Levels

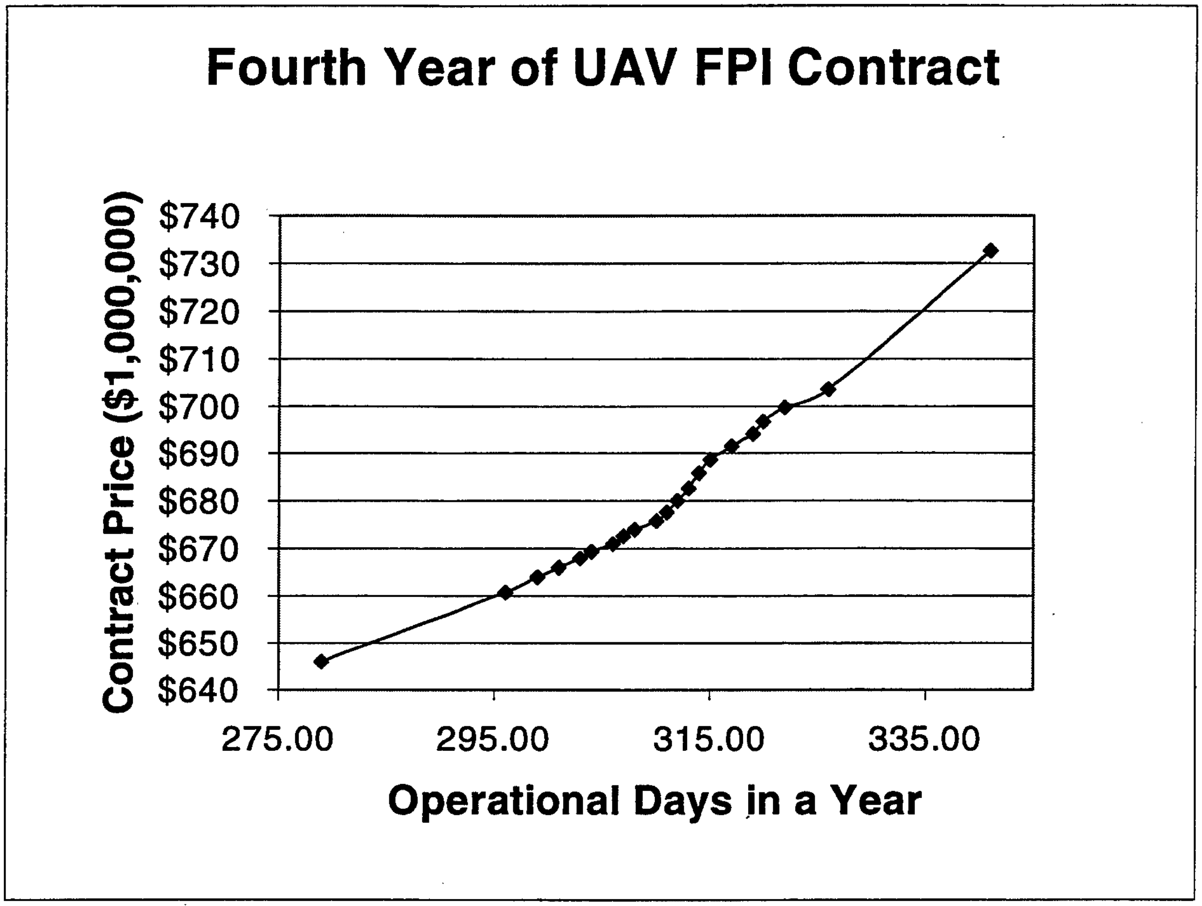


FIGURE 10 Simulation Results for the Fourth Year of the UAV FPI Contract Price for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Contract Price
0%	279.00	$645,959,913
5%	296.00	$660,813,435
10%	299.00	$664,012,654
15%	301.00	$666,126,425
20%	303.00	$668,011,679
25%	304.00	$669,554,161
30%	306.00	$671,039,513
35%	307.00	$672,581,994
40%	308.00	$674,124,475
45%	310.00	$675,838,343
50%	311.00	$677,723,597
55%	312.00	$680,008,754
60%	313.00	$682,693,814
65%	314.00	$685,835,905
70%	315.00	$688,692,351
75%	317.00	$691,434,540
80%	319.00	$694,176,729
85%	320.00	$696,804,659
90%	322.00	$699,718,235
95%	326.00	$703,545,873
100%	341.00	$732,567,368

TABLE 4 Simulation Results for the Fourth Year of the UAV FPI Contract Price for Possible Operational Availability Levels

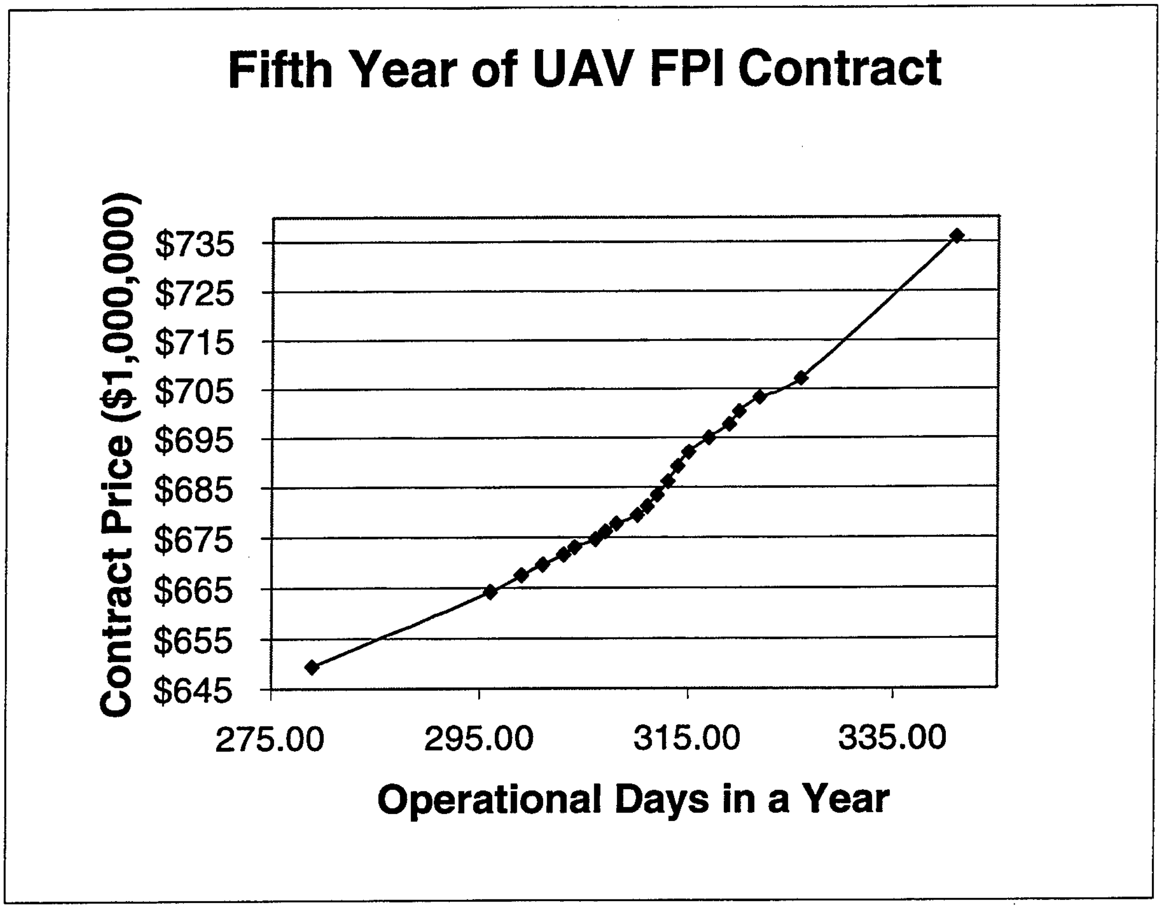


FIGURE 11 Simulation Results for the Fifth Year of the UAV FPI Contract Price for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Contract Price
0%	279.00	$649,449,535
5%	296.00	$664,303,057
10%	299.00	$667,502,277
15%	301.00	$669,616,047
20%	303.00	$671,501,302
25%	304.00	$673,043,783
30%	306.00	$674,529,135
35%	307.00	$676,071,616
40%	308.00	$677,614,097
45%	310.00	$679,327,965
50%	311.00	$681,213,220
55%	312.00	$683,498,377
60%	313.00	$686,183,436
65%	314.00	$689,325,527
70%	315.00	$692,181,974
75%	317.00	$694,924,162
80%	319.00	$697,666,351
85%	320.00	$700,294,282
90%	322.00	$703,207,857
95%	326.00	$707,035,495
100%	341.00	$736,056,991

TABLE 5 Simulation Results for the Fifth Year of the UAV FPI Contract Price for Possible Operational Availability Levels

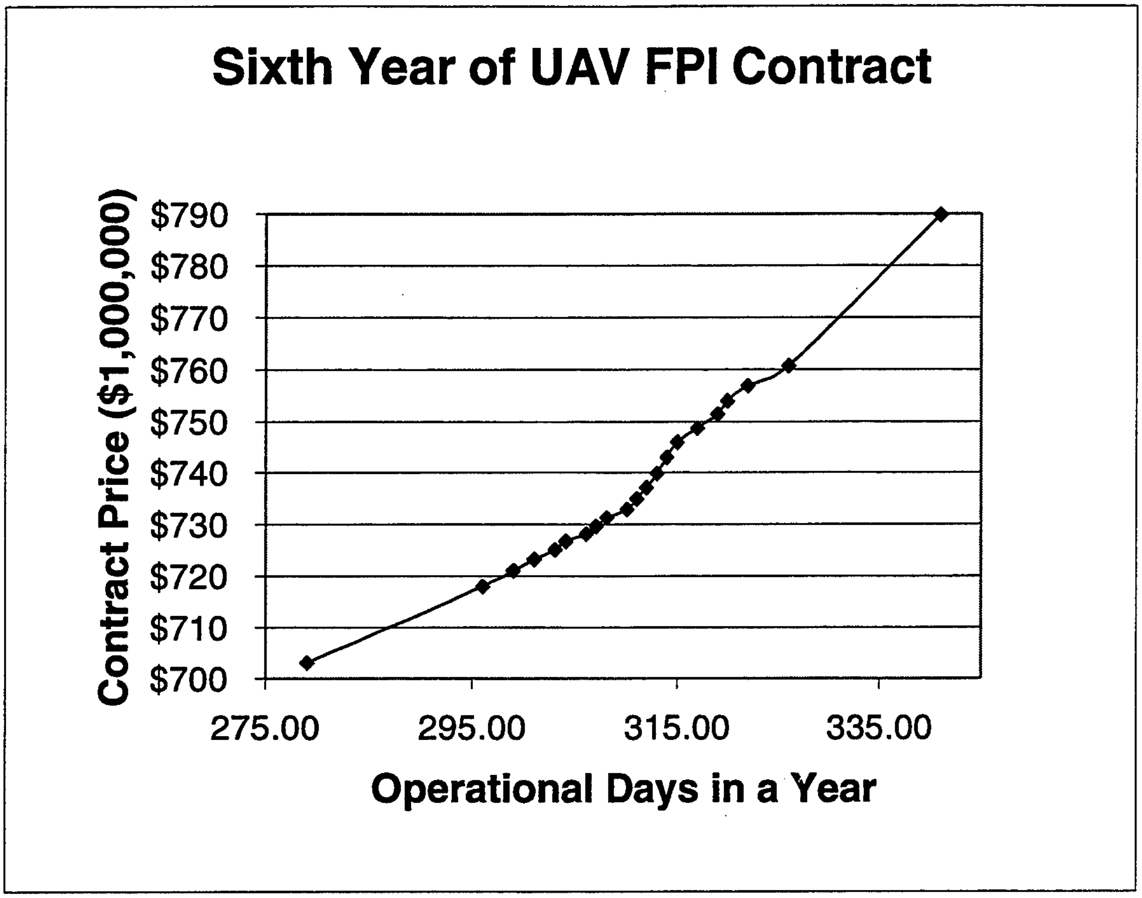


FIGURE 12 Simulation Results for the Sixth Year of the UAV FPI Contract Price for Possible Operational Availability Levels

Percentile	Ao (day in a year)	Contract Price
0%	279.00	$703,148,535
5%	296.00	$718,002,056
10%	299.00	$721,201,276
15%	301.00	$723,315,047
20%	303.00	$725,200,301
25%	304.00	$726,742,782
30%	306.00	$728,228,135
35%	307.00	$729,770,616
40%	308.00	$731,313,097
45%	310.00	$733,026,965
50%	311.00	$734,912,219
55%	312.00	$737,197,376
60%	313.00	$739,882,436
65%	314.00	$743,024,527
70%	315.00	$745,880,973
75%	317.00	$748,623,162
80%	319.00	$751,365,350
85%	320.00	$753,993,281
90%	322.00	$756,906,856
95%	326.00	$760,734,495
100%	341.00	$789,755,990

TABLE 6 Simulation Results for the Sixth Year of the UAV FPI Contract Price for Possible Operational Availability Levels

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