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Developing Requirements and Performing Early Workspace Analysis of Army Systems and Platforms

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ABSTRACT

Application of human figure modeling tools and techniques has proven to be a valuable asset in the effort to examine man-machine interface problems through the evaluation of 3D CAD models of workspace designs. Digital human figure modeling has also become a key tool to help ensure that Human Systems Integration (HSI) requirements are met for US Army weapon systems and platforms. However, challenges still exist to the effective application of human figure modeling especially with regard to military platforms. For example, any accommodation analysis of these systems must not only account for the physical dimensions of the target Soldier population but also the specialized mission clothing and equipment such as body armor, hydration packs, extreme cold weather gear and chemical protective equipment to name just a few. Other design aspects such as seating, blast mitigation components, controls and communication equipment are often unique to military platforms and present special challenges to implementing an effective design that maximizes Soldier performance. However, with regard to military acquisition programs, without HSI work and specifications integrated into the program in the Statement of Work and contract attachments, it becomes difficult to require the contractor to redesign or mitigate issues found when performing human figure modeling. Effective techniques for developing HSI contract language to appropriately incorporate human figure modeling and apply it early in the acquisition process are detailed in this paper.

INTRODUCTION

Application of human figure modeling tools and techniques has proven to be a valuable asset in the effort to examine man-machine interface problems through the evaluation of three dimensional (3D) Computer Aided Design (CAD) models. These models allow the analyst to pinpoint potential problems with fit, reach and vision early in the design cycle, often before any physical prototypes have been built, and in turn, help to eliminate problems before the actual equipment is placed in the hands of the user. With regard to US Army weapon systems and platforms, digital human figure modeling has become a key tool to help ensure that Human Systems Integration (HSI, AR 602-2) requirements are met. However, challenges still exist in ensuring that accommodation language is written into the contract directing the offerors to provide accommodation analysis and information in their Request for Proposal (RFP) for the government to assess during the Source Select Board. Once the contractor selection is made, the next challenge is for government personnel to acquire modeling data as early as possible after the contract is awarded to effectively assess the design and ensure that necessary redesign is made in the system to provide appropriate accommodation, emergency egress, usability with the crew and squad station and maintenance accessibility. Examples of HSI accommodation contract language are discussed as well as Human Figure Modeling that was accomplished as a result of this type of contract language.

DEPARTMENT OF DEFENSE (DOD) DIRECTIVE 5000.02 OPERATION OF DEFENSE ACQUISITON

SYSTEM, AR-602-2 HUMAN SYSTEMS INTEGRATION IN THE SYSTEM ACQUISITION PROCESS AND HSI CONTRACT LANGUAGE

DOD 5000.02, Operation of Defense Acquisition System, lays out the general acquisition process, while AR 602-2, HSI in the System Acquisition Process, directs the Army to ensure that HSI is integrated into the acquisition process. AR 602-2 tasks the Army acquisition community to ensure HSI is a key component of the acquisition process. It states "To ensure HSI considerations have the greatest positive impact on system design, they will be integrated into the system acquisition process as early as possible. To ensure HSI is embedded in the system acquisition process, analytical tools will be applied when they can provide the greatest influence to the total system." AR 602-2 also calls out cross walking of HSI parameters, objectives, and thresholds from the Capabilities Development Document (CDD) and Capabilities Production Document (CPDs) to the Request for Proposal (RFP) and Test Evaluation Master Plan (TEMP).

The most recent update of DOD 5000.02 describes several types of defense acquisition program models. Of interest to this discussion are Model 1 (Fig. 1), Hardware Intensive Program and Model 4, Accelerated Acquisition Program.

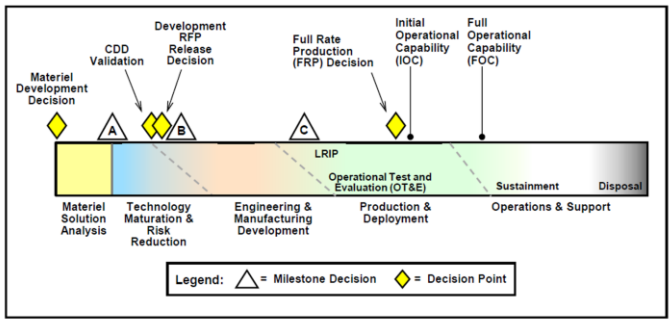

Figure 1. Model 1 - Hardware Intensive Program

Model 1, the Hardware Intensive Program is considered the traditional approach to acquisition with time allocated between Material Development Decision (MDD), Milestone A (MSA) and Milestone B (MSB) to perform technology maturation and risk reduction. This is very similar to the programs that produced the Abrams Battle Tank and the Bradley Fighting Vehicle.

During the Material Solution Analysis (MSA), Human Figure Modeling (Fig. 2) can be used in the Analysis of Alternatives (AoAs) to assist in requirements delineation for the CDD. The CDD should also call out the HSI requirements, including a requirement for accommodation. The CDD accommodation requirement is typically stated as "equipment, systems, and subsystems shall be designed to accommodate the central 90 percent of the anticipated user population." This requirement also encompasses maintenance accommodation (accessibility and lift requirements) in addition to operational accommodation within the system.

During the time period between MSA and MSB it is vital that the HSI practitioner remains fully engaged with the User Community to ensure that HSI requirements are included and remain in the CDD and CPD as these documents go through their reviews and validation. In the Program Manager's (PM) Office during this time frame, contract language is written that will set the stage for the rest of the program's HSI effort. If the contact is poorly written for the HSI program, it is very difficult and costly to make changes to the program's HSI effort once the contract is awarded. It is vital that the HSI practitioner remains fully engaged and active member of the PM Office during this time frame. This ensures that appropriate HSI language is written into the contract and that HSI specifications are correctly derived from the CDD requirements to ensure early human figure modeling for accommodation can be accomplished.

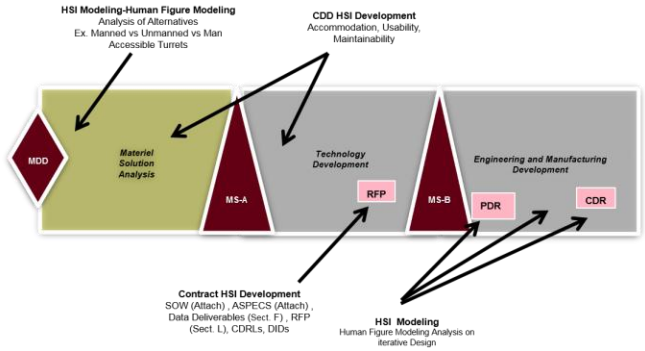

Figure 2. Human Figure Modeling in Acquisition

In Model 4, (Fig. 3) the Accelerated Acquisition Program, it becomes more of a challenge to ensure that the contract language is correct. In this type of program, the time frame between MSA and MSB has collapsed, so the criticality of having the correct HSI contract language cannot be overstated.

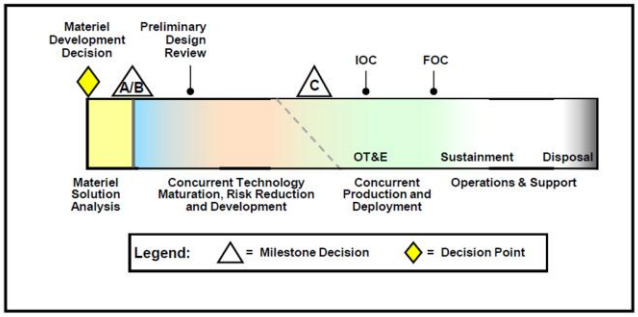

Figure 3. Model 4 - Accelerated Acquisition Program

With a significantly shortened program time frame to PDR, there is very little time available to correct the contract if the accommodation analysis language is missing. Without this language, the PM does not have contract language to leverage against the contactor to acquire the missing information.

In the Accelerated Acquisition Program, human figure modeling must be performed by the contractor after contract award and before the Start of Work Meeting (SOWM). At the SOWM, the contractor should provide their accommodation assessment of the system and provide models to the Government practitioner to perform their independent assessment. The contractor's human figure modeling can provide the Government HSI personnel waypoints to perform their assessment, saving some time and effort in a very compressed timeframe to perform an accommodation analysis leading up to PDR.

STATEMENT OF WORK (SOW)

There are several parts of a typical contract that should include accommodation language. These include the Statement of Work (SOW) (usually an attachment), Request for Proposal (RFP) (Section L), and Specifications (usually an attachment). The SOW should contain an HSI paragraph similar to the following for accommodation assessment using human figure modeling:

C.XX.X Soldier Workspace Analysis. The contractor shall conduct Soldier Workspace Analyses. The contractor shall provide documentation to include diagrams, illustrations, drawings with measurements and shall perform three-dimensional Human Figure Modeling Soldier Workspace Analysis using the Soldier Population Boundary Manikin Set (as documented in the GFI list located in Section X, Exhibit X)(AXXX). The contractor shall provide a 3D CAD model of the platform design in .XX file format (specific type of file format required by the government analyst, such as .jt, .wrl, .pss, .fig, .env, etc. inserted here). Additionally, the CAD model shall include all articulated components to be assessed, and shall include all joint centers and ranges of motion and limitations and adjustment mechanisms. The contractor shall document the differences, if any, between the analysis and the Vehicle's Performance Specification requirements for the threshold vehicle design. The contractor shall provide both overall and subsystem functionality risks with a detailed risk mitigation plan as part of the report (XXX) to include all necessary cost, schedule, and technical data to the Government if the Soldier Workspace Analysis shows that the design does not meet the threshold design.

In this particular example, human figure boundary manikins representative of the central 90 percent of the Army Soldier population are called out to perform the accommodation analysis for the contract.

SECTION L – REQUEST FOR PROPOSAL (RFP)

Another critical section of the contract is Section L, the Request for Proposal. Section L in a contract provides the instruction to the offerors on how and what information to submit for the Request for Proposal (RFP). HSI accommodation language is usually included under the Technical Factor, in the Integrated Design subparagraph.

Due to the limited time of a Source Selection Evaluation Board, HSI contract language should identify areas for assessment that would show critical differences in the offerors proposals. For example, in a vehicle program, this would typically include accommodation of crew and squad in a combat loaded vehicle with crew served weapons, crew accommodation at various positions in their crew station, accommodation of other personnel in the vehicle (for example squad members), weapon operations, weapons reloading, remedial action of the weapon system and emergency egress for two planes of the vehicle.

The following provides an example of the contract language for a vehicle contract concerning human figure modeling:

(a) The offeror's design, consistent with its technical approach, shall include the complete physical integration of all subsystems, stowage of all items in Attachment X, individual and crew served weapon associated with the vehicle.

(b) HSI CAD Model information:

(i) The offeror shall provide a representation of the crew and squad compartments with proposed controls/displays/ interfaces/control panels for both crew and

squad members along with the ingress and egress points to those compartments;

(ii) The offeror shall demonstrate that the crew compartments shall accommodate the Soldier Population using the Soldier Population Boundary Manikins anthropometric dimensions provided in Attachment XX (Manikin Table) with the exclusion of the Average Male Manikin #3.

(iii) The offeror shall provide a representation of how the Crew can be accommodated in indirect, periscope, and open hatch-weapons positions with interior illustration of seating, standing, and/or standing platforms. The offerors CAD model shall include representation of all Soldier Population Boundary Manikins sizes with the exclusion of the Average Male Manikin #3.

(iv) The offeror shall provide a representation of how the crew performs reloading and remedial action of the primary and secondary co-ax weapons with the #1 Small Female and #7 Large Male in Attachment XX (Manikin Table).

(v) The Squad compartment shall depict accommodation of the X number of squad members using only the Large Male Manikin #7 from Attachment XX (Manikin Table).

(vi) The offeror shall provide a representation of two planes of emergency egress paths for all platform occupants with the Soldier Population Boundary Manikins in clothing and equipment in Attachment XX (Manikin Table) using the #1 Small Female, Wide Shoulder Male #4 and #7 Large Male.

(vii) The offeror shall provide representation of one litter accommodation without any internal interference or displacement of crew or squad personnel using only the Large Male Manikin #7 from Attachment XX (Manikin Table) for crew, squad and litter patient.

Accommodation analysis during an RFP needs to be limited due to the sheer number of analyses that has to be completed in a very limited time frame. If there are seven boundary manikins and two crew positions, that results in a total of 14 analyses at only one seated position. If the crew has three positions at their crew station, i.e. Indirect, Periscope and Open-protected hatch positions, then 42 analyses have to be completed for just two crew stations.

The other critical part of the language in Section L are the types of models to be delivered for the RFP. A decision needs to be made when setting up the source Selection Evaluation Board if Human figure modeling will be utilized. If so, then the following language needs to be provided in the Section L paragraph which calls out the types of models to be delivered: The contractor shall provide a 3D CAD model of the platform design in .XX file format (specific type of file format required by the government analyst, such as .jt, .wrl, .pss, .fig, .env, etc. inserted here). Additionally, the CAD model shall include all articulated components to be assessed, and shall include all joint centers and ranges of motion and limitations and adjustment mechanisms.

SPECIFICATIONS

Specifications are derived from the CDD requirements and are usually found as an attachment to the contract. Accommodation specifications usually have an overarching specification similar to what is shown below for the crew, squad or mission station areas:

SPEC XXX. The vehicle shall be capable of being operated, maintained and sustained by the central 90 percent of Soldiers in operational environments while wearing or using standard combat equipment, Personal Protection Equipment (PPE), Chemical, Biological, Radiological and Nuclear (CBRN), and other environmental clothing. (T=O)

SPEC XXX. The System shall be capable of seating and being operated by a three man crew composed of the Soldier Population Boundary Manikin Set with organic weapons, PPE and Mission Essential Equipment, (to include individual ammunition, rations, and water) to support a 24-hour System Operational Mode Summary/Mission Profile (T=O).

SPEC XXX. The System shall be capable of seating and accommodating nine infantry squad members composed of the Soldier Population Boundary Manikin Set with organic weapons, PPE and Mission Essential Equipment, (to include individuals ammunition, squad weapons, rations and water) to support a 24-hour mission per the System Operational Mode Summary/Mission Profile (T=O).

Detailed accommodation specifications typically focus on areas of design that can be difficult to achieve such as hatch size or litter accommodation in looking holistically at the design requirements such as vehicle size (NATO tunnel specifications), survivability, system weight and speed in achieving a balanced design. Typical specification language would include the specifications similar to those shown below:

SPEC XXX. The vehicle shall have a combined frontal XXX degree Field of View from vehicle centerline from

crew periscopes, and a minimum of XXX degree FOV from vehicle centerline from the driver's periscope (T=O).

SPEC XXX. The System shall be re-configurable to accommodate one litter, without any internal interference for displacing any crew or squad personnel, in less than XX seconds (T=O).

SPEC XXX. The vehicle shall have manual means, within reach of the driver and commander to immediately safe the vehicle in the event of an emergency (T=O).

Early in the program design, focus is typically on operational accommodation. HSI practitioners should not lose sight of the need to assess maintainability and transportability accommodation at this stage of the program. Poor maintainability design can also increase risk to a system program as detrimental as operational risk. Design change in models is much less costly and more easily accomplished than after metal has been bent on prototypes. Typically there is an overarching accommodation specification for maintainability similar to the specification below:

SPEC XXX. The vehicle shall provide adequate visual and physical accessibility for maintenance and sustainment tasks (T=O).

And again, detailed maintenance accommodation specifications usually focus on areas of design that are routinely overlooked early on in the system design or that can be difficult to achieve.

SPEC XXX. The vehicle lifting, tie-down, and cargo constraint provisions shall be accessible to personnel performing the operations (T=O).

SPEC XXX. The vehicle shall minimize service ports by routing service lines to a centralized servicing location(s) and provide extended fittings to lubricant ports that would not otherwise be readily accessible or visible (T=O).

SPEC XXX**.** The vehicle shall have readily accessible Army Oil Analysis Program (AOAP) sampling valves, NSN 2590-01-293-8294, one each fluid system per AR 750-1, para 2-15, H4b. (T=O)

SPEC XXX**.** The vehicle shall provide lift points for line replaceable units (LRU's) that exceed two man lift/carry, to perform maintenance (includes removal/installation) of those components (T=O).

With the accommodation language included in the contract, the government HSI practitioner then provides the manikin models to the PM. These manikins will be fully clothed with their equipment per the requirements called out in the CDD and crossed walked into the specifications.

Human Figure Modeling

Historically, military ground vehicles were designed using requirements drawn from MIL-STD-1472, the Department of Defense design criteria standard for Human Factors Engineering. The traditional approach has been to use an accommodation range that relied on percentile values, typically 5^{th} and 95^{th} percentile values. When used as a means to define an accommodation range, percentiles are only relevant to one specific body dimension. Problems arise when univariate percentiles are applied to systems and equipment that are multivariate in their function and design. The use of univariate percentile language inserted into a requirements document to define a desired accommodation target will likely result in a design that actually accommodates less of the population than the percentile range would imply. In fact, it has been shown that placing 5^{th} and 95^{th} percentile limits on all key body dimensions in a multivariate design could actually exclude a much higher percentage of the population instead of the 10 percent implied by the percentile range (Bittner, 1974). This is aside from the fact that in real life, no human is comprised of all univariate percentile body dimensions such as 5^{th} or 95^{th}.

A more effective approach for defining an accommodation range is through the use of a multivariate statistical method such as Principal Component Analysis (PCA) (e.g., Bittner et al., 1987; Zehner et al., 1992; Gordon et al., 1997; Gordon, 2002) that incorporates a set of critical body dimensions intrinsic to the system design from an existing or known anthropometric database. This method allows a desired range of a population to be accommodated in such a way that the size differences as well as body proportion variability are taken into account. Additionally, this method allows for a set number of manikins or forms to define the boundary or range of the desired population accommodation.

PCA can then be used to derive an accommodation envelope by reducing this larger set of critical body dimensions to a more manageable number of dimensions (i.e., 2 or 3) that account for a large proportion of the variation by using linear combinations of the original measurements. After derivation of the principal components, a database of subjects can be scored and plotted in a new PCA space, and a two or three dimensional (2D or 3D) ellipse or ellipsoid can be fit to the population distribution in order to capture the desired percentage of the user population. The surface of the generated ellipsoid then

represents accommodation envelope or "boundary" (Fig. 4) associated with the percentage of the selected subjects (Lockett et al., 2005).

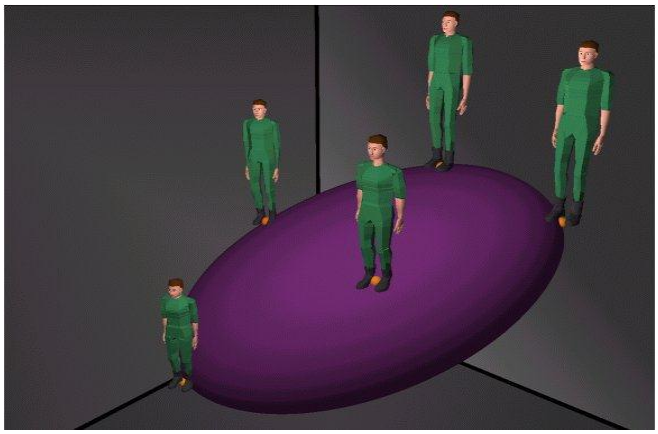

Figure 4. Illustration depicting the concept of boundary manikin human figure model

A subset of seven figures from a crew station boundary manikin set (Fig 5). The figure illustrates the variation in the body dimension proportions from within that set. These figures depict the population extremes with the small female and large male, as well as some of the widest variations in limb and torso dimensions.

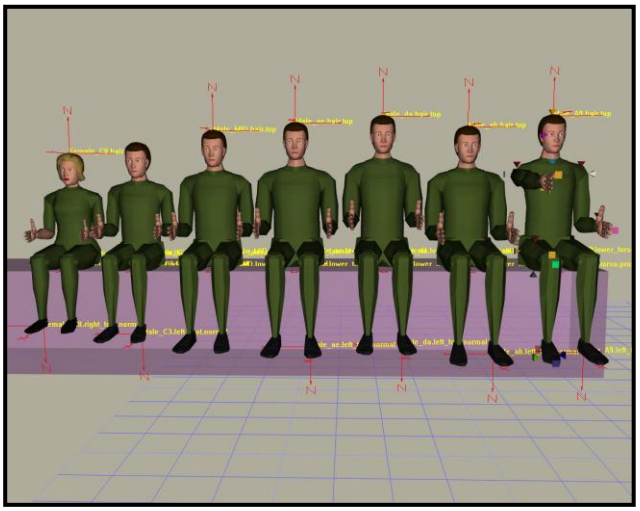

Figure 5. Selection of several boundary manikins from a crewstation manikin set.

From left to right the manikin are designated as 1- Small Female, 2 - Small Male, 3 - Mid-Sized Male, 4 - Wide Torso Male, 5 - Long Torso Male, 6 - Long Limb Male, 7 - Large Male Manikin.

Developing 3D Clothing and Equipment Models

While clothing and encumbrances are often disregarded in the design process for many types of office and commercial workspace designs, they are an important factor to consider for military systems where space is often at a premium and the additional clothing and equipment can add significant weight and bulk to each individual (Fig. 6). Some typical examples include multilayered ensembles that provide protection against nuclear, biological and chemical threats, clothing to operate in extreme cold weather environments and body armor for ballistic and fragmentation protection. Additionally, load bearing vests and packs are worn to help transport sustainment supplies, along with advanced tactical equipment such as communication gear, components for night-vision and thermal imaging capability, as well as lasers for range-finding and target designation.

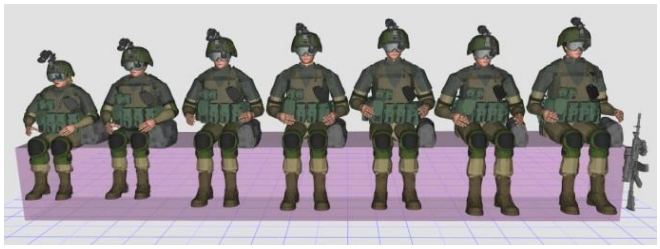

Figure 6. Boundary manikin set with clothing and equipment models.

When performing workspace analysis on military system designs, one must not only account for the physical body dimensions of the intended user population for the system design, but also the clothing and equipment that will be worn when operating, occupying or maintaining the system as well as ingress/egress issues. When clothing and equipment models are added to the design considerations, a new layer of complexity is encountered. This is because specialized clothing and equipment have a significant impact on a person's range of motion, field of view and ability to fit in a workspace, making it difficult for the person to complete required tasks successfully. For this reason, efforts using human figure models to analyze these workplaces and associated tasks should also include models of the same specialized clothing and equipment. An example of clothing and equipment having an impact on operator performance (Fig. 7).

Figure 7. Example of encumbered boundary manikin and the impact on driver accommodation.

Once the models have been defined and created, they are provided to the PM. The PM in turn, provides these models to the contractor as Government Furnished Information in an attachment to the contract. With these models in hand, the contractor can then proceed with a Soldier centric design to accommodate the central 90 percent of the targeted user population.

SUMMARY

With the use of human figure modeling called out in the contract, very early analysis can take place in the RFP timeframe, during the SSEB and continue once the contract is awarded. With both the contractor and the government using the same manikin models and CAD models, this ensures that the same "yardstick" is being used to assess the contractor's compliance with the specifications. The HSI practitioner needs to ensure independent government verification of the system design due to subsystem design stove piping that inevitably takes early in the program. Contractors are also human and errors will be made in the design integration. Finally, there can be conflicts in design specifications which are only brought to light when attempting to meet the specifications.

In the past, accommodation issues were typically caught during prototype production or even later in developmental testing. At this late stage in a program, the design has been established and significant engineering redesign would have to be implemented to recover adequate Soldier accommodation. Where there are challenges in meeting the contract specifications, the use of early human figure modeling provides time for the contractor and PM to relook requirements, specifications or system redesign before any metal has been bent on the production line. This is critical in reducing overall risk and cost to the program.

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