Towards a Decision Support System for Simulation Training Display Requirements

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ABSTRACT

The complexity of display system acquisitions increased in recent years due to the introduction of several disruptive[1] and emerging technologies including PC image generators, high resolution commercial projectors, solid state light sources, display calibration systems, and stereoscopic displays. This complexity surge, combined with increased end-user expectations, substantially diminished the value of the traditional procurement strategy of adopting updated specifications for current products as the requirements for the next training display system. Because of this churning in the supply chain, customers can no longer rely on incrementally improving product capabilities or long term supplier relationships to ensure their next training display system will meet the needs of their users. In response to these trends, the Air Force Research Laboratory (AFRL) and Aeronautical Systems Center (ASC) initiated the Immersive Display Evaluation and Assessment Study (IDEAS) in the summer of 2010. A long term goal of this program is to produce models and a decision support system (DSS) to facilitate:

(1) Rapid generation of defensible (i.e. training task driven) display system requirements
(2) Source selection decisions based on credible and achievable design approaches
(3) Planning of new product offerings

Two primary benefits expected from this effort include, an increased probability that delivered systems will meet customer expectations and training needs, and a reduction in the arguments and delays caused by unachievable, inappropriate, or missing requirements. Development and validation of the models/data for the DSS began in the fall of 2010 and are described elsewhere. The present paper focuses on how the first computational model developed for the DSS could be used. A primary goal of this paper is to solicit input from stakeholders prior to and concurrently with the development of the DSS.

ABOUT THE AUTHORS

Dr. Charles J. Lloyd has 25 years of experience in display systems and applied vision research at such organizations as the Advanced Displays Group at Honeywell, Lighting Research Center, BARCO Projection Systems, and FlightSafety International. The research described in this paper was performed while Charles was Lead Scientist for the IDEAS program at the Air Force Research Laboratory (L-3 Communications). Charles is now president of Visual Performance LLC.

Mr. James D. Basinger has 40 years of service in visual simulation and training systems research, development and acquisition with the Air Force Human Resources Laboratory and Air Force Materiel Command Simulator Systems Program Office. Since retiring from government service, Mr. Basinger has consulted with several training systems companies and provides an acquisition-based focus to the IDEAS program.

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BACKGROUND

The past decade has seen significant churning in the display technologies employed in the simulation training industry. For more than two decades the cathode ray tube (CRT) projector had served the industry well. Over that time period, many successive refinements were made to this relatively stable technology. By 2000, industry consolidation had progressed to the point that most of projectors were sold by a few suppliers who were all critically dependent on a single source of projection lenses. In the meantime, digital light processor (DLP) and liquid crystal display (LCD) projectors had matured to the point of taking over the majority share of the conference and class room markets.

In anticipation of declining CRT projector utilization, several parties attempted to use transmissive LCD projectors during the 2002-2003 time frame. Unfortunately, the early adopters of this new technology were dissatisfied with performance and life cycle cost. While generally brighter than CRT projectors, the early LCD projectors had far less contrast and produced unacceptable image blurring and lightpoint dimming when images moved at velocities typical of simulation training scenarios.

By about 2004, two emerging display technologies (DLP rear projection TV and the large flat panel active-matrix LCD) matured and displaced the CRT in the home theater market. With the decline of the mass market for CRT projector tubes, came more supplier consolidation and increased prices for replacement CRTs. Over the course of the next few years, a major supplier sold their CRT projector business and the lens supplier announced the last time buy of CRT projection lenses. Soon after this announcement, two additional suppliers ceased production of their CRT projectors.

About mid-decade, suppliers began touting the advantages of a “newer” new technology, the liquid crystal on silicon (LCoS) projector. The LCoS technology promised significantly improved contrast, motion rendition, and life cycle cost. Early adopters found contrast was noticeably higher; however, motion rendition and life cycle cost were only mildly improved. Today, effective motion blur reduction techniques are available for LCoS projectors but the per-pixel cost remains relatively high.

Concurrently with the maturation of LCoS projectors have come significant improvements in the less expensive DLP technology. One significant advantage of the DLP design is that the optical coupling efficiency with light emitting diode (LED) sources is high enough to be practical. LED light sources offer the advantages of very long life, independent infra-red stimulation for night vision goggle (NVG) applications, and ease of dimming which allows for high sequential contrast. Multiple LED/DLP projectors have been introduced in the past three years and it appears this technology will provide stiff competition for the LCoS technology.

The significant turmoil in the projector technology arena has been accompanied by equally tumultuous events in the image generation industry. The emergence and rapid maturation of PC-based graphics processor units (GPUs) targeted at the mass gaming market led directly to the sudden failure of two giants in the graphics/image generator industry. The last five years have seen a wholesale migration to COTS GPUs and graphics boards. With this migration has come a significant reduction in the cost per pixel of IG hardware. Today, the cost of an IG pixel is a small fraction of the cost of a projector pixel, which increases the pressure to migrate to lower cost projectors.

With the near term prospects of stereoscopic, laser, and large flexible (wrap-around) organic LED (OLED) displays: we do not expect stability to return to the display technology arena for some time. For the foreseeable future, we must expect a rich variety of technologies to be developed and proposed for training display systems. Each technology will have different performance capabilities, limitations, and artifacts that are expected to affect training task performance. The challenge for the acquisitions community is to develop a technology-independent way of specifying the performance requirements for training display systems that will not stifle the development or application of new technologies.

Asymmetry, Regulation, and Experience

Each major supplier in the simulation training industry has at least a few engineers who spend much of their time evaluating and adapting their systems to the new technologies. In contrast, few within the acquisition community are afforded the time to engage in such intense study. This situation can work to the disadvantage of customers because they are dependent on suppliers for information and design guidance.

The military acquisition community is required to perform within a highly regulated process that typically takes about three years to acquire a new training device. This process is long enough that entire display technologies can come and go (i.e., transmissive LCD and diffractive/scanned laser) within the duration of a single acquisition cycle. This fact largely obviates the age old strategy of relying on experience with past systems to understand the capabilities and limitations of the next system. The rapid pace of change also reduces the utility of asking Users of existing systems for advice about the next system. The next system, to be fielded three years from now, is likely to be much different from a system that was certified a year or two ago.

The acquisition regulatory constraints, coupled with the rapid rate of technology change, support the need for a new set of performance requirements and verification methods, with accompanying decision support tools to establish such requirements based on training needs.

THE IDEAS PROGRAM

In late 2009, the AFRL and Aeronautical Systems Center (ASC) proposed and initiated Phase I of the Immersive Display Evaluation and Assessment Study (IDEAS) that was launched in the summer of 2010. Some of the long term goals of this program are to:

- Develop display system performance requirements for Air Force programs that are defensible on the basis of training task performance.
- Define metrics and methods of measuring display systems to assess conformance with the requirements.
- Define the requirements for a decision support system (DSS) that would provide stakeholders ready access to the requirements, metrics, and measurement procedures.
- Demonstrate the utility of the approach so that long term funding might be secured to sustain the extension and maintenance of the requirements and DSS.
- Monitor and facilitate the development of the DSS by a third party and feed the developer content to extend the system.

For the first phase of the IDEAS program, the scope was limited to fast jet training of daylight operations with an emphasis on the F-16 Mission Training Center (MTC). Discussions with fast jet SMEs resulted in selecting the aircraft visual identification task for the first modeling effort. Discussions with key Air Force acquisition professionals produced a list of display design parameters that were in need of development or rework. High on the list of priorities was the need for a requirement and metric that regulated the motion induced blurring that was a significant problem for display systems that did not incorporate some type of blur reduction.

We thus chose to focus our efforts on the effects of five variables that were expected to be the primary determinants of task performance with moving images on high resolution display systems. These five variables were: angular velocity of the image, pixel hold time, pixel pitch, display luminance, and display contrast.

A Model of Identification Range

During the fall of 2010, a model of the effects of these and related variables on aircraft identification range was prepared and initially tested using the data from the few evaluations that could be found in the literature. The model and initial validation are described in a recent IMAGE conference paper[2]. This paper was written to satisfy the scientist or engineer who wishes to understand how the model works.

Over the next few months, two laboratory evaluations were composed and conduced to collect a much larger set of data that could be used to validate and tune the model. Across these two evaluations, aircraft identification range was measured as a function of 420 combinations of the settings of five design variables: pixel hold time, angular velocity, pixel pitch, display system luminance, and display system contrast. These evaluations are summarized in a second IMAGE conference paper[3] and the details of the evaluations are provided in technical reports to be submitted to the Defense Technical Information Center[4,5]. These papers are intended to satisfy the human factors engineer who wants to understand how well the model describes pilot performance.

Figures 1 and 2 illustrate the form of the model using surface plots. The correlation between the mean observer data and the model was very good producing an $R^2 = 0.97$ for the first evaluation and $R^2 = 0.91$ for the second. The figures show the mean performance of the ten experienced pilots who participated in the evaluations.

In the the present paper, the model is assumed to be a good representation of pilot performance. The primary purpose of this paper is to illustrate how this type of multi-dimensional model can be used by stakeholders.

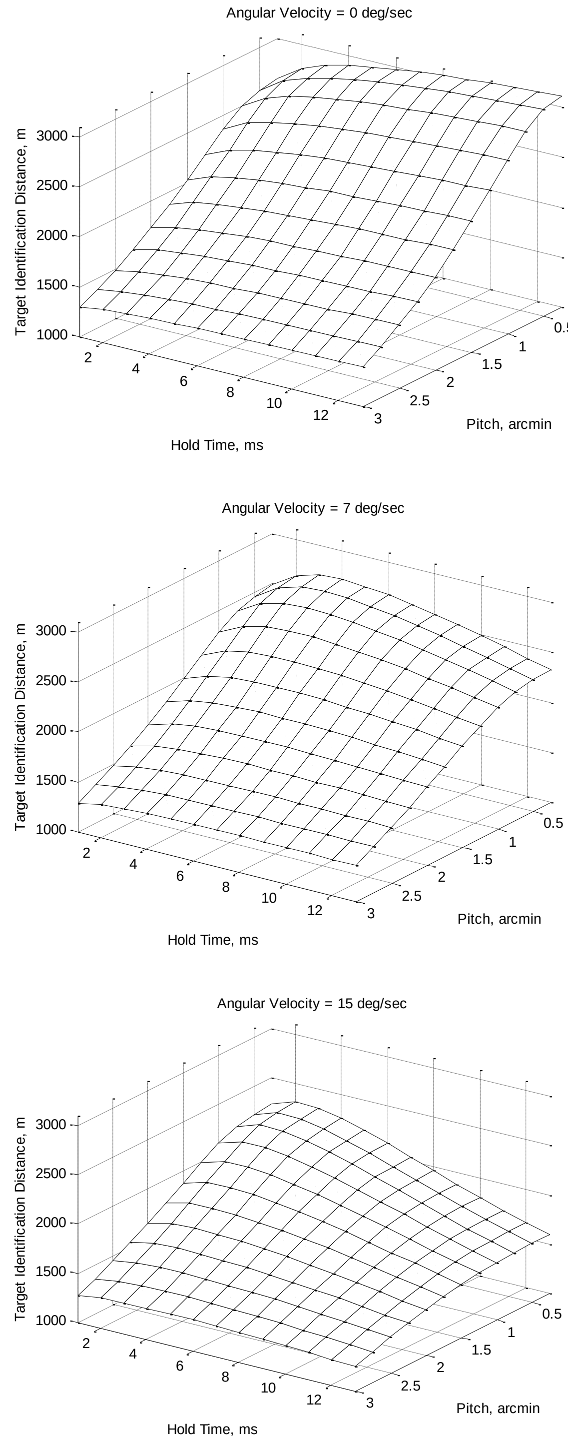

Figure 1. Threshold target identification range for fighter-sized aircraft as a function of Pitch and Hold time for three levels of target Velocity. For this plot, display luminance was 30 fL and display system contrast ratio was 20:1.

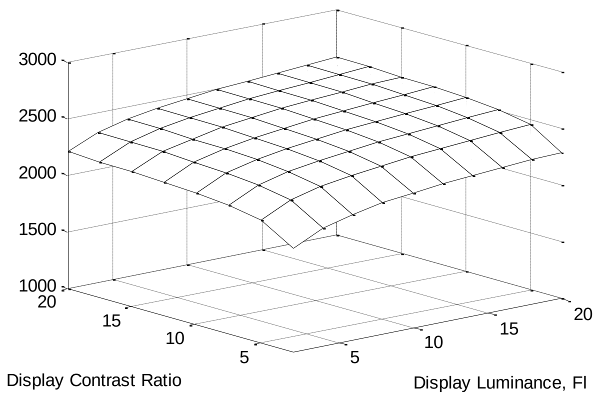

Figure 2. Aircraft identification range as a function of display Luminance and Contrast Ratio for a Display Pitch = 1 arcmin, Hold time = 8 ms, Velocity = 5 deg/sec, and target background at 85% of the peak display luminance.

MODEL USE CASES

The model described in our previous paper[2] was implemented as a set of software functions that compute expected identification distance as a function of 11 input parameters. These parameters are conceptually divided into two distinct categories; attributes of the training task and observer and, attributes of the display system design. These categories clearly delineate the roles of the stakeholders: customers are responsible for the task and observer parameters which become requirements; suppliers are responsible for the display design parameters which become specifications.

Task and Observer Parameters

- **Identification Range:** Range at which the identification must be made.
- **Target Size:** The real-world size of the target. For example, the "typical" dimension (wingspan) of a fighter-sized aircraft is 11 m.
- **Angular Velocity:** Angular velocity of the target (image) at the time the identification must be made. For typical identification ranges (e.g. 2 to 3 km), most of the target/image movement is caused by roll and pitch movements of the ownship.
- **Target Contrast:** The real world contrast of the target against its immediate background. In this model, the target contrast is not the same as the display system contrast.
- **Target Luminance Ratio:** The ratio of target luminance over the peak luminance of the scene. This parameter is used to compute the reduction in target contrast caused by washout luminance.
- **Observer Capability:** This parameter allows the model to account for the large differences between observers in the range at which they identified targets.

Display System Design Parameters

- **Pixel Hold Time:** The duration of time a pixel is illuminated and held at the commanded state during each frame.
- **Resolution:** Conveyed to this model using the modulation transfer function (MTF) as measured from the eyepoint. The MTF accounts for a number of design factors including pixel shape, optical blur, mis-convergence, scattered light, and anti-aliasing.
- **Sampling Rate (pitch):** The angular sampling rate of the display system (deg/pixel) which accounts for the viewing distance for direct view displays and the display optics in collimated systems.
- **Display Luminance:** Peak luminance of the display system, includes the washout light due to scattering within the display system.
- **Washout Luminance:** Scattered light within the system that is the primary determinant of the system contrast.
- **Noise:** Pixel-level noise produced by the display system. Examples include video amplifier noise and laser speckle.

Given a model of 12 parameters, there are literally hundreds of ways to plot the model to examine its behavior. In the previous figures, the model was plotted in two ways expected to be useful to our stakeholders. In subsequent figures, several alternate views of the same model are provided. Soon after the construction of this model, we realized that the most appropriate way of plotting the model is highly dependent on the design question. Only a few of the many potential ways to look at the model can be presented in this paper. It is clear that a DSS that incorporates multi-dimensional models of this type should allow users to select those combinations of parameters that best suit their needs.

STAKEHOLDER PERSPECTIVES

This section illustrates how a multi-dimensional requirements model of this type might be used by three distinct parties, at three phases of a display system acquisition.

Requirements Development

We envision the process of generating display system requirements beginning with the acquisition engineer meeting with SMEs to estimate the levels of the six parameters that describe the task and observer. For our example training task, the SMEs determine that pilots must identify aircraft with an 11 m wingspan from a distance of 3 km while maneuvering their aircraft at angular velocities as high as 20 deg/sec. They also estimate that the targets will be seen as dark against a bright overcast sky and will have a contrast of 2:1. Finally, they determine the display system should be designed for the average pilot.

The next step in the proposed process is to examine the effects of the display design variables to determine the design goal. A practical way to begin this process is to set these six parameters to typical levels and then to vary each parameter one at a time to determine how much each affects performance. For our example, this "sensitivity analysis" revealed two of the parameters, pixel hold time and sampling rate (pitch), clearly have the largest effects on performance. The effects of these parameters are plotted above in Figure 1. The analysis also revealed that the noise parameter would have no practical effect as long as modern digital light valve projectors and digital video cables were used.

Manipulation of the display luminance and contrast parameters revealed these variables are important; however, their effects on performance are relatively small as long as both luminance and contrast remain above about 8 (see Figure 2 above).

Back in the days of CRT projection systems, the MTF (spot size) and the sampling rate (pixel and line rates) of the display system could be independently manipulated, thus, our model keeps these parameters separated. With most modern digital projectors that are well converged and have good quality lenses, the MTF (scaled in cycles/pixel) does not vary greatly from projector to projector as the MTF is primarily determined by the anti-aliasing function in the IG and/or the production of spatial sampling artifacts. In other words, the parameter "sampling rate" has a much larger effect on performance than does the MTF for modern projectors.

Strategy A

An obvious strategy the acquisition engineer could employ for establishing requirements would be to continue manipulating the display design parameters to find some combination of parameter settings that produced the required identification range. These display parameter settings could then become the requirements for the display system. We do not recommend this strategy, since it will unnecessarily over-constrain the design of the system. In the general case, there are likely to be many combinations of the display parameter settings that will achieve the desired goal. If the customer were to fix down the display design parameters, they run the risk of unintentionally driving up cost or unknowingly disallowing some new technology option.

Preferred Strategy

A more effective strategy for the determination of requirements would be for the engineers and SMEs to exercise the display design parameters for the purpose of validating that their design goals (the task and observer parameters) are in the range of the capability of practical display designs. Once they decide that their goals are achievable, these task and observer parameter settings become the display system requirements. The suppliers are then given the same model that was used by the customer and they are free to use any combination of the display design parameter settings that produce the desired ID range.

Through exercising the model, the acquisition engineers and SMEs will occasionally find that they have to reduce selected goals, such as ID range or angular velocity, as these cannot be achieved with any practical display system. One of the most significant benefits expected of the recommended approach is that it forces the debate of what is possible and practical to occur prior to initiating the acquisition process. Also, it forces this debate to occur between the appropriate people: the SMEs and engineers on the *customer* side. We suspect that it is far more expensive to discover unrealistic requirements after the acquisition process begins since this introduces conflict between customers and suppliers. Suppliers are typically hesitant to reveal unrealistic requirements until after they have won the contract. Thus, the burden of vetting the requirements is on the customer side.

Source Selection

The proposed modeling approach offers the potential of significantly decreasing the complexity of source selection decisions. For example, assume an RFP levied the following requirements for a display system:

- Identification range >= 1.6 km
- Fighter sized aircraft, wingspan = 11 m
- Maneuvering rate = 20 deg/sec
- Dark targets against sky, CR = 5
- 50^{th} percentile pilot capability

Assume vendor ABC submitted a proposal offering a display system with the following specifications:

- Pixel pitch = 1.8 arcmin
- Pixel hold time = 11 ms
- Peak display luminance = 9 fL
- Display system contrast = 7.

Assume supplier XYZ offers a display system with the following specifications:

- Pixel pitch = 2.2 arcmin
- Pixel hold time = 7 ms
- Peak display luminance = 12 fL
- Display system contrast = 11.

This example illustrates a fundamental reason source selection decisions are difficult. In general, the requirements cannot be compared directly with the specifications. Requirements describe tasks and their attributes whereas specifications describe hardware devices and software components. Typically, the customer cannot be confident that either of these display systems will meet the requirements without building the systems and verifying if users can perform the task. Previously, when the rate of change of the display technology was slower, seasoned professionals could draw on their experience to make reasonable judgments of the impact of display parameters on task performance. Today's rapid change in display technology renders this strategy ineffective because no one has experience with the new designs, not even the suppliers.

A second reason source selection decisions are difficult is that specifications are multidimensional. How would you know if the ABC system is better or worse than the XYZ system unless you had some way to quantify the relative effects and interactions of these four display parameters?

With the proposed approach for supporting source selection decisions, both the display requirements and specifications would be placed into the model and the expected ID range computed. For supplier ABC the expected range is 1360 m and for supplier XYZ the expected range is 1508 m. This analysis indicates that neither offering quite meets the requirement; however, task performance would be noticeably better for the XYZ system.

Product Planning

From the point of view of suppliers, our approach is expected to be useful because it provides a clear and quantitative indication of what the customer needs over the long term. With this information, suppliers can better plan their display system developments and reduce the financial risk of investing in new product developments prior to selling them.

Assume supplier QRS has a display system designed for fast jet applications that has the following specifications:

- Pixel pitch = 2.0 arcmin
- Pixel hold time = 8 ms
- Peak display luminance = 8 fL
- Display system contrast = 8

Suppose that the product manager wanted to steer the engineering department along a path that will improve the value of the product for fast jet applications. To determine the best direction for the design, the planner would start by computing the expected performance necessary for a representative training task such as ID range. Assuming the task and observer requirements described above, the expected ID range for the baseline display system is 1481 m. From this baseline condition a sensitivity analysis of the design variables reveals the following:

- Add 27 m per 0.1 arcmin reduction in pitch
- Add 49 m per ms reduction in hold time
- Add 8 m per 1 fL increase in luminance
- Add 4 m for increasing CR from 8 to 9

Next, the supplier would estimate of the cost of improving the design along each of these dimensions. We suspect the supplier would quickly determine that the cost of reducing hold time is much lower than the cost of changing the other variables. Thus, it is clear the highest benefit/cost is produced by reducing hold time. Note, that the model has already taken into account the expected reduction in luminance that is produced by reducing hold time.

Maximizing Value/Cost

For both customers and suppliers, important insights are revealed when the model of task performance is coupled with models of relative cost. A simple but useful model of relative cost characterizes the effect of pixel pitch. Figure 3 illustrates how the cost of a simulation trainer increases as pitch is decreased. In this model, the number of projectors, IG channels, cables, and racks increases with the inverse square of pitch and these components account for 15% of the cost of the trainer. The cost model is normalized to 1 for a pitch of 2.25 arcmin which is about the average pitch of trainers delivered over the past few years. The model assumes typical projector and component prices of the past few years.

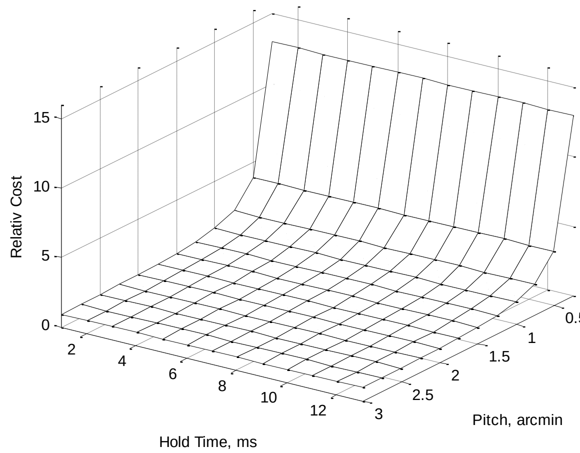

Figure 3. Relative cost of training device. Assumes projectors, IG channels, cables, and racks are 15% of the cost of the trainer for a pixel pitch of 2.25 arcmin.

From the model, reducing the pixel pitch below about 1 arcmin has a very strong effect on total cost. Thus, a customer would not likely request a pitch that fine. Recall, however, that the acquisition cycle is about 3 years in duration and that the cost of both display and image generator pixels is continuing to drop rapidly. Rather than use the average costs (of the past few years) for the display components, we might use the costs expected at the time we deliver our next generation display design. Figure 4 shows the cost model computed using component costs that are 25% of the cost of the previous model.

From Figure 4, the total cost of the trainer is increased about 20% when pixel pitch is reduced to 0.75 arcmin. Reducing the pitch to 0.5 arcmin increases the cost by almost 50%. From Figure 1, reducing the pitch from 0.75 to 0.5 arcmin increases identification distance by only a few percent. Thus, it would not seem to be worth the significant increase in cost.

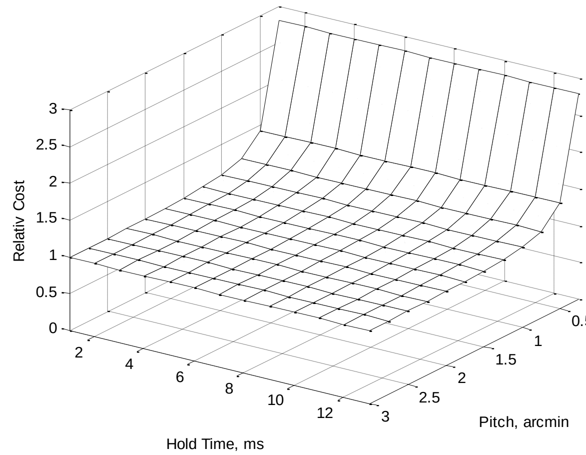

Figure 4. Relative cost of training device. Assumes projectors, IG channels, cables, and racks are 4% of the cost of the trainer for a pixel pitch of 2.25 arcmin.

By combining the performance and cost models, assessments of this type can be made more directly. One simple way to combine the functions is to simply divide the expected ID range by the relative cost model as shown in Figure 5. From the figure, we might conclude the pixel pitch should be set at about 1.25 arcmin for price sensitive customers and as fine as 0.75 for performance minded customers.

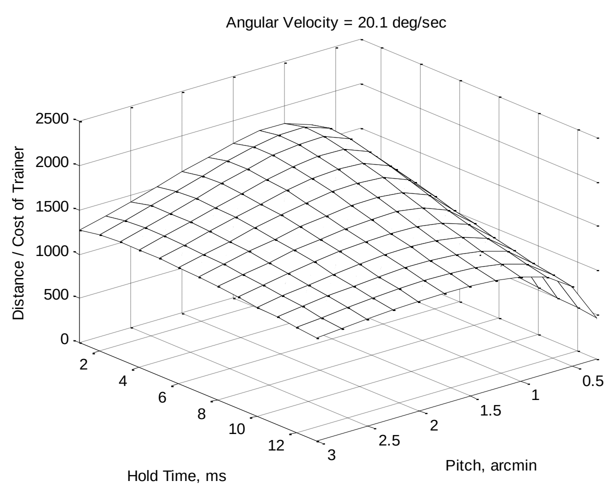

Figure 5. One method for illustrating the benefit/cost ratio for supporting design trades. Surface shows the expected ID range divided by the relative cost model.

SUMMARY AND CONCLUSIONS

- The time line of significant changes in display technology is now so short that it is comparable with the duration of a single training system acquisition. Thus, the ability of the acquisition community to benefit from their experiences with previous systems is diminished.
- Few in the acquisition community are afforded the time to study and maintain current knowledge of emerging technologies. Thus, there is an unavoidable lag in understanding that penalizes the customer in negotiations with suppliers.
- Prior to the IDEAS program, there was no apparent substantial or systematic effort to update or develop defensible requirements on either the customer side or supplier side.
- Significant schedule delays and cost overruns can be generated by the issuance of unachievable or inappropriate requirements, or by failing to consider and account for key attributes of new display technologies.
- Using the proposed model and the customer-defined settings of the task and observer parameters, a more precise description of the requirements can be conveyed to suppliers without over constraining the design.
- The approach potentially simplifies source selection decisions by quantifying the expected performance of candidate display designs that differ across multiple dimensions.
- Providing the model to suppliers will convey what customers are likely to want in future programs. This will allow suppliers to maximize the value of internally funded product developments.

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- James Gaska, L-3 Communications

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