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Optimal Configuration of Human Motion Tracking Systems: A Systems Engineering Approach

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Introduction

Human motion tracking systems represent a crucial technology in the area of modeling and simulation. These systems, which allow engineers to capture human motion for study or replication in virtual environments, have broad applications in several research disciplines including human engineering, robotics, and psychology.

These systems are based on several sensing paradigms, including electro-magnetic, infrared, and visual recognition. Each of these paradigms requires specialized environments and hardware configurations to optimize performance of the human motion tracking system. Ideally, these systems are used in a laboratory or other facility that was designed to accommodate the particular sensing technology. For example, electromagnetic systems are highly vulnerable to interference from metallic objects, and should be used in a specialized lab free of metal components [1].

In practice, specialized "tracker friendly" environments are not always available. A particular research project or simulation might force adding a human motion tracking system to a facility that does not possess the optimal sensor environment. This situation describes the setting at Marshall Space Flight Center's Collaborative Engineering Center Army-NASA Virtual Innovation Laboratory (MSFC CEC-ANVIL). The CEC-ANVIL is a collaborative environment that evolved over time and features a variety of engineering tools and technologies configured in a standard 20 meter X 20 meter modified office. This room, which features heavy metal induced interference, features a partial CAVE Automatic Virtual Environment (CAVE) that is used for modeling, analysis, and decision making. The Human Engineering component of the MSFC Systems Engineering Support Group desires to add a human motion tracking capability to this setting.

The Systems Engineering and Management Process

We will apply the Systems Engineering and Management Process (SEMP) in order to address this problem. This process, developed at the United States Military Academy, helps engineers systematically design large-scale, complex systems to address problems [2]. We will first introduce this process before applying it to the MSFC CEC-ANVIL Human Motion Tracking problem.

The SEMP, shown in Figure 1, is a four phase iterative process involving nine unique steps. A descriptive scenario specifies the current state of a given system or situation. A normative scenario describes the desired state of the system or situation. The difference between these two scenarios is the problem. In the case of the CEC-ANVIL, the descriptive scenario is a uninstalled MotionStar tracking system operating in a sub-optimal environment. The normative scenario is an optimal system that meets the human tracking needs of the CEC-ANVIL.

The engineering process on the inside of the diagram is an iterative process we execute to arrive at the normative scenario. The first phase of the process, the problem definition phase, involves two steps – needs analysis and value system design. The needs analysis step entails understanding, redefining, and formalizing the problem definition. The value system design step involves constructing an upfront value system that fits within the context of the problem definition and can later help ideate and evaluate potential alternatives.

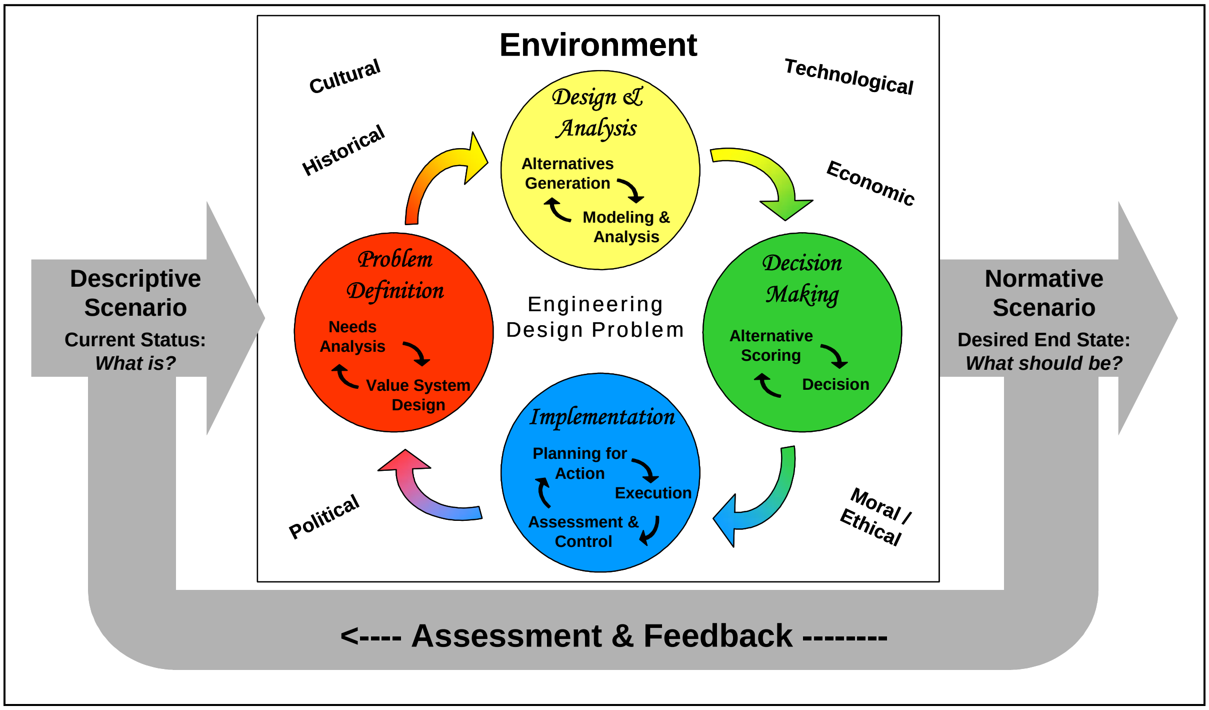


Figure 1 – The Systems Engineering and Management Process

The second phase of the SEMP is the design and analysis phase which is broken down into alternatives generation and modeling and analysis steps. Alternatives generation involves creating potential alternatives to address the needs defined in the needs analysis step. The modeling and analysis step is concerned with identifying the feasibility of alternatives, as well as optimizing and measuring each alternative.

The third phase of the SEMP is the decision making phase which is broken down into the alternative scoring and decision steps. In the alternative scoring step, we use the value system from the problem definition phase to calculate a “total value score” for each alternative. In the decision step, we use these value scores to recommend one alternative to the decision maker. This decision includes a detailed sensitive and cost-value analysis.

The final phase, implementation, involves the three remaining steps of the process – plan of action, execution, and assessment and control. The plan of action represents the project plan detailing how we will implement our winning alterative. Execution involves actually employing hardware, software, and other resources to create the alternative. Assessment and control involves observing and controlling the system over its lifetime.

It is important to note the iterative nature of the SEMP and its four major phases. The iteration at each phase represents the continual processing and prototyping that is conducted at each phase until certain conditions are set to commence the next phase. The iterative nature of the SEMP prompts us to re-execute when the descriptive scenario no longer matches the normative scenario.

Problem Definition

We begin the application of the SEMP to the MSFC CEC-ANVIL motion tracking problem at the problem definition phase. The problem definition phase begins with the needs analysis step.

Needs Analysis

Needs analysis begins with receipt of the Initial Problem Statement (IPS). This is a rough description of the problem provided by the chief decision maker. In the case of MSFC's CEC-ANVIL Motion Tracking problem, the Human Engineering Team Lead provided the following initial problem statement:

> *"We have a Flock of Birds we want to get working, and mounted into a position, either in the ceiling or on the floor, where we can use it for human factors research and engineering. We'd like the audience to be able to sit at the table and watch as the puppeteer demonstrates the work in front of the workbench [3]*

The next step of the problem definition process involves a detailed study of this initial problem statement and all involved systems. To accomplish this, we will identify facts and constraints and perform a complete system decomposition.

The following represent salient facts involving the MSFC CEC-ANVIL Human Motion Tracking System:

- The primary motion tracking system consists of an Ascension MotionStar system. This system features a CPU, 10 magnetic sensors, an extended range controller, a transmitter, and cabling. This system captures the location and attitude of each sensor and transmits this information to the CPU then onto a LAN/WAN via Ethernet.

- The motion tracking system also consists of an Immersion CyberGlove/CyberTouch system that features a sensor glove, controller, and cabling. This system captures positioning and orientation of the five fingers on one hand. This information is gathered by the controller then sent via serial cable to a subscribing CPU.

- The primary modeling and simulation program used by the stakeholders is EDS Jack. This program allows a puppeteer to control virtual humanoids with the human motion tracking system. The stakeholders are also interested in using the human motion tracking system with the Delmia Ergo modeling package.

- MSFC CEC-ANVIL will use the human motion tracking for briefings to decision makers and for detailed human engineering analysis.

To further define our problem, we identify the following constraints:

- The Human Motion Tracking system is confined to MSFC CEC-ANVIL. We cannot relocate the system to a more suitable facility.

- The published usable range of the MotionStar transmitter is 10 ft. This was later refined to 8 feet through analysis.

- The length of the required cabling connecting the MotionStar sensors and transmitter to the MotionStar CPU is approximately 10 meters. Therefore, the entire human motion tracking system (human, MotionStar, CyberGlove) is confined to a 10 meter radius.

- Observers must have an unobstructed view of the CAVE wall from a centrally located conference table. The conference table cannot move.

- The system should also allow the puppeteer to directly view the CAVE wall when observers are not present.

- The system must interface with EDS Jack software.

- Any structural components for mounting the transmitter, CPU, or sensors cannot be made of metal.

In order to gain further insight into what actually comprises the human motion system, we will conduct a detailed system decomposition. First, this will help us identify the key functions of the system, which we will use to build a value hierarchy later in the process. Second, the decomposition will aid us in better understanding what components are part of the system, which will help define potential alternatives.

The decomposition for the human motion tracking system, shown in Figure 2, consists of functional decomposition, component decomposition, and structural decomposition. The functional decomposition examines the key functions of the motion tracking system, and was conducted after observing how the human motion tracking system fits with the organization's processes. The main functions of the system are: display a virtual environment to the operator (person wearing the tracker), display the virtual environment to the observers (decision makers and VIPs), mimic the operator, facilitate interaction, facilitate maintenance, and provide a safe environment.

The component decomposition looks at all the physical components in the system, and consists of structural, operational, and flow components. Structural components are those that provide some sort of physical structure to the system - hardware mounts, consoles, harness, wires. Operational components are components that actually transform other components - sensors, CPU, software, transmitter. Flow components are components that are transformed – in this case the digital and analog signals that make up the human motion tracking information.

The hierarchical decomposition looks at the human motion tracking system within the context of higher, lower, and adjacent systems. The parent system for the human motion tracking system is the CEC-ANVIL. Lateral systems include other notable systems within the CEC-ANVIL that might impact the motion tracking system – namely the CAVE, a video teleconferencing system (VTS), and numerous CAD workstations.

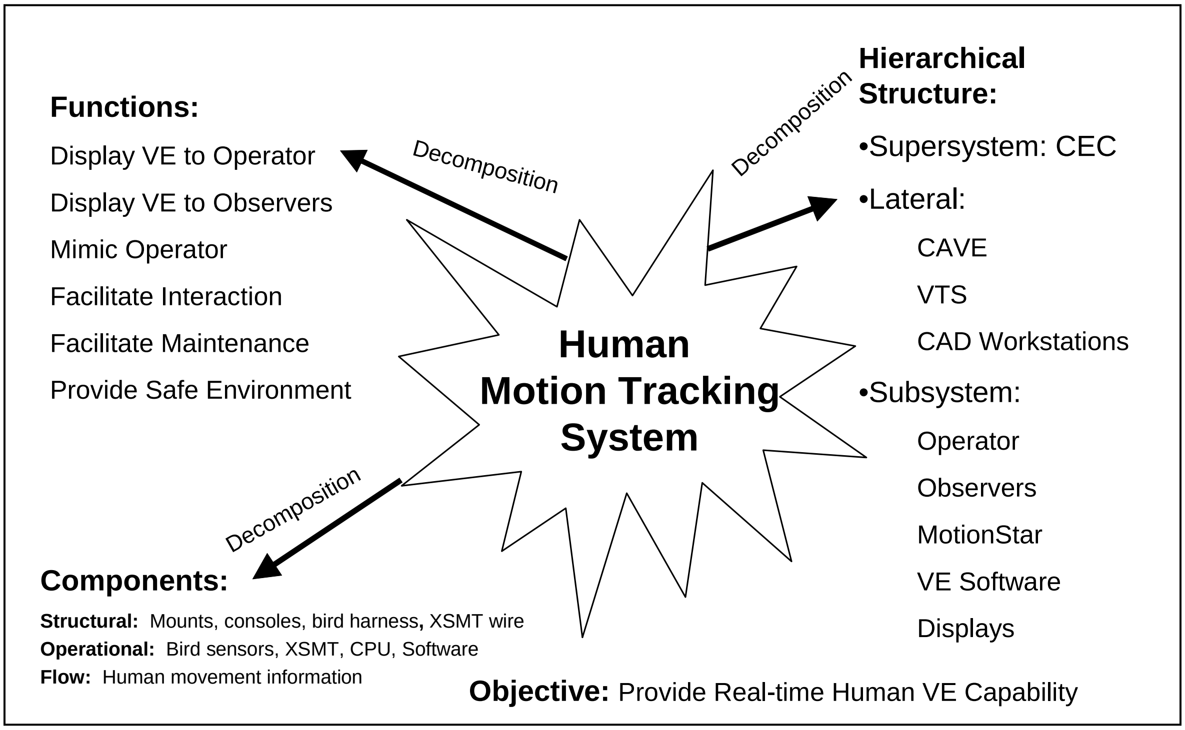


Figure 2 – System Decomposition of the HMCS

To augment our component and structural decomposition, we construct a context diagram of the system. This diagram, shown in Figure 3, provides another view of the component and hierarchical decomposition. The outer circle of the diagram represents the system boundary. This boundary represents everything we can control in the system, and is based off the decision maker's designated level of authority. The circles inside the boundary represent components of the human motion tracking system, with the MotionStar component represented with its own sub-system boundary and sub-components. The circles outside the system boundary represent objects in our environment (the CEC) that might impact the human motion tracker but over which the system has no control.

The decomposition process described above helps us scope the system. Identifying the system's boundary, functions, and components enables us to conduct an appropriate and meaningful stakeholder analysis. The goal of the stakeholder analysis is to identify stakeholder needs, wants, and desires. In this scenario, we will consider three stakeholders – the decision maker, the sponsor, and the users. After many discussions and interviews, we arrive at the following needs, wants, and desires.

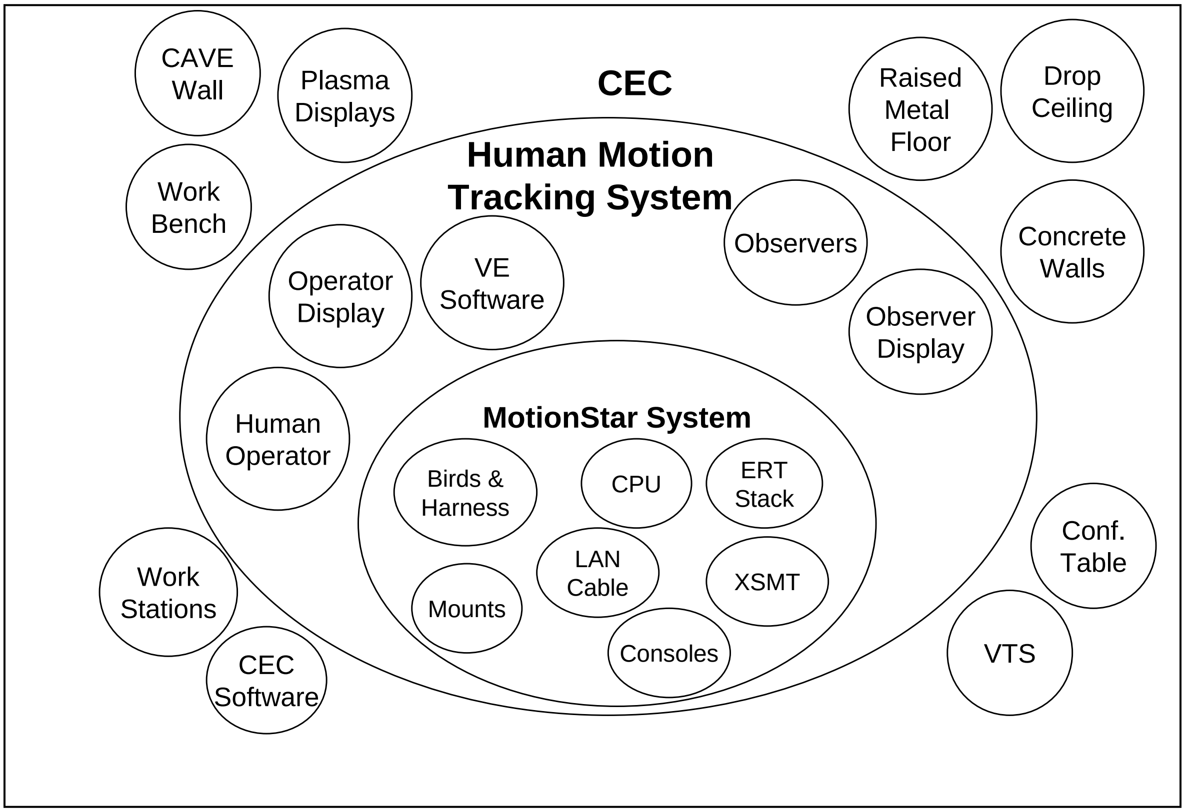


Figure 3 – HMTS Context Diagram

The decision maker, the Human Engineering Team Lead, desires a system configuration that allows engineers to easily and quickly incorporate human motion tracking into an overall engineering process. He desires a system that will enhance the human engineering research capabilities of the CEC and one that employs an aesthetically pleasing, organized hardware configuration. The system must offer accurate and reliable system performance and allow an audience of higher decision makers to observe use of the system. The system must also incorporate both the CyberGlove and MotionStar sub systems.

The sponsor, the MSFC Systems Engineering Support Group (ED42) Manager, is the person who actually owns the equipment and the CEC-ANVIL. He desires to fill a need to integrate human factors early on to drive the overall design process. He also wants to increase the CEC-ANVIL role in providing training to users of designed systems. He also wants to research how motion tracking can enhance the various engineering processes within the entire Systems Engineering Support Group. He sees the system developing into a unique capability that ED42 can “sell” to MSFC and NASA.

The users represent the last group of concerned stakeholders. These individuals, contract technicians who staff the CEC-ANVIL, want an easy to use system they can employ when assigned a human motion tracking mission. The system should also be easy to maintain and not interfere with other lab equipment and capabilities.

The last act in the needs analysis step is to use the facts/constraints, detailed system decomposition, and stake holder analysis to construct a revised problem statement. This statement represents what we think the decision maker needs, which may or may not reflect what they initially provided in the initial problem statement. The revised problem statement considers all the facts and stakeholders desires within the designated scope of the system. For our problem, we arrive at the following revised problem statement:

> *ED42 (CEC) desires to implement a functional human motion tracking system to enhance their human engineering and analysis capability. This system will acquire real-time human position data for controlling human models inside virtual and CAD environments. This system will augment their engineering processes by bringing humans into the design process early on, and enhance their ability to communicate analysis to decision makers and customers. Specific tasks include:*
>
> *(a) Configuring visualization software packages to read the location of motion sensors transmitted by the MotionStar "Flock" and CyberGlove and translate this into controllable human models*
>
> *(b) Developing techniques and procedures for integrating these controlled human models with other virtual environments and CAD models*
>
> *(c) Designating a place to permanently mount the MotionStar system*
>
> *(d) Developing an easy to use suit for wear of the MotionStar sensors*

Value System Design

The next step in the SEMP is value system design. The value system design step creates a value model that reflects the stakeholder needs, want, and desires. This value model will later serve to evaluate how well potential design alternatives meet the needs of the stakeholders.

Figure 4 shows a value hierarchy (tree) that reflects the value model for this system. The top of the tree lists the overall operational need for the human motion tracking system – provide human motion tracking capability. The next layer of the tree represents the main system functions discovered in functional decomposition conducted during the needs analysis step. For each of these functions, we created an objective that is used to gauge how well each function is being performed. Below each objective is an evaluation measure that represents a measurable metric that corresponds to each objective. These are briefly described below.

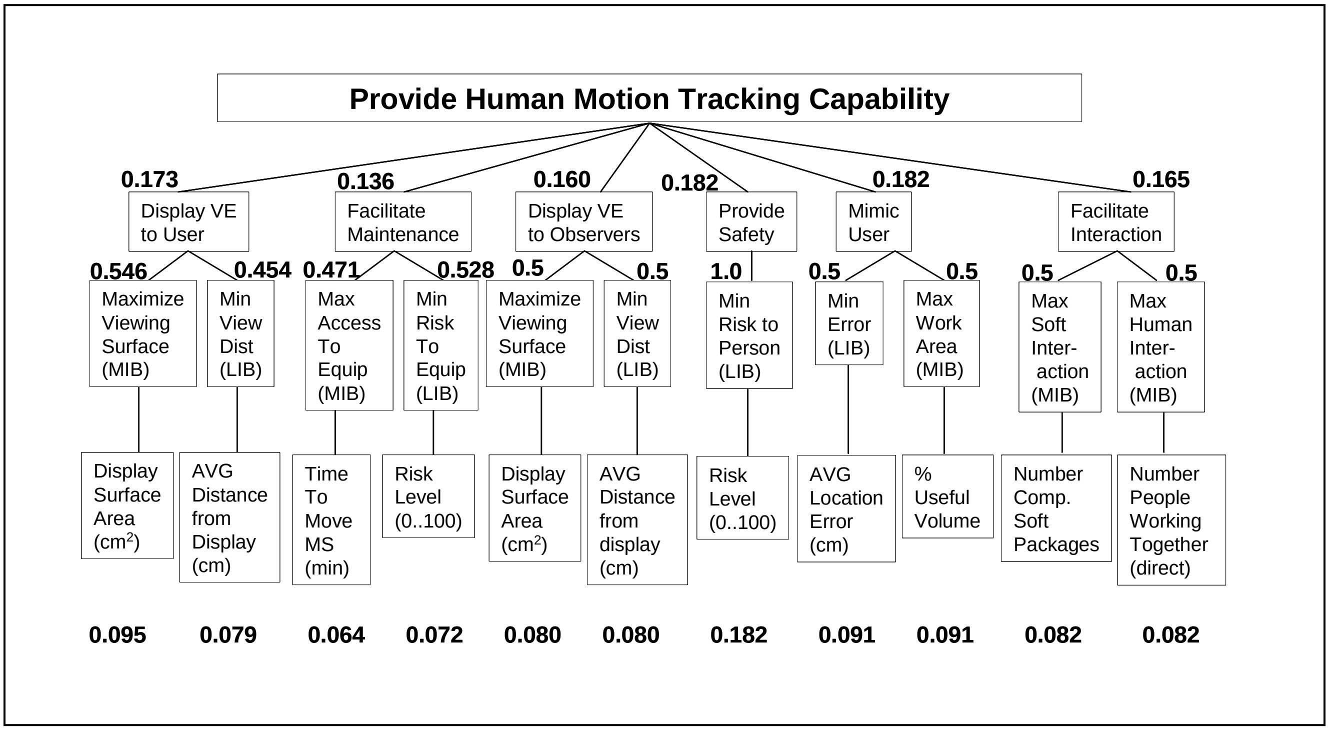


Figure 4 – HMTS Value Hierarchy

Function: Display Virtual Environment (VE) to User

Objective: Maximize Viewing Surface. Here we assume a bigger screen is better for the user to view the VE. More screen is better (MIB).

Evaluation Measure: Primary user display surface in cm^2.

Function: Display Virtual Environment (VE) to User

Objective: Minimize Viewing Distance. Here we assume that a closer screen (in general) is better for a user to view the VE. Less distance if better (LIB).

Evaluation Measure: Average user distance from display surface in cm.

Function: Facilitate Maintenance.

Objective: Maximize Access to Equipment. Here we assume technicians want quick access if they need to move or maintain the equipment. More access is better.

Evaluation Measure: Average time to move entire system in minutes.

Function: Facilitate Maintenance.

Objective: Minimize Risk to Equipment. Here we assume we want to minimize the risk of damage to the equipment. Less risk is better.

Evaluation Measure: Risk level on scale of 0 (no risk) to 100 (extremely high risk).

Function: Display Virtual Environment (VE) to Observer.

Objective: Maximize Viewing Surface. Here we assume that the system that a bigger screen is better for the *observer* to view the VE. More screen is better (MIB).

Evaluation Measure: Primary *observer* display surface in cm^2.

Function: Display Virtual Environment (VE) to Observer.

Objective: Minimize Viewing Distance. Here we assume that a closer screen (in general) is better for an *observer* to view the VE. Less distance if better (LIB).

Evaluation Measure: Average *observer* distance from display surface in cm.

Function: Provide Safety.

Objective: Minimize Risk to Persons. Less risk is better.

Evaluation Measure: Risk level on scale of 0 (no risk) to 100 (extremely high risk).

Function: Mimic User.

Objective: Minimize Error. Here we want to minimize the discrepancy between a sensor's reported location and a sensor's actual location. Less error is better.

Evaluation Measure: Average location error in cm.

Function: Mimic User.

Objective: Maximize Work Area. Here we want to maximize the area a user has to operate the system. More area is better.

Evaluation Measure: Percent Useful Volume. This metric is calculated by measuring what percentage of the user's body falls within 170 cm of the transmitter. This distance was determined as the useful work area based on experiments described in the modeling and analysis phase.

Function : Facilitate Interaction.

Objective : Maximize Software Interaction. Ideally, we want our tracking system to work with many various software packages. More is better.

Evaluation Measure : Number of compatible software packages.

Function : Facilitate Interaction.

Objective : Maximize Human Interaction. Here, we want our system to allow as many people as possible to simultaneously interact on a problem. More is better.

Evaluation Measure : Number of people who can directly interact while using the system.

The numbers at each node of the value model represent global and local weights. Global weights accompany the evaluation measures, while local weights correspond to the functions and objectives. These weights were calculated after interviewing each stakeholder about the relative importance of each function. Various stakeholder preferences were weighted based off the relative importance of the stakeholder. The results were then normalized to arrive at the values shown in Figure 4.

Design and Analysis

After defining our problem and value model, we now turn to the design and analysis Phase of the SEMP. This phase is broken down into two steps – alternatives generation and modeling and analysis.

Alternatives Generation

Based on two key constraints – must use the MotionStar/CyberGlove and must use EDS Jack software – our alternatives are limited to variations in hardware configuration. This includes where and how to mount the MotionStar CPU, transmitter, and sensors. Because this paper is focused on mitigating the effects of interference on the MotionStar system, we will confine our alternatives to the location of the MotionStar transmitter.

Based on the configuration of the CEC-ANVIL, we explored several reasonable potential alternatives for transmitter location:

Above Ceiling Tile Site
Below Ceiling Tile Site A
Below Ceiling Tile Site B
Below Ceiling Tile Site C
Below Ceiling Tile Site D
Below Raised Floor Site
Mobile Unit (32 in)
Mobile Unit (14 in)

These are shown in Figures 5a-5d. We also "considered" another clearly infeasible option – placing the system outdoors in a parking lot free of any metal – as a baseline.

Figure 5a – Above Ceiling Tile Site

Figure 5b – Below Raised Floor Site

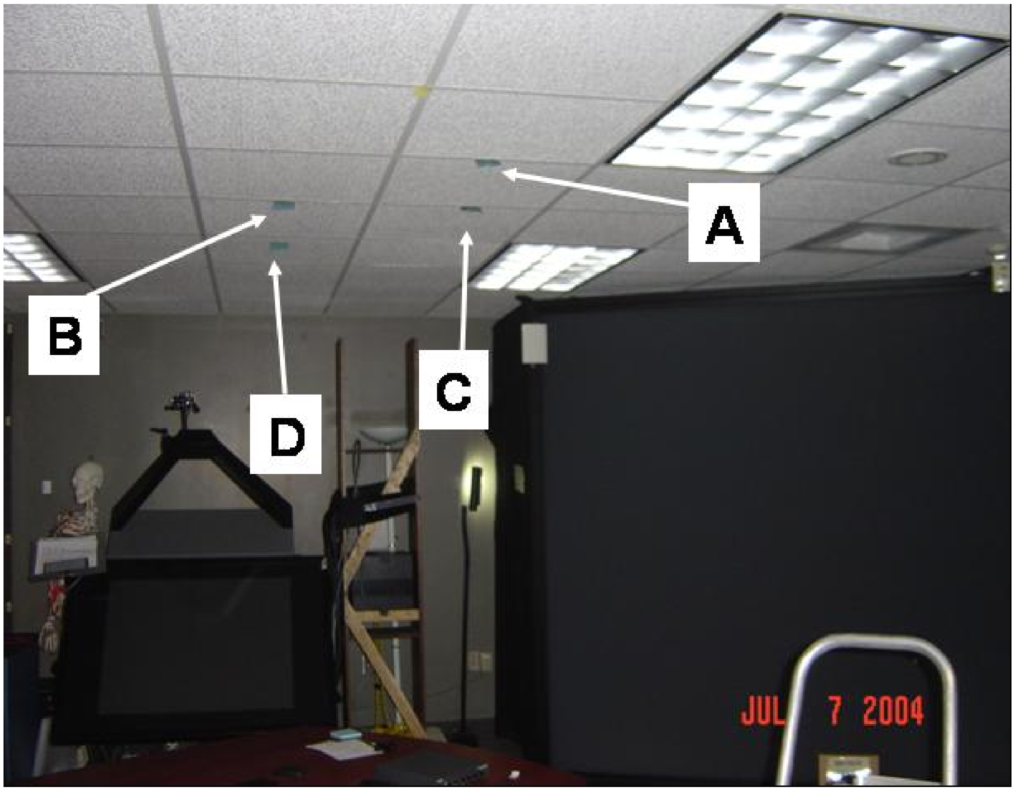


Figure 5c –Below Ceiling Sites A-D

Figure 5d – Mobile 32 and 14 inch sites

Our next step is to reduce these potential alternatives to a set of feasible alternatives. Figure 6 lists a matrix that summarizes the constraints uncovered during the Problem Definition Phase. Figure 7 shows a feasibility screen matrix that applies the constraints to each potential alternative.

CONSTRAINT TITLE	PHYSICAL CONSTRAINT	WHO PROVIDED	TYPE	NOTES
Confined to CEC	Inside CEC	Analyst	HARD	
MotionStar XSMT Limit	<= 8ft	Analyst	SOFT	Bird length from Transmitter (XSMT)
Bird Harness Length	<= 30ft	Designers	HARD	Location within 30ft of CPU
Unobstructed CAVE View (Observers)	N/A	Decision Maker	SOFT	
Usuable CAVE View (User)	N/A	Analyst	SOFT	
System must interface with JACK	N/A	Decision Maker	SOFT	
Static Conference Table	N/A	Decision Maker	HARD	
Acceptable Position Errors	< 40% error	Analyst	HARD	No excessive jumping or Major position errors

Figure 6 – Constraint Matrix

ALTERNATIVE	**Confined to CEC**	**MotionStar XSMT Limit**	**Bird Harness Length**	**Unobstructed CAVE View (Observers)**	**Usuable CAVE View (User)**	**System must interface with JACK**	**Static Conference Table**	**Acceptable Position Errors**	**OVERALL**
Above Ceiling	**YES (GO)**	**10ft (NO GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**NO (NO GO)**	**NO GO**
Below Floor	**YES (GO)**	**4 ft (GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**NO (NO GO)**	**NO GO**
Baseline (Parking Lot)	**NO (NO GO)**	**6 ft (GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**NO GO**
SITE A	**YES (GO)**	**8 ft (GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**GO**
SITE B	**YES (GO)**	**8 ft (GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**GO**
SITE C	**YES (GO)**	**8 ft (GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**GO**
SITE D	**YES (GO)**	**6ft (GO)**	**15ft (GO)**	**YES (GO)**	**NO (NO GO)**	**YES (GO)**	**YES (GO)**	**NO (NO GO)**	**NO GO**
MOBILE 14 inch	**YES (GO)**	**6 ft (GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**GO**
MOBILE 32 inch	**YES (GO)**	**6 ft (GO)**	**15ft (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**YES (GO)**	**GO**

Figure 7 – Feasibility Screening Matrix

From the feasibility screening matrix, we see that only five potential alternatives are feasible alternatives: below ceiling sites A-C, and the 14 and 32 inch mobile sites.

Modeling and Analysis

We next look at modeling and analyzing each alternative. This process consisted of measuring displacement errors at each site by comparing a sensor's actual location versus virtual location. For the virtual location, we used the Jack software's ruler function to measure the distance between the virtual transmitter and virtual sensor (bird). For the actual location, we attached the actual sensor to a wooden pole at the end of a 10 foot plastic chain attached to the MotionStar transmitter. The chain was marked at 2 foot increments. At each alternative site, we first moved the sensor (bird) to the 4ft mark on the chain. We then attached the chain (at point of sensor intercept) to the pole at a height of 80 inches. At this height, we took measurements at 90 degrees left of center transmitter, 45 degrees left of center, 0 degrees center, 45 degrees right of center, and 90 degrees right of center. We then moved the sensor to the 40 inch point on the pole, repeated the process, then moved the sensor to the 3 inch point on the pole and repeated the process again. Finally, we repeated this entire sequence at the 6 and 8 foot marks on the chain. Figure 8 shows an augmented photograph of this process.

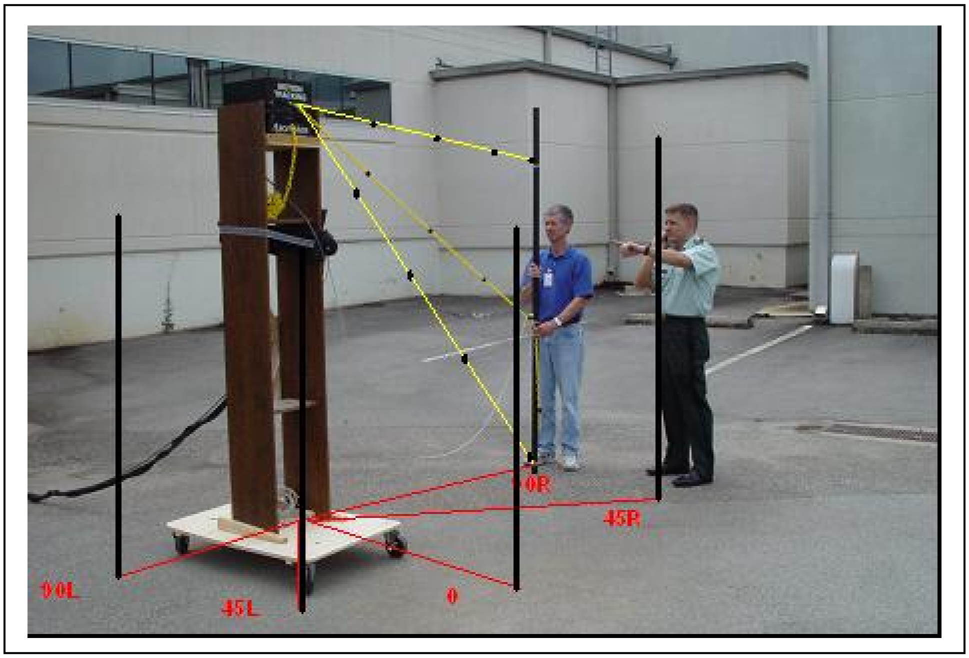


Figure 8 – Displacement Error Measurements

These measurements resulted in 45 displacement error calculations per site. Using these samples, we calculated error envelopes and an average error per site. Figure 9a and 9b show sample error envelopes, while Table 1 shows the average error calculations for each alternative.

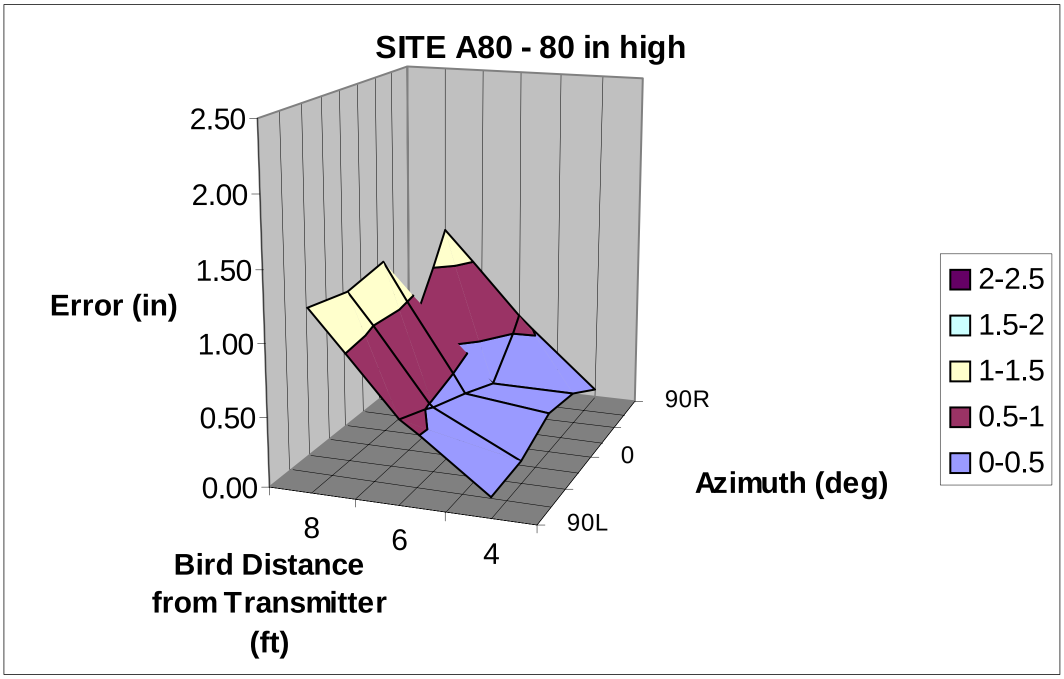


Figure 9a – Average Error for Site A (Sensor at 80 inches)

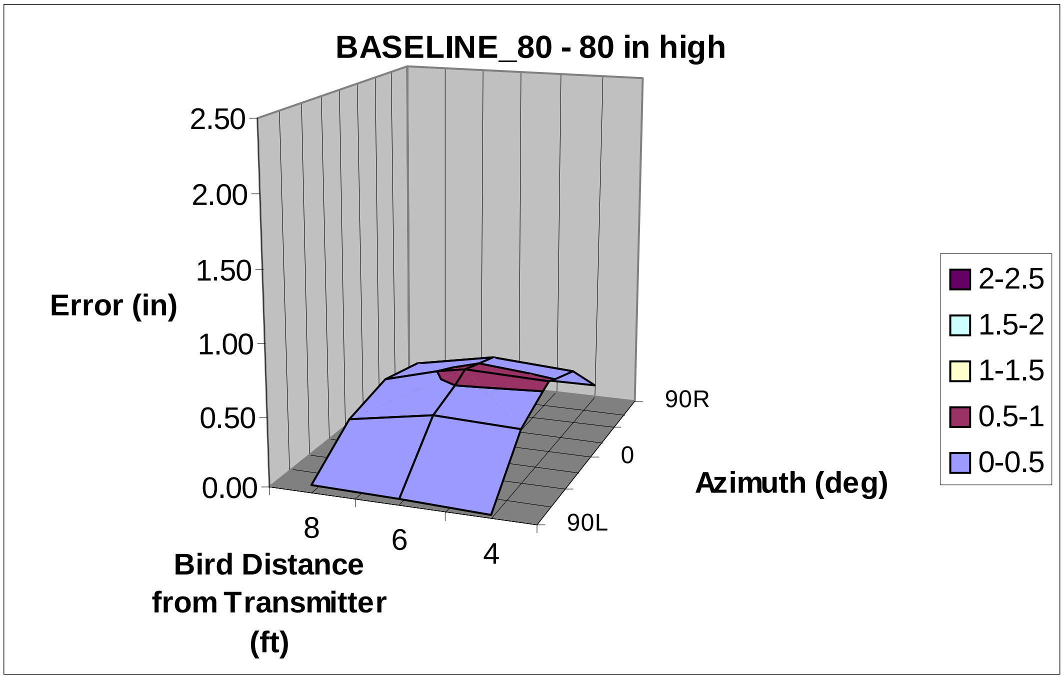


Figure 9b – Average Error for Baseline (Sensor at 80 inches)

ALTERNATIVE	AVG ERROR
ALTERNATIVE 1 (SITE A80)	0.615714286
ALTERNATIVE 2 (SITE B80)	0.652666667
ALTERNATIVE 3 (SITE C80)	0.670322581
ALTERNATIVE 4 (MOBILE 14)	0.59338022
ALTERNATIVE 5 (MOBILE 32)	0.510118355

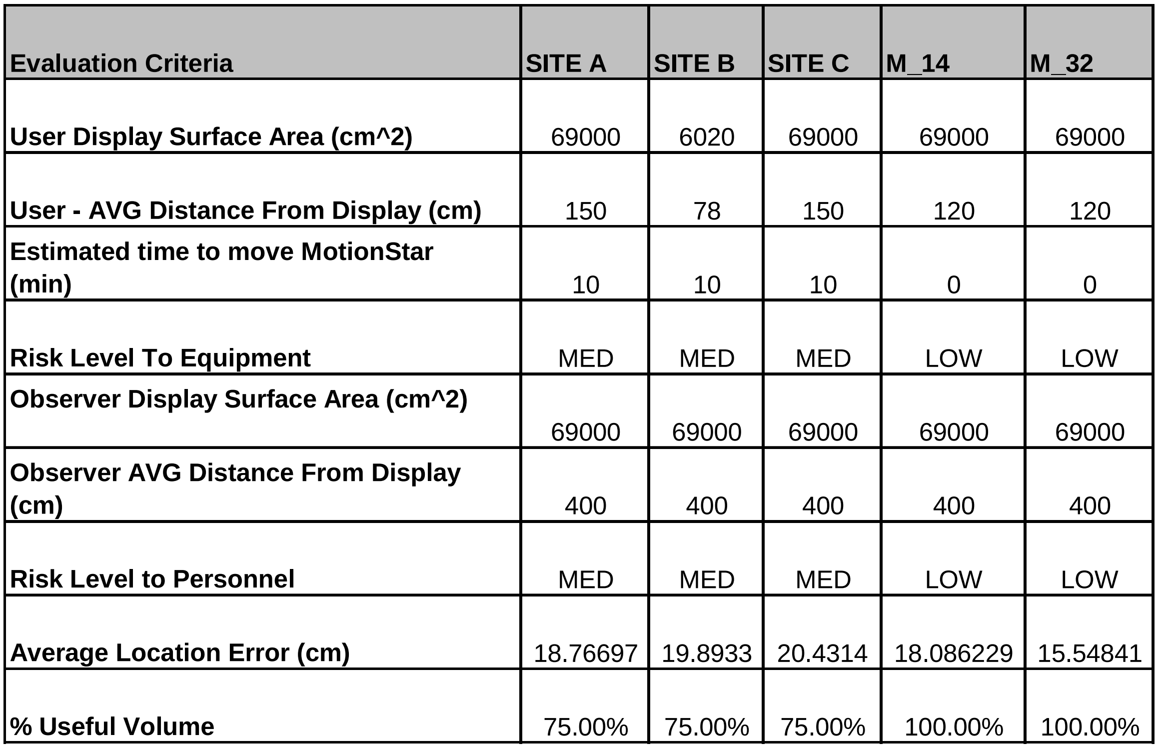
Table 1 – Average Error for Each Alternative

This modeling and analysis served several key purposes. First, it provided raw data we will later use to compare alternatives. Second, by comparing the sites to a baseline (Figure 10), we were able to confirm that measurement errors were a result of a “noisy” lab environment, not hardware or software malfunction. This led to several important discoveries about the laboratory, such as the fact that metal lined floor tiles caused serious degradation of sensors near the floor.

Figure 10 – Displacement Error versus Sensor Distance

Decision Making

The first step of decision making is alternative scoring. In this step, we first gather raw data for each of the evaluation measures in our value hierarchy. This data is gathered by direct measurement, and shown in the following raw data matrix (Figure 11):



Evaluation Criteria	SITE A	SITE B	SITE C	M_14	M_32
User Display Surface Area (cm^2)	69000	6020	69000	69000	69000
User - AVG Distance From Display (cm)	150	78	150	120	120
Estimated time to move MotionStar (min)	10	10	10	0	0
Risk Level To Equipment	MED	MED	MED	LOW	LOW
Observer Display Surface Area (cm^2)	69000	69000	69000	69000	69000
Observer AVG Distance From Display (cm)	400	400	400	400	400
Risk Level to Personnel	MED	MED	MED	LOW	LOW
Average Location Error (cm)	18.76697	19.8933	20.4314	18.086229	15.54841
% Useful Volume	75.00%	75.00%	75.00%	100.00%	100.00%

Figure 11 – Raw Data Matrix

Our next systems engineering task is to translate the raw data into comparable value scores. This allows us to combine evaluation measures with dissimilar units (e.g. cm^2 and risk level) into an overall value score for each alternative. We accomplish this with value curves. Each value curve shows value or utility (y-axis) as a function of a particular raw data value (Figure 12a-g). For example, in the case of Average Location Error (Figure 12a) we notice that a 12 inch error yields approximately 60% of total possible value to the stakeholder. We developed these curves by asking the stakeholders to describe how they value each evaluation measure.

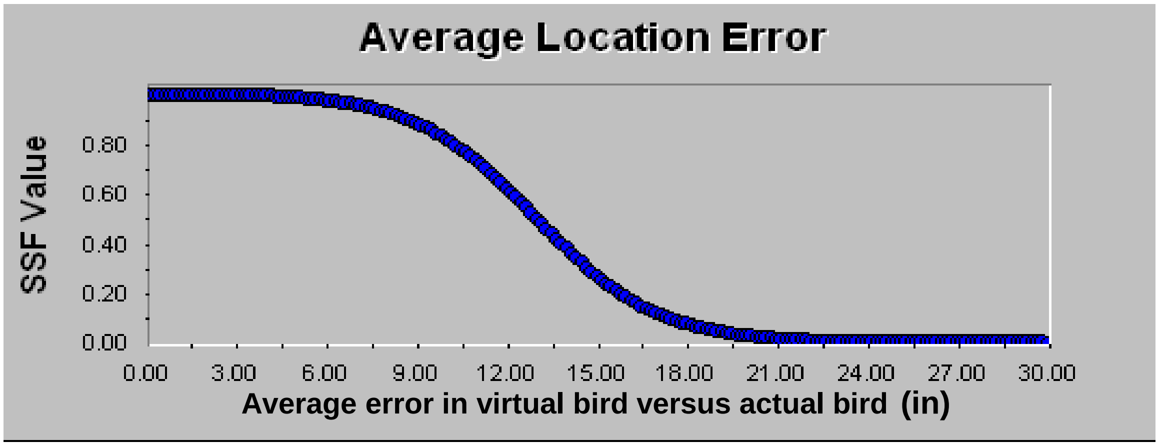


Figure 12a – Value Curve for Average Location Error

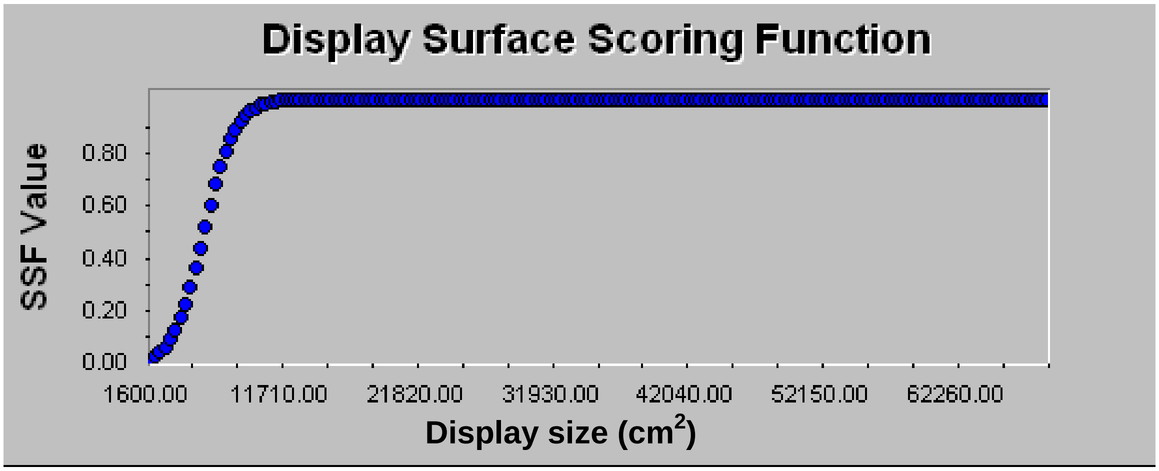


Figure 12b – Display Surface (User and Observer) Value Score

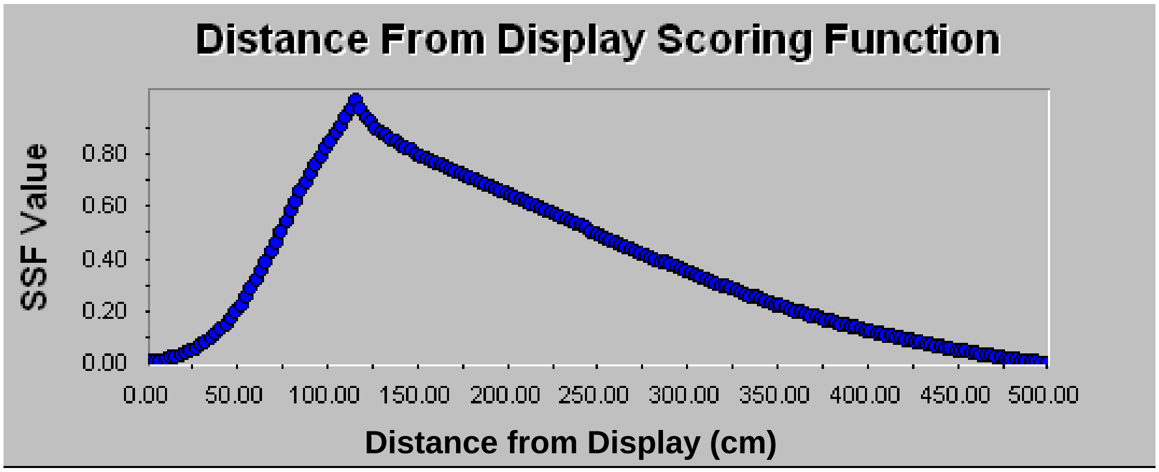


Figure 12c – Distance from Display (User and Observer) Value Curve

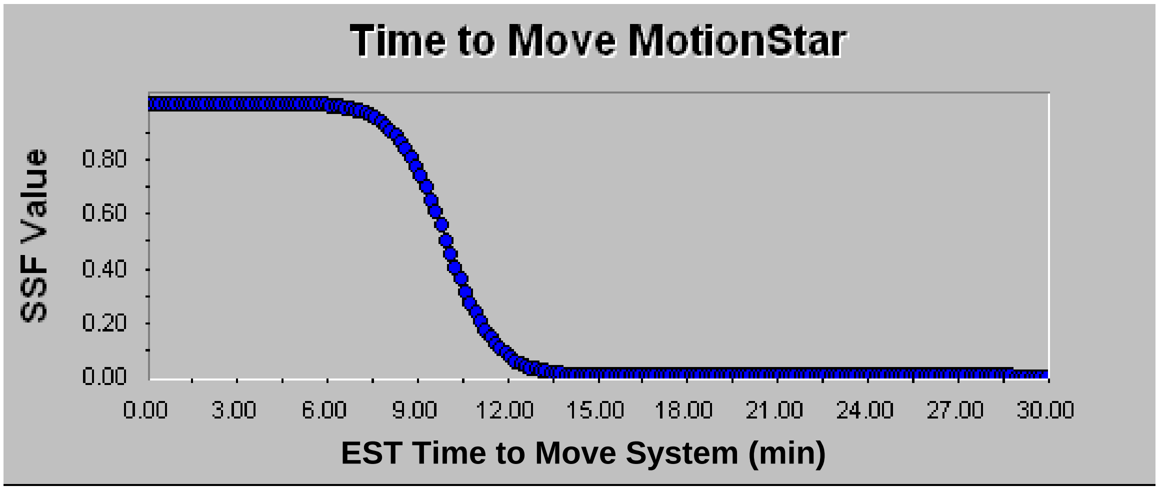


Figure 12d – Time to Move Motion Star Value Curve

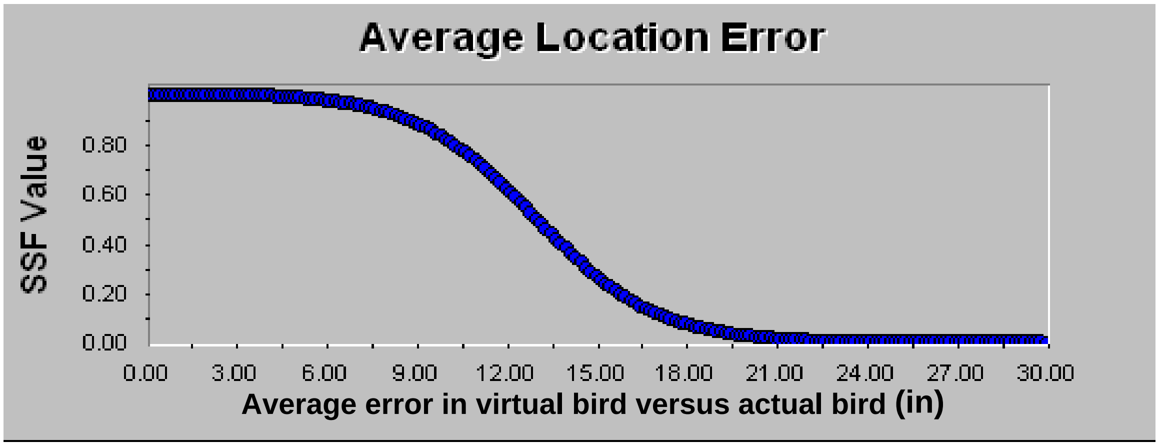


Figure 12e – Average Location Error Value Curve

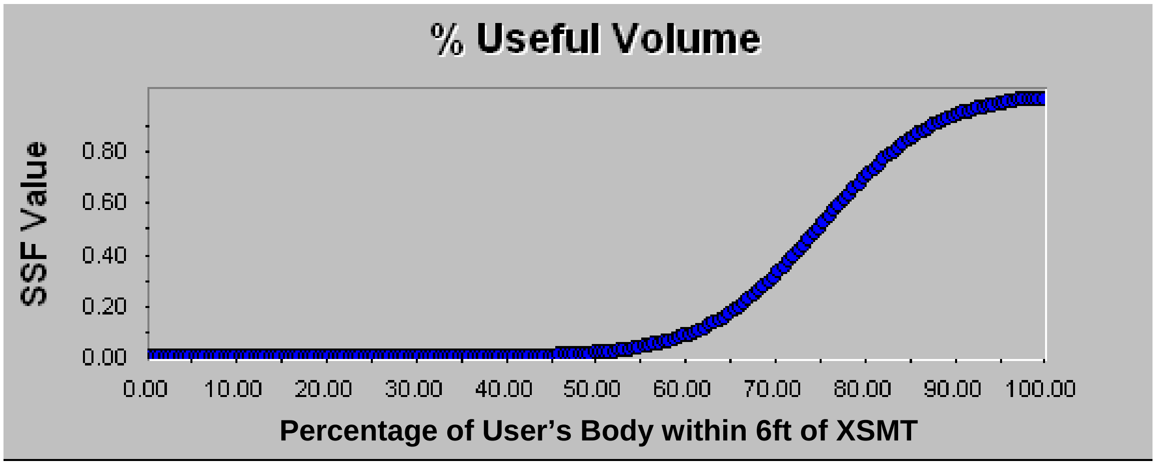


Figure 12f – Percent Useful Volume Value Curve

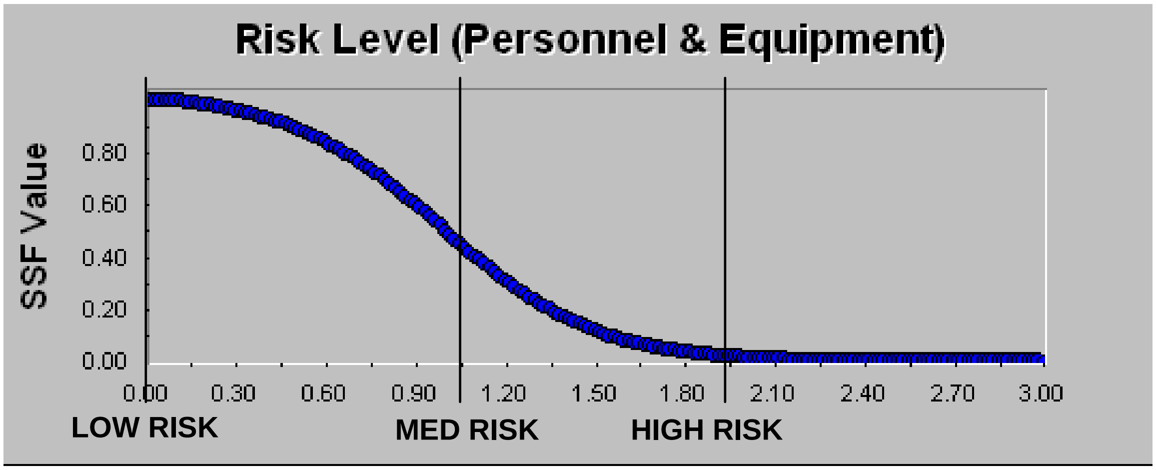


Figure 12g – Risk Level (Personnel and Equipment) Value Curve

The next step of the decision making phase is to recommend a decision. To accomplish this, we take the raw data matrix and use the value curves to construct a decision matrix (Figure 13). This shows the translated evaluation measure value scores for each alternative. These value scores are multiplied by the local weights for each evaluation measure as determined in our value model from the problem definition phase. These products are then added to obtain a total value score for each alternative.

Evaluation Criteria	Weight	SITE A	SITE B	SITE C	M_14	M_32
User Display Surface Area (cm^2)	**0.095**	100.00	50.00	100.00	100.00	100.00
User - AVG Distance From Display (cm)	**0.077**	80.30	50.00	80.30	100.00	100.00
Estimated time to move MotionStar (min)	**0.064**	50.00	50.00	50.00	100.00	100.00
Risk Level To Equipment	**0.072**	50.00	50.00	50.00	100.00	100.00
Observer Display Surface Area (cm^2)	**0.08**	100.00	100.00	100.00	100.00	100.00
Observer AVG Distance From Display (cm)	**0.08**	12.70	12.70	12.70	12.70	12.70
Risk Level to Personnel	**0.182**	50.00	50.00	50.00	100.00	100.00
Average Location Error (cm)	**0.092**	18.02	12.11	9.89	22.48	44.62
% Useful Volume	**0.092**	50.00	50.00	50.00	100.00	100.00
TOTAL SCORE		**46.86**	**39.23**	**46.11**	**69.28**	**71.32**

Figure 13 – Decision Matrix

From these results we notice that the 32 inch mobile configuration, with total value of 71.32, is the best choice. To bolster our confidence in this recommendation we also conducted a sensitivity analysis of the decision. In the sensitivity analysis, we individually varied the importance of each evaluation measure to see if our recommendation would change if an evaluation becomes more or less important. We found no such sensitivity.

Implementation

The last phase of the SEMP is the implementation phase. This phase is characterized by three steps - plan of action, execution, and assessment & control. Our plan of action entailed developing a CAD drawing (Figure 14) for an all plastic mobile cart made of PVC piping. We then executed this initial plan and built a to-scale prototype. We then conducted testing with the actual transmitter, and discovered the PVC pipe exhibited structural fatigue. This assessment and control step prompted us to execute another iteration of the implementation phase to modify our implementation plan and incorporate more supporting PVC components (Figure 15).

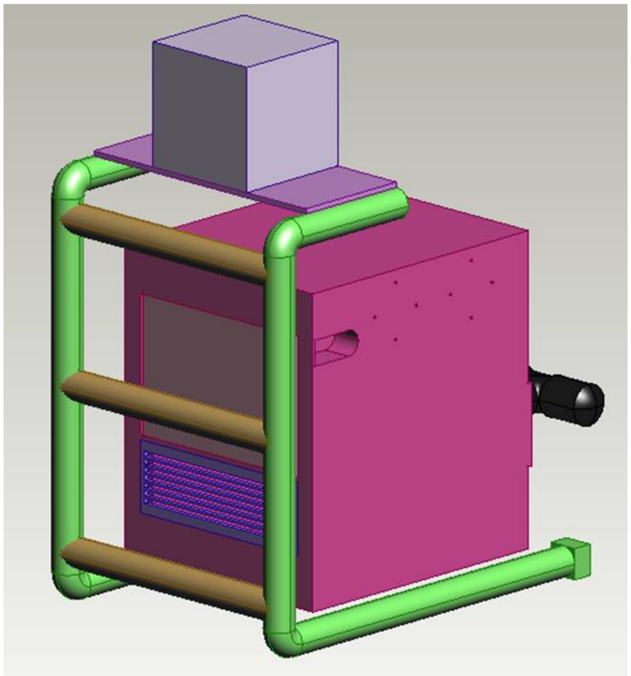


Figure 14 – Initial CAD for Implementation

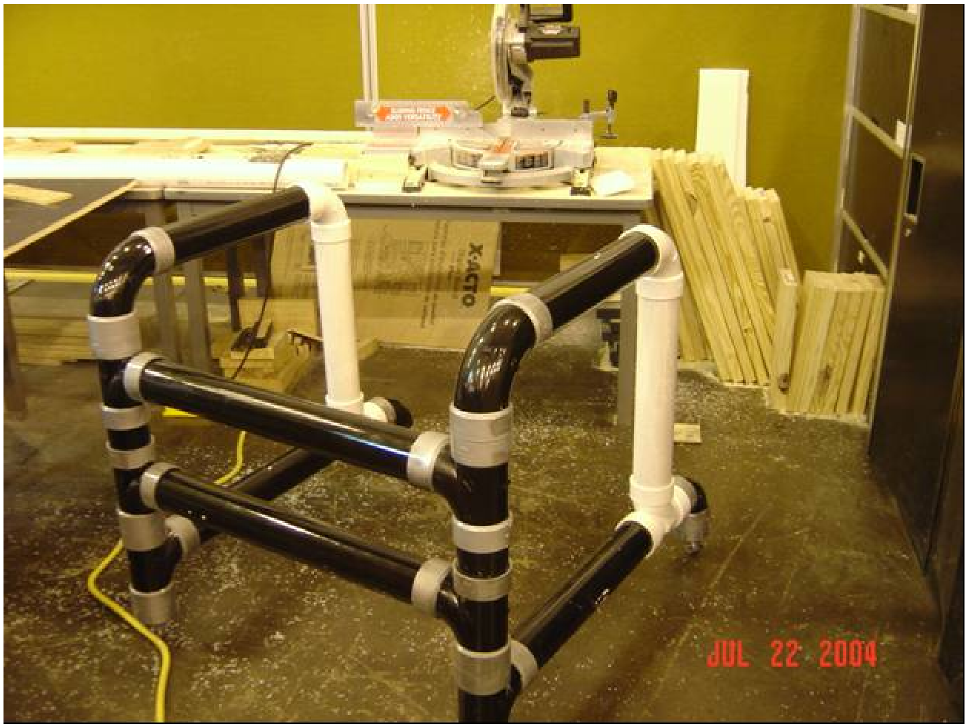


Figure 15 – Second Implementation Iteration

The implementation also included constructing a sensor harness, which also involved several iterations of the implementation phase (Figure 16).

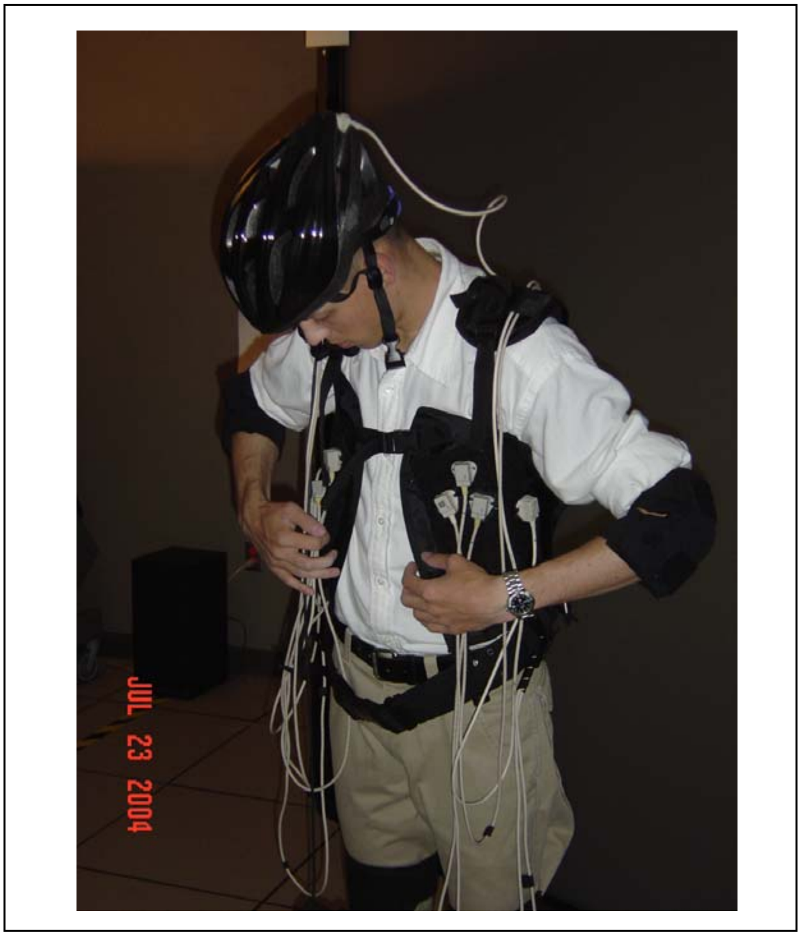


Figure 16 –Implementation of Sensor Harness

Conclusion

The net result of this systems engineering approach is a functional human motion tracking system that best meets the needs of the stakeholders in ED42 given the sub-optimal environment of the CEC-ANVIL. The SEMP's robust and thorough approach to the problem helped us grasp the essential need for the system and helped uncover design possibilities (a mobile unit) not previously obvious to the decision maker.

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