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APPROACHES TO AIR TRAFFIC CONTROL/AIR DEFENSE WORKSTATION SIMULATION AND TRAINING (CATEGORY: TECHNICAL)

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ABSTRACT

A commonly desired approach to supporting air traffic control (ATC)/air defense (AD) embedded training and simulation activities is to provide the equivalent of a fielded system with additional hardware and software to support scenario generation and target generation functions. The problem with this approach is that the ATC/AD workstations are costly subsystems and, during the later stages of the systems life cycle, organizations attempt to meet increasing training needs with low cost solutions that are not equivalent to the fielded systems. Further, the training and simulation requirements of the organization tend to merge and simulators used for system upgrades and system studies are tasked with also providing training services.

This paper presents two contrasting approaches to providing generic ATC/AD training and simulation workstations. The first approach was implemented by the FAA at the FAA Technical Center in the early 1980's using workstations with removable bezels and shelves. This was a hardware intensive approach with custom software to duplicate the existing En Route and Terminal Radar Approach Control (TRACON) ATC consoles. The second approach is based on current technology using Reduced Instruction Set Computer (RISC) workstations, Rapid Prototyping MMI Software, and variable function keys (buttons) on the monitor(s) to simulate the "knobology" of target workstations. Both systems are contrasted from cost, complexity, and operational efficiency points of view.

BACKGROUND

The traditional ATC/AD workstation has been a combination of mechanical packaging and computer controlled display and entry devices (figure 1). The mechanical packaging has included overhead backlit maps of airspace, devices to house paper flight strips, and provisions for supporting voice communications panels. The computer controlled display and entry devices have provided a picture of the air situation, which includes tracks, various maps (geographic, air routes, sectors, etc.), tabular displays, and control of the air situation display. The control of the air situation display has included display filters for information "decluttering" and system input such as track handoff. Each system has varied in the characteristics of these two basic elements: mechanical packaging and computer control.

The current FAA En Route and TRACON centers are good examples of how the ATC workstations vary. The primary mission of each system is the same, to provide safe and efficient air traffic control services. However, as the system evolved, different

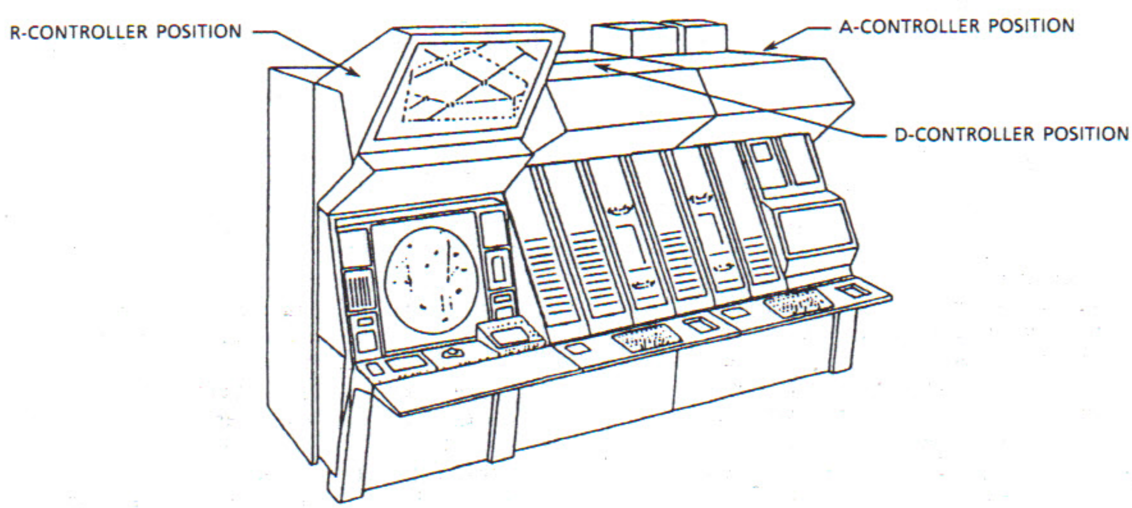

Figure 1. En Route ATC Sector Suite Workstation

technologies were applied to the En Route and TRACON workstations. With the current Advanced Automation System (AAS) program the goal is to provide the same basic workstation for En Route and TRACON operations.

In the current US ATC system, air traffic controller training has taken these system characteristics into account. An air traffic controller's training begins with classroom instruction, moves to hands-on simulation training at the FAA's national training facility in Oklahoma City, and continues with hands-on training at an operational site using site simulation/training capabilities and on-the-job exposure. The first time an air traffic controller "sees and feels" the actual operational equipment is at the site. This situation is further complicated in that the FAA Technical Center may be called upon to support training such as during the controllers' strike during the early 1980's.

The FAA Technical Center is responsible for test, evaluation, and support of all systems, including the En Route and TRACON facilities. To support the En Route and TRACON facilities, the FAA Technical Center houses two groups of laboratories. The first group of laboratories is the National System Support Facility (NSSF) formerly the Air Traffic Control Simulation Facility (ATCSF) and it is responsible for "Test and Evaluation" of "Advanced ATC Concepts." The second group of laboratory facilities is the En Route and TRACON support facilities which are responsible for maintenance of the fielded systems. These labs prioritize study, training, and field maintenance activities based on their primary missions.

EMULATION AND TRAINING CONSOLE APPROACH

Hardware Emulation Approach - Hardware Defined Removable Bezels and Shelves

In the late 1970's the FAA was looking to upgrade the ATCSF. All these background issues and system characteristics were present and impacted the upgrade approach. The old ATCSF consisted of displays that did not match either En Route or TRACON workstations. One of the goals of the upgrade was to provide workstations in the ATCSF that "looked and felt" like En Route and TRACON displays. It was believed that the ATCSF could then produce more meaningful emulations for system human factor studies and "occasional" training activities.

To use the actual field equipment in the ATCSF was cost prohibitive. Technology had progressed since the introduction of the fielded En Route/TRACON displays and a lower cost alternative was available. The approach was to use the Sanders Graphic 7 stroke display processor driving a 20" round beam penetration (4 color) CRT and removable bezels and shelves that would interface to the Graphic 7 internal PDP 11/04. These bezels and shelves were manufactured to look and feel like En Route and TRACON bezels and shelves (figure 2). They used the actual parts from the En Route and TRACON radar display position. The panel switches fed a custom switch scanner and the "Pots" (variable resistor controls) fed a custom Pot scanner. The trackballs were even mechanically modified to provide the feel of either an En Route or TRACON trackball. The En Route trackball sat on a bearing assembly and "rolled" with the swing of the hand while the TRACON trackball sat on a pedestal and stopped instantly without hand movement.

The surface area for the TRACON trackball was even reduced with the use of a cover plate to match the surface area of the fielded trackballs. Attaching an En Route bezel and shelf would activate En Route software in the console and the console would then emulate the En Route radar position. Attaching a TRACON bezel and shelf would activate TRACON software and the console would emulate a TRACON radar display. Attaching an R&D bezel and shelf would activate R&D software in the console and emulate the next generation ATC console.

There are several advantages to the generic console implemention using the removable bezels and shelves. The first is that the console's physical configuration can be emulated as opposed to simulated and the emulation can be accomplished with flexible software and low cost bezels and shelves. This would permit the operators in training to not only become proficient in the functions of the console but also imprint the physical characteristics of the console on the operators such as tactile feedback, reach, and field of view. This was an excellent solution for satisfying some of the goals of the ATCSF. Both En Route and TRACON radar position consoles were emulated and studies of new man machine interfaces (MMI) could be supported with the introduction of other bezels and shelves.

At the time some of us at the FAA believed we were developing a prototype for the technology to be used in the next generation ATC workstations. On-the-fly text generators replaced monoscopes. Computer control replaced mechanical controls such as brightness. Beam penetration CRT's would provide color. However, while supporting the Hughes DCP AAS program, we clearly saw that the next generation ATC console would be based on technologies with different foundations. High resolution 20" × 20" 2048 × 2048 raster color would replace stroke technology. Programmable variable and fixed CRT displayed function keys would replace switch panels and other mechanical devices.

SIMULATION AND TRAINING CONSOLE APPROACH

Software Simulation Approach - Software Defined

Figure 3 is an example of an ATC/AD workstation based on a commercial Reduced Instruction Set Computer (RISC) hardware and a software package that supports MMI implementation using rapid development/rapid prototyping tools. The switch panels of the previous generation ATC/AD workstation have been replaced with fixed and variable function keys displayed on the CRT. These keys could just as easily be implemented as picture representations of knobs and toggle switches. The mouse or trackball is used to control any of these CRT displayed switch panels, knobs, toggle switches,

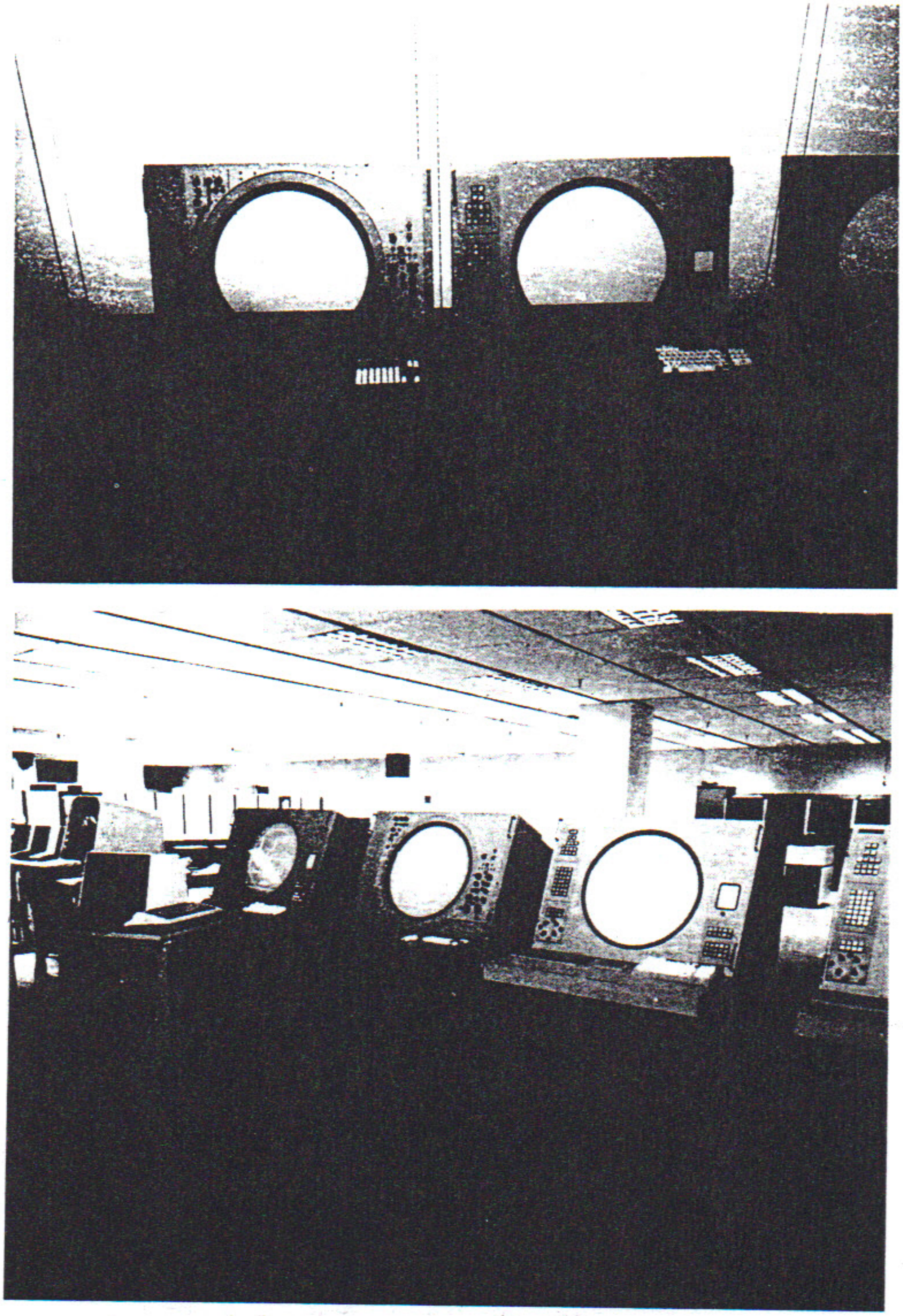

Figure 2. En Route and TRACON Bezels and Shelves

or other operator entry devices. The switch panels and windows on the situation display are always placed such that the situation display will not be covered with lower priority data. The main menu area calls up different switch panels such as Category Select and Feature Select. When a button is activated, it is highlighted and the appropriate function is performed. Tracks can be hooked with either the keyboard or the mouse.

The main menu bar is used to select the "virtual" panels, switches, and knobs found on the actual operational console. In this example, the main menu supports 12 buttons that are approximately .75" square. A main menu bar button supports 3 rows of 5 characters each to define its function. The submenus contain 6 columns × 9 rows of buttons for a total of 54 buttons. The submenus measure 2.75" × 4.75". The intent was to use 56 pixels in the horizontal direction of the 1280 × 1024 resolution display to provide a situation area of approximately 1024 × 1024 pixels. The current colors of the menu areas are two shades of blue with black text. When a "button" is selected, it turns green to show activation. The following submenus are provided as an example of an Air Defense workstation:

Category Select – Filters static areas on the display and filters broad categories of track data.

Feature Select – Filters data blocks shown on the display and filters tracks based on speed and altitude.

Range Scale – Provides traditional range scales and nontraditional features which permit the selection of predefined centers and range scales based on console defaults and air base locations.

Track Control – Provides the ability to initiate tracks, assign tracks, drop tracks, and create manual tracks.

Pilot Control – Used in simulation and allows the simulation pilot operator to control up to 10 airplanes.

Console Control – Permits the operator to create special areas, print tabular or situation data, and set the local time of day.

DQM Control – Permits various radar data to be filtered from the Data Quality Monitor (DQM) display, and provides various system management functions such as setting the system time.

This type of trainer can be developed a number of different ways. If specifications on the original system are available, those specifications can be used as the foundation for describing the trainer's MMI. E-Systems developed three separate MMI's using a storyboard method. In this approach all the keyboard entries, menu's, submenu's, and display results are shown on a standalone piece of paper. Many of the functions are well understood. Little explanation was required behind the underlying function of a "button" on the display and the resulting display symbology and text. If the underlying functions are new or complex, the appropriate paragraph numbers can be referenced in the original system specifications. This was not required when E-Systems developed the three separate MMI's (over-the-horizon surveillance, missile warning, and long-range radar air space management).

The primary advantage to this training workstation approach is the fast turnaround time for being able to simulate any ATC/AD workstation. On each occasion, E-Systems has been able to implement complex "air" surveillance MMI's in less than two months. An internal target simulation capability can provide the scenario to support various levels of training. This, coupled with the relatively low cost commercial work-station hardware, can provide a desktop trainer that can support all the functionality of any ATC/AD work-station. The limitation to this

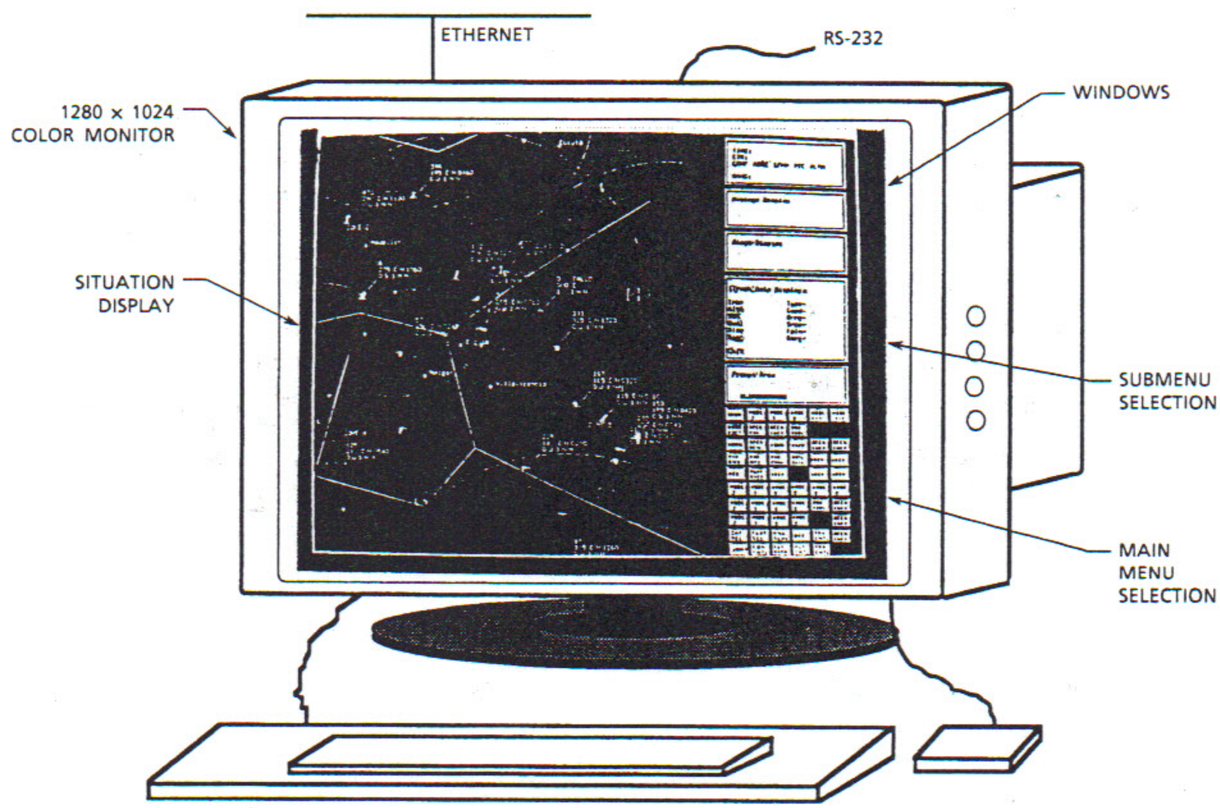

Figure 3. ATC/AD Workstation

approach is the ability to emulate the physical characteristics of the workstation such as the tactile feedback, reach, and field of view.

This CRT based trainer workstation taps into several current trends. The first trend is towards workstations based on fixed and variable CRT displayed function keys such as in the case of the Advanced Automation System (AAS) sector suite. The second trend is in the growing automation of commercial tasks. Many current commercial graphics applications requirements outstrip traditional ATC/AD graphics requirements. This was not the case only a few years ago. Today any RISC based workstation can perform a range scale and offset faster than any custom AT/AD workstation of the past. The final trend is in the area of software tools and standards. With the use of a software tool, hundreds of thousands of lines of code are bypassed with 10,000–20,000 lines of data definitions. The power of such a tool can be used for such actions as changing how the track data is hooked and where hooked data is displayed. Such modifications require only the change of data definitions which are used to define the look and feel of the display. These data definitions control track symbology, track content, display lists, display maps, and even functions such as intercept calculations.

Further, housing a software tool on standards such as UNIX, X-Windows, and GKS permits the MMI design to be vendor independent. This vendor independence was shown at E-Systems when the same MMI design was hosted on a Tektronics XD88/11 (discontinued), SUN SPARC2, DEC 5000, and DEC 3100. The changing platforms were the results of hardware availability. This vendor independence will permit the lab to "float" with commercial technology which will allow for graceful upgrades to the training lab environment.

HARDWARE EMULATION APPROACH VS. SOFTWARE SIMULATION APPROACH COST

Figure 4 contains a cost trade-off between the bezel/shelf approach and the software CRT based approach. There are three cost drivers when implementing a hardware based emulation of the bezels and shelves of an ATC/AD workstation.

The first cost driver is the display monitor and its associated graphics generator. Many complex ATC/AD workstations such as the AAS sector suite are based on the Sony 20" × 20" 2048 × 2048 monitor. This is still a costly hardware item (figure 4, item 2). Switching to a more common monitor with smaller diameter and lower resolution (1280 × 1024) will significantly reduce costs ($75,000). For example, there is only a small difference in cost between a 19" diagonal monitor and a 23" – 25" diagonal monitor (~$5,000).

The second cost driver is the console enclosure itself. While supporting two program pursuits, E-Systems found that depending on the complexity of the console enclosure, the costs can range from $3,000 to $9,000. This cost is further increased if custom bezels and shelves are manufactured which use the actual switch panels in the fielded configuration. This cost includes the ordering and tracking of the parts and the development of a switch and "pot" scanner. The ordering and tracking of the actual panels with piece parts is no trivial task and required an automated inventory control program at the FAA

Cost Items	Hardware Emulation			Software Simulation		
	Man Mon	Eng ($50/Hr)	Purchase Cost	Man Mon	Eng ($50/Hr)	Purchase Cost
HARDWARE						
1. Commercial workstation hardware such as SUN SPARC2			$18,000			$18,000
2. Display (20" × 20" in OPS environment 19" trainer)			$75,000			$0
3. One console enclosure			$6,000			$0
4. Non-recurring engineering for bezels and shelves	6	48,000	$1,000	0	0	$0
SOFTWARE						
5. MMI design	0	0		1	8,000	$0
6. MMI implementation with prototyping tool	0	0		3	24,000	$0
7. MMI implementation in software code such as "C"	96	768,000		1	8,000	$0
8. Software licenses/display	0	0		0	0	$20,000
TOTALS – Quantity 1	**102**	**$816,000**	**$100,000**	**5**	**$40,000**	**$38,000**
TOTALS – Quantity 10	**102**	**$816,000**	**$1,000,000**	**5**	**$40,000**	**$380,000**
TOTALS – Quantity 20 (Site software licenses)	**102**	**$816,000**	**$2,000,000**	**5**	**$40,000**	**$560,000**
Ratio of hardware emulation to software simulation training platforms (Qty 1)					**11**	
Ratio of hardware emulation to software simulation training platforms (Qty 10)					**4**	
Ratio of hardware emulation to software simulation training platforms (Qty 20)					**4**	

Figure 4. Cost Differences Between Hardware Emulation and Software Simulation Approaches

Technical Center for the ATCSF upgrade (this program was developed in BASIC on a Wang processor).

The third and largest cost driver is the approach for implementing the actual MMI design. If actual field software is selected, then actual field display hardware is required to support the training workstation. This hardware tends to be extremely expensive even if it is available. If there is an attempt to try to recode the display software on less costly hardware, then the non-recurring engineering costs are extremely high. Some organizations have concluded that the cost of developing the MMI using traditional software design and coding techniques can exceed 8 to 10 times the cost of using a prototyping tool such as InterMAPhics. E-Systems' internal experience has provided similar results.

However, this third cost driver could be eliminated with either approach if a rapid development/rapid prototyping software tool is selected.

COMPLEXITY

Figure 5 contains E-Systems' view of a complexity trade-off between the bezel/shelf approach and the software CRT based approach. There are three primary drivers in separating the complexity of these two approaches.

The first complexity driver is scheduling of training resources and executing the training session. In the hardware emulation approach, the laboratory resources are either idle or several users want access to the lab at the same time. This feast or famine characteristic in the lab leads to schedule conflicts and frustrated users, some of whom may have nothing to do with the training mission. This is a characteristic that plagues all valuable centralized resources. In addition, elements to establish a scenario are complex and include many personnel. For example, trying to emulate the actual operational floor requires voice communications and pilots on the other end flying airplanes in parallel with a predefined scenario. In the ATCSF and currently in the NSSF (reference 5), these pilots are seated at alphanumeric terminals and change the 12 or so airplanes they are "flying" based on voice communicated clearances from ATC controllers. Coordinating and running the script is no trivial task when the elements not only include the trainees but also other people in the loop to support the simulation of the actual system operations.

The second complexity driver is maintenance. With an attempt to emulate the operational floor of a fielded system, many other computer based components and subsystems are introduced. These can include trivial devices such as printers, to complex devices such as voice communications panels, or peripherally related items such as maintenance workstations. These components all form the lab and require maintenance to ensure proper operation of the training facility.

The third and perhaps most important complexity driver is the ability to change the training environment. All systems evolve, especially complex systems such as air traffic control or air defense. The training environments need to be able to support these systems no matter what the growth direction. The growth characteristics of two separate systems are never alike. The trainer must be more flexible than the operational environment to support a wider growth capability. Trying to emulate a fielded system with lower cost highly specialized hardware and software will most probably lead to less growth capability than the actual fielded system.

System Elements	Hardware Emulation	Software Simulation	Comments
1. MMI software in traditional code, such as "C"	1	N/A	The hardware emulation approach will probably be based on obsolete hardware
2. MMI implementation using prototyping tool	4	4	None
3. Scheduling of training resources	1	4	Anyone can "fire up" a standard desktop workstation
4. Executing training session	1	3 to 4	4 – Desktop setting, 3 – lab setting
5. Maintaining training laboratory	1	3	The software emulation approach is based on commercial products and less subsystems
6. Developing training scenarios	2	3 to 4	4 – Desktop setting, 3 – lab setting
7. Concurrency (Ability to change with operational environment changes)	1	4	The software emulation approach uses commercial hardware and commercial rapid prototyping software

4 – Very simple
3 – Simple
2 – Complex
1 – Very Complex

Figure 5. Complexity of Hardware Emulation and Software Simulation Approaches

In summary, the most significant issue is that the hardware emulation approach tries to emulate the operational floor, whereas the software simulation approach emulates the workstation functionality and simulates the interactions of the operational floor when desired. This is a significant difference and translates into a more manageable and more flexible training environment in the software simulation approach.

OPERATIONAL EFFICIENCY

Figure 6 contains E-Systems' view of an operational efficiency trade-off between the bezel/shelf approach and the software CRT based approach. There are three areas that are primary drivers in separating the operational efficiency of these two approaches.

The first operational efficiency driver is control room operations. The hardware emulation is the most effective approach for duplicating the operational floor. The software simulation approach can be configured in a laboratory setting with participants taking on the role of controller and pilot, but then the lab starts to take on some of the characteristics of the hardware emulation approach, especially from a complexity point of view as previously discussed. However, if the intent is to provide a training facility for a program such as AAS, which is using CRT displayed variable and fixed function keys, then the hardware emulation approach does not even apply.

The second operational efficiency driver is the ability to support multiple environments. Since the software simulation approach emulates only the functionality of a field workstation and it can be easily modified using a commercially available rapid development tool/rapid prototyping tool, it can easily be modified to support multiple environments. In the case of ATC, the current En Route workstations, TRACON workstations, Tower workstations, and the AAS workstations can be easily simulated with the functionality fully emulated.

The third operational efficiency driver is the availability of the trainers. Because of relatively small size and low cost, the software simulation approach trainers can be provided on the desktop, in a laboratory setting, or both. In a desktop application, the student or instructor can start, stop, or select a different scenario at will without impacting other students. This is enormous flexibility and permits the students to learn at their pace.

In summary, the primary difference between the two approaches is that the software simulation approach gives up the capability to physically emulate a workstation and the resulting operational floor for a trainer that is more available and tailored to the

Operational Efficiency	Hardware Emulation	Software Simulation	Comments
1. Console functions	4	4	None
2. Control room interactions	4	3	A lab is still possible with Software Simulation
3. Display surface (location of various items)	4	3	The hardware emulation approach may not even apply if system is based on CRT control
4. Field of view and reach	4	1	The hardware emulation approach may not even apply if system is based on CRT control
5. Tactile feedback	4	2	The hardware emulation approach may not even apply if system is based on CRT control
6. Operator response time performance	4	3	Reach is probably not a factor
7. Availability of training platforms/SIM facility	2	4	Lower cost means more platforms
8. Single operator dedicated trainer environment	1	4	Desktop possible
9. Student training time	2	4	Lower cost means more platforms
10. Student tailored lessons	1	4	Desktop environments
11. Ability to support multiple OPS environments (En Route, TRACON, Tower, etc.)	1	4	Provided by commercial rapid prototyping tool and commercial hardware

4 – Excellent
3 – Good
2 – Poor
1 – No Capability

Figure 6. Operational Efficiency Training Trade-off Between Hardware Emulation and Software Simulation Approaches

actual students. This is analogous to trading in the old batch computer room operations for the new interactive computer network with a terminal and now a PC in every office. Turnaround time is reduced, more flexible services are provided, and the resources are more accessible. The training lab is no longer providing system support or system study services.

CONCLUSIONS

The advantages and disadvantages of these two approaches are summarized in figure 7. The primary characteristic of the hardware emulation approach is that a traditional laboratory will be established where all the training displays are collocated in one facility that will duplicate the actual field environment. The primary characteristic of the software simulation approach is portability and low cost which can be used to establish relatively large numbers of desktop trainers.

History has shown that due to every day operations and cost constraints, traditional training labs have a difficult time of supporting even the functionality of ATC/AD workstations. With the use of software based CRT bezels and shelves, a RISC workstation, and a software tool, the functionality of the ATC/AD training workstation can be provided in a CRT based workstation. Further, the resulting low cost can provide up to four times more training time than with a training lab that attempts to emulate a field operational facility. In either approach, the development of the trainee's perception of the look and feel of the environment will be provided when the trainee arrives at the actual operational facility with its "unique" look and feel based on its particular operational characteristics.

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Mr. Sobkiw was formerly at the FAA Technical Center where he supported the upgrade of the Air Traffic Control Simulation Facility (ATCSF) and was responsible for the development of the generic En Route and TRACON workstations in that lab. Mr. Sobkiw holds a bachelor's degree in Electrical Engineering from Drexel University and is a member of IEEE, AFCEA, and ATCA.

Approach	Advantages	Disadvantages
Hardware Emulation	• Emulates real workstation • Provides same tactile feedback • Provides same operator field of view • Forces the same operator movement	• High cost • Specifically tailored to one system • No longer applicable to many next generation systems • Limited student availability
Software Simulation	• Low cost • Potential dedicated trainer for each student • Emulates functionality • Emulates physical characteristics of new generation workstations • Can support training for various systems and versions of systems	• Simulates not emulates physical characteristics of older workstations

Figure 7. Summary of Advantages and Disadvantages of Hardware Emulation and Software Simulation Approaches