A COST AND BENEFIT ANALYSIS OF PILOTING AND NAVIGATIONAL TEAM TRAINERS

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ABSTRACT

Successful Naval operations depend on the skills of qualified CIC teams and bridge personnel for shipboard piloting, navigation, collision avoidance, and target detection. Actual training at sea has potential limitations due to the low frequency of piloting and navigation exposure and the absence of extreme conditions. Piloting and Navigational Team Trainers are utilized by the United States Navy to provide at-sea realism in the classroom. The presently utilized trainers provide complete training for several team members, including radar operators, periscope operators, plotting team members, and fathometer operators. The trainers simulate actual radar presentations and periscope visual presentations, both correlated and responsive to vessel positions and maneuvers. The trainers provide for part-task training in radar operation, periscope operation, and target recognition. As a team trainer, all members of the piloting and navigational team interact and perform their associated navigational tasks.

Training systems such as the Piloting and Navigational Team Trainer are generally conceived as being cost effective and beneficial. Several questions arise when evaluating a training system such as this. They are:

- How effective is classroom training compared with at-sea training?
- Is a particular type of training curriculum more beneficial?
- What training capacity is required to satisfy the training requirements?
- How cost effective are the training systems, and specifically, how do per student-hour training costs in the classroom compare with the cost of at-sea training?
- Are technology improvements forthcoming that will reduce the training cost and increase the training benefits?
- Can additional training tasks be incorporated into the present piloting and navigational team trainers?

The answers to these questions should be of interest to all personnel involved with Naval navigation and Piloting and Navigational Team Trainers. This paper presents a summary of the existing technology and training concepts associated with Piloting and Navigational Team Trainers and provides the answers to the questions presented above. The research presented sets the groundwork for similar analysis that could be performed on any trainer system.

INTRODUCTION

At-sea piloting and navigational training has been reduced because of rising fuel costs and military budget reductions. To supplement the reduced training exposures at sea, classroom Piloting and Navigational Trainers are widely used by the United States Navy to provide at-sea realism. An overwhelming majority perceive these trainers as extremely beneficial and cost effective, but the magnitude of their usefulness and cost advantages are unknown to almost all those involved. One thing that everyone agrees with is that the emotional, safety, and cost impact associated with a vessel running aground are severe.

Historical Background

From the onset of human life, man has had a need to use navigation techniques in order to sustain his existence. The earliest forms of navigation were very crude. Early sailors recognized familiar landmarks through repeated use of established routes. From this information, they began to draw crude maps. This navigation technique is now called pilotage.

As time went on, more sophisticated navigational aids were utilized. The discovery that the sun, the moon, and the stars followed predictable paths throughout the sky lead to a technique now called celestial navigation. Celestial navigation is still in use today.

From this time on, several advancements in the art of navigation were developed. With each innovation came tools or techniques that made travel safer and easier. The development of the compass became an invaluable aid to navigation. Next came the introduction of the sextant, an optical device that is used for sighting stars. This instrument made navigation even more precise. The compass and the sextant are tools that are still in use today as supporting elements to the navigation process.

With the use of the sextant and compass and the aid of many mathematical innovations that eventually came about, ship crews were able to determine their position by translating star sighting to lines on a chart and calculating where the lines crossed to fix the vessel's position. Mathematics also made it possible to develop magnetic variation tables and to provide a system for calculating the effects of wind on ship course and speed. These principles provide a foundation for the technique of dead reckoning, which is still one of the first skills taught in navigation schools.

Detailed charts, along with the magnetic variation tables and the vessel handling characteristics due to environmental effects, created a sizeable task for the piloting and navigational crews. The continued advancements in technology provided relief to the overtasked navigators. The early 1900's brought the advent of the gyrocompass that could be used to provide an autopilot mode of navigation. In the 1920's, radio directional beacons were constructed for homing purposes. Since World War II, computers have been making huge strides in improving navigation techniques as well as positional accuracy. The development of radar was the primary device that allowed blind harbor piloting. Just a few of the many innovations are Inertial Navigation Systems, Navigation Satellites, and Direction-Setting Gyroscopes.

Present Day At-Sea Training

Until recently, the typical mode of training ship piloting and navigation techniques was to take to the sea and hope for the best. While this technique was effective, it was very time-consuming and costly. Entire ship crews would be present for the training exercise and many gallons of fuel would be burned in the process of carrying out a training mission.

While many years ago the captain might also be the navigator, recent demands for accuracy and timeliness in positional calculations require that a piloting and navigational team be aboard to ensure the integrity of ships course and speed. The piloting and navigational team and their assigned tasks are typically as follows:

Plotting Station Operator

Plots ship position on navigational charts, using bearing and/or range to navigational aides and inputs from navigation systems to determine ship position.

Officer of the Deck

Provides visual observation data to the piloting party and is responsible for piloting the ship safely.

Radar Operator

Uses radar repeaters to determine bearing and/or range to navigational aids and coastline features.

Fathometer Operator

Monitors the ship's depth below the keel for comparison with ship's actual and plotted position in order to prevent the ship from running aground. Also aides in determining ship position in the channel.

Periscope Operator

For submarines, maintains visual sighting and provides bearing data to navigational aids for the piloting party.

Simulation for Classroom Training

Over the last 15 years, improvements have been made in training techniques to enhance the skills of the piloting parties and navigators. Application of computer-based training devices that ease the burden of developing trained piloting and navigation crews have become popular. One of the obvious attractions of using simulators for unit training is the savings in consumables (i.e., fuel, manpower, and depreciation of equipment). The United States Navy currently uses a high fidelity piloting and navigational trainer to provide realistic training for surface and subsurface units. Eight of these trainers (identified as Device 15F12 Radar Piloting and Navigational Team Trainer) are currently in use today. These trainers use customized high fidelity data bases developed by the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC).

The Radar Piloting and Navigational Team Trainer offers very realistic sensor simulations and mockups of surface ship and submarine navigational control centers. Figure 1 illustrates the bridge mockup for Device 15F12 Submarine Piloting and Navigational Trainer. This mockup closely resembles the actual submarine equipment. These trainers provide the following features that add realism to the trainers:

- High fidelity landmass data bases for specific ports of call.
- Depth data bases for each landmass data base.
- Generic landmass and depth data bases for basic piloting and navigational training.
- Current (tidal) set and drift data, which vary as a function of ship position and time of day for complete simulation of ebb and flood tides.
- Wind effects, causing vessel displacement.
- Completely programmable radar-type simulation.
- Malfunction insertion for various navigational systems (e.g., Ships Inertial Navigation System (SINS), Gyro, Navigation Satellite, Dual Mini SINS, LORAN C, etc).

The training device has the capability to provide pre-programmable scenarios. Missions can be recorded and subsequently replayed for review or correction of student actions. In order to provide the most current harbor training, the landmass data bases can be edited on the same computational system that is used to provide training.

The system stimulates the same equipment that students would be using on actual ships. It can be used for stand alone basic piloting and navigational training or can be manned at many positions for the added benefit of coordinated team training. In the team training mode, the trainer is manned at 10 stations whose data are provided to the helmsman in order to maneuver the ship.

A typical training repertoire consists of the following training courses:

- Piloting Team Training
- Plot Team Training
- Basic Sonar Plot Training
- Basic Navigation Training
- Navigation Recertification Training
- Contact Coordinator Training
- Specific Harbor Recognition Training
- Generic Harbor Training
- Fire Control Training
- Preoverseas Deployment Training
- Analytical Geometry Instruction
- Spherical Trigonometry Instruction

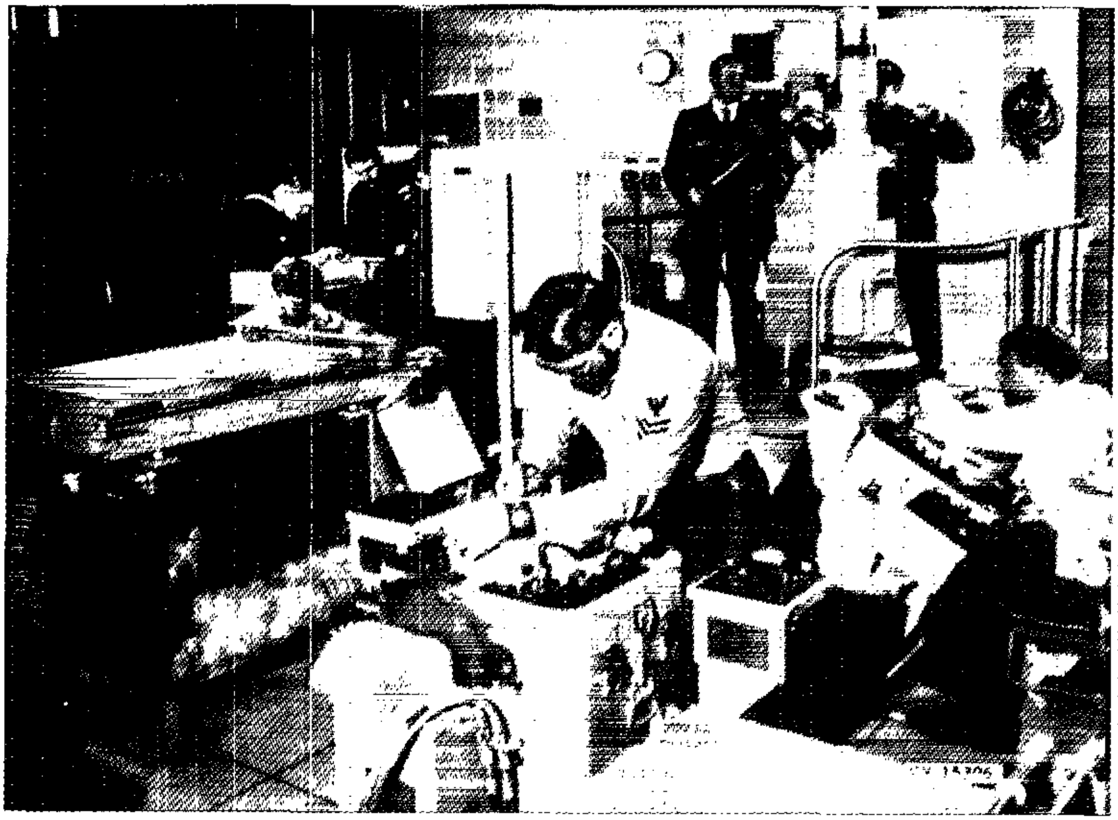

Figure 1. Device 15F12 Submarine Piloting and Navigation Trainer

This set of 8 radar piloting and navigational trainers are currently in use between 2 and 3 training shifts per day, for a total of 12 hours per day. The training prepares the piloting and navigational team for at-sea experiences and supplements the training obtained during the course of vessel deployment.

TRAINING EFFECTIVENESS EVALUATION

Both at-sea training and classroom training results in strengths and weaknesses. Everyone will agree that at-sea training and exposure is an absolute must to successfully navigate and become fully capable and responsible for performing the physical task. One question that is not always as clear is, how valuable are the hours spent in the classroom in preparation for the hands-on at-sea assignments. Table 1 provides an appreciation of the attributes of each type of piloting and navigational exposure. Table 1 lists the 10 most important piloting and navigational exposures and effects and provides an exposure and/or effectiveness value for each type of training experience. A total column is also provided to assess the relative composite value gained from each training concept. Although the at-sea exposure is an absolute must to be highly proficient and capable of piloting and navigating, the total composite effectiveness value for classroom training is greater than at-sea training (45 versus 25). For a more thorough understanding of the effectiveness assessments, further explanation is in order and is outlined below for each feature.

Key to Codes

0 = Not provided
1 = Very limited exposure/ effectiveness
2 = Occassional exposure/ effectiveness
3 = Good exposure/ effectiveness
4 = High exposure/ effectiveness
5 = Extremely high exposure/ effectiveness

Table 1. AT-SEA VERSUS CLASSROOM PILOTING AND NAVIGATION TRAINING COMPARISON

	At-Sea Piloting and Navigation Training	Classroom Piloting and Navigation Training
Frequency of Navigation Exposure	2	4
Feeling of Authenticity	5	3
Varying Environmental Effects	2	5
Equipment Malfunctions	2	5
Piloting and Navigational Error Training	1	5
Specific Harbor Navigation	5	4
Generic Harbor Piloting and Navigation	4	5
Varying Vessel Types	1	4
Multiple Operator Training	2	5
Replay and Debrief Capability	1	5
TOTAL COMPOSITE VALUE	24	45

Frequency of Navigation Exposure

It is obvious that piloting exposure on Navy vessels is limited in duration (usually 1 to 10 hours per departure or arrival) and frequency (an average of 18 departures/arrivals per 18-month period), whereas the classroom trainer is limited only by the availability of trainer time and trainee manpower commitments. The exposure value could be increased for at-sea training by performing repeated harbor departures and arrivals to train for specific piloting and navigational techniques. Classroom training exposure could be increased by operating the existing trainer on additional training shifts or establishing additional training sites.

Authenticity

Although the exposure is limited for at-sea experience, the authenticity of the experience is absolutely unquestionable. The high fidelity classroom navigation trainers approach the at-sea experience but will never be the same as the actual hands-on at-sea experience.

Environmental Effects and Equipment Malfunctions

The classroom trainers provide many attributes that are difficult to create during at-sea piloting and navigation. One important feature is the ability to create extreme navigational conditions that can prepare a navigational team for unusual circumstances not routinely experienced at sea. For example, the training exposure to a high wind and current condition in conjunction with simulated equipment degradations and/or malfunctions can be simulated and provide valuable nonroutine training. This exposure can possibly make the difference between a ship grounding and a successful navigation experience.

Piloting and Navigational Error Training

Piloting and navigational error training includes near-miss situations, groundings, incorrect equipment operation, and unusual maneuvers. These techniques present situations that require corrective action to avoid potentially dangerous conditions. The classroom trainer is the only reasonable method of introducing these situations and, therefore, has significantly greater usefulness than its at-sea training counterpart. Should extreme situations occur at sea, senior watch officers and piloting teams take over, thus preventing the less experienced personnel from encountering the situation.

Specific Harbor Navigation

At-sea training is very effective for providing exposure to the specific harbor that is being navigated. The classroom piloting and navigational trainer is capable of presenting many more harbors and is only limited by the number of data bases developed.

Generic Harbor Piloting and Navigational Techniques

Generic harbor piloting and navigational training develops skills that enhance conceptual ideas and provide the expertise to navigate unfamiliar harbors. These techniques are easily taught during at-sea navigating, but the classroom trainer is the ideal method for their teaching. In the classroom environment, these concepts can be repeated several times and instructor critique and feedback is easily provided without the concern for vessel safety.

Varying Ship Dynamics

The classroom trainer is the ideal place to train piloting and navigation utilizing varying vessel types and their associated maneuvering parameters. The at-sea navigation training is limited only to the vessel being piloted.

Multiple Operators

Multiple sensor operators can be taught simultaneously in the classroom, while the at-sea training is usually limited to a single operator with over-the-shoulder observation; therefore, the efficiencies of the classroom trainers can exceed the at-sea training exercises.

Replay and Debrief

Both at-sea and classroom training can provide debriefing of student actions. The student's physical actions and sensor presentations are easily replayed for debriefing by the classroom trainer. This is more difficult, if not impossible in some cases, to achieve for at-sea training exercises.

The data presented above indicate the need for both at-sea and classroom piloting and navigational exposure to provide the total training needs. Although the classroom experiences appear to present a more complete training environment, these experiences cannot satisfy the total training requirements and should be complemented by at-sea training.

TRAINING CURRICULUM

Within the training community, two schools of thought exist for providing the appropriate curriculum for Piloting and Navigational Team Trainers. They are generic navigation training techniques versus specific harbor and specific vessel-type navigational training. The generic navigation training is less expensive than the specific type of training, and therefore many times only generic training is provided. The trainer procuring agencies and some of the Naval training personnel are in favor of the generic approach. This approach has merit because it trains the methodology for piloting and navigation and, therefore, prepares the student for any harbor or navigation situation that may arise. This technique also limits the number of harbor data bases (i.e., radar, visual, depth, and current) that are required and eliminates the need to update data bases as navigational markers and land features change with time.

Many Naval operational personnel favor specific harbor training along with specific vessel dynamics modeling. This technique can provide familiarity with home ports and well traveled foreign ports. In addition, the correct maneuvering dynamics of the crew's vessel are experienced. This precise training is important when considering the difficulty involved with piloting to and from a home port such as Charleston, South Carolina or Kingsbay, Georgia. Kingsbay, for example, has many restricted channels with limited bottom clearances and requires precise timing for vessel maneuvers.

The additional cost factor associated with providing the proper number of up-to-date data bases is an important factor needed to determine the cost effectiveness of specific harbor training. The estimated initial procurement cost for a radar, depth, current, and visual data base is $425K, and *the yearly maintenance cost is approximately* $50K per data base complement. With the advances in storage technology and the associated cost decreases, the newer generation trainers will easily be capable of storing many data bases simultaneously. The more streamlined storage techniques will reduce the cost associated with data base development and maintenance.

When considering the initial investments that have been made to procure the training devices, it seems to be most reasonable to utilize the trainers to their fullest potential by providing both generic and specific piloting and navigational training. The cost of data base developmental support, though not insignificant, seems justifiable when considering the valuable training that is achieved.

TRAINING CAPACITY AND COST ANALYSIS

Due to the diversification of Naval vessels, their modes of operation, and the existence of multiple classroom training facilities, information regarding piloting and navigational training capacities and costs are not readily available within the training community. An overwhelming majority of those surveyed are convinced that training is extremely important and the classroom is the most effective and least expensive method of achieving this type of training. Establishing training capacities and costs are useful for supporting or countering the opinions held by members of the training community.

Training Capacities

The definition of training capacities requires an analysis of the training provided at-sea and by classroom piloting and navigational trainers. In *determining these capacities, several assumptions* were made for at-sea training. The classroom capacities were based on actual usage of Device 15F12 employed at eight Naval bases throughout the United States.

To estimate the training hours provided at sea, the following assumptions were made:

- Training is provided by 426 surface ships and 137 submarines for a total of 563 vessels.
- Average deployment times are 6 months for each 18-month period.
- Average harbor piloting time is equal to 4 hours.
- There are 13 harbor navigation deployments per 12-month period.
- Average piloting party team size is 10.

Based on these assumptions, the at-sea harbor piloting and navigation total training hours are computed as follows:

> Total training hours/12-month period = 563 vessels x 13 harbor deployments/vessel/12-month period x 4 hours/harbor deployment x 10 trainees/vessel = <u>292,760</u> Trainee hours/12-month period

The classroom training requirements established by the operational fleet creates a substantial classroom training load. For example, the Trident Submarine community has training requirements based on rotating crews that are deployed every 3 months. Each Trident site is slated for a full capacity of 10 Trident Submarines. During each off-cruise, the crews are scheduled for three types of training relating to plotting and navigation. The three types, frequency, course duration, and maximum trainer time required, are defined by Table 2.

Table 2. TRIDENT HOME PORT TRAINING REQUIREMENTS

Course Type	Frequency	Course Duration (Hours)	Total Trainer Hours Required for 10 Submarines (Hours)
Plot Team Training	Once/off-cruise (4 times/year)	24	960
Basic Sonar Plotting	4 times/year for each crew	40	3200
Piloting Team Training	2 times/off-cruise for each crew	40	3200
		TOTAL TRAINER HOURS REQUIRED	7360

Meeting this training load with one training device requires utilization of approximately three 8-hour shifts per day, 6 days per week, 50 weeks per year. More realistically, not all 10 submarines are actively involved in the maximum deployment rotation due to refitting, overhauls, and nonparticipation by the crews due to other commitments. Even if 50 percent of the theoretical maximum training is required, the trainer load is still substantial and is required for more than 12 hours per day, 5 days per week.

Total classroom training capacities for all Device 15F12's are based on actual usage at the eight training sites. The average usage at each site is 12 hours per day, 5 days per week, 50 weeks per year. The average class size is 10 trainees. Therefore, the total classroom training throughput is as follows:

> Total classroom training throughput (trainee hours/12- month period) = 8 training systems x 12 hours/day x 5 days/week x 10 trainees/training system = <u>240,000</u> trainee hours/year

TRAINING COST ANALYSIS

The costs associated with at-sea piloting and navigational training are difficult to determine due to the simultaneous tasks that take place during at-sea deployment. Apportioning the cost of equipment and manpower to the short durations involved for piloting and navigation is a very subjective task and could vary widely. Ignoring all nonfuel related operating costs, manpower costs, and depreciation due to vessel use and considering only the fuel cost for a surface Frigate or Destroyer for a 4 hour-period of harbor piloting provides a bottom limit on the cost associated with operating a vessel for harbor piloting training. Although seldom employed, if additional harbor piloting is performed solely *for the purpose of providing piloting training*, the vessel fuel cost for a 4 hour at-sea training mission can be fully allocated to the training exercise and is computed as follows:

Fuel Cost = 600 gallons/hour x 4 hours/training mission x $0.85/gallon = $2,040

A piloting team of 10 training for a 4-hour mission results in 40 trainee hours; therefore, the cost per trainee hour equals $2040 divided by 40 trainee hours or $51 per trainee hour.

The total costs associated with classroom piloting and navigational trainers are much more definable; utilizing the previously defined training throughput of a navigation trainer such as Device 15F12 along with the costs of procuring and operating the training devices, a cost per student hour can be computed as shown in Table 3. Table 3 defines the cost per trainee hour for Device 15F12 based on 1989 dollars. Excluding trainee labor costs, the cost per trainee hour of classroom instruction is $24. The total yearly cost for eight training sites, excluding trainee labor cost, is $5.76M ($720K/trainer).

Comparing the at-sea fuel related training cost of $51 per trainee hour to the classroom training cost of $24 per trainee hour shows classroom training to be less than one-half as costly as at-sea training. When considering all the additional at sea costs that have not been accounted for, classroom training is even more cost effective. Furthermore, the cost of a vessel running aground can be substantial. The repair cost for a grounding of a $250M Frigate or a $1B Submarine could possibly be in excess of $50M. Therefore, if the classroom trainers prevent one piloting and navigational accident within the next year, the purchasing and operating cost will be covered for the next 10 years.

NEW TECHNOLOGIES FOR NAVIGATION TRAINING

Technology/Cost Trends

As is well known in the simulation industry, computational power is continuing to increase at a rapid rate. At the same time, the cost for these increases in computation speed and memory capacity continues to decrease. This provides the training community with a bright outlook for the future, because the next generation of trainers utilizing the state-of-the-art technology available today will significantly outperform their predecessors.

In the case of the high fidelity piloting and navigational trainer, the trend has been from the custom hardware-intensive system to a compact software-intensive design. These software intensive designs usually require small amounts of code, (5000 lines of code or less), and implement the same or similar models that were performed by the custom hardware - intensive system.The advantage of the software approach is the number of off-the-shelf components, the shorter production unit delivery time, the readily changeable system models, easier system maintenance, less facility requirements, and, last but not least, the lower purchase price. More for less money is truly where we are today.

Predicted Future Classroom Training Costs

New Radar Piloting and Navigational Team Trainers utilizing full fidelity software-intensive approaches are predicted to be 30 percent less expensive than the devices fielded today. In *addition, due to the reduced equipment size and* complexity, the life cycle costs are also predicted to be 30 percent less. The result is a substantially reduced cost per trainee hour. The dollars saved in training costs could be applied toward obtaining additional training capabilities and capacities.

Meeting New Mission Needs

With the advances in training devices and simulation technology, several cost effective improvements can be made to Piloting and Navigational Trainers. These enhancements can easily be added to classroom trainers, and, due to reduced size and cost, it is now feasible to install training equipment aboard each vessel for at-sea training.

A few of the new mission needs that are of growing importance to the United States Navy and are reasonably priced and obtainable with present technology are:

- Bottom Sounding Navigation Training

  This training need will require enhancements to the existing trainers to provide higher fidelity depth contour data when piloting or navigating.

- Close-In Docking Maneuvers

  The ship dynamics models can be enhanced to provide for close-in docking maneuvers.

- Interactive Team Training

  Separate navigation teams from several ships can practice piloting and fire control techniques in coordinated and interactive missions.

- Onboard Training

  Advances in technology will soon permit the integration of the navigation training device into the operational onboard equipment. With high fidelity specific harbor data bases resident in the onboard training device, crews can practice piloting in advance of encountering the actual port.

It is clearly evident that technology innovations have opened many doors in the simulation world. Although these improvements often arrive on the scene at a faster pace than the time it takes to absorb them into the Government inventory, the net effect has been good: more simulation capability for less money.

TABLE 3. TRAINING SYSTEM COST ANALYSIS

COST ITEM	COST BASIS ASSUMPTIONS	YEARLY COST/UNIT	TOTAL COST PER YEAR (8 SYSTEMS)
1. Trainer Systems	• Present day dollar cost to procure the systems (including upgrades) as they exist at the training sites • Total trainer life of 15 years	$400/yr/unit	$3.2M
2. Government Procurement Overhead	• Manpower for acquisition and contract administration through device acceptance by training schools • Estimated at 25 percent of procurement costs • Based on 1989 dollars • Costs pro-rate over 15-year life cycle of device	$100/yr/unit	$0.8M
3. Trainer Life Cycle Support	• 2 onsite representatives/10 training systems • 1 offsite support person/10 training systems • Tasks include configuration control and device support management	$28K/yr/unit	$0.224M
4. Trainer System Maintenance Costs	• Systems maintained by contractor-operated maintenance • *Maintenance requirements =* 3 hours/day/system • Maintenance personnel cost based on annual rate of $35K/year • Maintenance materials costs based on $20K/year/system	$33K/yr/unit	$0.26M
5. Training Facility Costs	• 3,000 square feet/trainer • $8/square foot/year	$24K/yr/unit	$0.19M
6. Instructional Costs	• 6,000 hours of instructional time/year	$150/yr/unit	$1.2M
7. Student Labor Costs	• 30,000 trainee hours • $14/trainee hour	$420/yr/unit	$3.36M
	TOTAL COST	$1.15M/system	$9.2M

Conclusions:

- For 240,000 total training hours:
  Total cost/trainee hours
  = $ 9.2M/240,000 hours
  = $38/trainee hour

- Discounting student labor costs of $14/trainee hour:
  Total cost/trainee hour
  = $5.76M/240,000 hours
  = $24/trainee hour

CONCLUSION

The data presented strongly support the idea that Classroom Piloting and Navigational Team Trainers are cost effective means of providing high fidelity training of Naval piloting and navigational personnel. Although the trainers cannot totally replace or eliminate the at-sea experiences, they are very good at replicating the real-world situation and provide many modes of operation that are difficult to duplicate at sea. The per student hour training cost of $24 is less than one-half of the fuel cost alone required to provide similar at-sea exposure. When considering the emotional and physical danger and cost associated with a piloting or navigational accident, the trainers are well worth their cost. With predicted rises in fuel costs for at-sea maneuvers and reduced simulator cost due to present day technological advancements, the cost effectiveness of this type of training will increase in the future.

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