Cost Benefit Analysis for Incorporation of Prognostics

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Prognostics is the sensing, recording or interpreting or a systems operational parameters to monitor the operational health of that system. A system can be an assembly of components such as industrial machinery, an automobile, an airplane. Or it can be a single component such as a motor, airplane propeller or solid rocket motor. Prognostics offer increased system availability by notifying a system operator of an impending failure, allowing preventive maintenance to be performed which will keep a system running. Prognostics can also reduce Life Cycle Cost by reducing maintenance costs, maintenance can be performed only when the need is indicated. To determine if the implementation of a Prognostics system will reduce Life Cycle Cost a Cost Benefit Analysis should be performed. A Cost Benefit Analysis compares the cost of implementing and operating Prognostics to determine if maintenance costs are reduced. If maintenance costs are reduced in excess of the Prognostic systems' procurement and operating costs it is economically advantageous to implement prognostics. Some system operators may decide that the increased system availability is worth the cost of a Prognostics system even if maintenance costs are not reduced enough to pay for the system. While Prognostics can also provide increased system availability, safety and other services this paper focuses on economic payback and system availability.

What Form Prognostics?

Prognostics can take many forms; from a simple strip of moisture sensitive paper that turns color when exposed to excessive humidity or sensors that read electronic signal levels. Depending on the level of system readiness required, Prognostics sensors can be checked occasionally or monitored continuously; the US InterContinental Ballistic Missiles (ICBMs) of past decades were monitored onsite by a 2 person crew 24 hours a day 7 days a week. Expensive, but for a potential enemy to be deterred from attacking the US with their own ICBMs they had to know the US missile response was 100% ready. Prognostics can be active or passive; a prognostics sensor can report findings continuously by means of an imbedded transmitter or require manual inspection or a test set to read its output. Prognostics can also be performed by analyzing usage and performance data to determine when system maintenance is required.

Determine if Prognostics Are Beneficial

In order to save money and\or increase system availability the prognostics must defer or prevent maintenance. Deferred maintenance is maintenance that is postponed for a time because the system is still operational so that the maintenance can performed as a part of other regularly scheduled service. Prevented maintenance is maintenance that does not need to be performed because the system is still operational. The challenge in considering prognostics for a new system is being able to demonstrate a reasonable probability of support cost savings and\or increase in system availability. A Cost Benefit Analysis can predict whether or not prognostics will save support costs and\or increase availability.

Identifying Prognostics' Cost Elements
To determine if Prognostics provides an economic payback all cost elements of the system and the potential prognostics must be defined. System cost elements include: maintenance which consists of testing, spare parts, labor and the cost of non-productive time (or the cost of not having an asset available). Prognostics costs include: Acquisition, installation, data collection and analysis. Identifying the cost elements will facilitate quantifying the cost savings and\or increased system reliability.

Developing The Cost Benefit Analysis
A Cost Benefit Analysis is performed by comparing the cost elements of the system having prognostics incorporated to the cost elements of the prognostics themselves. Cost comparison can be done on a spreadsheet, a graph produced from spreadsheet data may be used to put the data into a visual form. A Cost Benefit Analysis may provide a yes or no answer to as to whether or not prognostics should be incorporated or it could offer options on the best type of prognostics to incorporate.

The first step is to define costs for each of the cost elements. There are a number of cost definition methods that can be used:

Analogy: This type of cost definition can be performed for an entirely new system, it is based on costs of an existing system. A similar system with historical costs must exist for this method to be useful. This method is probably the quickest to perform.

Parametric: Costs can be defined by developing Cost Estimating Relationships (CERs), that is assigning cost to physical and performance parameters. For example, the range of an aircraft can be determined to cost $XX per mile, based on this value the cost an aircraft with a longer range can be estimated. This estimation method requires historical data from previous programs to define the CERs. Assigning actual cost to a physical or performance parameter is the key element of this method.

Engineering Estimate: Costs are defined 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 that are similar to the one being evaluated. Intuition based on knowledge and experience is the distinctive element of this method.

Projection of Actuals: Defining costs from current costs for existing hardware, facilities, and services. This type of cost analysis is useful for incorporating prognostics into an existing system. Because the costs used in this method are actual current costs a Projection of Actuals has a high degree of accuracy and credibility. The case study in this paper uses Projection of Actuals.

Data Gathering
Once the method of cost definition is selected, data for the Cost Benefit Analysis can then be developed and gathered. The failure rate for the rocketmotor is defined by the manufacturer. Costs for depot rocketmotor replacement are a function of labor hours to

perform disassembly, testing, repair and reassembly. Depot labor costs are provided by the depot. Depot maintenance includes support engineering. Storage labor costs for testing are provided by the storage facility contractor. The prognostics vendor provides the cost of the prognostics system and installation and test set.

Depending on the preference of the customer and program office, costs can be expressed in terms of constant dollars (eg FY '09) 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. The inflation rate for 2009 is 2.4% which is the figure used throughout this paper.

Cost Benefit Analysis Example

Incorporation of prognostics into a missile's solid rocket motor will be used to illustrate a Cost Benefit Analysis. Solid rocketmotors used in missiles are susceptible to delamination, cracking and other physical damage caused by age, humidity and vibration that renders the motor unreliable and unusable. They have a specified shelf life and should be replaced once the shelf life has been exceeded. But if a prognostic device could be applied to the rocket motor so that it could be tested and verified as viable the missile could stay in the inventory. Prognostics can be applied to solid rocketmotors in the form of a optic Fiber mounted on the surface of the rocketmotor. The optic Fiber is interrogated by sending light of a known wavelength along the cable, if it has been strained in any way by deformation of the rocketmotor the light reflected back to the tester will be of a different wavelength. Testing the optic Fiber would be conducted as part of periodic maintenance testing to eliminate additional labor costs.

Lets say the Ace Missile Company wants to market the Mighty Missile; a super high performance missile with superior speed, range and payload. Acme Rocketmotors LLC has a rocketmotor that will provide the performance the Mighty Missile requires. But the highly specialized materiel used in the rocketmotor has a relatively short guaranteed operational life of 10 years. Acme Rocketmotors LLC tells the Ace Missile Company for a "small additional fee" that an optic Fiber cable can be installed on the rocketmotor so that it can be tested and verified operational for up to another seven years. Figure 1 shows how the failure rate increases over the 7 years (X axis) beyond the guaranteed life. The failure rate (Y axis) is of the entire inventory; in year 1 the failure rate is 4% of the entire inventory, in year 7 the final 36% of the rocketmotor inventory fails.

Figure 2 shows the number of rocketmotors that fail each year for two inventories. The customer will put 125 missiles into storage of which 7 will be used for test and training leaving 118 added each year to the storage inventory. Another 125 missiles will be fielded.

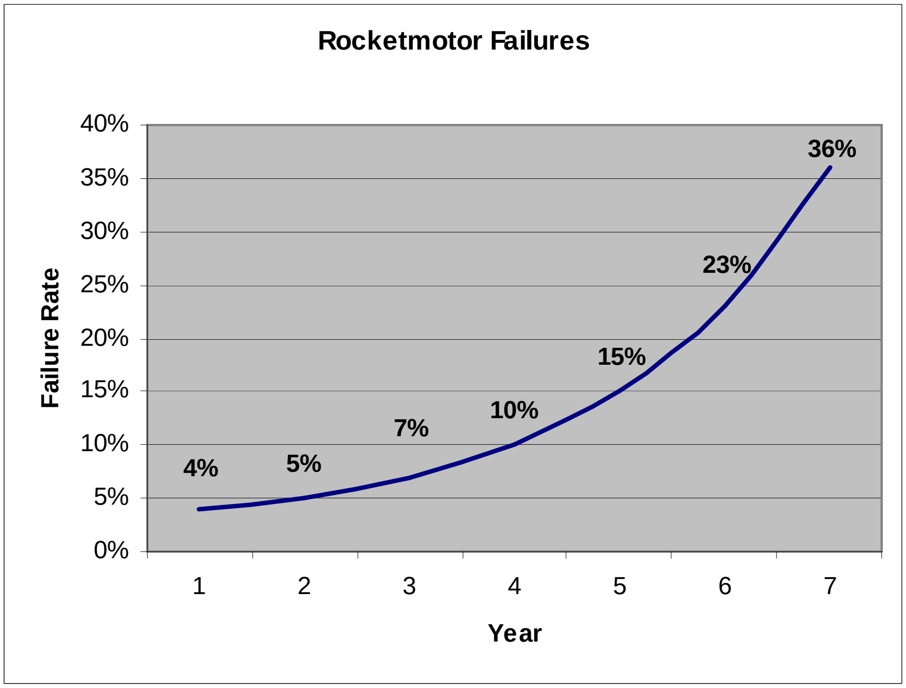

Figure 1. Rocketmotor failure rate after guaranteed life

Year	Failure %	Storage 118	Fielded 125
1	4%	5	5
2	5%	6	6
3	7%	8	9
4	10%	12	12
5	15%	17	19
6	23%	27	29
7	36%	43	45
Totals	100%	118	125

Figure 2. Yearly Rocketmotor Failures

Would there be an economic benefit or increased system reliability by installing a prognostics device on the rocket motors to test and verify their viability through the seven years after their guaranteed life? The potential economic benefit would be realized by the extended useful life of the missiles.

Manufacturing and Operation

The Mighty Missile is produced at a rate of 250 missiles per year for 10 years. The customer keeps half the inventory at its storage site and fields half the inventory. Seven missiles are expended each year for testing and training, the seven missiles are taken from the storage inventory. The contractor will provide maintenance support for missiles through the remaining useful life of the rocketmotors after manufacturing has been completed, this amounts to 26 years. The customer will test its missiles in storage and send missiles with failed rocketmotors to the contractor depot for rocketmotor replacement. The contractor will send out a team to test rocketmotors of the fielded missiles, fielded missiles with failed rocketmotors will be sent back to the contractor depot for rocketmotor replacement. Acme Rocketmotors LLC guarantees the rocketmotor for 10 years, though the rocket motor can remain viable for 7 years beyond the guaranteed life. The customer decides it will replace the rocketmotor once to extend the service life of the missile.

The Cost Benefit Analysis
Run Rules & Assumptions:

1. Support costs during the 10 years of production are not included.
2. Rocketmotors function normally during guaranteed 10 year service life.
3. No other missile failures are considered in this study.
4. Demilitarization costs are not included in the study.
5. Costs are based on 2009 dollars with 2.4% yearly inflation.
6. Fielded missiles are assumed to be at a single location.
7. The customer stores missiles at a single location.
8. Rocketmotors will be available through the 10 years of production and 10 years of rocketmotor replacement.
9. Missile service life is not affected by other life limited components such as a battery.
10. Labor costs are fully burdened, they include profit.

Cost Elements

Table 1 lists the cost elements used in this study. The costs are actual quotes from vendors and contractors, the inflation percentage is taken from the National Defense Budget Estimate for 2009.

Cost Element	Cost ('09 $s)
Rocketmotor	$20,500
Optic Fiber installation (per rocketmotor)	$250
Fiber Optic Test Set	$100,000
Depot Labor (touch) per hour	$68
Depot Labor (engineering support) per hour	$118
Customer Storage Facility labor per hour	$92
Ground Transportation; dollars per pound per mile	.000418792
Inflation (annual)	2.4%

Table 1. Cost Elements

Risk
Assessing the risk to costs contributes to the validity of the estimates and the Cost Benefit Analysis. All price quotes are from vendors and contractors, adding an inflation factor documents the rise in yearly cost, the greatest risk is the continued availability of the rocketmotor and the Fiber Optic Test Set since it will not be purchased until Program year 11. The program risk manager can assign a risk index to these two items and determine what action can be taken to reduce the risk of availability for these two items.

Four stages in the life cycle of the Mighty Missile are used to illustrate the effect incorporation of a Optic Fiber will have on the service life of the rocketmotor and how that affects the service life of the missile.

A	B	C
1	Program Year	11
2	Assets used for testing (cumulative)	77
3	Prognostics cost	$712,218
4	Test set	$126,765
5	Depot Rocketmotor replacement cost	$29,425
6	Storage test labor cost	$9,554
7	Fielded test labor cost	$13,899
8		
9	**Rocketmotors with Optic Fiber replacement**	
10	Failed rocketmotors - storage	48
11	Failed rocketmotors - fielded (tested)	5
12	Rocketmotors replaced	53
13	Rocketmotor test\replacement (in storage) cost	$1,768,522
14	Rocketmotor test\replacement (fielded) cost	$643,899
15	Total Yearly Cost	$2,412,420
16	Available missiles	2,423
17		
18	**Lot by Lot rocketmotor replacement**	
19	Rocketmotors replaced	173
20	Rocketmotor replacement (in storage) cost	$1,412,413
21	Rocketmotor replacement (fielded) cost	$3,678,158
22	Total Yearly Cost	$5,090,571
23	Available missiles	2,423

Figure 3. Program Year 11; First year of Rocketmotor Replacement

Figure 3 documents Program year 11 the first year of rocketmotor replacements.

Cell B1 Program Year
Missile production occurs during the first 10 years of the program. In Program year 11 the ten year guaranteed useful of the rocketmotors in Lot 1 missiles has expired and the rocketmotors need replacement.

Cell C2 Assets used for testing (cumulative)
Each year through Program year 11 seven Lot 1 assets are used for testing, the assets are taken from Lot 1 so that fewer missiles have their rocketmotors replaced in Program year 11 (this is true for both maintenance options; rocketmotors with or without Optic Fiber). In subsequent years the seven test missiles are taken out of storage from subsequent Lots; Lot 2 in Program year 12, Lot 3 in Program Year 13 and so on so that seven fewer rocketmotors need to be replaced each year.

C3 Prognostics Cost
The cost of installing the Optic Fiber on 10 production lots of 250 missiles each, including yearly inflation.

C4 Test Set
The test set is used in the field to test the Optic Fiber for strain which indicates physical damage to the rocketmotor rendering it unreliable. The test set is purchased in Program year 11 the first year it will be used to test missiles.

C5 Depot Rocketmotor replacement cost
All missiles are returned to the Contractor Depot for rocketmotor replacement. This per missile cost includes the cost of transporting the missiles to and from the depot, material and labor cost. As stated in the assumptions the yearly rocketmotor failure rates are in accordance with Figure 2, though there may be some variability in those percentages. If there is variability the number of rocketmotors being replaced, and the cost, will vary slightly from year to year.

C6 Storage testing labor cost
Missiles with rocketmotors that have a Optic Fiber have their rocketmotors tested in storage and sent to the depot for replacement. This is the labor cost for testing 118 missiles of a single Lot in storage.

C7 Field Rocketmotor test labor cost
The field labor cost includes transportation, housing, meals and labor (40 hours per person) for a two person team to perform testing of the 125 missiles in a single Lot at a field deployment site.

Rocketmotor with Optic Fiber replacement
The missiles that have rocketmotors with Optic Fiber are tested each year, the failed rocketmotors are replace as they fail.

Cell C10 Failed Rocketmotors – storage (tested)
Through Program year 11 all missiles used for yearly testing have been taken from Lot 1 missiles in storage. Rather than testing the relatively small number of 48 remaining missiles over the next 7 years all Lot 1 missiles in storage have their Rocketmotors replaced.

Cell C11 Failed rocketmotors - fielded (tested)
125 Lot 1 missiles in the field are tested, 4% (five missiles) have failed rocketmotors in accordance with the predicted failure percentage (Figure 1). The five missiles with failed rocketmotors are returned to the contractor depot for rocketmotor replacement.

Cell 12 Rocketmotors replaced
Equals Cells C10 and C11, the total rocketmotors replaced from missiles in storage and fielded missiles.

Cell C13 Rocketmotors replaced (in storage) cost
Equals Cell C5 x cost of rocketmotor replacement + prognostics installation cost. The cost does not include testing since all remaining 48 Lot 1 missiles have their rocketmotors replaced, testing missiles in storage starts in Program year 12. Starting in Program year 12 missiles with rocketmotors with the Optic Fiber in storage are tested to identify the ones that need to be replaced.

Cell C14 Rocketmotor test\replacement (fielded) cost
Equals Cell C11 x cost of each rocketmotor replacement + prognostics installation cost + Fielded test labor cost + test set cost. The cost of field testing consists of transportation, per diem and labor for a two person team for 5 days.

Cell C15 Total Yearly Cost
Adds Cells C13 and C14 to get the Program year 11 total cost for replacing rocketmotors on Lot 1 missiles that requiring replacement. This years cost was increased by including the prognostics installation costs for all missiles and the field test set. For Program year 11 the total yearly cost is the total cost to date for the rocketmotor replacements.

Cell C16 Available missiles
The total number of mission ready missiles in the inventory fielded and in storage.

Lot by Lot rocketmotor replacement
Missiles that have rocketmotors without Optic Fiber are replaced at the end of their guaranteed 10 year service life. In Program year 11 missiles from Lot 1 have their rocketmotors replaced.

Cell C19 Rocketmotors replaced
Through Program year 11 all missiles used for yearly testing have been taken from Lot 1 missiles in storage. That leaves 48 missiles in storage and 125 fielded missiles, 173

total, that have their rocketmotors replaced. In subsequent years test assets are taken from the lot with its rocketmotors being replaced to save the cost of replacing seven rocketmotors.

Cell C20 Rocketmotor replacement (in storage)
Equals Cell C10 x the cost of rocketmotor replacement. The rocketmotors on these missiles do not have the prognostic Optic Fiber installed nor do they require testing which accounts for the difference in cost between Cells C13 and C20.

Cell C21 Rocketmotor replacement (fielded)
Equals 125 fielded missiles x the cost of each rocketmotor replacement.

Cell C22 Total Yearly Cost
Adds cells C20 and C21 to get the Program year 11 total cost for replacing rocketmotors on Lot 1 missiles. For Program year 11 the total yearly cost is the total cost to date for the rocketmotor replacements.

Cell C23 Available missiles
The total number of mission ready missiles in the inventory fielded and in storage.

A	B	C	D
24	Program Year	20	21
25	Assets used for testing (cumulative)	140	147
26	Depot Rocketmotor replacement cost	$36,427	$37,301
27	Storage test labor cost	$11,827	$12,111
28	Fielded test labor cost	$17,930	$18,444
29			
30	**Rocketmotors with Optic Fiber replacement**		
31	Failed rocketmotors - storage	118	113
32	Failed rocketmotors - fielded (tested)	125	120
33	Rocketmotors replaced	243	233
34	Rocketmotor test\replacement (in storage) cost	$4,310,179	$4,227,119
35	Rocketmotor test\replacement (fielded) cost	$4,571,269	$4,494,559
36	Total Yearly Cost	$8,881,448	$8,721,678
37	Cumulative Cost	$45,320,010	$54,041,688
38	Available missiles	2,360	2,307
39			
40	**Lot by Lot rocketmotor replacement**		
41	Rocketmotors replaced (in storage)	118	0
42	Rocketmotors replaced (fielded)	125	0
43	Rocketmotors replaced	243	0
44	Rocketmotor replacement (in storage) cost	$4,298,352	$0
45	Rocketmotor replacement (fielded) cost	$4,553,339	$0
46	Total Yearly Cost	$8,851,692	$0
47	Cumulative Cost	$77,681,592	$77,681,592
48	Available missiles	2,360	2,187

Figure 4.

Program Years 20 & 21; Final Year of Rocketmotor Replacement and Missiles Are Removed From Service

Figure 4 documents Program years 20 and 21, year 20 is the final year of replacements for rocketmotors without the Optic Fiber. Program year 21 is the first year missiles begin to fall out of the service inventory due to rocketmotors.

Cell B24 Program Year
For Program years 12 thru 20 the rocketmotors with Optic Fiber are tested and replaced as necessary. Missiles not equipped with the Optic Fiber have their rocketmotors replaced Lot by Lot. In Program year 20 the ten year guaranteed useful life of rocketmotors in Lot 10 missiles has expired, the Lot 10 missiles are the last lot to have their rocketmotors replaced. In Program year 21 rocketmotor replacement stops for missiles that are not equipped with the Optic Fiber. Missiles having rocketmotors equipped with the Optic Fiber are tested and have their failed rocketmotors replaced in Lots 4 – 10 in Program year 20. In Program year 21 the number of missiles having their rocketmotors replaced begins to diminish, missiles in Lots 5 – 10 are tested and have their failed rocketmotors replaced.

Cell C25 and D25 Assets used for testing (cumulative)
In Program year 20 seven assets are taken from Lot 10 for test and training. In Program year 21 seven assets are taken from Lot 1 since it is being removed from service. In year 22 the seven test and training assets will be removed from Lot 2 and so on.

Cell C26 and D26 Depot and Field Rocketmotor replacement cost
Storage testing costs have risen due to the annual 2.4% inflation.

Cell C27 and D27 Storage test labor cost
Storage testing costs have risen due to the annual 2.4% inflation.

Cell C28 and D28 Field test labor cost
Field test labor costs have risen due to the annual 2.4% inflation.

Rocketmotor with Optic Fiber replacement
In program year 20 rocketmotors replacements are made for Lots 4 – 10 for both storage and fielded missiles.

Cell C31 Failed rocketmotors - storage
Consists of missiles from Lots 4 thru 10. See Figure 2 for years 11 – 17 storage for quantity from each lot.

Cell D31 Failed rocketmotors - storage
Consists of missiles from Lots 5 thru 10. See Figure 2 for years 12 – 17 storage for quantity from each lot.

Cell C32 Failed rocketmotors – fielded (tested)

Consists of missiles from Lots 4 thru 10. See Figure 2 for years 11 – 17 fielded for quantity from each lot.

Cell D32 Failed rocketmotors – fielded (tested)
Consists of missiles from Lots 5 thru 10. See Figure 2 for years 12 – 17 fielded for quantity from each lot.

Cell C33 Rocketmotors replaced
The sum of Cells C31 and C32.

Cell D33 Rocketmotors replaced
The sum of Cells D31 and D32.

Cell C34 Rocketmotor test\replacement (in storage) cost
Equals Cell C26 times Cell C31 plus Cell C27, the cost of testing all missiles in storage and sending 118 missiles back to the contractor depot for rocketmotor replacement.

Cell D34 Rocketmotor test\replacement (in storage) cost
Equals Cell D26 times Cell D31 plus Cell D27, the cost of testing all missiles in storage and sending 113 missiles back to the contractor depot for rocketmotor replacement.

Cell C35 Rocketmotor test\replacement (fielded) cost
Equals Cell C26 times Cell C32 plus Cell C28, the cost of testing all fielded missiles and sending 125 missiles back to the contractor depot for rocketmotor replacement.

Cell D35 Rocketmotor test\replacement (fielded) cost
Equals Cell D26 times Cell D32 plus Cell D28, the cost of testing all fielded missiles and sending 125 missiles back to the contractor depot for rocketmotor replacement.

Cell C36 Total Yearly Cost
Adds Cells C34 and C35 to get the Program year 20 total cost for testing and replacing rocketmotors on missiles in all Lots.

Cell D36 Total Yearly Cost
Adds Cells D34 and D35 to get the Program year 21 total cost for testing and replacing rocketmotors on missiles in all Lots.

Cells C37 and D37 Cumulative Cost
The cumulative cost for rocketmotor replacements through Program years 20 and 21. For missiles with rocketmotors having the Optic Fiber replacement costs are accrued for year 21 since rocketmotor replacements continue (Lots 5 thru 10).

Cells C38 and D38 Available missiles
The total number of mission ready missiles in the inventory fielded and in storage. The inventory of available missiles with rocketmotors having the Optic Fiber is reduced by 53 which is the 48 Blk I missiles in storage that had their rocketmotors replaced in

program year 11 and 5 Blk I fielded missiles which is the four percent of the missile in storage which fail in year 11 of their service life (See Figure 2).

Lot by Lot rocketmotor replacement
Missiles that have rocketmotors without Optic Fiber are replaced at the end of their guaranteed 10 year service life. In Program year 20 Lot 10 missiles will have their rocketmotors replaced, in Program year 21 the guaranteed service life of 10 years for Lot 1 missile rocketmotors will expire and the missiles will be removed from service.

Cell C41 Rocketmotors replaced (in storage)
The guaranteed rocketmotor service life of 10 years for the 118 Lot 10 missiles in storage has expired so all 118 missiles have their rocketmotors replaced. This is the last year of rocketmotor replacements for rocketmotors without the Optic Fiber.

Cell D41 Rocketmotors replaced (in storage)
Rocketmotor replacement for missiles having rocketmotors without Optic Fiber ended in Program year 20.

Cell C42 Rocketmotors replaced (fielded)
The guaranteed rocketmotor service life of 10 years for the 125 Lot 10 fielded missiles has expired so all 125 missiles have their rocketmotors replaced.

Cell D42 Rocketmotors replaced (fielded)
Rocketmotor replacement for missiles having rocketmotors without Optic Fiber ended in Program year 20.

Cell C43 Rocketmotors replaced
The sum of Cells C40 and C41.

Cell D43 Rocketmotors replaced
The sum of Cells D40 and D41.

Cell C44 Rocketmotor replacement (in storage) cost
Equals Cell C26 times Cell C40, the cost of sending 118 Blk 10 missiles back to the contractor depot for rocketmotor replacement.

Cell D44 Rocketmotor replacement (in storage) cost
No rocketmotors are replaced in Program year 21, no cost is incurred.

Cell C45 Rocketmotor replacement (fielded) cost
Equals Cell 26 times Cell C41, the cost of sending 125 Blk 10 missiles back to the contractor depot for rocketmotor replacement.

Cell D45 Rocketmotor replacement (fielded) cost
No replacement cost is incurred because no rocketmotors are replaced in Program year 21.

Cell C46 Total Yearly Cost
Adds Cells C43 and C44 to get the Program year 20 total cost for testing and replacing rocketmotors on Lot 10 missiles.

Cell D46 Total Yearly Cost
No cost is incurred because no rocketmotors are replaced. For the missiles without the Optic Fiber no money is being spent for rocketmotor replacement. In Program year 21 rocketmotor replacement costs stop for rocketmotors without Optic Fiber but replacement costs continue for another six years for rocketmotors with the Optic Fiber. See paragraph on Cell D46 for further

Cells C47 and D47 Cumulative Cost
For missiles having rocketmotors not equipped with the Optic Fiber the cumulative cost of all rocketmotors stops increasing in year 20 since that is the last year of rocketmotor replacements. In year 21 the cumulative cost for missiles having rocketmotors not equipped with the optic Fiber the cumulative cost for replacements is $23.5 million more than for rocketmotors with optic Fiber. This is because 837 more rocketmotors without optic Fiber have been replaced.

Cell C48 Available missiles
The total number of mission ready missiles in the inventory fielded and in storage. In Program year 20 all Lot 1 thru Lot 10 missiles are available.

Cell D48 Available missiles
173 Blk I missiles whose rocketmotors do not have the Optic Fiber are removed from the inventory. The 2,187 missiles available is 120 less than the 2,307 missiles having rocketmotors with the Optic Fiber.

Through Program year 21 23.5 million dollars less have been spent replacing missiles equipped with rocketmotors with Optic Fiber and there are 120 more of these missiles available.

A	B	C	D	E	F	G	H	I	J	K
49	Program Year	22	23	24	25	26	27	28	29	30
50	Depot Rocketmotor replacement cost	$38,196	$39,113	$40,052	$41,013	$41,997	$0	$0	$0	$0
51	Storage test labor cost	$12,402	$12,699	$13,004	$13,316	$0	$0	$0	$0	$0
52	Fielded test labor cost	$18,974	$19,518	$20,078	$20,655	$0	$0	$0	$0	$0
53	**Rocketmotors with Optic Fiber replacement**									
54	Rocketmotors replaced	221	204	180	144	88	0	0	0	1
55	Total Yearly Cost	$8,472,731	$8,011,246	$7,242,370	$5,939,819	$3,695,749	$0	$0	$0	$0
56	Cumulative Cost	$62,514,419	$70,525,665	$77,768,035	$83,707,853	$87,403,602	$87,403,602	$87,403,602	$87,403,602	$87,403,602
57	Available missiles	2,291	2,260	2,209	2,127	1,999	1,799	1,556	1,313	1,070
58										
59	**Lot by Lot rocketmotor replacement**									
60	Rocketmotors replaced	0	0	0	0	0	0	0	0	0
61	Total Yearly Cost	$0	$0	$0	$0	$0	$0	$0	$0	$0
62	Cumulative Cost	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592	$77,681,592
63	Available missiles	1,944	1,701	1,458	1,215	972	729	486	243	0

Figure 5. Program Years 22 - 30; Missile Inventory Comparison

Figure 5, documents Program Years 22 – 30 in which replacements of rocketmotors with the Optic Fiber end. The inventories of missiles with and without Optic Fiber decrease but at different rates.

Cells C49 – K49 Program Year

Rocketmotor with optic Fiber replacement

Cells C50 thru G50 Depot Rocketmotor replacement cost
Replacements of rocketmotors with Optic Fiber continue through Program 26. Storage testing costs have risen due to the annual 2.4% inflation.

Cells C51 thru G51 Storage test labor cost
Storage testing costs have risen due to the annual 2.4% inflation. In Program year 26 all rocketmotors replaced are from Lot 10, an assumption of this study is that the rocketmotors will fail at the rate shown in Figure 2. The missile serial numbers that have had rocketmotor replacements will be recorded, so the final 43 missiles needing rocketmotor replacement could be removed from storage and sent to the depot without first being tested. There may be variability in the yearly failure rates of the rocketmotors so the Missile Operations Command may choose to test all rocketmotors through their entire service life.

Cells C52 thru G52 Fielded test labor cost
Field test labor costs have risen due to the annual 2.4% inflation. In Program year 26 the final 45 Lot 10 fielded missiles could be returned to the depot for rocketmotor replacement without testing for the same reason as the stored Lot 10 missiles described above.

Rocketmotors with Optic Fiber replacement

Cells C54 thru G54 Rocketmotors Replaced
During Program years 22 thru 26 missiles with rocketmotors equipped with the Optic Fiber are tested and replaced at a decreasing rate as rocketmotors' from fewer and fewer lots are replaced. In Program year 22 missiles from Lots 6 thru 10 have rocketmotors replaced, in Program year 23 missiles from Lots 7 thru 10 have rocketmotors replaced and so on through year 26.

Cells C55 thru G55 Total Yearly Cost
Maintenance costs for missiles equipped with Optic Fiber rocketmotors continues as rocketmotors are replaced.

Cells C56 thru G56 Cumulative Cost
For missiles having rocketmotors with Optic Fiber the cumulative cost for rocketmotor replacements continues to increase through Program year 26 as rocketmotors continue to be replaced.

Cells C57 thru G57 Available missiles
In Program years 27 thru 30 the missile inventory decreases further as the rocketmotors pass beyond their useful life. In years 31 thru 35 the inventory decreases to zero. In Program year 30 1,070 missiles with Optic Fiber rocketmotors are available while the inventory of missiles without Optic Fiber rocketmotors is zero.

Lot by Lot rocketmotor replacement

Cells C60 thru K60 Rocketmotors replaced
Program year 20 was the last year for missiles not equipped with Optic Fiber to have rocketmotors replaced, no rocketmotors are replaced in Program years 22 – 30.

Cells C61 thru K61 Total Yearly Cost
No rocketmotors are replaced so no cost is accrued.

Cells C62 thru K62 Cumulative Cost
The cumulative cost remains the same since Program year 20 was the last in which rocketmotors without Optic Fiber were replaced.

Cells C63 thru K63 Available missiles
The missile inventory decreases Lot by Lot as the useful life of their rocketmotors without Optic Fiber expires.

For Program years 22 – 26 maintenance costs continue to accrue for the missiles equipped with Optic Fiber rocketmotors, the inventory of these missiles decreases at a lower rate than missiles without Optic Fiber rocketmotors. In Program years 27 – 30 all replacement costs for rocketmotors stop, the inventory of missiles without Optic Fiber rocketmotors diminishes to zero while the inventory of missiles with Optic Fiber rocketmotors remains above 1,000. In Program years 31 – 35 the inventory of missiles with Optic Fiber rocketmotors decreases to zero.

A	B	C
64	**Rocketmotors with Optic Fiber replacement**	
65	Rocketmotor test\replacement (in storage)	$41,087,608
66	Rocketmotor test\replacement (fielded)	$46,315,994
67	Cumulative Cost	$87,403,602
68	Available missiles (years)	45,031
69	Rocketmotor Maintenance (per missile)	$37,035
70	Rocketmotor Maintenance (per year)	$1,941
71		
72	**Lot by Lot rocketmotor replacement**	
73	Rocketmotor replacement (in storage)	$36,662,374
74	Rocketmotor replacement (fielded)	$41,019,219
75	Cumulative Cost	$77,681,592
76	Available missiles (years)	34,850
77	Rocketmotor Maintenance (per missile)	$32,916
78	Rocketmotor Maintenance (per year)	$2,229

Figure 6. Program Year 36; Final Maintenance and Operational Data

Rocketmotor with Optic Fiber replacement

Cell C65 Rocketmotor test\replacement (in storage)
The cost of replacing rocketmotors with Optic Fiber on missiles in storage for 16 years.

Cell C66 Rocketmotor test\replacement (fielded)
The cost of replacing rocketmotors with Optic Fiber on fielded missiles for 16 years. The seven missiles used each year for testing and training are taken from storage and don't have their rocketmotors replaced, this accounts for the replacement of rocketmotors for the fielded inventory costing more.

Cell C67 Cumulative Cost
The total cost of changing rocketmotors with Optic Fiber for all missiles.

Cell C68 Available missiles (years)
The available missiles for each year adds up to the missile availability in years.

Cell C69 Rocketmotor Maintenance (per missile)
Dividing Cell C67 Cumulative Cost by the number of missiles that had rocketmotors replaced, 2,360, determines the per missile cost for replacing rocketmotors.

Cell C70 Rocketmotor Maintenance (per year)

Dividing Cell C67 Cumulative Cost by Cell C68 Available Missile (years) amortizes the cost of replacing rocketmotors over the available years.

Lot by Lot rocketmotor replacement

Cell C73 Rocketmotor replacement (in storage)
The total cost of replacing the rocketmotors of missiles in storage one Lot per year.

Cell C74 Rocketmotor replacement (fielded)
The cost of replacing rocketmotors with Optic Fiber on fielded missiles for 16 years. The seven missiles used each year for testing and training are taken from storage and don't have their rocketmotors replaced, this accounts for the replacement of rocketmotors for the fielded inventory costing more.

Cell C75 Cumulative Cost
The same number of rocketmotors without Optic Fiber, 2,360, are replaced as rocketmotors with Optic Fiber, but the total maintenance cost is almost ten million dollars less. The additional cost for replacing the rocketmotors with Optic Fiber comes from Optic Fiber installation, the test set, field testing, storage testing and inflation.

Cell C76 Available missiles (years)
The available missiles for each year adds up to the missile availability in years. Missiles without the Optic Fiber are removed from service Lot by Lot resulting is fewer missile years of availability that for missiles with the Optic Fiber which are removed from service as the rocketmotor fails the Optic Fiber test.

Cell C77 Rocketmotor Maintenance (per missile)
Dividing Cell C75 Total Cost by the number of missiles that had rocketmotors replaced, 2,360, determines the per missile cost for replacing rocketmotors. The per missile replacement cost is less for rocketmotors without the Optic Fiber because there is no testing involved and the replacements go on for 10 years rather than 16 so there is less inflation cost.

Cell C78 Rocketmotor Maintenance (per year)
Though the per missile replacement cost is less expensive for rocketmotors without Optic Fiber the amortized yearly expense is greater because the years of availability are fewer than for rocketmotors with Optic Fiber.

Additional Missile Availability at Additional Maintenance Cost

This prognostics Cost Benefit Analysis give the customer a choice; a lower rocketmotor replacement cost or more years of missile availability at a greater expense. Missile rocketmotor replacement is one factor among many logistics factors to be considered in determining how to allocate support dollars. As with other logistics factors the decision to incorporate prognostics needs to be made at the beginning o the program to commit the dollars for installation and testing through the life of the system.

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