

## **Forecasting Operation & Support Costs For Missiles and Munitions**

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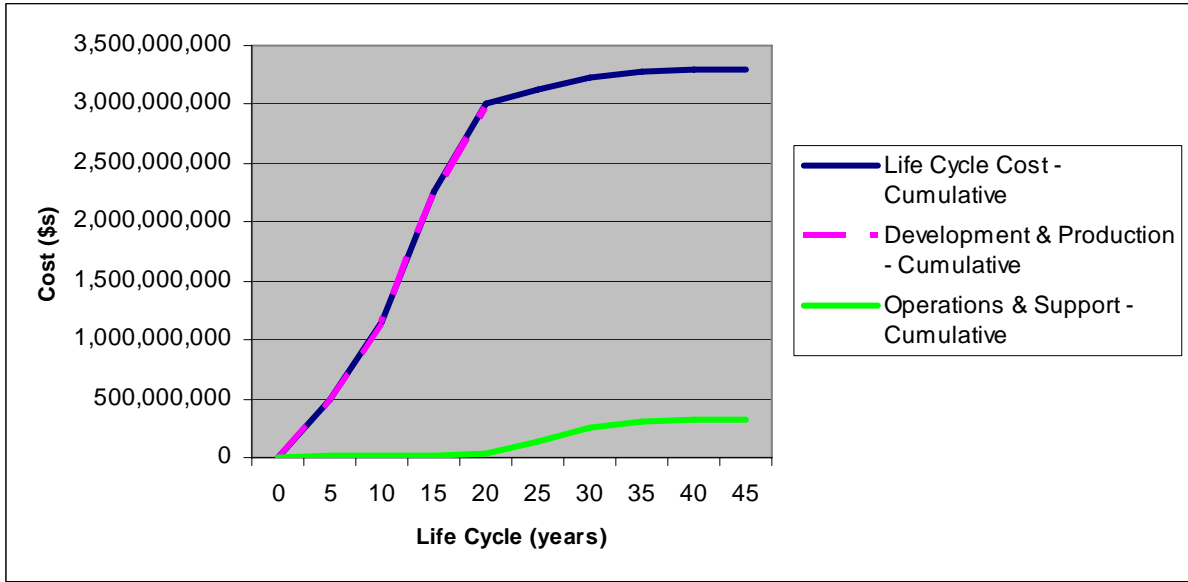
### **Missiles and Munitions – A Unique O&S Profile**

Operations and Support (O&S) cost models for many weapons systems consider factors such as maintenance and operational costs for continuous or periodic usage. But what about weapons such as missiles or other types of munitions that are used only once? Most of the assets from missile and other munitions program will initially be put in storage after production rather than being deployed to operational units. Missiles and other munitions have unique operational, storage, testing and maintenance profiles that call for a unique cost model. This article will describe how to develop an O&S cost model for a missile or munition weapon system during each phase of a program.

### **Introduction**

Life Cycle Cost (LCC) is the total cost to the customer for a specified system program life, including all costs that would not be realized if the system was not built. O&S costs are a large part of LCC for military weapon systems ranging anywhere from 8% – 80%. Accurately defining O&S costs for a weapon system is a function of knowing what the cost factors are, and when and where the costs are incurred. O&S costs include maintenance planning and analysis, technical publications, training, spares, scheduled and unscheduled maintenance, surveillance testing, recertification and demilitarization. The O&S cost factors are then used to develop cost models for the different contracts or phases of a program. The O&S model in this article is developed for the Military Service level since a Military Service is the customer and the level at which O&S costs are accrued. An assumption of this article is that storage and other support services will be provided by the Military Service customer rather than a Department of Defense agency.

O&S costs occur through the entire development, deployment, operational and demilitarization phases of a program. Below is graph illustrating a weapon systems program life cycle, it's cumulative LCC made up of Development and Production, and O&S costs. LCC rises sharply during the Develop and Production phase, then levels out through the support phase when O&S costs alone contribute to LCC. For this weapon system O&S is 9.7% of LCC.

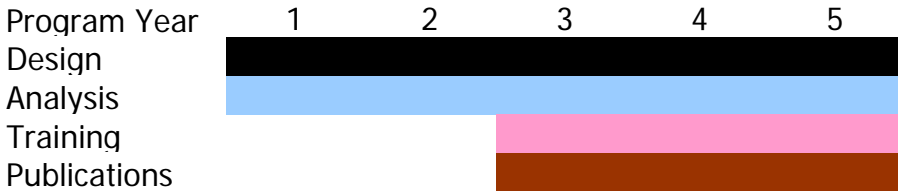


**Cumulative Weapon Systems Life Cycle Cost Elements**

Notes: Weapon Average Unit Production Price is \$80,000, 30,000 units are produced. Costs are in '05 dollars.

**Design Phase O&S**

Each phase of the weapon system will contain different O&S costs phasing in and out at different times. During the design phase of a program O&S costs will include analysis, training development and publications planning. Analysis consists of Logistics Support Planning, Hardware Maintainability Analysis, Human Factors analysis, Support Equipment planning, Spare Parts recommendation and Repair\Discard analysis. The chart below shows O&S costs during the design phase of a missile\munitions program.



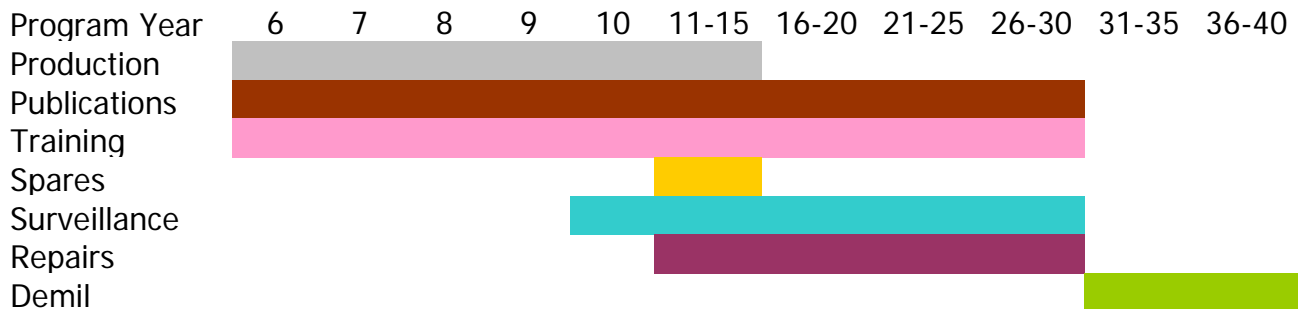
Program Design Phase Operation and Support Costs

Notes: Design is not an O&S cost, it is shown for the purpose of understanding when O&S costs occur in the program. Program Year time line is consistent for all charts.

## Production Deployment and Demilitarization Phase

During the production and deployment phase O&S costs will include classroom training, publications development and release, spares planning and acquisition, periodic testing (surveillance), Repair repairs and demilitarization. The chart below illustrates a missile\munitions system in its Production, Deployment and Demilitarization phases. The weapon has a 10 year production run and 25 year operational life span. Publications (Operations and Maintenance Manuals) are updated for new weapon configurations. Training for new operational units and for technology upgrades occurs throughout Production and Deployment.

Implementing a surveillance program, repair activity, and procurement of spares is necessary to support missiles and "smart" munitions with testable and repairable electronic sections. The predicted failure rate for the weapon and required asset availability determine when testing, repair and spares become necessary. A missile or other munition can spend 97% or more of its operational life span in a dormant state within protected storage (earthen bunker). The failure rate for a dormant asset in protected storage is very low. Spares will be procured while the weapon is in production. When the weapons begin to pass beyond their operational life the surveillance program and repairs may be stopped to reduce maintenance costs. Assets that pass an operational test can be deployed; assets that fail testing are demilitarized. Demilitarization is the disposal of hazardous materials (batteries, propellants, explosives) and recovery of reusable materials, and occurs as assets exceed their operational life.



### Program Production Phase Operation and Support Costs

Notes: Production is not an O&S cost, it is shown for the purpose of understanding when O&S costs occur in the program. Production starts at Program Year 6.

Knowing when and where money is spent for logistics services will aid the support provider plan spending accordingly. Logistics services may be provided under a Performance Based Logistics (PBL) contract in which the customer pays for a level of Operational Availability ( $A_o$ ), usually around 95%, rather than for specified logistics services. Under a PBL contract the logistics services provider (LSP) has the flexibility to

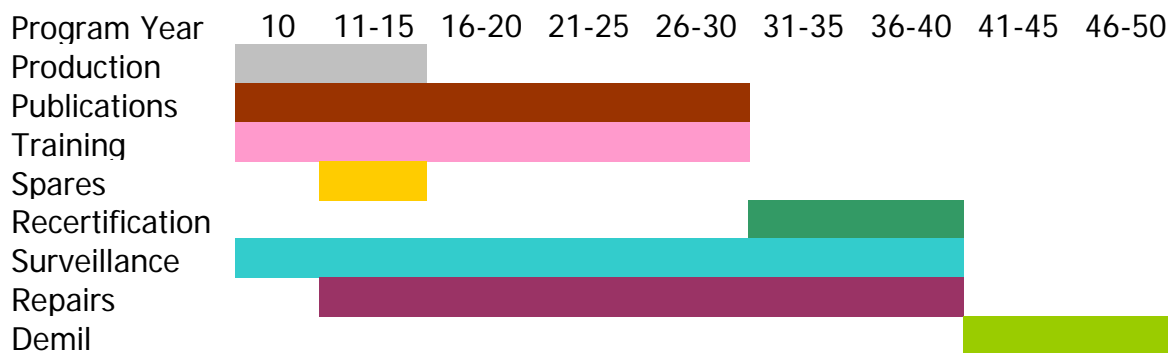
do what is necessary to maintain the contracted asset readiness level. For example, the number of assets tested annually can be determined by the LSP to ensure enough failures are identified and repaired to maintain asset availability.

One support approach a PBL contract can include to make the best use of the existing Military support infrastructure is the Public Private Partnership (PPP). In a PPP a weapons contractor pays a Military facility to provide storage and maintenance services. Many Military facilities function as a business providing services for Military assets. By having a Military facility provide storage and maintenance supports the concept of the customer buying performance rather than services, the Military facility manages the personnel and maintains their own support equipment rather than the Military Service level customer. The Military facility provides actual storage and labor costs to LSP in order for the LSP to perform an O&S cost analysis.

### Recertification

For a missile or munition to reach its full operational life span a battery, rocket motor or other life limited component may need to be replaced (recertification). Recertification also requires demilitarizing the old rocketmotor and battery. The O&S model can determine the O&S cost of recertification by adding the costs to the model.

The chart below shows the years in which O&S costs are accrued for recertification. O&S costs for extending the operational life of a missile or munition come from the additional surveillance and repair activity in years 31 thru 40, the recertification costs in years 31-40 and the demilitarization costs associated with replacement of the battery and rocketmotor. The usual demilitarization costs at the end of operational life are accrued in years 41 thru 50.



### Weapon Life Recertification Operation and Support Costs

Note: Production is not an O&S cost, it is shown for the purpose of understanding when O&S costs occur in the program. Chart begins at Program Year 10 for simplification.

### Developing The Model

There are a number of cost analysis methods that can be used to forecast weapon systems O&S costs:

**Analogy:** Cost forecasting based on costs of an existing system. An analogous system with historical costs must exist for this method to be useful.

**Parametric:** Developing Cost Estimating Relationships (CERs) correlating cost with physical and performance parameters. This estimation method requires historical data from previous programs to define the CERs.

**Engineering Estimate:** Costs are forecasted based on the engineering judgment and experience of an expert or group of experts. An engineering estimate should be based on data from previous programs.

**Projection of Actuals:** Developing a cost forecast from current costs for hardware, facilities, and services. Because the costs used in this type of forecast are actual current costs A Projection of Actuals has a high degree of accuracy and credibility.

Since a missile or munition is entering an established Military support infrastructure with known costs the best method for forecasting O&S costs is a Projection of Actuals. While most of the costs used in the missile or munition model are actual costs the one O&S cost element with appreciable uncertainty is the failure rate which will influence the number of required spares and the amount of repair activity. Best case and worst case support cost scenarios based on the upper and lower limits of the predicted failure rate can be added to the model to factor in variability and uncertainty of the cost elements. Bracketing the uncertainty of the model will contribute to the negotiation of the support contract(s).

## Data Gathering

Once the method of cost analysis is selected, data for the model can then be developed and gathered. Using a Projection of Actuals method the actual costs can be used for many of the cost elements in the model. Storage and labor costs can be gathered from potential Military storage facilities; a military facility may not charge a fee to store government assets. Surveillance program costs are a function of annual labor hours multiplied by the hourly labor rate and a one time cost for test equipment.

Demilitarization costs can be derived from companies that perform the work. The number of spare parts required is determined by failure rate and the required  $A_0$  for the weapons. Repair costs are a function of contractor hours to perform assembly and testing, and applicable labor rates for hands-on administration and support engineering, plus materials. Material costs for repair are averaged at 20% of the cost of the hardware being repaired. Recertification is a function of labor hours times the hourly labor rate plus materials. Analysis, Training and Publications are a function of labor cost times hours spent.

	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
<b>1</b>	Production Year		14	15
<b>2</b>	Deliveries		1700	1361
<b>3</b>	Test\Train assets fired		10	10
<b>4</b>	Population		28,649	30,000
<b>5</b>	Surveillance cost		\$33,558	\$35,140
<b>6</b>	Surveillance failures		48	50
<b>7</b>	Surveillance failures repair cost		\$218,604	\$227,713
<b>8</b>	Rocketmotor and battery replacements		135	1305
<b>9</b>	Rocketmotor and battery replacement cost		\$1,238,625	\$11,973,375
<b>10</b>	Cumulative section replacements		339	389
<b>11</b>	Weapon container replacement cost		\$76,653	\$61,367
<b>12</b>	Yearly maintenance cost		\$1,567,440	\$12,297,595

Depending on the preference of the customer and program office, costs can be expressed in terms of constant dollars (eg FY '05) or a yearly inflation factor can be added using the tables provided by the Office of Under Secretary of Defense Comptroller (website: <http://www.dod.mil/comptroller/budgetindex.html>). On the website click the 'Defense Budget' button, then click 'DoD Summary Budget Materials/Budget Links'. Open the 'National Defense Budget Estimates For The FY 20xx' and go to Table 5-10.

An effective O&S cost evaluation can be performed using a spreadsheet. Cell equations calculate asset population, spares requirements, yearly failures, surveillance testing costs, maintenance costs and recertification costs. From these cost elements the yearly and Operational Life costs are summed. The cells shown in the chart below illustrate the last two years production of a typical missile program. Column C is included to help explain the equations in Column D.

### Basic O&S Spreadsheet Model

Note: The cells shown are from the last 2 production years of a proposed program. Explanation of cell equations is below. An assumption of this model is that there is no charge for storage.

#### Cell D2 Deliveries

The number of missiles delivered in that year.

Cell D3 Test\Train assets fired: Each year 10 assets are fired for testing and training. Assets fired are taken from the oldest lot available, not current deliveries.

#### Cell D4 Population: =C4+D2-D3

The equation adds the previous year's population to current year production and subtracts test fired assets.

#### Cell D5 Surveillance testing cost: =((2\*((2\*((D4)\*0.2))/60))\*87.85)

The equation calculates the cost of 2 people testing 20% of the population (cell D5) at an average of 2 minutes per missile. The facility labor rate is \$87.85 per hour.

#### Cell D6 Surveillance failures: =(8766\*D4)\*-1/((10\*8766)/LN(0.92))\*0.2

The equation is a log function used by Reliability to predict the failure rate for 20% of the weapon assets in protected storage.

#### Cell D7 Surveillance failures repair cost: =4554\*C6

The equation multiplies the cost of an average repair (\$4554) times the previous year's failures. The average repair cost is calculated from the number of failures for each replaceable section per 100 missiles and the repair cost for each section, plus the amortized cost of the spares pool.

#### Cell D8 Rocketmotor and Battery replacements: = 1,305

The weapon needs to have its rocketmotor and battery replaced at 13 years; the 1,305 assets having their Rocketmotor and battery replaced were delivered 13 years ago. Note: the number of assets having their rocketmotor and batteries replaced in Cell C8 is much lower because missiles fired for testing and training were taken from this lot.

#### Cell D9 Rocketmotor and battery replacement cost: =9175\*D8

The equation multiplies the material and labor cost of replacing the rocketmotor and battery by the number of weapon assets having the work done.

#### Cell D10 Cumulative section replacements: =C10+D6

The equation adds the previous total of replaced sections to the number of sections replaced this year.

#### Cell D11 Weapon container replacement cost: =(0.03\*D2)\*1503

3% of the weapons have their containers replaced each year due to damage or deterioration. The equation multiplies 3% of the years weapons delivery by the cost of container replacement (\$1,503).

Cell D12 Yearly maintenance cost:  $=D5+D7+D9+D11$

The equation sums all testing, maintenance and replacement costs for the year. Yearly maintenance costs can be added into a total testing, maintenance and replacement cost for the Operational Life of the weapon.

The advantage of developing a spreadsheet model instead of using a generic software package is that the spreadsheet will contain only the cost elements and equations specific to the weapon system. A spreadsheet model can be annotated with data sources and historical information to validate the models accuracy. The model can also be easily modified to perform business case analyses (trade studies) of different support options. Trade studies can be performed to identify the most cost effective support concept or to offer a customer different support concepts. The spreadsheet below illustrates a trade study comparing three maintenance concepts for a missile system composed of replaceable sections:

“Baseline Support Plan” (black text rows 1 – 10), the missiles rocketmotor and battery are replaced twice and container desiccant is replaced 4 times during its 25 year lifetime, no surveillance testing or repair of failed missile sections takes place.

Cell C2 Deliveries

Total deliveries made over a 10 year production run.

Cell C3 Test\Train Assets

10 assets selected from the oldest lot are used each year for testing and training.

Cell C4 Population

The missile population is the number of missiles in storage. To compare different maintenance options this trade study assumes all assets are kept in protected storage.

Cell C5 Storage Failures (cumulative)

Total failures for the population of missiles over 45 years of protected storage. The reliability prediction for protected storage is .99; meaning nearly 1% of the population fails each year.

Cell C6 Mission Ready missiles:  $=C4-C5$

Mission Ready missiles (capable of successfully completing a mission) are calculated by subtracting the number of predicted failures from the population remaining after Test\Training firings (cell C3).

Cell C7 Mission Ready %:  $=C6/C4$

The percentage of missiles in storage that are mission ready based on the predicted reliability of the missiles in protected storage. The equation divides the number of Mission Ready missiles (C6) by the population (C4).



Cell C8 Total System Life Cycle O&S Cost:  $=C9 * C2 * 25$

The equation multiplies Total System Life Cycle O&S Cost by the total number of delivered missiles (cell C2) by the 25 year missile life cycle (25).

Cell C9 Base O&S cost per missile per year: \$1,150

Total System Life Cycles O&S costs are calculated per missile per year, this information lets the contractor and customer calculate LCC. The base O&S cost of \$1,150 per missile per year consists of initial transportation to a storage site, replacing the rocketmotor and battery twice, replacing container desiccant four times, development and maintenance of Interactive Electronic Technical Manuals (IETMs), training material development, ongoing training, missile test firings, software maintenance and demilitarization.

Cell C10 O&S Cost per mission ready missile per year:  $= C8 \backslash (C6 * 25)$

The equation divides the Total System Life Cycle O&S Cost (C8) by the number of mission ready missiles (C6) multiplied by the 25 year missile life cycle. The yearly O&S cost for a mission ready missile demonstrates the cost effectiveness of a maintenance option.

"Repair Failed Missile Sections When Replacing Rocketmotor Plan" (red text rows 12 – 19), the missiles rocketmotor and battery are replaced twice and container desiccant is replaced 4 times during its 25 year life cycle, missile sections that fail BIT during rocketmotor and battery replacement are repaired.

Cell C13 Section repairs made along with rocketmotor and battery replacement = 487

The equation adds the number of missiles sections repaired during 20 years of rocketmotor and battery replacements.

Cell C14 Cost of section replacements made with rocketmotor replacement:

$= (4195 * D13) + 503,750$

When a missile has its rocketmotor and battery replaced, the failed sections are also repaired. The equation multiplies the cost of an average repair (\$4195) times the total failures (cell D13) plus the cost of the spare sections (\$503,750). The average repair cost is calculated from the number of failures for each replaceable section per 100 missiles and the repair cost for each section.

Cell C15 Mission Ready Missiles:  $= C6 + C13$

Mission Ready missiles are capable of successfully completing a mission. The missiles repaired when their rocketmotors and batteries are replaced (cell C13) are added to the Mission Ready Missiles (cell C6).

Cell C16 Mission Ready %:  $= (C15) / C4$

The percentage of missiles in storage that are mission ready based on the predicted reliability of the missiles in protected storage. The equation divides Mission Ready missiles (cell C15) by the population (C4).

Cell C17 Total System Life Cycle O&S Cost:  $=C8+C14$

The equation adds baseline Total System Life Cycle O&S Cost (cell C8) to the Cost of Section Replacements Made Along with Rocketmotor Replacements (cell C14).

Cell C18 O&S Cost Per Missile Per Year:  $=C17/(C2*25)$

The equation divides Total System Life Cycle O&S Cost (cell C17) by missile deliveries (cell C2) multiplied by the 25 year missile life cycle.

Cell C19 O&S Cost Per Mission Ready Missile Per Year:  $=C17/(C15*25)$

The equation divides Total System Life Cycle O&S Cost (cell C17) by Mission Ready Missiles (cell C15) multiplied by the 25 year missile life cycle. For this maintenance option the total O&S costs are greater than the baseline option, compare cells C8 and C17, but by increasing the number of Mission Ready Missiles by 487 (cell C13) the yearly O&S cost is less, compare cells C10 and C19.

“Identify and Repair Failed Missile Sections with Surveillance Testing Plan” (blue text rows 21 – 29). Instead of repairing failed missile sections when the rocketmotor and battery are replaced this maintenance option allows for tests on 75% of the population individually to identify and repair missiles with failed sections.

Cell C22 Surveillance Cost: \$3,519,197

The cost of testing for missiles in protected storage for 31 years. The labor rate is \$87.85 per hour plus test equipment cost of \$2,500. Surveillance is performed on 75% of the population minus the missiles removed for rocketmotor and battery replacement.

Cell C23 Missiles Repaired: 5,154

The sum of all missiles repaired by having failed sections identified during surveillance testing over 31 years.

Cell C24 Cost to Repair Missiles: \$22,656,517

The sum of all surveillance repair costs over 31 years. An average repair cost is calculated from the number of failures for each replaceable section per 100 missiles and the repair cost for each section, plus the amortized cost of the spares pool.

Cell C25 Mission Ready Missiles:  $=C6+C23$

The missiles repaired during surveillance testing (cell C23) are added to the Mission Ready Missiles (cell C6).

Cell C26 Mission Ready %:  $=C25/C2$

The percentage of missiles in storage that are mission ready based on the predicted reliability of the missiles in protected storage. The equation divides Mission Ready missiles (cell C25) by the population (C4).

Cell C27 Total System Life Cycle O&S Cost:  $=C8+C22+C24$

The equations adds baseline Total System Life Cycle O&S Cost (cell C8) to the Surveillance Cost (cell C22) and the Cost to Repair Missiles (cell C24).

Cell C28 O&S Cost Per Missile Per Year:  $=C27/(C2*25)$

The equation divides Total System Life Cycle O&S Cost (cell C27) by missile deliveries (cell C2) multiplied by the 25 year missile life cycle.

Cell C29 O&S Cost Per Mission Ready Missile Per Year:  $=C27/(C25*25)$

The equation divides Total System Life Cycle O&S Cost (cell C27) by Mission Ready Missiles (cell C25) multiplied by the 25 year missile life cycle. For this maintenance option the total O&S costs are greater than the baseline option, compare cells C8 and C27, but by increasing the number of Mission Ready Missiles by 5,047 (cell C23) the yearly O&S cost is less, compare cells C10 and C29.

In this trade study the missile meets its yearly protected storage reliability requirement of .99. The trade study compares the total system life cycle Operations and Support cost of three maintenance options as well as the yearly O&S cost per mission ready missile. The study shows that while the "Baseline Support Plan" option has the lowest Total System Lifecycle O&S Cost (cell C8) it also has the highest Yearly O&S cost per mission ready missile (cell C10). In comparison the "Identify and Repair Failed Missile Sections with Surveillance Testing" option has the highest Total System Lifecycle O&S Cost (cell C27) and the lowest Yearly O&S cost per mission ready missile (cell C29). The trade study provides the missile contractor with different maintenance options to offer the customer.

A	B	C
1	<b>Baseline Support</b>	
2	Deliveries	30,000
3	Test\Train assets	350
4	Population	29,650
5	Storage Failures (cumulative)	7,310
6	Mission Ready Missiles	22,340
7	Mission Ready %	75%
8	Total System Lifecycle O&S Cost	\$862,500,000
9	Base O&S cost per missile per year	\$1,150
10	O&S Cost per mission ready missile per year	\$1,544
11		
	<b>Repair Failed Missile Sections When</b>	
12	<b>Replacing Rocketmotor</b>	
	Section repairs made along with rocketmotor	
13	and battery replacement	487
	Cost of section replacements made with	
14	rocketmotor replacement	\$2,546,715
15	Mission Ready Missiles	22,827
16	Mission Ready %	77%
17	Total System Lifecycle O&S Cost	\$865,046,715
18	O&S cost per missile per year	\$1,153
19	O&S Cost per mission ready missile per year	\$1,516
20		
	<b>Identify and Repair Failed Missile Sections</b>	
21	<b>With Surveillance Testing</b>	
22	Surveillance Cost	\$3,519,197
23	Missiles Repaired	5,047
24	Cost to Repair Missiles	\$22,207,652
25	Mission Ready Missiles	27,387
26	Mission Ready %	92%
27	Total System Lifecycle O&S Cost	\$888,226,849
28	O&S cost per missile per year	\$1,184
29	O&S Cost per mission ready missile per year	\$1,297

### O&S Spreadsheet Model Trade Study

Note: The cells show the total numbers and costs compared in the trade study.

## **Documenting the Cost Forecast**

A cost analysis may be performed on a spreadsheet but the results may have to be presented in a format specified by the customer. Either the spreadsheet should produce information that can be put directly into the customer software or easily modified into the correct format.

Why not perform the analysis using the customer's software? The software may not be formatted to allow for easy comparison of cost options. A spreadsheet program has the advantage of simultaneously analyzing different cost options and presenting them for visual comparison. As with all models the big factor is the expertise and experience of the person using it. A thorough knowledge of the weapon system and logistics support is a must in order to produce an accurate cost forecast.

## **The Benefits of a Cost Model**

Accurate forecasting of O&S costs aids the customer in making acquisition decisions and allows the logistics services provider to plan when and where O&S costs will be spent. O&S costs models can reveal opportunities for cost avoidance and help develop an effective spending plan for the O&S budget. Trade Studies for different support options can be documented and easily compared for economic impact. Ultimately, performing Trade Studies is an exercise in the optimization of readiness and reliability as affected by O&S factors.

Once the optimal solution is identified, O&S spending can be planned which will minimize waste. The cost forecasting method presented in this paper can be applied to any product or system entering an established distribution and/or support infrastructure.

## **Conclusion**

O&S costs for Missile and Munitions programs can be accurately defined using a cost model that accounts for cost factors in the time period when they are accrued. Military customers are increasingly asking for O&S cost forecasts as early as the design phase so that agreements can be made with logistics support service providers while there is time to analyze and determine the best choice, rather than waiting until production of the weapon begins and having to use facilities and services available at the time. Saving the customer money and providing the best support available is the right way to do business.

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