EMBEDDED TRAINING SYSTEM FOR A COMPONENT LEVEL INTELLIGENT DISTRIBUTED CONTROL SYSTEM (CLIDCS)

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ABSTRACT

This paper describes the Component Level Intelligent Distributed Control System (CLIDCS) architecture for the next generation shipboard Machinery Control System (MCS), and how this design readily provides an environment conducive to embedded training. This architecture, combined with automated control applications, aspects of condition based maintenance (CBM), and integrated automated logistics systems, will reduce the manpower required to operate the plant or shipboard equipment, which is an important design parameter in future MCS designs. The CLIDCS, combined with built-in subsystem redundancy, increases system readiness, maintainability, reliability, and survivability while decreasing the operating and support (O&S) costs. CLIDCS utilizes a true object oriented design (OOD) philosophy for not only the component level embedded software, but also for the hardware and system design.

The shipboard environment must support training scenarios for the crew both at and away from port, while not compromising any normal or damage/hazard operations. The CLIDCS architecture with the intelligence distributed to the device level, promotes subsystem training without sacrificing safety of the ship and crew. The embedded training system is immersed within the CLIDCS architecture, allowing the crew to run applications that simulate the subsystem responses to operator inputs. In the training mode, the subsystem control applications operate in the background, and will interrupt the training application to report any adverse condition requiring an immediate operator response. The embedded training system supports both tactical and damage/hazard control scenarios to increase operator effectiveness and awareness of the operator interface and control system responses. The crew can be trained on the actual hardware, and the opportunities for training at sea promote the versatility of the crew. In manpower reduced environments, these factors are critical not only to normal operations, but also to war fighting readiness.

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CLIDCS ARCHITECTURE

In the next generation MCS, the components of a shipboard Hull, Machinery, and Electrical (HM&E) system will appear as object nodes on the ship network infrastructure. Each node will have the intelligence to make decisions based on its own data, as well as information from neighboring nodes. This allows the HM&E systems to be controlled and monitored from any operator workstation connected to the network, or from a wireless node through a wearable/handheld computer or Personal Digital Assistant (PDA). Each node will be self-calibrating, and capable of performing its own condition assessment. These features improve the flexibility, survivability, and maintainability while reducing the manual maintenance tasks required on ships. This approach is referred to as a Component Level Intelligent Distributed Control System (CLIDCS).

Various branches of the US Navy are carrying out significant application efforts to develop and implement CLIDCS technology for several shipboard systems, as described in the following examples:

- The Advanced Auxiliary Machinery program at the Naval Surface Warfare Center Carderock Division (NSWCCD) has developed a CLIDCS-based architecture for a Reduced Scale Advanced Demonstrator (RSAD) for a DDG-51 ship class chilled water system, and a Ship Service Low Pressure Air (SSLPAir) distribution system.
- The Office of Naval Research (ONR) has contracted Adept Systems Incorporated (ASI) to configure a Yard Patrol (YP) class service craft at the US Naval Academy with CLIDCS-based architecture. YP 679 was successfully configured to control and monitor the propulsion, power generation, fuel distribution, steering, and seawater alignment systems. This platform was also used to demonstrate network fragment healing (NFH).
- The Naval Research Laboratory (NRL) has implemented a CLIDCS architecture aboard the Landing Dock Ship (LSD) the ex-USS Shadwell (LSD-15), the Navy's full-scale damage control and firefighting Research, Development, Test, and Evaluation (RDT&E) platform. CLIDCS was used to automate the Firemain and Smoke Evacuation Systems as part of the Damage Control Automation for Reduced Manning (DC-ARM) program.

These implementations utilize LonWorks tools and network architecture to reduce manning through automated control, monitoring, maintenance, reconfiguring, and repair of the HM&E subsystems. LonWorks is a full-featured industrial standard with an affordable, open architecture governed by EIA/ANSI 709.1 that has significant commercial support and growing market penetration.

What is CLIDCS?

In the CLIDCS approach, each component (sensor, actuator, or controller) has an embedded processor, which makes intelligent control decisions and communicates in a peer-to-peer fashion through a local device network. Each CLIDCS device is also capable of determining its proper operational configuration based on command context provided through Operator Workstations and the status of other devices all interconnected through a network. It is also possible to download new configuration to the device during run time.

The CLIDCS architecture (Figure 1) allocates control to the component level. The local device network connects individual smart devices together in a single network using a standardized electrical interface and protocol. Access to the shipboard wide area network is provided through gateways/routers that converts the device network protocol to an industrial standard network protocol like Ethernet, Fast Ethernet, Gigabit Ethernet, or ATM. The CLIDCS architecture is distributed with no central point of control and therefore, no single point of failure. Hierarchical authority is implemented through contexts provided through the Operator Workstations.

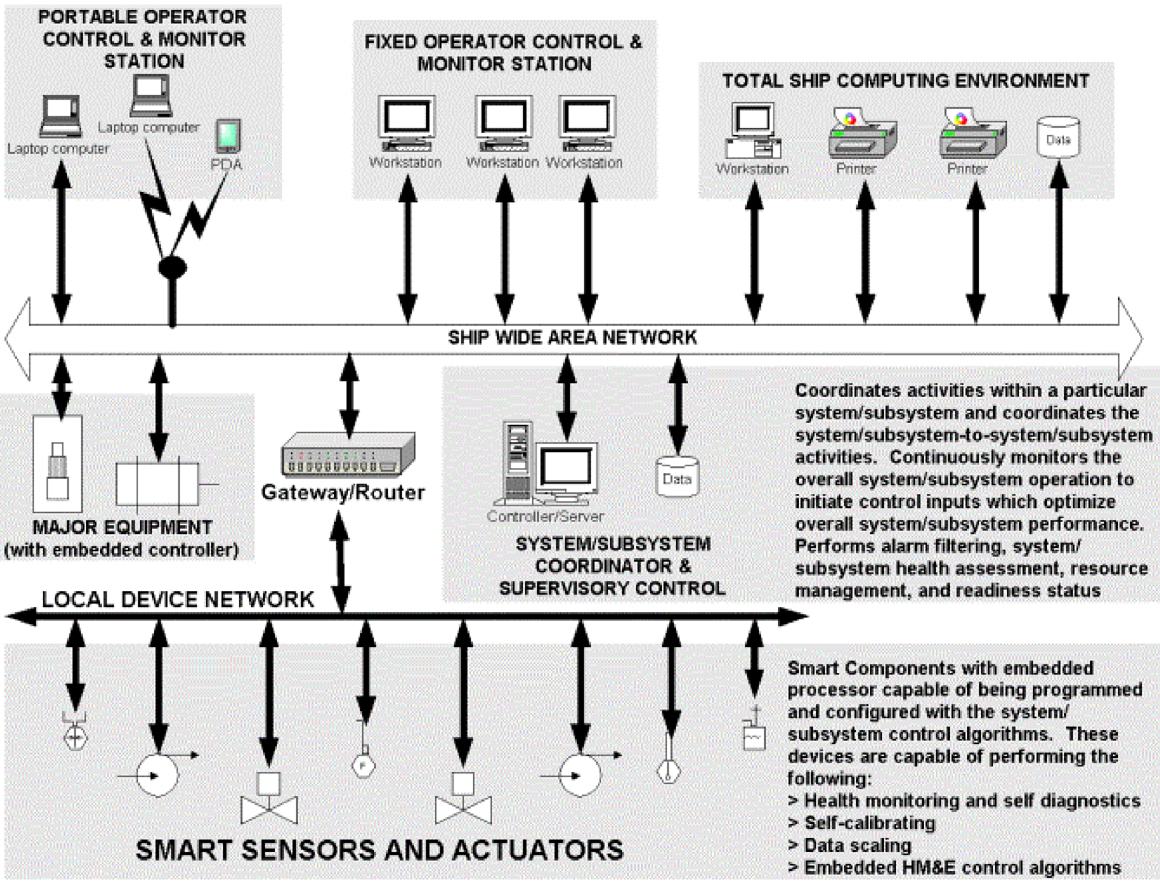

Figure 1 – CLIDCS Architecture

Smart agents exist for each logical grouping of ship subsystems to provide a supervisory control and monitoring function. These smart agents are software applications that can reside on the Operator Workstation, Data Logger, Smart Gateway/Router, or a real-time controller residing on the local device network or ship wide area network. The smart agents provide the system level supervisory control and monitoring tasks, and the plant or network coordination tasks.

Automation To Reduce Manpower

Automating control functions reduces manpower by allowing the automated control system to perform tasks normally performed by a human. There are seven different levels of automation (Table 1) to be applied to the control system functions ranging from fully automated to manual. A formal decision procedure exists (Figure 2) to select the level of automation for a given MCS function.

Table 1– Levels of Automation

Automation Level	Description
AUTOMATED	The automation system executes an action and may or may not inform the human.
EXCEPTION HANDLING	The automation system normally executes the action and may or may not inform the human. The automation system informs the human when intervention is required (such as ambiguous data or an overlay constrained problem space).
FORGIVENESS	The automation system notifies the human an action will be executed unless the human vetoes within a specified time period.
PERMISSION	The automation system executes a suggested alternative only if the human approves.
DECISION SUPPORT	The automation system generates action alternatives and may narrow alternatives down to a manageable few.
ACTIVE MONITORING	For some automated systems, the human is interested in the status of the subsystem and will periodically monitor the activity for situation awareness
MANUAL	Human makes decision, actions, and/or generate action alternatives.

Reliability, Availability, and Survivability

The survivability, reliability, and overall system availability can be enhanced with a combination of a redundant shipboard wide area network, and local device network with a ring topology (Figure 3). The embedded controllers for the major machinery pieces like the generators, propulsion motors, switchboards (SWBDs), etc. will require dual network interfaces, as does the Operator Workstations. Employing a redundant network architecture to the ship wide area network is a standard approach to achieve redundant communication paths to each item. The distributed smart components (sensor, actuators, etc.) typically have a single network interface, so a ring bus architecture is used with redundant gateways/routers to provide dual paths to the ship wide area network. The ring bus can be severed in one place without losing connectivity to any component, and it can be severed in two places with each severed half still having a communication path to the ship wide area network through the redundant gateway/router. Sentinels can be placed on the ring bus to provide the capability to isolate shorted bus segments to prevent the entire ring from going down and isolate devices, which are transmitting erroneous data on the network.

The sentinels are physical components, which can open the network connections through internal switches to route messages away from broken/shorted bus segments. The number and location of those sentinels residing on a particular ring will be determined through the process of a cost-benefits analysis. The smart network agent monitors network traffic to detect open or shorted bus segments. Network Fragment Healing (NFH) is provided through the sentinels.

The redundant gateways/routers are physically mounted at different ends of the space or Damage Containment Area (DCA) to reduce the possibility of an external hazard damaging both gateways/routers. To accommodate a high number of nodes, a partial mesh of rings topology would be implemented. In the partial mesh of rings architecture, device rings have two paths to adjoining rings which eventual has a path to the ship wide network through redundant gateways/routers.

Figure 2 - Decision Tree for Selection of Automation Level

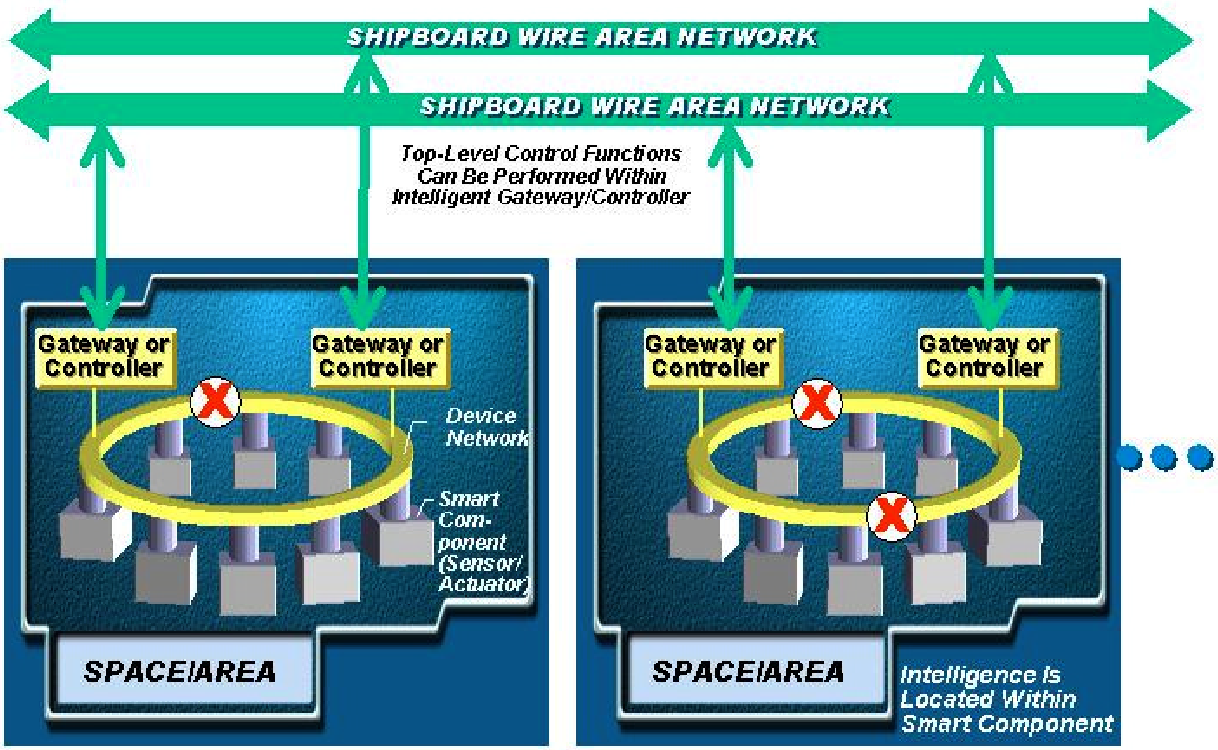

Figure 3 – CLIDCS Network Survivability

Sensors and Actuators

The smart components themselves also increase the survivability of the HM&E systems, by providing local autonomic control when the component becomes disconnected from the network. The intelligent actuator would be programmed to operate in a defined state, when communications is lost. Embedding sensors within the actuator (examples shown in Table 2), increase the information that is available for the actuator during this degraded state and improves the decision-making capability.

Table 2 – Embedded Sensors Within Actuators

Component	Embedded Sensor
Motor Operated (Automated) Valves	Flow meters, Inlet and outlet pressure, Fluid temperature, Position feedback, Motor drive voltage/current/ power, Stroke time, and Stroke counter
Manually Operated Valves	Flow meters, Suction and discharge pressure, Fluid temperature, Position feedback, and Stroke counter
Pumps	Suction and discharge Pressure, Fluid temperature, Speed, Drive voltage/current, Pump run time, and Two axis vibration monitor
Manual Circuit Breakers (CB) or Bus Tie Breakers (BTB)	Current, Open/close status, and Stroke counter
Motor Operated CBs or BTBs	Current, Open/close status, Stroke counter, and Motor drive current/voltage/ power

The sensors and actuators that interface to the HM&E Systems will connect to the system using a smart CLIDCS-type interface. The intelligence is embedded in the device directly by the manufacturer, or it may be provided through a CLIDCS adapter card. These intelligent actuators can support condition assessment and prognostics for themselves.

The increased level of automation required to meet the reduced manning requirements increases the number of sensors. Using actuators with embedded sensors will reduce the number of nodes on the local device network and reduce the overall component count, along with using devices that combine sensor functions. Examples of the types of multi-sensor components are:

- Flow meters with pressure and fluid temperature
- Pressure and fluid temperature

Wireless sensors are utilized if the data is not critical to any operational or mission needs. The Reduced Ships Crew by Virtual Presence (RSVP) Advanced Technology Demonstration (ATD) program sponsored by ONR incorporates Micro-Electromechanical System (MEMS) and wireless communications to provide ships personnel with real-time information for effective decision making with a reduced crew, utilizing battery-less MEMS devices, intelligent data fusion, and advanced reasoning systems.

Maintenance Concepts

The embedded controllers contain the applications necessary to determine the health of the machinery/equipment. It uses its internal Built-In-Test (BIT) features to determine equipment health. The equipment may also employ some CBM methodologies to make predictions on the future readiness of the equipment.

CBM, and other integrated logistics technologies, will reduce the manpower required to perform equipment repairs. CBM prognostics will allow back-up systems to be brought on-line before the primary system is goes off-line due to failure. This prevents system down time caused by equipment or component failures. Maintenance can be performed when the ship is in port, or scheduled around other personnel tasks to make the best utilization of available people. The tools, replacement subassemblies, and manpower can be scheduled before the ship arrives in port through the integrated logistics system.

An organization for the Open System Alliance for Condition Based Maintenance (OSA-CBM) maintains a website (http://www.osacbm.org/) that offers briefings and standards dealing with CBM technologies.

Power

Power to the various sensor and actuators on the local device network will be battery-backed redundant power supplies collocated and packaged within the Gateways/Routers. Power Supplies for the embedded controllers within the major machinery items and the sensors and actuators that they monitor and control will be part of the controller, and will also be redundant with UPS backed-up. The ships power distribution system is the power source for the Gateways/Routers, embedded controllers, and Power Supplies for the components on the local device network. Device Network rings and embedded controllers operating critical systems will receive input power through automatic bus transfer (ABT) breakers, supplied by two separate Load Centers. Devices and equipment requiring high current AC power will get their input directly from the Load Centers or SWBD, with critical systems receiving redundant power through ABT breakers.

Limited HM&E equipment can respond in conjunction with the training event during the training mode. Audible alarms can be sounded, doors can be closed to set damage containment boundaries, etc., during a training event. However, there are limitations to the types of responses that will be allowed in the training mode. Limitations will be based on the current and near future ship modes and evolutions to assure that the training function will not interfere with normal ship functions or crew safety. The Trainer will be made aware of these limitations while the training scenarios are being setup.

The goal would be to utilize the equipment approximations or simulations that were developed during the design analysis and test phase. Separate databases will exist for the training data and the actual ship data. Actual equipment alarms will alert the trainers and trainees to allow them to abort the training exercise to focus their attention on the alarm. High priority alarms like fire, flood, battle threats, etc., will automatically abort the training mod

TRAINING SYSTEM ARCHITECTURE

The control functions are distributed for the training system (Figure 4), similarly like it is for the control system functional distribution. The major difference is that the training system control processing is mainly performed on the Operator Workstations, and not at the component level. This assures that training scenarios will not cause an overload in the local device networks. The inter-communications between Trainee Workstations are accomplished thought the ship wide area network that has a significantly higher bandwidth than the device level networks. Because of the limited programming space available in the smart devices, the training system control algorithms and equipment/system simulations reside on the Workstations.

Trainers at the Information or Total Ship Computing Environment (TCSE) can initiate scenarios or setup initial states in the Training Mode. The Trainees will sit at a fixed workstation and respond to status displays, which have the same look and feel as the actual control displays.

Training with Reduced ManPOWER

The ability to have crew training exercises still exists.

Increased pressure is felt in the cost conscious defense industry for naval operations with high levels of readiness combined with decreased manpower levels. Technological advancements as described above have contributed to making reduced manpower naval operations a reality. However, a reduction in force leads the naval forces into more obstacles to overcome. Among the most prevalent and expected is that the fewer number of crew members will have to be more versatile in training. In addition, it should be recognized that the more junior positions have been among the ones eliminated with automation. Therefore the newest members will have to have higher experience levels. More effective training must be developed for the newest recruits so that their experience base qualifies them to stand specific watches or be able to perform maintenance as soon as possible after joining the crew. In effect, there will be very little margin in the ability to carry any unqualified personnel.

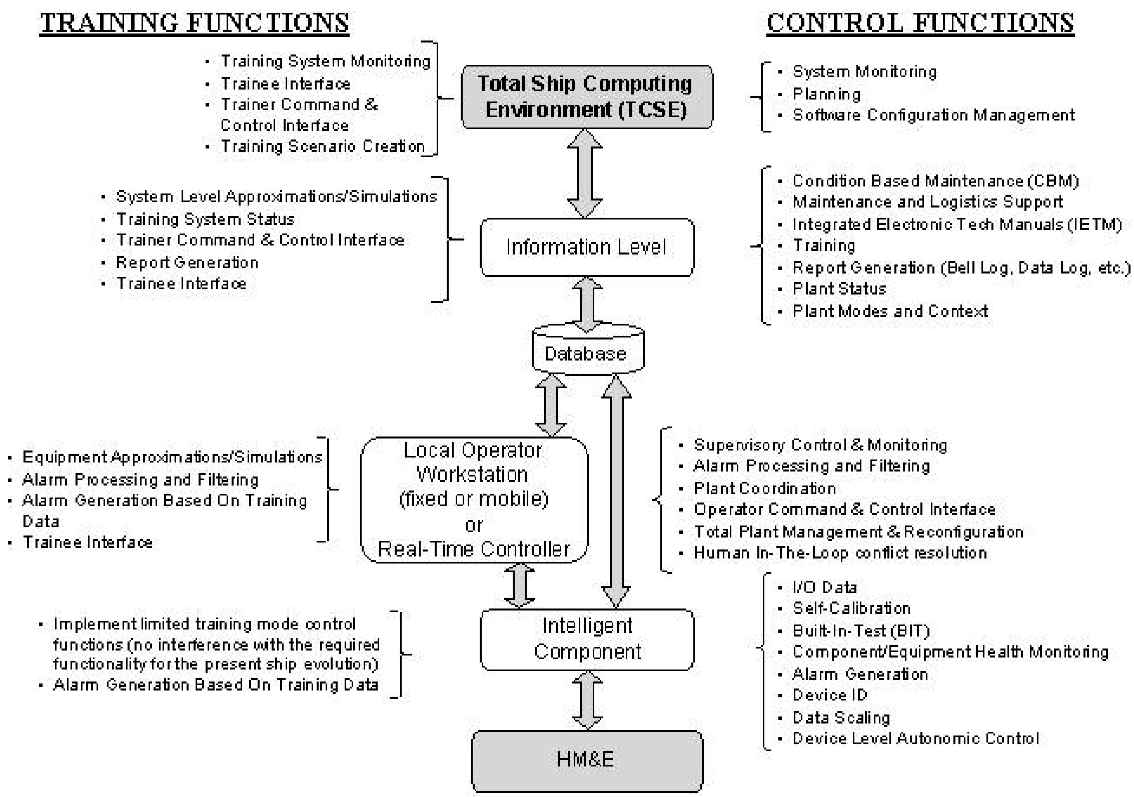

Figure 4 – Distributed Control

Due to the rapid technological advancements in automating ships in recent years, there will be very few instructors with experience in manning an automated ship. The training will migrate from the traditional instructor based training to techniques that place the student in a realistic, dynamic operational scenario, which can be provided with use of the actual hardware through embedded training. The complex environment provided by an automated ship requires that the crewmember's shipboard training consist of advanced techniques that emulate not only operational, but also damage control situations. As the automated shipboard is a new environment, it is essential that the training be capable of a range of complexity compatible with the student's skills to fully train the user on the nuances of the equipment through various scenarios. The training techniques must be individualized and provide each student the maximum benefit with each training session.

In today's naval operations, there is significant shore-based training utilized in setting the foundation for the crewmember prior to his or her deployment on-board the ship. With a more automated ship, it is important that the shore-based training prepare the crews for assuming increased responsibilities when they are deployed. There will be very little shipboard introduction time due to the decreased manning levels. Advanced training techniques can provide such training with use of embedded training, interactive multi-media instructional systems, etc. The shipboard training must focus on mission rehearsal and personal development. Embedded training assets can help meet this need and can be integrated almost seamlessly into normal operations.

A major focus on shipboard training is to do more with fewer resources and in new ways without sacrificing the safety of the crew or ship. CLIDCS provides not only the "new way" to make the automation happen, but it also provides the mechanism for training the crew members in the basic skills and knowledge of the normal operations and the mission rehearsal situations. Technological advancements made possible by CLIDCS, combined with the appropriate instructional processes, will further provide the ability to train crew members anytime and anywhere, while lowering the training costs.

CLIDCS devices enable the non-intrusive monitoring and assessment of dynamic operator/maintenance and team behavior. Training enabled by CLIDCS can contain useful diagnostics and prognostics of human and equipment behavior that will help improve performance and reduce workload. Individualized tailored instruction can be provided through the use of such devices.

The integrated computing infrastructure that can be deployed with CLIDCS, as an architectural component will further expand the potential of management of training information and ensuring that individualized training plans focus on an individual's deficiencies. This will enable significant gains in human proficiency and operational readiness, offsetting the limitations of manpower reductions. Furthermore the shipboard training systems can be easily modified for use in shore-based training or to support on-demand training.

Use of component level intelligence within the ship's architecture will provide detection of changes in equipment operating parameters, which can precede equipment degradation or failure. This greatly simplifies the maintenance plans for shipboard operations, which in turn simplifies the maintenance training requirements. Complex troubleshooting procedures will be reduced, simplifying the nature of the training.

The infrastructure and collaborative environment of the future naval ship will focus on new crew member training through approaches such as discovery learning and active learning while integrating the interactive capabilities of networking. This type of hands on training will provide the crew members training in their contextual environment. The component level intelligence will be supportive of this type of training.

Embedded training stimulates the ship systems and equipment so that the operational equipment can respond as it would in a real world situation. This cost effective use of operational assets in tactical training exercises can be employed at the commander's discretion while the ship is in transit without the necessity of involving other operational forces. In the training mode, the subsystem control applications operate in the background, and interrupt the training application to report any adverse condition requiring an immediate operator response. Embedded training with the ship's integrated command system could enable the various watch stations to have access to all shipboard sensor and information data for training scenarios. This necessitates the use of sensor intelligence at the component level. Likewise embedded training with the ship's integrated ship control functions would be possible through the intelligence at the component level. A natural candidate for embedded training lies with the condition assessment systems that provide condition based maintenance and prognostics.

With the advancements made possible by automation, commanders for these ships will be presented with unusual and previously unheard of capabilities and information overloads. Through highly tailored and individualized training on the cadre of new capabilities, the commanders will become finely tuned in the use of the tools of their trade. The new naval vessels will now represent the equivalent of Star Trek's ***Enterprise***, with information available at the commander's fingertips. However, the commander faces the most demanding of any of the crewmember's training. He must be able to employ as well as embrace the technologies in nontraditional ways.

CONCLUSION

With the reduced ship crew initiatives changing ship operations, ship functions are being critically reviewed for either deletion or reallocation. The emergence and employment of automation concepts is radically changing the naval industry. A paradigm shift is occurring, and the nature of training is becoming crucial with the implications of timeliness and operator effectiveness being more visible than ever. Not only are the ship functions being performed in new ways, but also the makeup of the ship's crew is emerging with radical changes. Smart strategies for embedding training can propel the instructional design discipline into a leading role, enabling training to truly be shapers of the new naval operations.