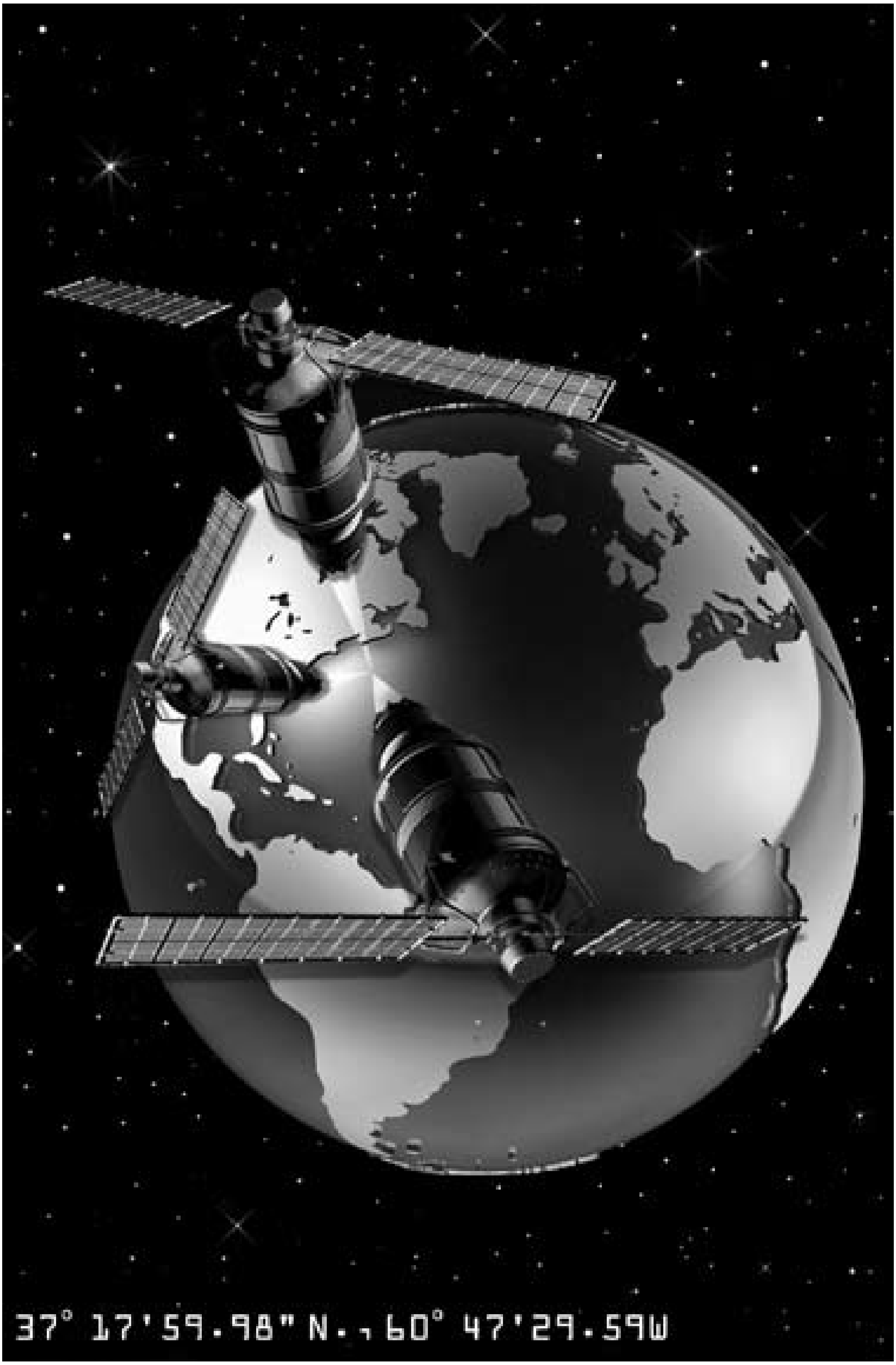

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TRANSLATED GLOBAL POSITIONING SYSTEM RANGE SYSTEM TRADE STUDY

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The Translated Global Positioning Systems Range System (TGRS) is currently in production and is being used at most relevant Department of Defense missile ranges. The Enhanced-Translated Global Positioning System Range System (E-TGRS) was ultimately designed and prototypes built to replace the TGRS. However, the E-TGRS was cancelled due to budget constraints. In light of these events, the purpose of the trade study presented in this article is to recommend selection of one alternative based on the comparison of benefits and cost of three alternatives: continue with TGRS as is, perform upgrades to TGRS, or reinitiate E-TGRS to replace TGRS.

The Translated Global Positioning System Range System (TGRS) is part of a compatible family of equipment designed to provide Time-Space-Position Information (TSPI) for low- and high-dynamic participants in Department of Defense (DoD) test, training, and operational ranges. TGRS provides the capability for real time line-of-sight (LOS) tracking and recording of high-quality pre-track Global Positioning System (GPS) signals, which are a primary source of target and interceptor post-mission independent truth data, position and velocity, and real time flight safety track.

TGRS consists of two primary subsystems, which include the Digital GPS Translator (DGT) that is placed on the airborne vehicle and the GPS Translator Processor (GTP) that is the ground segment. The DGT receives the L-band signal from available satellites, translates it to the S-band, and transmits the S-band signal to the GTP. The GTP receives the S-band signal from the DGT and processes the data.

TGRS began development in 1996 and production in 2001. The engineering design is based on 10-year-old technology resulting in questionable capability to meet future deployment needs. To reduce risks, the future system needs to be more efficient and flexible with better performance and lower costs. In addition, many parts of the current TGRS are becoming obsolete, which will eventually lead to failure to meet future production needs.

E-TGRS was designed to be the next generation of TGRS, offering enhanced performance capabilities at a cheaper cost. E-TGRS development started in 2003 to replace TGRS, but was canceled in October 2005 due to lack of funding. E-TGRS also consists of two primary subsystems which include the Enhanced Digital GPS Translator (EDT) to replace the DGT and the Enhanced GPS Translator Processor (E-GTP) to replace the GTP.

One possibility to consider is performing upgrades to the existing TGRS, which would address only the immediate, short-term concerns about the system. These upgrades would mostly involve replacing key components in the system but would require some research and redesign work to be done. However, concern has been expressed that the upgrades would only be a temporary fix instead of addressing the root problems of the system.

Interstate Electronics Corporation (IEC), the prime contractor for design and manufacturing of TGRS and E-TGRS, is located in Anaheim, California. IEC has provided nonrecurring engineering (NRE) and recurring engineering (RE) cost estimates for both the upgrades and for the completion of E-TGRS.

TRADE STUDY METHODOLOGY

The following is an overview of the trade study process used in this analysis. Each of these steps is detailed in the sections immediately following.

1. Background: The problem, decision context, decision makers, time frame, project life, interest rate, and constraints are defined.
2. Objectives: Once the objectives are defined and ranked, the weighting for each objective is calculated using an appropriate method.
3. Alternatives Identified: The alternatives to be evaluated are identified and defined.
4. Benefits Score: Each alternative is evaluated against each objective by narrative description and by numerical score. A total value of benefits score is calculated for each alternative.
5. Cost Model: A model for economical cost analysis is developed to obtain a cost estimate for each alternative. Monte Carlo simulations are performed on the subjective cost estimates for each alternative.
6. Sensitivity Analysis: Sensitivity analysis is performed on the alternative selection. Although a well-defined process for doing sensitivity analysis does not exist, the sensitivity analysis should be robust enough to provide confidence to the decision makers that the best decision is being recommended.

7. Conclusions and Recommendations: A benefits-to-costs plot is constructed to obtain a visual aid that combines the total value of benefits score and estimated cost for each alternative. Conclusions and recommendations are presented based on the benefits-to-costs plot.

BACKGROUND

The purpose of the trade study presented in this article is to recommend a selection of the best alternative based on the comparison of benefits and cost of TGRS, upgrades to TGRS, and E-TGRS. TGRS will play a very important role for the next several years in DoD testing of airborne vehicles. Management should place emphasis on planning for future GPS needs and ensure the proper capabilities and resources are available at a reasonable cost. The project life used for this study is 5 years because flight test plans are initiated 5 years in advance, and TGRS will be a required test asset for at least 5 more years. The annual interest rate used for this cost analysis was 8 percent, which is traditionally used for independent government cost estimates for this agency. This rate compares well with Office of Management and Budget (OMB) guidance found in Circular A-94, which calls for proposed investment and regulatory changes to be evaluated using a 7 percent discount rate (OMB Circular A-94, 1992). Flight test program offices were surveyed, and it was determined that the projected number of units needed for the 5-year study period are 11 GPS Translator Processors (GTPs) and 148 DGTs. The decision makers for this trade study are the program manager of TGRS and the director of the Directory of Test Resources. The results of the analysis will be presented to upper management within the Missile Defense Agency (MDA) for final selection and approval of funding. The decision must be made in early FY 2007 to allow for long-lead procurements.

OBJECTIVES

The objectives of the GPS system were obtained via numerous working group meetings with subject matter experts. The subject matter experts helped to identify and define areas of concern for the current TGRS program. The working groups focused on key objectives that if not met may lead to failure to support future missions for the next 5 years. The group also considered objectives that would benefit the performance of the system but are not as critical as others. Therefore, the rank sum method was used to give the weights a linear decrease as the rank importance decreases. E-TGRS or any upgrades to the current TGRS must meet or outperform the interface and performance requirements as specified in the Interface Control Document for the GTP Subsystem of TGRS (Interface Control Document 36900002, 2003) and the Interface Control Document for the DGT Subsystem of TGRS (Interface Control Document 36900001, 2004). Figure 1 provides a summary of the objectives, the ranking, and the weighting for each objective.

The rank sum method was selected to weight objectives because the team had exhibited a high degree of consistency in their discussions concerning the objectives. This method also limited the cognitive burden on the decision makers. Other approaches, such as pair wise comparison, can be used when there is less agreement on the relative priority of objectives; however, care should be taken to address inconsistencies in decision-maker preferences (Gholston, 1999).

First, rank the objectives and place them in descending order starting with the most important. Second, create a column for the inverted rank of each objective. For example, assume you have five objectives. The highest objective, objective No. 1, would have an inverted rank of 5; the second highest objective, objective No. 2, would have an inverted rank of 4, and so on. Third, sum up the column of inverted ranks (i.e., 5+4+3+2+1 = 15). Last, divide the inverted rank for each objective by the sum of the column of inverted ranks. In our example, the weight for objective No. 1 would be 5/15 = 0.333, the weight for objective No. 2 would be 4/15 = 0.267, and so on.

Down-link bandwidth–Real Time objective refers to the amount of bandwidth the systems require when transmitting the data from the airborne unit to the ground unit. Requiring a large amount of bandwidth adds risk to the program because a possibility exists that the upper S-Band frequencies may not be available in the future. Currently, the system can operate at either 8 MHz. or 4 MHz.

FIGURE 1. OBJECTIVES, RANK, AND WEIGHT

Objectives	Rank	Weight
Down-Link Bandwidth Required - Real Time	1	16.7%
Down-Link Bandwidth Required - Post Mission	2	15.2%
Production Lead Time	3	13.6%
Modular	4	12.1%
Encryption	5	10.6%
DGT/EDT Power Consumption	6	9.1%
DGT/EDT Weight and Size	7	7.6%
High Dynamics	8	6.1%
Plume Effects	9	4.5%
TTFF	10	3.0%
Design Schedule	11	1.5%

Down-link bandwidth–Post Mission objective refers to the level of fidelity needed in the post-mission data. While lowering the required amount of bandwidth is desired, higher bandwidths allow for a higher data transfer rate that can be used to create more detailed post-mission data.

Production lead time refers to the amount of time it takes to produce a system once an order has been placed. Production lead time is strongly influenced by the availability of parts needed to produce the system. Modular refers to the capability of interchanging components in the field to customize the system for each individual test. Modularity adds flexibility to better serve the needs of each individual project office.

Encryption refers to the capability to encrypt the data transmitted from the DGT unit to the GTP unit, which is required for some tests. Encryption capability can be designed with different types of encryption chips. However, the design must be approved by the National Security Agency (NSA).

Power consumption refers to the amount of power that is required to operate the DGT. The current requirement is 50 watts or less.

Weight and size of the DGT are important because the spaces and weight requirements for most airborne vehicles are very restrictive. These requirements vary depending on the specific vehicle.

High dynamics refers to the flight characteristics the airborne vehicle endures. The GPS system must be able to accurately track the vehicle even during high accelerations. The airborne unit must be able to withstand at least 75g per second.

Plume effects refer to the degradation of signal level caused by plume the vehicle causes during flight. The TGRS system must have the ability to track the vehicle through the plume. Tracking through plume effects plays an important role in safety to ensure the vehicle is not significantly off course.

Time to First Fix (TTFF) refers to the amount of time it takes the system to acquire the airborne vehicle immediately after launch. TTFF also plays an important role in safety to ensure the vehicle is not significantly off course.

Design Schedule refers to the amount of time needed to complete design work and any necessary qualification testing. Long design schedules add risk to meeting future requirements.

ALTERNATIVES IDENTIFIED

Over the last few months several discussions have occurred, and currently three alternatives are being considered. Alternative 1 is to continue with the current TGRS design as is and accept the risk associated with not meeting future deployment needs. The purpose for keeping this high-risk alternative is to provide a basis for comparison to other alternatives. Alternative 2 is to add upgrades to the current TGRS system including: new S-Band Converter (SBC) switch, 5 MHz. filter on the SBC, replace obsolescent Fiber Channel Data Acquisition Card (FCDAC), upgrade Pre-Track

Signal (PTS) recorder, replace data archive unit (DAU), and replace the GTP Tracker Controller. Alternative 3 is the E-TGRS, which consists of the Performance Enhanced Tracker (PET) Board that would be placed in the E-GTP unit and the EDT.

BENEFITS SCORE

Each alternative was evaluated against each objective by narrative description and by numerical score. One subject matter expert used for this evaluation is the TGRS program manager, who currently works as a civilian for the Missile Defense Agency. He has been working the TGRS program since it was initiated over 10 years ago. The other two subject matter experts were personnel from GRAY Research, one who has also been with the program for over 10 years and the other for over 5 years. The narrative evaluation, shown in Figure 2, gives a brief description of the advantages or disadvantages of each alternative with respect to each objective. The numerical score ranged from poor, which was scored as a "1" to excellent, which was scored as a "5," and the numerical score evaluation for each alternative is shown in Figure 3. Figure 4 shows the weighted evaluation results for each alternative. The bottom row of Figure 4 is the sum of the benefits for each alternative. These numbers are relative rather than absolute. Alternative 2 offers approximately 71 percent of the total benefits that Alternative 3 offers. Likewise, Alternative 1 offers approximately 60 percent of the total benefits compared to Alternative 3.

COST MODEL

Cost modeling was performed to reduce the risks associated with subjective cost estimating. The first step was to create present value cost estimates for each FY based on NRE and RE estimates of each alternative and the projected number of GTPs and DGTs required for FY 2007 through FY 2011. Next, subjective probability functions were estimated for each alternative, shown in Figure 5. All probability functions were elicited from the TGRS program manager and a contractor who supports the management of the program and has been with the program for over 10 years. Finally, a Monte Carlo simulation was performed on the probability functions with 30 simulations in order to utilize the Central Limit Theorem. Three hundred iterations were performed on each simulation in order to aim for a convergence level of 1.5 percent. Figure 6 shows the summary results of the Monte Carlo simulation, which are the average and standard deviation of the means for the 30 simulations performed on each alternative. The variance of each set of 30 simulations was relatively small for each alternative. A summary of relevant cost data is provided in the appendix.

Some assumptions were made in order to create a realistic cost model.

1. All units are ordered in the previous FY to meet the following year's flight requirements. This will allow for production lead times.
2. The costs occur at the end of the FY at the same time the order is placed.

3. If Alternative 3 (E-TGRS) is to be selected, DGTs would be used for FY 2007 until E-TGRS could be developed and slowly phased into operation.
4. Current operational GTPs and DGTs would be sufficient until Alternative 3 (E-TGRS) was developed and tested.
5. Alternatives 1 (TGRS) and 2 (Upgrades) would use existing DGTs as is.
6. NSA Certification Costs could be spread over a period up to 3 years. However, all NSA Certification Costs were treated as initial costs.

FIGURE 2. NARRATIVE EVALUATION

Objectives	Alternative 1. TGRS	Alternative 2. Upgrades	Alternative 3. E-TGRS
Down-Link Bandwidth Required - Real Time	Requires 4 MHz.	Requires 4 MHz. but gives a little more control over where frequencies can be set.	Requires 200 KHz.
Down-Link Bandwidth Required - Post Mission	Provides detailed data for post mission analysis.	Provides detailed data for post mission analysis.	Less data collected but is sufficient to do some analysis.
Production Lead Time	12 month lead time for DGTs. Parts are hard to find for GTPs.	12 month lead time for DGTs. Parts for GTPs would be easier to get.	6 month lead time for EDTs. Parts would be commercial off the shelf for PET Board.
Modular	Translator only. Encryption is factory set. Only 1 power setting.	Translator only. Encryption is factory set. Only 1 power setting.	Translator or Receiver. Encryption module can be added in the field. High or low power module.
Encryption	Old encryption chips.	Old encryption chips.	New chips are faster and smaller. May be easier to get NSA certification.
DGT/EDT Power Consumption	50 W. Loses 6 dB when operating in encryption mode.	50 W. Loses 6 dB when operating in encryption mode.	50 W or 5 W for GPS Receiver only. Does not lose 6 dB in encryption mode.
DGT/EDT Weight and Size	13 oz. 12 in^3	13 oz. 12 in^3	16 oz. for EDT or 3 oz. if using GPS Receiver only. 22 in^3 for all modules or 3 in^3 for GPS Receiver only.
High Dynamics	75 g/s	75 g/s	> 200 g/s
Plume Effects	Susceptible	Susceptible	Minimal
TTFF	Cannot meet the 1 sec. TTFF	Cannot meet the 1 sec. TTFF	Better than 1 sec. TTFF.
Design Schedule	Already designed.	No prototypes built and tested.	Prototypes have been built but have not been through qualification tests.

SENSITIVITY ANALYSIS

Although the trade study appears to be very robust, a simple sensitivity analysis was performed on the performance results.

Lowering the numerical score evaluation by 1 point for each objective for Alternative 3 (the preferred alternative) leads to a total benefits score of 2.97, which is still higher than Alternatives 1 and 2.

Likewise, leaving Alternative 3 as is and increasing the numerical score evaluation by 1 point for each objective leads to a total benefits score of 3.41 for Alternative 1 and 3.42 for Alternative 2. Both of these values are still lower than the 3.97 value originally obtained for Alternative 3.

CONCLUSIONS AND RECOMMENDATIONS

The trade study methodology was followed to provide a defendable, logical, and structured selection. The results of the trade study are that E-TGRS has a much

FIGURE 3. NUMERICAL SCORE EVALUATION

Objectives	Rank	Weight	Alt. 1 TGRS	Alt. 2 Upgrades	Alt. 3 E-TGRS
Down-Link Bandwidth Required - Real Time	1	16.7%	1	2	5
Down-Link Bandwidth Required - Post Mission	2	15.2%	5	5	3
Production Lead Time	3	13.6%	1	3	4
Modular	4	12.1%	2	2	4
Encryption	5	10.6%	2	2	4
DGT/EDT Power Consumption	6	9.1%	2	2	5
DGT/EDT Weight and Size	7	7.6%	3	3	2
High Dynamics	8	6.1%	4	4	5
Plume Effects	9	4.5%	1	1	3
TTFF	10	3.0%	4	4	5
Design Schedule	11	1.5%	5	3	2

FIGURE 4. WEIGHTED EVALUATION RESULTS

Objectives	Rank	Weight	Alt. 1 TGRS	Alt. 2 Upgrades	Alt. 3 E-TGRS
Down-Link Bandwidth Required - Real Time	1	16.7%	0.17	0.33	0.83
Down-Link Bandwidth Required - Post Mission	2	15.2%	0.76	0.76	0.45
Production Lead Time	3	13.6%	0.14	0.41	0.55
Modular	4	12.1%	0.24	0.24	0.48
Encryption	5	10.6%	0.21	0.21	0.42
DGT/EDT Power Consumption	6	9.1%	0.18	0.18	0.45
DGT/EDT Weight and Size	7	7.6%	0.23	0.23	0.15
High Dynamics	8	6.1%	0.24	0.24	0.30
Plume Effects	9	4.5%	0.05	0.05	0.14
TTFF	10	3.0%	0.12	0.12	0.15
Design Schedule	11	1.5%	0.08	0.05	0.03
		=	2.41	2.82	3.97

FIGURE 5. SUBJECTIVE PROBABILITY FUNCTIONS FOR COST OF EACH ALTERNATIVE

Type of Cost	Probability Functions		
	Alternative 1 (TGRS)	Alternative 2 (Upgrades)	Alternative 3 (E-TGRS)
NSA Certification Cost	P($1M) = 0.5; P($0.667M) = 0.3; P($0.333M) = 0.2	P($1M) = 0.5; P($0.667M) = 0.3; P($0.333M) = 0.2	P($1M) = 0.25; P($0.667M) = 0.3; P($0.333M) = 0.45
Initial Cost	Certainty Initial Cost of $00	N($4,165,000, $75,000)	N($1,763,300, $50,000)
FY 07 Cost	N($4,590,000,$400,000)	N($5,175,000, $400,000)	N($3,956,700, $300,000)
FY 08 Cost	N($1,740,000, $400,000)	N($1,740,000, $400,000)	N($725,000, $300,000)
FY 09 Cost	N($3,610,000, $500,000)	N($3,675,000, $500,000)	N($1,731,300, $400,000)
FY 10 Cost	N($3,010,000, $500,000)	N($3,075,000, $500,000)	N($1,481,300, $400,000)

higher benefits value and is also much cheaper over the 5-year study period. However, information should continue to be collected and evaluated over the next few weeks to reduce some of the uncertainties in the trade study. The current recommendation is to continue with TGRS through FY 2007 in parallel with completing development and testing of E-TGRS to begin production at the end of FY 2008.

FIGURE 6. COST SIMULATION RESULTS

Alternative	Average Mean Output	Standard Deviation
1. TGRS	$11,586,669	$1,141
2. Upgrades	$16,392,675	$1,319
3. E-TGRS	$9,111,763	$813

APPENDIX

RECURRING ENGINEERING (RE) COSTS PER UNIT

Description	Cost
RE Cost per GTP	$370,000
RE Cost per DGT	$60,000
RE Cost per GPT with Upgrades	$435,000
RE Cost per E-GTP	$381,300
RE Cost per EDT	$25,000

NUMBER OF UNITS PER FISCAL YEAR

Projected # of Units	FY 2007	FY 2008	FY 2009	FY 2010	TOTAL
GTP or E-GTP	9	0	1	1	11
DGT or EDT	21	29	54	44	148

TOTAL COSTS PER ALTERNATIVE MINUS
NATIONAL SECURITY AGENCY (NSA) COSTS FOR EXISTING UNITS

Existing Units			
		Nonrecurring Engineering (RE)	Recurring Engineering (RE)
Translated Global Positioning System Range System (TGRS)	GTP	$0	$0
	DGT	$0	$0
GTP Upgrades	S-Band Converter (SBC) Switches & 5 MHz Filter	$350,000	$410,000
Fiber Channel Data Acquisition Card VME (Bus) Card		$500,000	$1,025,000
Pre-Track Signal (PTS) Recorder		$100,000	$410,000
Data Archive Unit (DAU)		$250,000	$205,000
GTP Tracker Controller		$300,000	$615,000
E-TGRS	E-GTP	$650,000	$463,300
	EDT	$650,000	$0

Projected Units for FY 2007 - FY 2011			
		Nonrecurring Engineering (RE)	Recurring Engineering (RE)
Translated Global Positioning System Range System (TGRS)	GTP	$0	$4,070,000
	DGT	$0	$8,880,000
GTP Upgrades	GTPs	$0	$4,070,000
	DGTs	$0	$8,880,000
SBC Switches and 5 MHz Filter		$0	$110,000
FCDAC		$0	$275,000
PTS Recorder		$0	$110,000
DAU		$0	$55,000
GTP Tracker Controller		$0	$165,000
E-TGRS	E-GTP	$0	$4,194,300
	EDT	$0	$3,700,000

	Nonrecurring Engineering (RE)	Recurring Engineering (RE)	TOTAL
Alternative 1	$0	$12,950,000	**$12,950,000**
Alternative 2	$1,500,000	$16,330,000	**$17,830,000**
Alternative 3	$1,300,000	$8,357,600	**$9,657,600**

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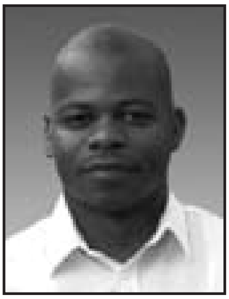

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REFERENCES

Gholston, Sampson E. (1999). *An Interactive Multiple Objective Optimization Approach with Application to Hydrostatic Bearing Design.* PhD dissertation, The University of Alabama in Huntsville.

Missile Defense Agency (2004, September 27). Internal Document Tracking No. 36900001. *Interface control document for the digital global positioning system (GPS) translator (DGT) subsystem of translated GPS range system (TGRS)*.

Missile Defense Agency (2003, November 11). Internal Document Tracking No. 36900002. *Interface control document for the GPS translator process (GTP) subsystem of translated GPS range system (TGRS)*.

Office of Management and Budget. (1992, October 29). Circular No. A-94 Revised: *Guidelines and discount rates for benefit-cost analysis of federal programs*.