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PROSPECTIVE RESEARCH AND DEVELOPMENT AREAS FOR U.S. CRUISE AND --ETC(U)
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PROSPECTIVE RESEARCH AND DEVELOPMENT AREAS FOR
U.S. CRUISE AND BALLISTIC MISSILE GUIDANCE UPDATING SYSTEMS

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To James F. Mullen
for the encouragement provided
during the preparation of this paper

I. INTRODUCTION

Given the U.S. commitment to strategic force modernization in the 1980's, a variety of new weapon systems, including cruise missiles and Pershing II, will be deployed. In each case, a key factor associated with overall mission effectiveness is guidance system accuracy and reliability. For cruise missiles, due to flight times of up to several hours, and Maneuvering Reentry Vehicles (MaRVs), to reduce collateral damage or remove initial uncertainties or maneuvering errors, guidance updating systems based upon map-matching techniques are either necessary or desirable. In fact, without some form of guidance updating (even with a highly accurate Inertial Guidance System (INS)), the present U.S. land-attack cruise missile would not be possible.[1]

Terrain Contour Matching (TERCOM) and Digital Scene Matching Area Correlation (DSMAC) have been developed for use on land-attack cruise missiles. TERCOM is used for midcourse and terminal guidance on nuclear-armed missiles, DSMAC for terminal guidance (after TERCOM midcourse updating) on conventionally-armed cruise missiles, and Radar Area Guidance (RADAG) for Pershing II terminal guidance.[2] These systems are termed map-matching, and compare a live sensor image with a prestored reference scene in the missile's computer to determine the along and cross-track vehicle position error at the update location.

[1] This paper was submitted to the Center for Strategic and International Studies, Georgetown University, Panel on Military Research and Development. Views expressed in this paper are those of the author, and do not necessarily represent the positions of The Aerospace Corporation, The Rand Corporation or the U.S. Government.

[2] For a general background on map-matching guidance updating systems, see Conrow, E. H. and J. A. Ratkovic, "Almost Everything One Needs To Know About Image Matching Systems", Proceedings of the 24th International SPIE Symposium, July 28-August 1, 1980, pp. 426-453.

Given the need for high accuracy strategic missiles, it is reasonable to ask what potential operational payoffs may exist for improving these systems (and developing others), and where should Research and Development (R&D) funding be channeled to permit Preplanned Product Improvement (P³I) or the introduction of advanced systems.

The purpose of this paper is to discuss potential R&D funding areas which can improve the effectiveness of map-matching guidance updating systems. As such, it represents an initial attempt in this field to examine the components of these systems, and to provide estimates of their potential payoff, technical risk, and required funding levels.

Individual potential R&D areas addressed here include: missile sensors, missile processing algorithms, scene modeling and simulation, systems integration, fix quality evaluation, application of space assets, and advanced applications. A brief discussion of the need for improved planning and costing for map-matching guidance updating systems is also presented. Potential payoffs evaluated for each proposed R&D funding area include: vehicle survivability, operational coverage, update reliability and force effectiveness. In each applicable case, potential improvements are noted along with estimates of the technical risk and cost. Although these ratings are subjective (low to very high), they nevertheless represent an attempt to evaluate each candidate R&D funding area for the decisionmaker. A summary of the potential payoffs, technical risk and funding required for each concept discussed is given in Table 1.



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Table 1

SUMMARY OF POTENTIAL PAYOFFS AND COSTS OF U.S. RESEARCH AND DEVELOPMENT FUNDING FOR CRUISE AND BALLISTIC MISSILE GUIDANCE UPDATING SYSTEMS

Potential Payoff	Research and Development Funding Area *							Advanced Applications
	Missile Sensor	Missile Algorithms	Scene Modeling and Simulation	Systems Integration	Fix Quality Evaluation	Application of Space Assets		
Increased Vehicle Survivability	M	L	M	M/H	---	M/VH	---	
Increased Operational Coverage	M	L/M	M	M/H	---	M/VH	---	
Increased Update Reliability	M	M	M/H	M/H	M/H	---	M/H	
Increased Force Effectiveness**	---	---	---	M/H	---	H/VH	M/H	
Cost								
Technical Risk	L/M	L/M	M	M	M	L/H	H	
Funding Level	M/H	L/M	M/H	M/H	L/M	VH	L/M	

* L = Low, M = Moderate, H = High, and VH = Very High, --- = Not Applicable.

** Independent of increases resulting from improved update reliability.

II. POTENTIAL RESEARCH AND DEVELOPMENT FUNDING AREAS

MISSILE SENSORS

The first broad area of potential payoff from R&D funding involves sensors used on-board the missile for terrain following and guidance updating applications. Funding should be applied here in three different areas. First, due to missile survivability considerations, improved altimeters for terrain following and TERCOM applications should be investigated. Promising altimeter concepts include developing low probability of intercept systems based on power management, frequency-hopping, and reduced antenna sidelobes; using a 60 GHz transmitter/receiver (located in a strong oxygen attenuation band); coupling this 60 GHz altimeter with the above reduction methods; and finally using a 10.6 micron (CO_2) laser as an altimeter. The 60 GHz system would be acceptable in all but heavy precipitation, while the CO_2 laser case would perform acceptably in low altitude applications in all but heavy fog conditions.

The second area that should be investigated involves the sensors to be used in the map-matching role on-board the missile. Since optical/near IR and passive microwave systems at 35 GHz are fairly well developed at this time, little is to be gained from increased exploration here. Three sensors with promise, however, include the development of a low cost and volume, high efficiency CO_2 laser, improved two-dimensional (staring) arrays in the thermal IR (i.e., 10 to 12.5 micron) region and an increased power transmitter coupled with an improved low noise receiver at 94 GHz (in the millimeter microwave

region). Finally, an improved illuminator for an advanced DSMAC system using either a high-output, short pulse xenon strobe or a Q-switched laser (provides atmospheric range-gating capability) is desirable for P³I given the commitment by the U.S. to this system for all first generation land-attack, conventionally armed cruise missiles.

The third area that should be investigated involves multimode sensor systems. Two promising candidates include a system based upon a CO₂ laser, which could be operated in a reflectance or range-gated mode for terrain following, TERCOM and a two-dimensional ("imaging") form of TERCOM; and a microwave system at 35 GHz, which could be operated in a passive (radiometry), active (radar) or range-gated active mode (altimeter) for terrain following and TERCOM.

For MaRVs, potential payoffs are possible for continued development of Pulsed Doppler Map Matching (PDMM) and Range Only Correlation System (ROCS) for both Air Force and Navy programs. In addition, while TERCOM does not provide the operational flexibility of PDMM and ROCS, it should also be continued because of the present data base for cruise missiles (although this requires modification for use), and as a technological hedge against potential problems in these other systems. (While RADAG is acceptable for the relatively low velocities of Pershing II, it would not be applicable to the MaRVs presently under development. In addition, ROCS is basically a segmented version of RADAG and should function properly in a MaRV (as PDMM).) Advanced sensors being developed for MaRVs include those in the Ballistic Intercept Program (BIM). Technology programs underway for BIM show promise and should be continued.

Potential payoffs for R&D funding in this area include: moderate increases in vehicle survivability, operational coverage, and update reliability. The estimated technical risk for this area is low to moderate and the estimated funding level required is moderate to high.

MISSILE PROCESSING ALGORITHMS

The second broad area of potential payoff from R&D funding involves the algorithms used for the map-matching operation. Four broad classes of applications exist in increasing order of complexity, being: down-looking operation for a land-attack missile, forward-looking operation for an anti-ship missile, forward-looking application for a land-attack missile against fixed targets, and the same but against moving or movable targets.

There are three general classes of map-matching algorithms, including: correlation, feature matching and hybrid types.[1]

Algorithms in the first two categories have been traditionally used in map-matching applications. Briefly, correlation types of algorithms use the intensity values associated with the resolution elements of each map (or some transformation of these intensity values, i.e., normalization) as the map data to be used in computing the metric. Feature matching algorithms do not utilize intensity data per se but attempt to work with only features in the scene.

The third type of algorithm, which is proposed as an R&D funding candidate because of potential payoffs, is the hybrid. Basically, the hybrid algorithm uses a combination of intensity level and region identification information in determining a match location. In this

[1] Ibid, pp. 17-20.

class of algorithm homogeneous regions in the reference scene are identified and all resolution elements within the region are tagged as belonging to the region. When the sensor map is compared to the reference map, an assumption is made that this position of comparison is the correct one, and the sensor image is broken up into homogeneous regions as identified by the counterpart elements of the reference map. The elements in each region are correlated separately using a correlation algorithm, and the total correlation between the two maps is found by summing the individual correlations taken over each homogeneous segment of the reference map.

Hybrid algorithms are generally good performers in the presence of regional errors (i.e., intensity changes in a region contained within a heterogeneous reference scene) and nonstructured errors (where regions within the sensor scene may appear obliterated when compared to the reference map). Unless relatively invariant imagery is available either due to the fortunate selection of the sensor spectral operating region and mode (active and passive) coupled with the target structure, or the use of near real-time imagery, these two error classes may predominate.

Potential payoffs in R&D funding in this area include: a low to moderate increase in operational coverage, and a moderate increase in update reliability. The estimated technical risk for this area is low to moderate, as is the estimated funding level required.

SCENE MODELING AND SIMULATION

The third broad area of potential payoff from R&D funding involves scene modeling and simulation. Within this subsection, there are two separate but interrelated areas. The first involves imaging physics models, while the second uses this and other necessary models (i.e.,

describing the vehicle trajectory) to produce an evaluation of the quality of the potential reference area.

The first area that should be investigated involves the development of imaging physics models for each of the candidate sensor spectral operating regions and modes. Models of this type can be used in several different analyses applicable to guidance updating systems, including: sensor and illuminator spectral bandpass shaping, and reference scene screening and evaluation. Basically, imaging physics models should contain three submodels, which in increasing order of difficulty describe: the sensor, atmosphere/illumination, and the target/background signature characteristics. The submodels should allow computations to be performed over the non-zero spectral bandpass of the sensor, as well as over the range of expected target/vehicle/and solar or artificial illuminator geometries.

To this point in time, the Department of Defense (DoD) has generally failed to take advantage of the considerable amount of unclassified and readily available analyses previously performed by the National Aeronautics and Space Administration (NASA) and other non-DoD government organizations in support of civilian remote sensing programs. Within the DoD community, imaging physics modeling efforts are generally uncoordinated and often times repeated. In example, the author is aware of at least four separate programs funded by DoD to produce a model capable of accurately simulating target/background surface temperature imagery (or in the thermal IR spectral region). Researchers within these groups have typically had little or no contact with each other. One result of this type of activity may be a proliferation of non-standardized models of varying degrees of

sophistication, accuracy and validation. At least part of this problem can be blamed on the Not Invented Here (NIH) syndrome, but independent of this, a lack of communication and coordination currently exists between imaging physics model developers and prospective users within the DoD community.

One potential solution to this problem of proliferation and disarray is to designate one organization (e.g., the Defense Mapping Agency (DMA)) the coordinator of all imaging physics models to be used for DoD scene simulation purposes. Such a move may improve the effectiveness of the working relationship between DoD project offices, DMA, and industry contractors on guidance updating systems (e.g., RADAG (Pershing II), and DSMAC (cruise missile)), and hence reduce overall program risk.

Models developed should be sophisticated enough to accurately represent the "real-world", but not so much so that they either require an inordinate amount of inputs (that may not be available even under the best of conditions), or machine processing time. An example of this is given for surface temperature (or thermal IR imaging) models. Past experience has shown that the accuracy of the model in predicting surface temperature should be greater than the overall effect due to the measurement accuracy of the input parameters themselves, but not so accurate so that the resulting machine processing time is inordinately large. (In example, if the combination of input parameters leads to a 2° Celsius surface temperature prediction error with a perfect model (zero model error) whose run time is 100X, a more reasonable approach may be to use a model with a typical error on the order of 0.5° Celsius if the run time is one tenth to one hundredth of it.)

In addition to current modeling difficulties, there is presently a lack of a coordinated and complete data base pertaining to the physical and electrical material properties (i.e., thermal inertia and spectral reflectance respectively) and atmospheric properties necessary to model candidate sensor systems in each spectral operating region and mode. Even for the optical/near IR spectral region the existing data base is insufficient to permit the simulation of a representative target structure. (In example, few calibrated data apparently exist that can be used in an imaging physics model for spectral atmospheric properties within this region, including: cloudy sky irradiance, path radiance, and atmospheric transmittance for moderate to severe atmospheres over short path lengths.)

A measurement program should be conducted for the relevant parameters, much like that performed by Willow Run Laboratories (now the Environmental Research Institute of Michigan (ERIM)) for the U.S. Air Force during the 1960's, and for NASA during the early 1970's. In fact, any such effort should build upon the existing ERIM target data base to save time and funding. If other partial data bases exist, comprised of calibrated data and recorded measurement conditions, then this information should be aggregated to reduce the magnitude of the task.

Although obtaining such data measurements may aid the scene simulation process, it should be recognized that merely performing a measurement program for its own sake without preplanning and obtaining calibrated data may be a potentially wasted effort. Measurements obtained should not only be from a set of calibrated sensors, but represent a range of expected "real-world" conditions. (In example,

soil property measurements should be determined over a range of moisture conditions (i.e., dry, damp and wet), electrical properties measured over the range of expected viewing geometries, and atmospheric properties measured over the range of expected viewing geometries and severity.)

A major potential payoff area using imaging physics models involves optimizing the missile's sensor and/or illuminator spectral bandpass characteristics. At least in some cases, this may increase the imaged scene contrast (permitting operation under degraded atmospheric conditions), reduce time-varying reference area signature changes (improves fix correlation), and decrease detection for active systems and reduce the jamming possibility for passive systems (increases vehicle survivability). Obviously, the degree of improvement possible will depend upon the selected target structure; hence the atmospheric conditions and the target/background signature characteristics present.

The second candidate area for R&D funding deals with the development of models for the reference scene screening and simulation process. The first area that should be investigated involves reference scene simulation models. Basically, a model of this type is composed of a (previously mentioned) imaging physics, map-matching algorithm, and missile trajectory submodels, and integrated into a Monte Carlo simulation to cover the range of expected environmental conditions and vehicle trajectory characteristics. To ensure operational systems performance, a simulation should be available for the candidate guidance updating system at least by its Full Scale Development (FSD) phase. At least one map-matching guidance updating system (DSMAC) is presently near deployment without having such a simulation available or even in

development. Though a lack of funding is cited as a reason why this has not occurred, it should be recognized that a thorough simulation could be developed for approximately the price of one conventionally-armed Sea Launched Cruise Missile or Medium Range Air to Surface Missile. Considering that thousands of these cruise missiles may be produced by 1990, the investment in an accurate simulation of this type can hardly be considered an unwarranted exercise or expenditure. As in the imaging physics model case (previously discussed), the designation of one organization to be responsible for the development and validation of reference scene screening and simulation models may increase the effectiveness of the working relationship between DoD project offices, DMA, and industry contractors, thus reducing overall program risk.

The second area that should be investigated involves the use of advanced computers currently being developed by the private sector to increase throughput rates, hence reduce the time and cost necessary to evaluate each potential reference area or target viewing geometry for a guidance updating system. Computers of this type, possibly using dedicated hardwired modules for sensor characteristics, imaging atmospheric properties, and the map-matching algorithm processing of sensor and reference images (once these parameters have been selected), could increase the reference scene simulation throughput rate by a factor of ten to one hundred fold over comparable simulations presently available. In this case, private sector funding will probably be sufficient, but it is incumbent upon DoD to exploit this emerging computer technology and incorporate it as soon as it is available. Using specialized computers of this type, tens of millions of dollars may be saved during this decade alone on the reference scene evaluation

process for guidance updating systems. Additional benefits may also include a substantial reduction in time necessary for scene development, hence system deployment. Clearly, this is one area of emerging U.S. technical superiority over the Soviet's that should be exercised to the fullest extent possible.

The third area that should be investigated involves the implementation of more efficient and accurate intermediate screening models. These models are used before the costly Monte Carlo simulation to reject potentially poor reference areas or target viewing geometries before this final step. Though such screening techniques based upon the use of correlation surface statistics exist,[2] they have not been widely utilized by DoD.

The fourth area that should be investigated involves the development of a more thorough simulation than the Monte Carlo type presently used (at least for high value targets). Basically, the quality of all possible subregions within the reference scene is determined for the number of independent elements (which controls failures due to Signal-to-Noise Ratio (SNR) problems (i.e., lack of information)), and intrascene redundancy (i.e., the checkerboard problem, which causes failures in addition to SNR effects). If the number of subregions (possibly weighted around the imaging location of the vehicle over the reference area due to the statistical properties of this parameter) producing a failure due to either of these factors is determined to be above a critical threshold, then the reference scene is either rejected or modified (i.e., by increasing the sensor scene size or reducing the reference and sensor area resolution). Given the

[2] Ibid, pp. 20-23.

advanced computers being developed (previously described) that could be tailored for this form of processing, an extensive simulation of this type would not be impractical, at least for high value targets.

Potential payoffs in R&D funding in this area include: a moderate level of increased vehicle survivability and operational coverage, and a moderate to high level of increased update reliability. The estimated technical risk for this area is moderate, and the estimated funding level required is moderate to high.

SYSTEMS INTEGRATION

The fourth broad area of potential payoff from R&D funding involves guidance updating systems integration with respect to target characteristics (i.e., hardness and geographic distribution), warhead type and yield, and prospective missile sensors and algorithms. To date, a considerable amount of systems integration has been performed with TERCOM, while less has been performed for DSMAC and RADAG; particularly with regard to the target structure. Other less mature guidance updating concepts generally have had far less systems integration than this. For optimal results, the missile sensor and algorithm should be selected based upon target characteristics and warhead considerations. A more detailed examination of this procedure follows.

A trade-off analysis should be performed to determine the optimal missile sensor(s) and algorithm(s), and warhead type and yield, based upon operational constraints present for the designated target structure. A study of this type should incorporate a number of individual analyses to ensure the accuracy of the results and to minimize the expenditure necessary to perform the task. An example

analysis outline is provided here for the land-attack terminal guidance case (in the vicinity of the target). Obviously, a separate midcourse analysis is also required to ensure missile survivability (including flight path and trajectory selection), and placement within an acceptable position error basket (which impacts the missile midcourse guidance updating sensor and algorithm selection) for hand-off to the terminal guidance system (if different from the midcourse one).

In the first analysis, the expected target structure (hence hardness), and approximate missile impact accuracy (based upon the candidate sensor, algorithm, and expected INS drift rate), are examined to thoroughly select the warhead type and yield. In the second analysis, operational constraints (i.e., survivability) are examined to eliminate inadequate approach azimuths and routing to the target, as well as missile sensors.

In the third analysis, given the operational constraint results and bounds on the warhead type (i.e., nuclear and non-nuclear) and yield (i.e., 0.5 ton or 0.5 megaton) possible, the candidate sensors and algorithms are reevaluated versus the designated target structure (and the surrounding area) to produce a more refined set of update (hence missile impact) accuracy and reliability estimates. As a result of this, sensor and algorithm combinations not producing the required accuracy or reliability are eliminated.

In the fourth analysis, the accuracy and reliability of the remaining candidate sensors and algorithms are evaluated and ranked versus the target structure (and the surrounding area) using a vehicle simulation and imaging physics model (previously discussed) to represent the range of expected trajectories, atmospheric conditions, and

target/background signature characteristics. As a result, a missile sensor and algorithm can be selected from the ranked list (with an estimated accuracy and reliability) and used to adjust the warhead type and yield (within "acceptable" bounds), and operational tactics (i.e., based upon the expected update reliability) against the designated target structure.

Potential payoffs in R&D funding in this area include: moderate to high increases in vehicle survivability, operational coverage, update reliability, and force effectiveness. The estimated technical risk for this area is moderate, and the estimated funding level required is moderate to high.

FIX QUALITY EVALUATION

The fifth broad area of potential payoff from R&D funding involves research into the adaptive determination of fix quality from the correlated reference and sensor scene data on-board the missile itself. This is desirable since the reference scene screening process will always be imperfect due to the inability to examine all possible cases, inherent limitations due to the accuracy of the submodels used, and the inability to often times predict the material and imaging properties present within the reference area at the time of overflight.

Some procedure to "guarantee" that a valid update has occurred is necessary to ensure mission effectiveness and safe warhead arming. One technique, which is presently used for TERCOM and DSMAC, involves a voting logic with three successive fix scenes. Here, the determined fix point of two of the three correlated scenes must be matched within an acceptable bound; else the fix sequence is rejected as an update. Although simple to implement and suitable for use with relatively

invariant reference areas, the validity of this technique breaks down when the fix area is missed altogether, or when significant variations from the expected scene signature exist that can not be modeled a priori. When coupled with the inherent modeling limitations of most sensor operating regions and modes, this technique does not provide any indication of the uncertainty in the individual fixes themselves.

One approach which can potentially minimize operational problems resulting from deficiencies in the present voting logic uses the correlation surface data generated by the map-matching algorithm for each in-flight fix to estimate the quality of the fix itself. (If necessary, a similar voting sequence can be utilized based upon a minimum acceptable threshold associated with the probability of correct match for the number of fixes used per update.) Techniques of this type use a comparison of the statistical distributions associated with the main and secondary peaks of the map-matching surface to estimate the quality of the fix itself.[3] If fix quality evaluation techniques prove successful in testing, then further refinements can be incorporated for use with guidance updating systems to be deployed (i.e., tailoring the algorithms to each system).

Potential payoffs in R&D funding in this area include: a moderate to high increase in update reliability. The estimated technical risk for this area is moderate, and the estimated funding level required is low to moderate.

[3] Ibid, pp. 23-24.

APPLICATION OF SPACE ASSETS

The sixth broad area of potential payoff from R&D funding involves the development and deployment of space assets to assist in the generation of map data and possibly for communication with cruise missiles. The first case that should be investigated involves deploying one or more radar altimeter mapping satellites with vertical measurement accuracies on the order of one meter, and element sizes of ten to twenty meters. A system of this type, using Doppler processing to achieve the necessary resolution, is currently well within the state of the art, and in fact, was demonstrated on SEASAT several years ago. High quality terrain elevation data would be an output product of this satellite and could be used directly for terrain following and as a TERCOM reference scene input. The primary benefits of this approach are that the elevation data would be more readily available and less costly than is presently possible from data generated by conventional methods.

The second case that should be investigated involves an improved, high-capacity secure communications system (with satellites and user ground links). This system could be utilized for near real-time data transmission to support guidance updating applications where the reference image is prepared just prior to missile launch. If configured properly, this type of system could also be used in conjunction with selected cruise missiles to provide a means of reporting back either missile position, missile position and damage assessment imagery of a targeted area, or for two-way communication between cruise missiles and the user command. Payoffs in increased force effectiveness may occur in these three cases by allowing follow-on wave retargeting to avoid enemy

defenses, to minimize the "empty hole" silo (or similar) problem, and to permit dynamic retargeting of at least selected vehicles respectively. Obviously, for near real-time targeting with a moderate sized force of cruise or ballistic (MaRV) missiles, an efficient, high throughput rate conversion process between the reconnaissance imagery and the final reference scene used in the guidance updating system must exist. Consequently, comments previously given pertaining to techniques to improve the efficiency of the reference scene screening and evaluation process also apply here.

Potential payoffs in R&D funding in this area include: moderate to very high increases in vehicle survivability and update reliability, and high to very high increases in force effectiveness. The estimated technical risk for this area is low to high, and the estimated funding level required is very high.

ADVANCED APPLICATIONS

The seventh broad area of potential payoff from R&D funding involves artificial intelligence concepts applied to cruise missile guidance updating systems. The first area that should be investigated involves implementing an autonomous damage assessment system (in contrast to the report-back mode previously discussed), given the necessary on-board data processing capability. Even if a secure communication system is available for report-back, the designated interrogation interval and data capacity rates may severely limit attempts to transmit entire images (even in a highly data compressed form). Consequently, some on-board capability is desirable to preprocess the imagery, or ideally to determine the damage level present to minimize data transmission requirements.

In order to develop an autonomous damage assessment system, candidate sensors and algorithms capable of determining crater location (and possibly size and depth) relative to the target should be evaluated. For conventionally-armed cruise missiles, this problem may be compounded because the target may only be partially damaged, or damaged in the wrong location. If the magnitude and location of target damage is to be assessed, the performance requirements of the on-board sensor and damage assessment algorithm may become considerably more complicated.

The second area that should be investigated involves developing adaptive algorithms for down and forward-looking guidance updating systems, which at least in some cases "recognize" a pre-specified condition present in the missile sensor data (obtained for the update). Given this, and depending upon the perturbation "identified" (by software within the on-board computer) and its extent present, different pre-processing or map-matching algorithms may be utilized. To be successful, the perturbation in question must have a significantly different scene signature to ensure "identification" within the reference area from the "nominal" signature (at least at the time of reference scene preparation). Application of this technique may be limited to cases where a significant degradation in map-matching algorithm quality (hence fix reliability) exists due to signature variations, and where the signature in question is readily identified against a background matrix under a widely different set of atmospheric conditions.

Potential payoffs in R&D funding in this area include: a moderate to high increase in update reliability and force effectiveness. The estimated technical risk for this area is high, and the estimated funding level required is low to moderate.

III. IMPROVED PLANNING AND COSTING

Although not a topic for R&D funding, the final area addressed relates to improved planning and costing for guidance updating systems. The first "high quality" system of this type operational with U.S. forces is TERCOM, which is utilized on all first generation land-attack cruise missiles. Although considerable experience has been gained by DMA in preparing reference scenes for this system, little of this can be directly applied to any other guidance updating system, with the exception of using some digitized source and elevation data for DSMAC; and PDMM, RADAG, and ROCS respectively.

As cruise missiles are introduced into the U.S. inventory, the need for additional TERCOM reference scenes will continue to grow at least through the end of this decade; particularly for tactical variants that may be used for third world force projection missions. Although DMA has had the capability to generate high quality elevation data and the resulting TERCOM reference scenes for several years, it is obvious that the total costs associated with map generation for this cruise missile guidance updating system have grown significantly with time. This is in large part due to increases in the potentially targeted areas requested by users as different cruise missile variants enter development (then production).

Unfortunately, the magnitude of the cost, operator man hours, and calendar time required to generate TERCOM (or other guidance updating system) reference scenes is still not understood by a large segment of DoD and within the contractor community. Early interaction between

users, the DoD project office, DMA, and the appropriate contractor(s) is necessary to specify reference scene requirements, determine any resulting operational limitations for the host missile, budget the proper funding, and set a realistic deployment schedule to prevent a partial operational capability from occurring (due to the lack of reference maps being available) or slippage in the missile's IOC date.

Lessons learned from TERCOM indicate that interactions between DoD project offices, DMA, and industry contractors should begin during the host missile's advanced development phase to verify the guidance updating system's fundamental integrity, and to establish and verify the necessary procedures for reference scene preparation. Similarly, screening and simulation techniques used in the production of operational reference scenes should be developed as early as is prudently possible in the host missile's Full Scale Development (FSD) phase. Coupled with this is the need to identify manpower requirements and any specialized hardware or software necessary to produce operational reference scenes for the guidance updating system over the designated geographical regions. To delay this process until later in FSD may place the credibility and timely application of not only the guidance updating system, but the host missile itself in jeopardy.

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