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Modeling, materials, and metrics: The three-m approach to FCS signature solutions

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ABSTRACT

There is a push in the Army to develop lighter vehicles that can get to remote parts of the world quickly. This objective force is not some new vehicle, but a whole new way of fighting wars. The Future Combat System (FCS), as it is called, has an extremely aggressive timeline and must rely on modeling and simulation to aid in defining the goals, optimizing the design and materials, and testing the performance of the various FCS systems concepts. While virtual prototyping for vehicles (both military and commercial) has been around as a concept for well over a decade and its use is promoted heavily in tours and in boardrooms, the actual application of virtual prototyping is often limited and when successful has been confined to specific physical engineering areas such as weight, space, stress, mobility, and ergonomics. If FCS is to succeed in its acquisition schedule, virtual prototyping will have to be relied on heavily and its application expanded. Signature management is an example of an area that would benefit greatly from virtual prototyping tools. However, there are several obstacles to achieving this goal. To rigorously analyze a vehicle's IR and visual signatures extensively in several different environments over different weather and seasonal conditions could result millions of potentially unique signatures to evaluate. In addition, there is no real agreement on what "evaluate" means or even what value is used to represent "signature"; Delta T (°C), Probability of Detection? What the user really wants to know is: how do I make my system survivable? This paper attempts to describe and then bound the problem and describe how the Army is attempting to deal with some of these issues in a holistic manner using SMART (Simulation and Modeling for Acquisition, Requirements, and Training) principles.

Keywords: Signature, Infrared, visual signature, modeling, FCS, materials, metrics, SMART, virtual prototype

1.0 INTRODUCTION

The Army is in the midst of a grand transformation. It has become increasingly clear, that in order to best support the emerging role of the United States and to meet the evolving threat, the Army needs to be able to deploy much more quickly than current capability allows. According to GEN Shinseki, Chief of Staff of the Army and the driving force behind the transformation, "We must provide early entry forces that can operate jointly, without access to fixed forward bases, but we still need the power to slug it out and win decisively. Today, our heavy forces are too heavy and our light forces lack staying power. We will address those mismatches."[1]

Getting there quickly means "by air", but there is a bottleneck--the C-130 cargo aircraft. This aircraft was originally designed four decades ago and is still in production today (longer than any other aircraft in history); yet it imposes certain weight and size limitations[2]. The Army is forced to design to 20tons or less in order to meet its early entry goals. Our legacy systems don't meet this requirement—they are too heavy to be transported quickly. Until (if at all) a new method of transport is devised, the Army has to design to what is available. The solution? The Future Combat System (FCS)--twenty ton (or less) vehicles that can still be survivable and "slug it out and win decisively".

In addition to new vehicles, the entire way of fighting is being reinvented. The Future Combat System is not just a new ground vehicle, but a "system of systems" potentially employing unmanned vehicles on ground and air, high tech soldiers and helicopters and air craft. All networked together in a brand new way.

The details have yet to be determined, but the schedule is extremely aggressive--in fact arguably impossible. There have been several tongue-in-cheek references to the FCS program being a "schedule as an independent variable" program.

Impossible as it may seem, the fact remains that the Army needs transformation and it doesn't have the luxury of time. The Army leadership had demanded that all factions come together to identify the issues and start solving them. Figure 1 shows the current schedule.

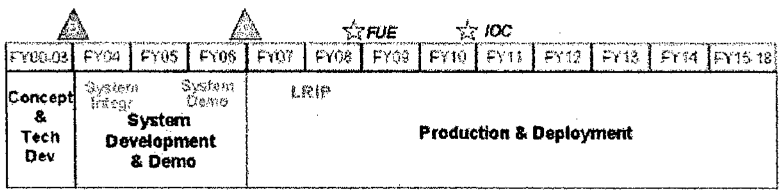

Figure 1: FCS Schedule

The FCS schedule and stated goals bring up several concerns. The first one relates to the often quoted schedule comment: how, when it traditionally has taken more than four years to develop one vehicle weapon system, is the Army going to develop a robust system-of-systems conception, design the individual concepts/components (vehicles, robots, etc) that make up that conception, and start low rate initial production (LRIP) by 2008? Plainly, the Army and its contractors are going to have to rely on modeling and simulation and a variety of virtual prototyping tools if there is any possibility of completing the project on schedule.

A second concern is how these lightweight vehicles that will be part of FCS are going to maintain survivability. According to the Mission Needs Statement (MNS) and the Statement of Required Capabilities (SoRC): "Ground platforms in FCS will leverage the best combination of: Low observable technologies to degrade enemy detection and terminal targeting from all spectrums by signature management and stealth capabilities; Ballistic protection; on-board immediate multi-spectral capabilities as well as the ability to employ wide area, long duration multi-spectral obscurants; long-range acquisition; early discrete targeting, shoot first every time, and target destruction each time we pull a trigger; highly responsive suppressive fires; camouflage." In addition, they will "Support counter-reconnaissance effort to blind enemy RSTA through use of obscurants, jamming, signature reduction, deception, dis-information, and pattern avoidance techniques. Employ RSTA to detect and find, then defeat, disrupt or neutralize enemy sensors through security operations."[3]

Clearly then, signature management is projected to be one of the key aspects in FCS survivability. But, given the above discussions, some questions arise: does the Army have the technology available to meet the threat and are there virtual prototyping tools currently available to answer this question and aid in the design process?

This paper will attempt to expose the barriers to successful signature management, address some of the reasons why no satisfactory simulation exists (though some would contradict this statement) and will also explain how some of the problems are being addressed. We will narrow the focus of the discussion to the visible through thermal wavebands, since electromagnetic signatures are somewhat less problematic (or can be extrapolated from the discussion) and acoustic source prediction is still an immature field.

2.0 THE GOAL

Virtual prototyping means creating a computer representation of a component or system and then examining it and measuring its performance--just as one might do with a physical prototype. In signature management, this would mean we could virtually "build" a system and virtually put it "out in the field" and "test the signature" under some given conditions. We would take this feedback, make modifications if necessary to optimize the design, repeat the "testing" and continue the process until we were satisfied with the results.

This is the general idea of signature management virtual prototyping and there is little to debate at this level. We probably could go one step further and say that such a simulation must contain the ability to predict visual through thermal signatures in specified environments within a reasonable level of confidence and that it should be able to predict the performance of specific treatments against specified threats in those environments.

However, a discussion of how to accomplish this can quickly lead to confusion and disagreement. Why this is so will be examined later. At this point however, we present the author's version of the ideal capabilities of a signature management virtual prototyping simulation.

The ideal simulation would have the following capabilities:

1. Integrate seamlessly with a commercial CAD system on which the concept is designed (i.e. little or no geometry conversion or the need to "touch" the geometry before it can be analyzed with signature prediction models. Tools that require weeks to convert and prepare the model will quickly become useless in this accelerated environment).
2. Contain variable levels of "fidelity" to enable both fast concepting and the slower but more accurate physics based simulation required to determine system performance (depending on the signature band, added fidelity could mean shadowing effects, exhaust impingement on the terrain, vehicle-terrain interaction in all bands, BRDF, etc).
3. Contain the physics to "adequately represent" the transient effects of targets and scenes including active sources. This means varying engine states, plumes, dusty vehicles, artificial lighting in urban settings, etc
4. Contain the physics to "adequately represent" the atmospherics and sensor models (and ideally weather and sky models) with enough fidelity to predict signature relevant effects and not create false signature cues via modeling short cuts. Such as shadowing effects, glint, fog, scanning versus staring arrays, variable sky temp, etc.
5. Have the ability to analyze systems in a standard scene or set of scenes and locations that serve as a virtual field-test in an acceptable number of representative situations to determine overall performance.
6. Generate images based on the above scenes for analysis.
7. Contain the physics or logic to "adequately represent" the projected threat.
8. Aid in applying metrics to systems or treatments in order to judge overall performance.
9. Produce a report to the user--feedback based on the metrics.

On the surface, these capabilities may sound straightforward. And in fact, many of the pieces exist individually to accomplish the ideal. However, the author's are willing to state that the ideal as mentioned above does not yet exist because of several very real barriers that need to be overcome. Signature management is at best an extremely complicated science (one could argue an "art") that is nearly impossible at this time to quantify-in part, because on average, the community refuses to acknowledge the complexity of the situation and it has not worked cooperatively across the expert areas to solve the problem.

3.0 THE BARRIERS

Does the Army have the signature management technology available to meet the threat and are there virtual prototyping tools currently available to answer this question and aid in the design process? If one is to try and answer these questions, there is an assumption that we:

- Understand the threat
- Be able to quantify how we stand against this threat from a baseline perspective
- Be able to measure the improvement in performance current technology can buy us.

Unfortunately, in the area of signature management (at least for visual and thermal), these assumptions do not hold up well. In this type of paper, it is not appropriate to talk much on the threat, but obviously by its very nature, it is difficult to quantify with any level of confidence. Aside, from that challenge however, there are others much more complex. The author's have been involved in the integrated process teams (IPTs) of all the Army related ground vehicle acquisition programs in recent history. In their experience, the following barriers can be identified:

1. Modeling and Simulation has not kept pace with signature management technology. It is also difficult to predict. Even simple nets are problematic in a straightforward first principles approach model.
2. IR and Visual signatures are extremely difficult to quantify. Simple measures such as Delta T while useful to some are completely meaningless to others. Probability of Detection holds more promise, but deriving probability of detection using a model is extremely challenging since human behavior continues to be a challenging nut to crack..
3. Model Prep Time. The models that exist today for signature prediction have model preparation times that are too long for multiple iterations. FCS will have multiple systems and in order to iterate during the design optimization process, changes to the concept need to be able to be analyzed quickly. 80 hours is not an unreasonable estimate to create a thermal model of a vehicle with precise detail. This is too long.
4. Multiple isolated viewpoints. Material developers, vehicle integrators, sensor and missile designers all say that they work in IR signatures. However, each comes at the problem from a completely different viewpoint. While there have been attempts to work the problem together, for the most part, there is little to no coordination between these organizations. They have worked mostly in isolation and have developed their own models and metrics. The result has been target models that have robust target descriptions and no or poor sensor effects and sensor models that have minute detail on the sensor electronics and optics and course or simple target descriptions and missile simulations with detailed 6-DOF simulations with low resolution sensor and target descriptions. This of course is a generalization and in some cases, the view-point-specific simulations can be adequate for a given situation. However, more often these simulations are then used in situations for which they were not designed.
5. 180 million v.s. One. There is the desire to want THE signature of a vehicle. At best, there is the begrudging allowance for a hemispherical representation of the signature of the vehicle. A list of delta T (or hopefully at least Delta T-RSS) values at certain azimuths and elevations. In truth, there are potentially millions of values of a signature depending on vehicle state, surface state, environmental state, and sensor type.
6. Hard to test. IR and Visual signatures are difficult to test, since as stated above, you can only test a limited set of cases. It is expensive to hold observer trials over enough varying scenes to get numbers that have statistical relevance.

4.0 OVERCOMING THE BARRIERS

In the past few years, there have been real attempts to address some of these barriers. This section describes some of those attempts. The approach taken has followed certain guidelines:

- Research current state-of-the-art in DoD, industry, Foreign MODs, and academia.
- Use STOs (Army Science and Technology Objectives), partnering, SBIRs (Small Business Innovative Research program), MOU between ARL-RDECs, CHSSI program (Common High Performance Computing Software Support Initiative), and CRADAs (Cooperative Research and Development Agreements between Gov and industry) to fill in gap.
- Use best existing models: Improve physics to account for current technology. Link together to create a virtual test environment.
- Use SMART strategies. Work issue DoD wide and with industry. Re-use models in RDEC Federation. Have User help bound the problem: What scenarios do we want to "test" in and in what clutter environments?
- Establish consortia where feasible--especially in metrics

4.1 Keeping pace with technology

Even simple camouflage technology can be difficult to model in a CAD based first principles simulation. For example, applying a camouflage pattern to geometry would be extremely tedious if done by hand. A user would have to design the pattern and apply it to individual mesh elements to create the pattern. The author's are looking at two approaches. One is utilizing pattern optimization software and the other is to provide an assist to the user in creating camouflage patterns and then "wrapping" them onto geometry.

The Army Aviation Technology Directorate (AATD) has been sponsoring the development of the Paint Map Optimizer. Aerodyne, Inc has been working on a program that uses simulated annealing to iterate between given parameters to optimize a pattern in a given scene or set of scenes. This work is very experimental and carries some risk, but could prove useful even as a tool to carry out parametric studies.[4]

TARDEC has been the sponsor of the thermal signature prediction code Multi-Service Electro-optical Signature Code (MuSES-discussed later in this paper) and is adding a feature for camouflage pattern application. The tool will allow the user to project a pattern over a meshed geometry using a GUI, instead of having to paint a pattern on by hand. (see figure 2)

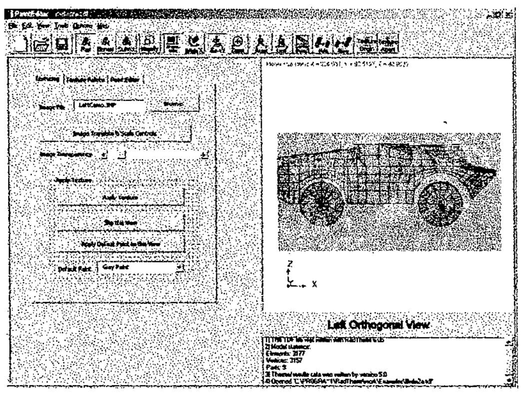

Figure 2. Camouflage Pattern GUI for MuSES

In addition, as computing power increases, it is finally feasible to start discussing more challenging aspect of signature prediction, such as the Bi-directional Distribution Function (BRDF.). In order to accommodate real time needs as well as more rigorous predictions, it was determined that we need to allow for multiple levels of BRDF calculations. These multiple levels will be incorporated into the MuSES software. The four levels are described as follows:

- Radiosity – Deterministic, view-factor-based, all-diffuse solution. Very fast. Independent of user position.
- Directional Reflectivity – Radiosity with directional incident (first bounce) reflectivity
- Single-bounce ray cast – First bounce with BRDF. Secondary reflections are pre-calculated rays with BRDF to all visible target and environment facets (view factor with BRDF). Last ray cast bounce = radiosity solution.
- Multi-bounce path trace – Rays traced from observer to target, then multi-bounce until rays absorbed or reaches environment. Each bounce produces multiple rays in/near specular direction.

Some simulations say they perform "full radiosity", but are still too simple to account for an-isotropic materials. In order to accommodate all cases, at least in the visual and in the 3-5 micron bands, this level of detail must be accounted for in the simulation.

Deriving the absolute, or even relative, temperatures of objects in a scene from real imagery is not a trivial matter. Even knowing the real, absolute temperature of every material in the image does not assure correct rendering. Spectral and directional reflectance coupled with the reality that every thing in the scene has to be considered a source in the MWIR and LWIR makes this a very complex problem.

4.1.1 Multiple levels of fidelity

The previous section on BRDF addresses how a user will have multiple levels of fidelity with respect to rendering BRDF. In addition, in the scene generation, in order to accommodate real time needs, there will be options to turn off first principles shadowing, BRDF, vehicle/terrain interactions. By the same token, these items need to be available to the user who needs them to analyze treatment effectiveness. By building-in this flexibility under one simulation, we are able to prepare for the time when computational speeds will reach a level where the switches will no longer be needed and one will be able to have the speed as well as the detailed interactions.

One area that will be computationally expensive, but will be essential for signature management prototyping is in the area of the exhaust plumes. Vehicle plumes interact with the vehicle AND the environment as well as acting as a cue. The figure below shows the six areas where a plume is important. These six issues are being addressed under a SBIR with ThermoAnalytics, Inc. and is currently in Phase II.

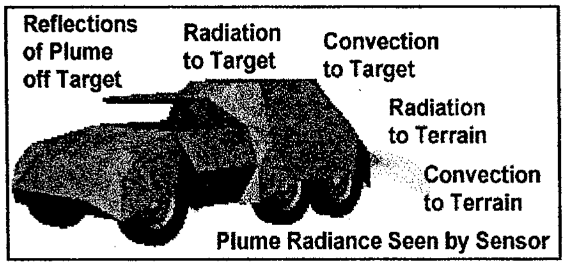

Figure 3 Plume interactions in a scene

4.2 Difficult to Quantify

In order to rank the performance of a signature management treatment, there needs to be some quantitative measure to be able to assign to a treatment that describes its goodness. No satisfactory value exists that is easily measurable and will work for all treatments. Historically, Delta-T has been the metric used for signature. This dates back to experiments used to evaluate sensor performance using four bar targets of a given size and thermal contrast. These experiments were successful in creating a model for evaluating sensor performance[5], but as figure 4 shows, this metric has the potential to predict erroneous results when used improperly or blindly in the area of signature management assessment. The

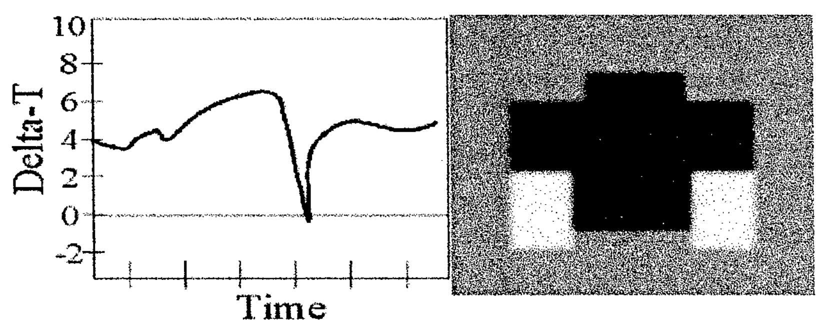

Figure 4. Problems with Delta-T

technique used in this example was feed the model an area, height and contrast that represented a vehicle. The contrast was based on the average temperature over the vehicle's projected area and the average background temperature. The plot on the left shows the area weighted average temperature difference between the target and the background over the length of the simulation (several hours). During the simulation, it was noticed that the contrast crossed zero. Since, probability of detection is based on contrast, at the time the Delta-T goes to zero, the probability of detection decreases to zero as well. In other words, the assumption would be that the vehicle was undetectable at this point in time. In this case, a picture of the vehicle was rendered at the exact point in the simulation this occurred. What was observed, was that the cold hull and hot tracks averaged to be the same temperature as the background. Clearly the vehicle would be very visible. Once this problem was realized, there was a push for an improved metric. Delta-T RSS --which includes the standard deviation of the target in addition to the contrast difference between the target and the background, was developed and implemented to solve this problem[6].

The debate on what type of Delta-T metric is better (whether it should also include the standard deviation of the background for instance) continues. However, some have felt that in the end a more useful metric is the probability of detection (Pd), since that is the main focus of signature management--avoiding detection. This however, is extremely difficult either to measure or predict. The aforementioned acquisition model produces a probability of detection and there is always the temptation is to use these models to predict Pd. In fact, since this is the best there is to offer at the moment, this is the probability of detection that is input into war gamming models such as CASTFOREM. But once again, that is based on the controversial contrast metric. The standing argument holds that if the vehicle being modeled has a signature that is contrast driven, then the contrast based sensor models has some merit in predicting the probability of being detected (once the Delta T RSS is used). But eventually one has to ask what happens once signature management treatments are applied to a vehicle, since by their very nature, they will try to reduce contrast? Clearly new metrics must be developed to account for lower contrast targets.

4.2.1 Metric Solutions

Several approaches are being taken to address this issue. CECOM's Night Vision and Electronic Sensors Directorate (NVESD) is working to develop new methods of modeling that will give more fidelity to the target. The spatial frequency content, or internal detail, of the target as perceived by the sensor, is a significant contributor in field performance. In addition, while they are far from all encompassing, there are other image-based models that the author's will investigate, such as VDM2000 under development by Gary Witus.[7] Also, while not without its own problems, once the scene generation capability has been more fully developed, it will be feasible to generate images for a perception lab and probability of detection values can be derived from those trials. An initial series of experiments has already been performed and used to improve the existing models for detection time [Recent Improvements in Modeling Time Limited Search, Edwards and Vollmerhausen, SPIE, April 2002]. Obviously, studies (both existing and new) correlating perception lab results to field results will have to be factored into the analysis.

Finally, the Army Missile Command RDEC (AMRDEC) has been approached to provide missile/seeker algorithms and devices that could be coupled with the virtual prototyping system to supply another performance measure. Determining whether or not a treatment affects tracking and locking algorithms would be a very valuable metric of performance.

4.3 Model Preparation time

It is not uncommon to spend 80 hours and even a full month (or longer) on creating a detailed vehicle model during the virtual prototyping phase[8]. The type of model described here is one that accurately represents every thickness, material property, and engine characteristic is correct and that the representation is free from errors. This is why it can take upwards of 80 hours.[9] Often there are deadlines that have to be met and the model preparation time takes so long, that signature analysts are usually rushed to get in a few runs and then make a quick analysis before the time runs out.

In order to reduce this bottleneck, the developers of MuSES, ThermoAnalytics have partnered up with Parametric Technologies Corporation, the developers of the CAD code Pro/E. Pro/E can now export out a MuSES (.tdf) input file. By November of 2002, Pro/E will then be able to read in the results from the .tdf file and render the results right from within the Pre/E CAD package. This is the initial stage. At first, this will only fix the geometry problem. Eventually material properties and component integrity will be maintained throughout the entire process. This first capability will be released in the Spring of 2002 in version 6.1.[10]

However, this will not solve the problem for everyone. Many geometry/CAD programs create meshes. The problem arises however, when those meshes have long slim polygons or meshes that do not lend themselves to thermal calculations. TARDEC engineer and software designer Jack Jones has developed the Eclectic program to enable users to read in any mesh and vary its size and more importantly--clean it up for thermal solutions. The beta version 1.0 will be released in the spring of 2002.[11]

4.3.1 Design it in

The most effective way to have an optimized virtual prototype involves no modeling and simulation. In the late 1980's TARDEC undertook a program to develop the Component Advance Technology Test Bed. A tank built from scratch. This was the first attempt to use virtual prototyping at TACOM and it was also ground breaking in the automotive industry. During this process, through their iterative interaction with the signature analysts, the concept designers became educated in signatures management. These same designers carried that information on into the major acquisition programs that followed in the Army and some have gone on to be the survivability integration lead for the PMs in these programs. The Concept Technology Design Phase can be made extremely more efficient simply by training every design engineer to design it right in the first place and to think "signature" during the entire concepting phase--particularly with respect to radar signatures. This may seem obvious, but in this high turnover environment, it is an overlooked step.

4.4 Multiple Isolated Viewpoints

One person's notion of signature may not be another person's notion. What's more, the different organizations with these varied perspectives have no central communication channel or strong incentive to cooperate. This has lead to confusion around the topic. In Army ground vehicles alone, there are three RDECs, at least 4 directorates within the Army Research Lab, and individuals at AMSAA who consider themselves experts on ground vehicle thermal signatures (not to mention the National Ground Intelligence Center). The varied viewpoints evolve from the different missions. One RDEC designs sensors so that they can see targets better. The other RDEC tries to design vehicles so sensors won't see them. A third RDEC develops missiles with sensors in order to find targets and destroy them. Several directorates within ARL perform various signature related modeling support tasks, while others work on material solutions. AMSAA is then expected to somehow act as guide and accreditation authority within the community for data and models and metrics. But in reality there is no central authority between these different organizations and all are autonomous and free to cooperate (or not) with the other organizations. Separate missions, competition for funding, busy schedules, lack of adequate personnel (both in numbers and training) and the aforementioned varied perspectives all contribute to keeping the community fractured and inefficient. Consider then that this is just the ground vehicle portion of the Army--there is also the aviation side of the Army and then the other services as well. All are doing "signature modeling".

To be fair, this problem exists not because of negligence on the part of the DoD, but because of the nature and complexity of the problem. It cannot be corrected until the problem is understood and acknowledged. The first step towards correcting the problem is believing that there is a problem in the first place. Where is the proof that the multiple viewpoints do indeed exist? In order to research this point, a small survey that examined views on signature modeling capabilities and types of signatures was designed.

Thirty surveys were sent out to professionals who had self-proclaimed interests in signatures. As of this writing, twelve responses were returned. The respondents covered the spectrum of material designers, sensor designers, overall vehicle system integrators, vehicle signature analysts (both industry and government), and U.S. and U.K. representatives. The results clearly show that while much of the community tends to use the word "signature", there is no general agreement on what that means from a requirements standpoint or what capabilities need to be included in a signature simulation.

The respondents were asked to score the questions based on their own needs as well as what they perceived the needs to be of the Army overall. Table 1 only shows a portion of the rolled up data, but it plainly shows that there is no clear agreement on the subject. The rating system is shown on the table--the smaller the value the higher the importance. While many of the averages, not surprisingly tended toward the middle, the standard deviation, confidence interval and the min and max tell the story that the values tended to cover the full range of opinions for most questions.

What is encouraging is that many realized that their own needs often differed from others in the Army showing the community has awareness of the differing needs. In addition, two items stand out as having closer to universal agreement: "A day and night typical signature for the scenario I am interested in" and "A day and night exercised, idle, and at rest" both ranked high (value less than 2) with smaller standards of deviation and confidence intervals. Related to this is the result that the more simplified viewpoints, such as "one signature or a generic or representative signature", had higher values denoting less importance. This was not always the case as will be discussed in the next section.

Signature Expert Viewpoint Survey Summary

(1-Crucial, 2-Important, 3-Desired, 4-nice, 5-What I currently settle for,but I'd like better 6-not necessary/No use)	Over all mean	stdev	95% confidence interval	min	max
Score each as to it's importance (roll up between overall Army needs and personal needs)					
a. Real time interactive synthetic scene capability	3.6	1.7	0.8	1	6
b. Synthetic scene runs (non real time)	2.6	1.3	0.6	1	6
c. Synthetic scenes with Sanford-Robinson BRDF in rendering	2.8	1.4	0.8	1	6
d. Synthetic scenes with anisotropic BRDF in rendering	2.7	1.3	0.7	1	6
e. Synthetic scenes with predictive terrain and vehicle	3.9	1.7	0.8	1	6
capabilities (no interaction)					
f. Synthetic scenes with predictive terrain and vehicle	2.2	1.4	0.6	1	6
capabilities (interaction between both)					
g. Ability to move from commercial CAD concepts	2.6	1.5	0.7	1	6
into engineering analysis models in 2 days or less					
h. Ability to move from commercial CAD concepts	3.2	1.9	0.9	1	6
into engineering analysis models in 1 day or less					
i. Ability to model engine and transmission in detail given specs	2.5	1.7	0.8	1	6
from the manufacturer					
j. Ability to model internal sources based on average or typical	2.6	1.5	0.8	1	6
values					
k. Ability to model sensor using stock blur and noise functions	3.5	1.9	0.9	1	6
l. Ability to model sensor using a few MTFs based on a	2.9	1.7	0.8	1	6
handful of critical features I can manipulate					
m. Ability to model sensor using a fully detailed model that	2.5	1.4	0.7	1	6
let's me adjust number and types of detectors, optics, noise, etc.					
Desired signature requirements:					
a. One generic average or typical signature	4.2	2.0	1.8	1	6
b. One typical signature for a specific scenario I am interested in.	3.2	2.0	1.6	1	5
c. A generic day and night typical signature	3.0	1.0	0.7	1	4
c. A day and night typical signature for the scenario I am interested in	1.9	1.0	0.7	1	3
d. A day and night exercised, idle, and at rest	1.8	1.3	0.9	1	5
e. Diurnal intervals, in variable clutter, variable sky/atmosphere/weather	2.2	2.2	1.4	1	6

Table 1 Signature expert viewpoint survey summary

Since these multiple viewpoints are not readily acknowledged, problems arise. Firstly, models that are developed for one perspective (and based on specific assumptions valid for that perspective) are often used for situations for which they were not designed, as illustrated above in the quantification section. Secondly, because of the isolated nature of the community, there is duplication of effort. In the late 1980's there were multiple thermal signature prediction models used by Army Organizations--the top five being-GTSIG, PRISM, IRMA, SPIRITS, and SIRIM. An informal meeting held around 1989 by representatives of those models at the National Ground Intelligence Center came to the conclusion that there was no clear winner, that each model served its own purpose and that for ground vehicles GTSIG and PRISM both had different strengths and weaknesses, but were similar[12]. In other words, a great deal of effort and money had gone into creating several models that were very similar in nature and no organization was willing to stop the development of his/her own model.

4.4.1 The movement towards cooperation

The first step towards fixing this problem was taken in the early 1990's when an attempt was made to take the best of PRISM and GTSIG (the two determined the strongest for ground vehicle prediction) and put it into one model. The result was PRISM 3.2[13]. The next step was taken in 1993 when TARDEC, NVESD, and Wright Patterson Air Force Base (WPAFB) assembled interested parties together to help develop the next generation thermal model and scene simulation. A multi-service consortium was developed called MuSES (Multi-Service Electro-optical signature code consortium). The goal was to bring the services together to address the thermal signature modeling issues jointly.

NVESD embarked on developing Paint the Night as the scene rendering portion of the process and TARDEC lead the development of a new thermal prediction code to be available to all. The code, bearing the name of the consortium (MuSES) has been under development since 1997 and has been financially supported by all the services plus the automotive industry--particularly the Ford Motor Company.[14] The MuSES code has been recognized as a model dual use program and received 4 awards in the 2000-2001 time frame. Most notable of these was the Army SBIR Quality Award and the SBIR program's Tibbet's award given to the top SBIR programs.

PM Survivability Systems existed throughout the 1990's and tried to address some of the modeling deficiencies under a Low Observables Modeling Improvement program. However, since many of the underlying problems also discussed in this paper were not also addressed and because of the overly ambitious nature of the program, there was limited progress. One notable step was the inclusion of the Delta-T RSS as mentioned earlier. PM SS was absorbed into a larger PEO and its mission eliminated.

With the advent of FCS came the opportunity for a new Army Science and Technology Objective (STO) to address these specific problems of signature management. The STO "Signature Management for FCS" was developed and approved and forms the basis for much of the work described in this paper. The STO provides the mission statement for addressing the signature management virtual prototyping needs specific to FCS. TARDEC is the STO manager, but there is a strong partnership between the Army Research Laboratory (ARL) and the NVESD.

ARL has taken the lead in developing high performance computing (HPC) capabilities that will be offered in support of FCS. ARL personnel and computers will be available to support the PM, but also will be available to the contractors on the program. In addition, they have taken the lead in the electromagnetic signature arena of the STO and are evaluating and becoming proficient in the menu of codes available to addressing the problems, from the popular XPATCH to finite difference time domain codes. In addition, they have taken on the task of parallelizing the MuSES code for their HPC facilities. They will also add support in the area of material development modeling and metrics/assessment.

TARDEC has taken the lead in defining the virtual prototyping needs and in the development of the MuSES thermal code. They have taken the lead in addressing the graphics bottleneck issue through Eclectic and sponsoring the Pro/E-MuSES direct interaction. They also provide support in integrating the thermal predictive capability into the scene generation capability, incorporating it into the Advance Collaborative Environment (ACE), sponsoring an interim solution to visual modeling until a fully predictive capability is developed, validation data collection, and in addressing the metrics issue.

NVESD is the Army focal point for sensors. In the partnership, they are responsible for the sensor modeling as well as taking the lead in developing the scene rendering process. This includes sensor effects and atmospheric effects. They have taken the responsibility for addressing both the real time needs of the community as well as the more rigorous non-real time predictions. They will provide support to AMRDEC in integrating the hardware-in-the-loop capability.

As mentioned above, recently AMRDEC has been approached and has agreed to participate in the partnership. They will be the lead for integrating missile/seeker algorithms and/or simulators into the simulation thereby providing an additional metric for the virtual prototyping capability and giving AMRDEC an added capability in which to analyze their systems.

Finally, this partnering would not be useful unless it worked with the PM. PM FCS has been briefed on the STO and is supporting it with a technology transfer agreement. In addition, a white paper describing this program was presented to the lead system integrator (LSI) for FCS was ranked top in survivability. The LSI will be briefed continually throughout the program and will have opportunities to direct the effort. As mentioned earlier, the tool is being developed for the LSI and support contractors for the Block I and certainly for Block II efforts.

Finally, the Army has embraced SMART-Simulation and Modeling for Acquisition Requirements and Training.[15] The Strategic Goals of SMART as defined on the website are:

1. Promote comprehensive modeling and simulation (M&S) policies, disciplined processes, and a high performance workforce to stimulate innovation and agility in developing enhanced Army capability.
2. Establish a means to continuously and quantitatively measure, in a joint environment, life cycle cost and relevant measures of effectiveness.
3. Create and maintain disciplined collaborative M&S environments for all stakeholders to exchange and reuse data and information to support "SMART" modernization decisions.
4. Establish habitual associations and incentives to leverage the investments and inventions of academia, industry, and other government partners so that the Army benefits from the synergy of mutual investments.

Clearly these four principles can all be found in the proposals in this paper--specifically geared towards the signature management modeling and simulation area. The partnering of elements within these organizations will go a long way towards eliminating the barriers caused by isolation. And as the partners work together, each organization will help to educate the other in the specific needs/viewpoints needed by each in order to create a robust capability. This should eliminate the expensive/wasteful practices brought about by "one man shows" and "not invented here" attitudes.

The collaboration described in this paper can also help address another pitfall not unique to signature management. In the isolated environment described above, some support contractors armed with a little bit of knowledge, who have no ties to vehicle designers and no real experience or depth to their understanding, have been able to perpetuate the duplication problem. Since there is poor communication throughout DoD on the subject, contractors are able to make proposals that effectively reinvent-the-wheel or they can provide duplicate work to different organizations that don't speak to one another. Often, so much attention is paid to computer science issues, that the physics is secondary. Overly simplified and outright erroneous simulations have been evident in symposium presentations and conference exhibit halls in the past decade. Until a strong communication link is established, these conferences and some joint groups that occasionally address this issue (such as the electromagnetic code consortium EMCC) are the only opportunities in the past for peer review and/or collaborations to occur. Hopefully, the momentum created by this partnering and by the SMART initiative will provide an opportunity for a new direction in the Army and in the DoD in general.

4.5 180 million versus one

In the mid-1980's, two engineers from TARDEC were called upon by a group performing the AOA on the "Armored Family of Vehicles" (AFV) tank concept. They were given a sheet to fill in. On it, they were asked for "the" radar signature of the Abrams tank and "the" projected radar signature of the AFV Tank and "the" thermal signature of the same vehicles. In addition they were asked for the thermal signature of the vehicles in hull defilade mode (partially obscured). They were given one space to fill in for each of the numbers requested. The radar signature was to be given in square meters and the thermal signature was to be given in delta-T.[16] The survey indicates that while the idea still prevails, there is a shift from the old way of thinking.

The term "signature" itself could be said to be the very crux of the problem. By definition, it means "A distinctive mark, characteristic, or sound effect indicating identity."[17] And indeed, depending on who is asking the question, there are those who would like to think that a vehicle has "a signature". While some may argue there are circumstances when "one signature representation" can suffice (as discussed below), a compelling argument can be made that there is no such thing as "a" signature or even a representative or average signature. For the sake of brevity, the rest of the discussion will focus on visual-thermal signatures. There is a similar, but not as strong a case to be made for electromagnetic signatures as well.

One can say that the only need for the use of the term "signature" is in the discussion of acquisition...or put more simply: Can a vehicle be seen? The answer as to whether any vehicle can be seen depends entirely on the "scenario" involved. The conditions that define a scenario are numerous. There could be said to be four areas that contribute to a vehicles being detectable.

- Vehicle Inherent Conditions
- Surface conditions
- Environmental conditions
- Acquisition conditions

Undoubtedly, the virtual prototyping capability that has been discussed here supplemented by field testing where possible (on a demonstrator and component level) would go a great deal towards filling in the information gaps that have been identified.

5.0 SUMMARY

If FCS is to meet its objective, signature management will have to play a role in survivability. The Army must coordinate within itself, and where possible with the other services to work the signature management models, materials, and metrics issue in a COORDINATED environment. This environment should consist of the different signature perspectives: material/treatment developers, system integrators, and acquisition/sensor, plus PM FCS.

There is a developing partnership between elements within ARL, TARDEC, NVESD, and AMRDEC and it promises to address many of the barriers that have prevented effective signature management virtual prototyping from becoming a reality in the past. The goals of this partnership are to cooperatively improve the physics, reduce model preparation time, work to develop improved performance metrics, educate each other on the various signature viewpoints, and by coordinating with the PM and the LSI and have them help bound the "180 million" problem. Also, by sharing resources, leveraging the SBIR program, the CHSSI program, and other cooperative ventures, the funding for this effort will be more efficiently managed. In other words, this program is right in line with the SMART initiative promoted by the Army M&S community and if successful, should dramatically increase the signature optimization capability for FCS.

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[1] GEN Shinseki, CSA, 23 June 1999. As reported in Dr. Jane Alexander's briefing Industry Day briefings, November 2001. Available online at www.darpa.mil/FCS/public.html

[2] http://www-cgsc.army.mil/usaf/AMC_Toolbook/c130data.htm

[3] November Mission Needs Statement and Statement of Required Capabilities as described in Industry Day briefings, November 2001. Available online at www.darpa.mil/FCS/public.html

[4] "Optical (IR/VIS/UV) multispectral vehicle coating/pattern optimizer," F.J. Iannarilli, Proc. IRIS Symp. on Camouflage, Concealment, and Deception, (1997).

[5] J. Ratches, W. Lawson, L. Obert, R. Bergemann, T. Cassidy, J. Swenson, "Night Vision Laboratory Static Performance Model for thermal viewing systems", ECOM-7043, U.S. Army CECOM NVESD Ft. Belvoir, 1975.

[6] B. O'Kane, C. P. Walters, J. D'Agostino, M. Friedman, U.S. Army CECOM NVESD, "Target Signature Metrics Analysis for Performance modeling", March 1993.

[7] Gary Witus - witusg@umich.edu

[8] Based on experience of TARDEC (personal and observed in IPTs) and by interviews with experts in industry.

[9] Certainly quicker models can be (and have been) developed. There have been several attempts to create large databases of thermal models in a short time. Depending on the usage, this can be a valid exercise or a dangerous one. Often, because of the tedious nature of such an ambitious task, young engineers or computer scientists are chosen to work in an assembly line fashion to create these databases. It is impossible for these individuals to intimately know the layout, armor thickness and material make-up of these vehicles if the geometry is taken from surface models only. Hence, the usage of these models must be restricted until they can be verified for correctness. Models such as these are suitable for training purposes to give general ideas of what one can expect when looking through a thermal sensor. Even those models developed using the much more reliable BRL-CAD database must be double checked as some of the models in that database were built for radar purposes and while extremely accurate for radar can produce erroneous thermal models if care is not taken.

[10] www.thermoanalytics.com

[11] www.thermoanalytics.com or jonesja@tacom.army.mil

[12] Personal recollections by TARDEC representative at the meeting.

[13] A.Curran,, "User's Manual for PRISM 3.2," ThermoAnalytics, Inc. Calumet, MI 49913

[14] K. Johnson, A.Curran, D. Less, D. Levanen, E. Marttila, T.Gonda , J.Jones, "MuSES 4.1: A New Heat & Signature Management Tool", Ninth Annual Ground Target Modeling & Validation Conference, Houghton, MI, August 1998.

[15] www.amso.army.mil/smart

[16] Personal experience reported by one of the authors
[17] American Heritage Dictionary, 2nd college edition, 1982, Houghton Mifflin Company