NSAM Naval Shipbuilding & Advanced Manufacturing Center

# Safe Employment of Augmented Reality in a Production Environment

# Final Report

**Deliverable # 7**

**Project #: Q2804**

**Naval Shipbuilding & Advanced Manufacturing Center**

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**Contracts**

**(EB) 2015-457, (Ingalls) 2015-456, (NNS) 2015-455, (BIW) 2016-401, (Boeing) 2019-383**

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NAVY MANTECH manufacturing technology program

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# 1.0 Executive Summary / Abstract

The Office of Naval Research, Navy Manufacturing Technology (ONR Navy ManTech) program and its Naval Shipbuilding and Advanced Manufacturing Center of Excellence (NSAM) collaborated with a cross-functional team of US Defense Contractors to perform a technology baseline study that identified the state of Augmented Reality (AR) technologies and the leading technology providers in a number of specific technical areas. The technical areas include Wearable and Mobile devices for Augmented Reality and Mixed Reality (MR), safety requirements, security considerations, and user interfaces.

# 2.0 Background / Problem Statement

The capabilities of Augmented Reality technologies have grown rapidly in recent years. Though this growth has been driven largely by commercial market development, it is clear that AR has great potential to improve performance of US Defense Contractors. Broad deployment of AR-based tools faces several significant barriers that can most effectively be resolved by a naval shipbuilding and aerospace industry collaboration representing the major stakeholders in such a deployment. The conclusions of this report represent a consensus of top tier naval shipbuilders General Dynamics Electric Boat (GD-EB), Huntington-Ingalls Industries-Newport News Shipbuilding (HII-NNS), Huntington-Ingalls Industries-Ingalls Shipbuilding (HII-Ingalls) and General Dynamics Bath Iron Works (GD-BIW), as well as AR development leader The Boeing Company.

Though there are barriers that must be resolved, naval shipbuilding and DOD manufacturing, in general, is a target-rich environment for AR technologies. This project team identified and analyzed ten use case types that represent practical opportunities to improve the cost and schedule performance, improve product quality and improve workforce safety. The opportunities to improve US Defense Contractor performance through AR introduction are amplified by generational changes in the workforce, as younger more AR-aware “digital natives” replace retiring Baby Boomers.

Barriers to broad AR deployment in manufacturing have been encountered with the current state of fundamental AR technology performance, challenges with workforce acceptance and limited AR and mobile device integration with existing contractor infrastructures. The project team evaluated the root cause of these barriers to assess the current gap to acceptable performance and the viability of DOD investment to resolve the issues.

# 3.0 Objective(s)

The Safe Employment of Augmented Reality in a Production Environment project determined and documented the current state of the market capabilities and also determined the technology requirements for implementing AR in a production environment. As part of this study each major shipyard and Boeing performed an infrastructure assessment on the current and future use of AR technology that were the building blocks for the gap analysis. That analysis resulted in an implementation roadmap identified the best practices to safely implement this technology and identify where this technology can potentially save cost and provide benefits to the Defense industry.

# 4.0 Technical Approach (by task)

**Task 1 – Project Initiation**

During Task 1, each of the project team members participated in a Kickoff Meeting to coordinate team member efforts and confirm the various project requirements.

**Subtask 1.1 –Kick-off Meeting** – Reviewed project detail, including a detailed breakdown of the project efforts and responsibilities, spend plan, goals/objectives, deliverables, risk assessment, etc.

**Subtask 1.2 – Background and Technology Area Definition** – Industry teams coordinated with other team members to reach a consensus definition of each technology area. This bounded the research, avoided overlapping efforts and assured common understanding of each area's breadth and scope.

**Task 2 – Technology Area Research**

For each technology area assigned in Section A of the Statement of Work, industry teams investigated the state of the technology to determine the current state of the market, and performed an analysis of how that technology fits within the context of production facilities in the Defense industry. Specific areas of investigation included:

**Subtask 2.1 – Market Research** – The project team determined the state of the market capabilities. For each assigned technology area, the team researched and documented the capabilities of state of the market technologies. The focus was on technologies that can be implemented in a production environment with little or no further development. The team then identified leading technology providers. For each assigned technology area, the team researched and documented the technology providers; i.e. companies or other entities that could provide the capabilities determined in Subtask 2.4. The focus was on providers that provide hardware/software/tools that are commercial-off-the-shelf (COTS) or modified COTS.

The results of this subtask was summarized in a report and shared with all project team members. The report was provided to Navy ManTech as Deliverable #2.

**Subtask 2.2 – Determine Technology Requirements** – For each assigned technology area, the team determined the hardware and software needed to implement the technology in the production environment(s) typical of the Defense industry, with particular focus on shipbuilding and aircraft manufacturing. The requirements for each technology area were documented in Deliverable #3.

**Subtask 2.3 – Infrastructure Assessment** – With respect to the specific technology area and to the extent possible, the team determined the current state of all industry partners. This required coordination with each of the other project team members to determine the state of maturity in each member's organization.

**Subtask 2.4 – Gap Analysis** – For each technology area, the team identified the differences between the "As-Is" condition (as determined in Subtask 2.3) and "To-Be" state (as determined during Subtask 2.1). Deliverable #4 documented the results of these analyses.

**Task 3 – Process Development**

The project team assessed the current state of process and technology. The output of Task 3 served as a platform to develop the modified process and operational concept

**Subtask 3.1 – Develop Implementation Roadmap** – In this task, team members determined the types of things that must be done before the subject technology can be put into practice in our team members' industrial facilities. A discussion of potential cost savings and other potential benefits was included. The results of this subtask was summarized in a report, shared with all project team members, and provided to Navy ManTech as Deliverable #6.

**Subtask 3.2 – Develop Pilot Plans** – It was envisioned that this technology assessment would lead to one or more specific ManTech projects to further develop technologies, tailor existing technologies, or develop practices and procedures necessary for integrating AR technologies in Defense industry production facilities. Team members considered and developed (at a summary level) recommendations for specific, candidate ManTech projects that could develop the technology and make it applicable to aircraft manufacturing- and shipbuilding-specific use cases. A high-level WBS for each project was included.

**Task 4 – Conclusions and Recommendations**

The project team reported the results of the research and development conducted during the project. For consistency purposes across the project team, the final report was structured in accordance with the template provided in Attachment 1.

**Subtask 4.1 – Final Report** – Based on the research completed, and drawing on each team's technical expertise, the project team delivered a comprehensive final report summarizing the activities, accomplishments and, lessons learned. The team provided conclusions regarding each technology area's suitability for implementation in shipbuilding and aircraft manufacturing production environments. The team provided, as part of their Final Report, specific recommendations for follow-on efforts that have the potential for improving manufacturing efficiency or effectiveness.

# 5.0 Technical Activities Performed

1) Trade study of state of the market for mobile and wearable devices at the technical, safety, secure, and user friendly level.
2) Development of a test framework for the evaluation of various AR registration algorithms.
3) Self-assessment of current implemented, if any, AR technology as well as a self-assessment on the current infrastructure state to support AR technology.
4) Gap analysis comparing self-assessment and identified future requirements to currently available AR devices and technology that support it.
5) Develop an Implementation roadmap with identified use cases for future pilot projects.

For this project, the team researched the current AR hardware technology along with supporting software. Using this data, along with the self-assessment of each group's requirements, environment, and infrastructure, document the identified gaps between what is available today and what needs addressing in order to be implemented in a production environment. The team also collaborated together and developed a series of

PICK (Possible, Implement, Challenge, and Kill) charts to assign the perceived value of each use case identified within the Implementation Roadmap.

## 6.0 Results and Discussions

The market research confirmed that the market is still experiencing early stage development and significant churn. Though AR technologies have been emerging for quite a while, a dominant architecture for AR solutions has not yet emerged, particularly for industrial applications. AR software and hardware suppliers are developing solutions that still represent a broad diversity of options and approaches. Each approach offers important advantages over competitor solutions, but also brings inherent limitations.

The current targeted market is highly consumer based applications and more tailored towards office or living room setting as opposed to a manufacturing floor. Equipment ruggedness coupled with safety requirements can limit the selection among what is offered in the market today. The wireless communication and broadcast technologies used within the current available products have some security challenges when it comes to implementing within a normal secured production environment. AR technologies rely heavily on camera based technologies along with wireless connectivity all of which proposes challenges in not just a security standpoint but also external environment element such as environment lighting and signal inference. To help move AR forward the industry could benefit from standardization from user interfaces to data publication but, developing standards for an industry that is young and immature might hinder advancement as the market moves forward with development.

Building upon identified use cases and leveraging the Market Research Analysis, the Technology Requirements Document, the Infrastructure Assessment and the Gap Analysis, the project team collaborated on an implementation roadmap. Since the number and variety of use cases is continuously growing, the roadmap was built upon use case “types” which are common among the manufacturers and can be limited to a manageable, finite number. By organizing the Implementation Roadmap by use case type the project team also bound the number of potentially useful AR technology combinations. For example, the Training use case type requires a different collection of AR technologies when compared to the Work Instruction use case type or the Remote Expert use case types.

The project team members assessed the value of the identified AR use case types and the difficulty to deploy them in their facilities. The purpose of the use case type assessments is to identify use cases that are commonly recognized as representing high value, and identifying barriers to deployment that are common among the project members. In order to organize the growing number and variety of AR use cases and impose some level of commonality across manufacturers, ten standard use case types were identified:

1. **Inspection Use Cases:** This is the set of use cases that utilizes AR technologies to assess and record how well a component, part or assembly conforms to defined requirements.

2. **Work Instruction Use Cases:** This is the set of use cases that apply AR technologies to guide or direct task execution by front line workers.
3. **Training Use Cases:** This is the set of use cases that employ AR technologies as a medium for training shipyard employees to improve for task execution performance.
4. **Supervision Use Cases:** This is the set of use cases that apply AR technologies to improve supervision’s ability to plan and execute workflows for a team.
5. **Operational Use Cases:** These are use cases that employ AR technologies for visualization of data about environmental conditions, ongoing operations or system states (square footage, energy in a circuit breaker, flow rate in a pipe, etc.).
6. **Safety Use Cases:** Although safety is a critical attribute of all uses cases, this is the set of use cases that exist to specifically enhance situational awareness of craftspeople.
7. **Logistics Use Cases:** This is the set of use cases that apply AR technologies to help workers and supervision determine where resources are in the space or facility.
8. **Remote Expert (Telepresence) Use Cases:** This is the set of use cases that use AR technologies that enable multiple users in remote locations to interact with onsite user's shared virtual environment. Remote users represented with avatars.
9. **Remote Expert (Shared Augmentation) Use Cases:** These use cases employ AR technologies to allow users to view same virtual content while in remote locations. Virtual content is anchored based on user preference.
10. **Remote Expert (Shared World Anchors) Use Cases:** This is the set of use cases that apply AR technologies to enable remote users to draw augmentations on real world objects that are anchored to the onsite user location.

The ten standard use case types were evaluated and mapped on a scale of high, medium or low Value to the enterprise, and high, medium or low Time to Deploy.

| Use Case Assessment Notes: BIW | | | | |
|---|---|---|---|---|
| **Use Case Type** | **Benefit Rating** | **Benefit Notes** | **Time to Deploy Rating** | **Time to Deploy Notes** |
| **Inspection** | High | Confirms 1st time quality, does not ensure it. | Low | Technologies and infrastructure in place to support implementation. |
| **Work Instruction** | High | Use case has direct effect on 1st time quality by improving task comprehension. | High | Requires advanced AR capabilities that are not ready for production, data secure environments. |
| **Training** | High | Use case has direct effect on 1st time quality by improving worker knowledge. | Low | Technologies and infrastructure in place to support implementation. |
| **Supervision** | High | Use case has direct effect on 1st time quality by improving supervisor awareness and communications. | Medium | Technologies are largely available but integration with shipyard enterprise systems required. |
| **Operational** | Medium | Use case improves second order shipbuilding tasks by improving operations of active systems. | Medium | Technologies are largely available but integration with shipyard IoT infrastructure required. |
| **Safety** | High | Improving worker safety always a high shipyard priority. | High | AR technologies still to intrusive to enhance awareness without being distracting. |
| **Logistics** | Medium | Missing material is a chronic shipbuilding problem but other technologies such as RFID may be better solution. | Medium | Technologies are largely available but integration with shipyard enterprise systems required. |
| **Remote Expert (Telepresence)** | High | Use case has direct effect on 1st time quality by leveraging SME knowledge. | High | SW needs development and heavy dependence on infrastructure and HMD hardening. |
| **Remote Expert (Shared Augmentation)** | High | Use case has direct effect on 1st time quality by leveraging SME knowledge. | Medium | SW is largely available but heavy dependence on infrastructure and HMD hardening. |
| **Remote Expert (Shared World Anchors)** | High | Use case has direct effect on 1st time quality by leveraging SME knowledge. | Medium | SW is largely available but heavy dependence on infrastructure and HMD hardening. |

| Use Case Assessment Notes: EB | | | | |
|---|---|---|---|---|
| Use Case Type | Benefit Rating | Benefit Notes | Time to Deploy Rating | Time to Deploy Notes |
| Inspection | High | EB plans to use AR for both internal inspection and supplier inspection as a deficiency aid. | Medium | Technologies and infrastructure in place to support implementation. Apps require additional development. |
| Work Instruction | High | Use case has direct effect on 1st time quality by improving task comprehension. | Low | AR capabilities are already in development and ready to deploy. |
| Training | Low | EB plans to utilize VR for training | Low | EB efforts in training have been concentrated in the VR arena. EB is not currently pursuing AR for training. |
| Supervision | High | Use case has direct effect on 1st time quality by improving supervisor awareness and communications. | Medium | Technologies and infrastructure in place to support implementation. Apps require additional development. |
| Operational | Medium | Use case improves second order shipbuilding tasks by improving operations of active systems. | Medium | Technologies are largely available but integration with shipyard IoT infrastructure required. |
| Safety | High | Improving worker safety always a high shipyard priority. | High | AR technologies still too intrusive to enhance awareness without being distracting. |
| Logistics | Medium | Missing material is a chronic shipbuilding problem. | Medium | Technologies are largely available but integration with shipyard enterprise systems required. |
| Remote Expert (Telepresence) | High | Use case has direct effect on 1st time quality by improving worker knowledge. | Low | Deployment of COTS solutions are currently underway, |
| Remote Expert (Shared Augmentation) | High | Use case has direct effect on 1st time quality by improving worker knowledge. | Low | Development efforts are currently in work. Timely deployment expected to follow. |
| Remote Expert (Shared World Anchors) | High | Use case has direct effect on 1st time quality by improving worker knowledge. | Low | Development efforts are currently in work. Timely deployment expected to follow. |

| Use Case Assessment Notes: NNS | | | | |
|---|---|---|---|---|
| Use Case Type | Benefit Rating | Benefit Notes | Time to Deploy Rating | Time to Deploy Notes |
| Inspection | High | Confirming as designed to as built can be applicable in several use cases. | Low | Capabilities already available. |
| Work Instruction | Medium | Ability to see what needs to be done through visuals however, may not always be the simplest way to deliver information. | High | Authoring through templated platforms is not mature. |
| Training | Low | Information can better be retained through 3D model exploration and virtual environments. | Low | Capabilities already available. |
| Supervision | High | To understand a complicated situation such as ship construction at a glance would be a fundamental change in industry. | High | Components of AI and AR localization need further maturity. |
| Operational | High | Instant answers to your current task or system status. | Medium | Technology is available if the data was available in a consumable format. |
| Safety | Medium | Can lead to performance decrements when the automation fails. | High | AI situational awareness technology is in its infancy. There are legal ramifications for investing in a system responsible for worker safety and the amount of research required for validation will be high. |
| Logistics | High | Same benefits as supervision. | High | Same deployment hurdles as supervision. |
| Remote Expert (Telepresence) | High | Increase quality of communication and level of immersion. | High | Limited network bandwidth and no standardization for avatar representation and remote user interactions. |
| Remote Expert (Shared Augmentation) | Medium | Potential for same experience through 3D models and screen sharing. | Low | Technology already available. |
| Remote Expert (Shared World Anchors) | High | Increase quality of communication and reduced cost of hiring multiple experts. | Medium | Limited network connectivity in the ships and AR tracking still needs work for production environments. |

| Use Case Assessment Notes: Ingalls | | | | |
|---|---|---|---|---|
| Use Case Type | Benefit Rating | Benefit Notes | Time to Deploy Rating | Time to Deploy Notes |
| Inspection | Medium | While 1st-time quality may be improved in some instances, Ingalls does not believe it will be possible for the majority of instances. Ingalls believes this use case type is largely reactive and not proactive | Medium | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms |
| Work Instruction | High | (1) Several high-potential application instances for this use case type have been identified. (2) Continuing to do business "old school" will become difficult as future members of the workforce will be much more familiar with modern technologies and far less capable of reading engineering drawings, etc. | High | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; Upgrade and integration of several legacy data systems will be necessary. |
| Training | Medium | (1) Only a small number of applications for this use case type have been identified. (2) Use case will only have moderate benefit for 1st-time quality. | Medium | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms |
| Supervision | Medium | (1) Only a small number of application instances for this use case type have been identified. (2) Use case will only have moderate benefit for 1st-time quality. | High | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; Upgrade and integration of several legacy data systems will be necessary. |
| Operational | High | Several high-potential application instances for this use case type have been identified: Lock-out/Tag-out, Identification of Hot-Work Zones; Compartment Temperatures; Equipment Identification and Location | High | Requires investment and development of IoT and edge-computing infrastructure. Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; Upgrade and integration of several legacy data systems will be necessary. |
| Safety | Medium | (1) Only a small number of application instances for this use case type have been identified: Fire Watch; Security Watch; Identification of presence of dangerous gases (2) Use case will only have moderate benefit for 1st-time quality. | High | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; Upgrade and integration of several legacy data systems will be necessary. |
| Logistics | Medium | Ingalls mainly sees application for this use case type in warehousing. However, lead time for fully-automated warehousing is estimated to be approximately the same as the lead time for implementing this AR/VR use case. | High | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; Upgrade and integration of several legacy data systems will be necessary. |
| Remote Expert (Telepresence) | Medium | The utility of this use case type is not well understood. While potentially useful wherever a producer/consumer relationship exists, Ingalls only sees significant benefit for off-site users (3rd party vendors, etc.). On-site SME's are fairly available and accessible for in-person, on-station interaction. | High | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; in the case of 3rd party vendors, etc., the risk of inadvertent disclosure of information to non-U.S. persons must be understood and managed, possibly preventing associated use cases from being deployed. |
| Remote Expert (Shared Augmentation) | Medium | The utility of this use case type is not well understood. While potentially useful wherever a producer/consumer relationship exists, Ingalls only sees significant benefit for off-site users (3rd party vendors, etc.). On-site SME's are fairly available and accessible for in-person, on-station interaction. | High | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; in the case of 3rd party vendors, etc., the risk of inadvertent disclosure of information to non-U.S. persons must be understood and managed, possibly preventing associated use cases from being deployed. |
| Remote Expert (Shared World Anchors) | Medium | The utility of this use case type is not well understood. While potentially useful wherever a producer/consumer relationship exists, Ingalls only sees significant benefit for off-site users (3rd party vendors, etc.). On-site SME's are fairly available and accessible for in-person, on-station interaction. | High | Lack of PPE integration and hardware ruggedness; lack of device provisioning and management capability; Lack of enterprise AR/MR device authentication methods and frameworks; Lack of yard-wide, ship-deep wireless communication infrastructure; Lack of "Plug-and-Play" end-user-driven content creation platforms; in the case of 3rd party vendors, etc., the risk of inadvertent disclosure of information to non-U.S. persons must be understood and managed, possibly preventing associated use cases from being deployed. |

| Use Case Assessment Notes: Boeing | | | | |
|---|---|---|---|---|
| **Use Case Type** | **Benefit Rating** | **Benefit Notes** | **Time to Deploy Rating** | **Time to Deploy Notes** |
| Inspection | High | Potential to automate QA acceptance of installation of parts and wiring. | High | Complex machine vision problem. Clutter environments, partially occluded parts etc. Flexible wiring. |
| Work Instruction | Medium | Most mechanics know the steps to perform a job, but need to understand the product design. | Medium | Underlying data usually does not exist in a format useful in an AR experience. Would need to be generated - costly. |
| Training | Medium | Valuable on complex jobs - most jobs not complex enough to warrant. | Medium | Preparation of underlying data is time consuming. |
| Supervision | Low | Many tools besides AR already available for this use case. | Low | Technology requires lower levels of accuracy and is readily available. |
| Operational | High | Real time feedback during factory layout very valuable. | Low | Factory assets mostly 3D modelled already. Limited data interfaces required. |
| Safety | High | Safety is top priority, and AR can assist is hazardous environments (eg standing on a wing) | Medium | Proliferation of AR devices required first. |
| Logistics | Low | Value AR brings to this use case is typically low. This information can be represented by other means | High | Infrastructure to generate location data required. |
| Remote Expert (Telepresence) | High | Better collaboration with remote users allows for rapid problem solving and ad-hoc decision making. An enabler to a lot of solutions. | High | Hardware instruction needs to be in place. High bandwidth network. |
| Remote Expert (Shared Augmentation) | Medium | Reduces time wasted on searching for help. | Medium | Infrastructure requirements, high network bandwidth through factories. Proliferation of AR hardware. |
| Remote Expert (Shared World Anchors) | Medium | Reduces time wasted on searching for help. Spatially registered content would aid in communication. | Medium | Infrastructure requirements, high network bandwidth through factories. Proliferation of AR hardware. |

## Use Case Assessment: Value Distribution

| | | Value | | |
|---|---|---|---|---|
| **Use Case Type** | **Description** | **Low** | **Medium** | **High** |
| Inspection | Determines how well a component or part conforms to defined requirements. | | I | B E N B |
| Work Instruction | Guides a person or otherwise provides information useful for task execution. | | N B | B E I |
| Training | A medium for training craftspeople, especially on complex and/or expensive systems. | E N | B I | B |
| Supervision | Helps a supervisor plan and execute workflows for a team. | B | I | B E N |
| Operational | Use-cases for visualizing data about spaces, ongoing operations or system states (square footage, energy in a circuit breaker, flow rate in a pipe, etc.). | | B E | N B I |
| Safety | Enhance situational awareness for craftspeople. | | N I | B E B |
| Logistics | Helps a craftsman or supervisor understand where people and things are in space. | B | B E I | N |
| Remote Expert (Telepresence) | Multiple users in remote locations interact with onsite user's shared virtual environment. Any remote users represented with avatars. | | I | B N B E |
| Remote Expert (Shared Augmentation) | Users view same virtual content while in remote locations. Virtual content is anchored based on user preference. | | N B I | B E |
| Remote Expert (Shared World Anchors) | Remote user can draw augmentations on real world objects that are anchored to the onsite user location. | | B I | B N E |

**Key:**
B BIW
E EB
N NNS
I Ingalls
B Boeing

Consensus

**Value Assessments:** Although there was a wide distribution of ratings from the manufacturers, the general trend was towards higher value assessments of medium and high indicating broad agreement over the potential for AR technologies to improve performance. Value assessments are summarized as follows:

1. **Consensus:** Strong agreement was seen in the high value of Inspection and Remote Expert (Telepresence) use cases.
2. **General Agreement:** All 5 manufacturers agreed that several use cases represented high or medium value including Work Instruction, Operational, Safety, Remote Expert (Shared Augmentation) and Remote Expert (Shared World Anchors).
3. **Disagreement or Broad Disparity:** Clear differences of opinion were evident with outlier assessments in only two use cases: Training and Supervision.
    a. For the Training Use Case BIW was the outlier. BIW attached high value to the use of AR for training while EB and NNS noted a greater interest in the use of (e.g. Virtual Reality) for training, indicating low value for this application.
    b. For the Supervision Use Case Boeing was the outlier. **Similar to the above case,** Boeing noted a greater interest in the use of other technologies for the Supervision use case.

## Use Case Assessment: Time to Deploy Distribution

| Use Case Type | Description | Time to Deploy: Low | Medium | High |
|---|---|---|---|---|
| Inspection | Determines how well a component or part conforms to defined requirements. | B, N | E, I | B (Boeing) |
| Work Instruction | Guides a person or otherwise provides information useful for task execution. | E | B (Boeing) | B, N, I |
| Training | A medium for training craftspeople, especially on complex and/or expensive systems. | B, N, E | B (Boeing), I | |
| Supervision | Helps a supervisor plan and execute workflows for a team. | B (Boeing) | B, E | N, I |
| Operational | Use-cases for visualizing data about spaces, ongoing operations or system states (square footage, energy in a circuit breaker, flow rate in a pipe, etc.). | B (Boeing) | B, E, N | I |
| Safety | Enhance situational awareness for craftspeople. | | B (Boeing) | B, E, N, I (Consensus) |
| Logistics | Helps a craftsman or supervisor understand where people and things are in space. | | B, E | N, B (Boeing), I |
| Remote Expert (Telepresence) | Multiple users in remote locations interact with onsite user's shared virtual environment. Any remote users represented with avatars. | E | | B, N, B (Boeing), I (Consensus) |
| Remote Expert (Shared Augmentation) | Users view same virtual content while in remote locations. Virtual content is anchored based on user preference. | N, E | B, B (Boeing) | I |
| Remote Expert (Shared World Anchors) | Remote user can draw augmentations on real world objects that are anchored to the onsite user location. | E | B, N, B (Boeing) | I |

**Key:**
- B BIW
- E EB
- N NNS
- I Ingalls
- B Boeing

Consensus

**Time to Deploy Assessments:** The assessments of the manufacturers on Time to Deploy AR solutions showed somewhat greater disparity than the Value assessments. The wider distribution of ratings is attributed to the fact that Time to Deploy is a combination of two factors, one common to project members and one that may more particular to each manufacturer. Time to Deploy depends on the current or near term capabilities of AR technology, but also on the readiness of each manufacturer's infrastructure to enable and manage AR.

1. **Consensus:** Strong agreement was seen in the long (or high rating) Time to Deploy of Safety and Remote Expert (Telepresence) use cases. This indicates near unanimous agreement that these use cases depend on more advanced, less mature AR technologies.
2. **General Agreement:** All 5 manufacturers agreed that the AR technologies that enable the Training use case was either readily deployed or cold be deployed in the medium term.
3. **Disagreement or Broad Disparity:** Wide differences of opinion on the readiness to deploy were evident in the majority of use cases. The causes for this disparity are enlightening and can best be described for each use case based on the mapping notes provided by the manufacturers:
    a. **Inspection Use Cases:** The shipyards indicated that AR technologies that enable Inspection use cases are ready to be deployed in a near to medium time frame. Boeing, on the other hand, noted that Time to Deploy was high. The discrepancy may be due to

Boeing's focus on the most advanced case of automated inspection rather than inspection management or discrepancy notations. Boeing noted the limitations of machine vision and he visual clutter that can hamper proper occlusion.

b. **Work Instruction Use Cases:** There was significant disagreement on the maturity of AR technologies to support these use cases. While BIW and NNS thought considerable development is still required, EB noted that they are currently developing these technologies and are near deployment. The discrepancy may lie in the notably broad scope of the use case type which could encompass the deployment of handheld devices or head mounted displays. Barriers noted by BIW and NNS include the lack of industrial strength "hands free" AR devices, data security concerns and limited authoring/publishing applications.

c. **Training Use Cases:** As noted above, all manufacturers assessed that the "capabilities are already available" with minimal barriers to deployment. There was no such agreement, however, on the value of AR technologies for Training use cases, as noted in the Value Assessments section, above.

d. **Supervision Use Cases:** General agreement among the shipbuilders that AR technologies are not ready to be deployed in support of the Supervision use cases. The Time to Deploy was judged to be in the medium to high time frames. Barriers noted include the relative immaturity of Artificial Intelligence (AI), limited capabilities of AR localization and the need for further development on supporting applications. Boeing was not of the same opinion noting a low Time to Deploy due to the relatively low accuracy requirements of the use case.

e. **Operational Use Cases:** General agreement among the shipbuilders that Time to Deploy is in the medium to high range. The barrier in this use case is identified as the availability of consumable data through an available Internet of Things (IoT) infrastructure. Boeing was not of the same opinion noting a low Time to Deploy because factory assets are largely 3D modeled and the low number of required interfaces. This disparity probably highlights the significant differences in the state of automation and serial production between the shipbuilding and aeronautics industries.

f. **Safety Use Cases:** As noted above, there was a consensus agreement among the shipbuilders that Time to Deploy is in the high range for the Safety use cases. The barriers ranged from the inherent distractions of augmentation to the legal challenges and validation required to rely on automation for worker safety. Boeing assessed the Time to Deploy to be medium noting that the only barrier was proliferation of AR devices.

g. **Logistics Use Cases:** General agreement that AR technologies are not ready to be deployed in the near term in support of the Logistical use cases. The Time to Deploy was judged to be medium to high time frames. Barriers noted include the relative immaturity of AI, limited capabilities of AR localization and the required integration into manufacturers' enterprise systems.

h. **Remote Expert (Telepresence) Use Cases:** As noted above, there was a consensus that the AR technologies that enable this use case are not readily available. EB offered an assessment of more advanced capability indicating that the relevant technologies were already in development and will be deployed soon.

i. **Remote Expert (Shared Augmentation) Use Cases:** There was general agreement that the AR technologies that enable this use case are not readily available. NNS, however, indicated that the Time to Deploy was low based on the availability of applications that accomplish this today. Ingalls Shipbuilding documented the opposite case noting both infrastructure readiness and technology capability limitations.

j. **Remote Expert (Shared World Anchors) Use Cases:** There was general agreement that the AR technologies that enable this use case are not readily available. As with Telepresence, EB offered an assessment of more advanced capability indicating that the relevant technologies were already in development and will be deployed soon. Ingalls Shipbuilding offered the opposite case noting both infrastructure readiness and technology capability limitations.

The project team has identified several potential pilots. They are described below and are listed in priority order. It should be noted that although there was agreement on the value of these proposed projects, there was not complete agreement on the priority. One project member recommended that priorities 1 and 2 be reversed based on assumptions of a more aggressive pace of technology development.

- **Priority 1: Virtual Load-Out Interference Detection Project.** Use AR enabled devices to verify load out paths in real time on the deck plates. Although ship load out is designed and planned in 3D CAD, substantial delay and disruption can be avoided if clashes with temporary services and structure or out of sequence work can be detected and resolved before work commences.
- **Priority 2: Mixed Reality Work Order Project.** Use AR enabled head mounted displays (HMD) for the execution of ship construction, particularly outfitting installation. The information displayed through the AR devise will completely replace the current hard copy-based work instruction methodology and enable real time, remote subject matter expert assistance in the event of construction difficulties.
- **Priority 3: Augmented Reality for Virginia Class Submarine (VCS).** Adapt tools and processes originally developed to support Columbia (CLB) class submarine for use on VCS. CLB tools all relied on TeamCenter/NX CAD as their input source of data. This project would extract the needed VCS data from CATIA V4 and (CATIA Data Management (CDM).

## 7.0 Issues / Problems / Workarounds (if applicable)

One of the biggest issue with this project was trying to collaborate in a field where groups have all forged their own paths. A lot of the work is custom, so far, with different goals, terminology and experiences. As a first attempt to collaborate on this topic it was, for the most part, pretty successful. At times it was like speaking 5 different languages. Also, the structure and focus of the teams seemed a little haphazard, but the team worked through it.

The biggest issue with studying the AR subject matter is the lack of performance standardization and agreed-upon test protocols. There is no standard way to measure virtual object placement accuracy, for example, which is critical to the applications I am trying to develop.

- Collaboration between industry partners was difficult due to the need to keep industry information private. Additional phone conferences were needed to assure collaborators that care would be taken with their proprietary information
- Clearer templates would have helped set expectations for technical deliverables. Although submitting documents in Word format was an acceptable delivery, having a clear format would have helped to expedite documents.

## 8.0 Lessons Learned

Through exhaustive efforts to identify and document the state of the market in industrial applications for AR/MR, the following was noted:

- Naval shipbuilding and DOD manufacturing, in general, is a target-rich environment for AR technologies. AR has the potential to bring the transformative benefits of "digital thread" development from the back office to the shop floor.
- The potential to improve manufacturer performance through AR is complimented and accelerated by generational changes in the workforce.
- There is significant value to the government in collaboration among the DOD contractors for common AR technology development and information sharing in a rapidly evolving technology.
- Some of the greatest barriers to industrial deployment of AR tools will require government investment to accelerate relatively slow progress of commercially driven development. Most significant barriers include greater accuracy of augmentation, registration and tracking, and hardening of AR devices.
- Any wearable AR display device must either be qualified to replace, or be physically compatible with other PPE that is required to meet minimum standards set for each work area.
- Software applications should be developed with ergonomics of the users in mind (avoiding prolonged gestures, of avoiding place the user's neck or other body parts in a strenuous position for extended periods).

- Software applications should provide visual/audible or other warnings when the user is at risk for injury due to improper posture for prolonged periods.
- Software applications should provide visual/audible or other warnings when the user moves in proximity of a hazardous area (for example near the edge of an aircraft wing or ship's deck at height).
- Software applications should not distract the attention of the user while the user is walking or moving through an area.
- Software applications should not occlude any potential safety hazards in the area of the wearer.
- Training must be given, in a non-hazardous environment on the safe use of the device, including making the use aware of safety hazards that could be introduced through the use or a wearable AR display.
- Users must be trained on the use of the software application in a non-hazardous environment before entering a production area.
- Use of heard worn AR devices should be introduced over time for persons new to the technology, and the wearer should be monitored during the introduction through surveys and other standardized data collection techniques to detect any potential issues.
- Follow on funding should allow for at least at least one face-to-face meeting
- More guidance on the proprietary expectations/challenges resulting from cross industry collaborations is needed.
- Each partner must assess the acquisition of AR technologies with an understanding of the Return on Investment (ROI) and the perceived value of implementation to their individual business models.

## 9.0 Conclusions and Recommendations

While some progress has been made by AR/MR hardware manufacturers and solution providers in addressing industrial manufacturing use cases, several challenges remain in the implementation and use of AR/MR technologies in shipbuilding manufacturing. Chief among the challenges are hardware interferences with personal protective equipment, the absence of device provisioning and management capabilities, lack of easy-to-use content creation services, and the development of easy-to-use, reliable, authentication methods for AR/MR devices.

Today's AR/MR devices are primarily designed for use by non-industrial users and are not well-suited for use in harsh, rugged, outdoor manufacturing environments. Devices must be tough, waterproof, and capable of several hours of continuous use. Hardware designs (specifically for head-mounted wearables) will require integration with personal protective equipment (i.e., hard-hats, hearing and eye protection) and comply with applicable OHSA requirements as necessary. AR/MR devices are also fairly expensive, and don't come with an out-of-the-box capability for enabling content creation by non-specialized personnel.

Defense contractors are particularly sensitive to unintended information disclosure, device protection, and network security. Risks associated with introducing cutting-edge, evolving technologies like AR/MR into defense-related computing and manufacturing environments are not well-developed and fully understood. The ability to provision and remotely manage AR/MR devices and content through current enterprise device management systems has not been proven, and requires further investigation. Practical, secure, and easy-to-use authentication methods suitable for AR/MR devices need to be developed, tested, and implemented. Current authentication methods are cumbersome and difficult to use in industrial environments, especially while wearing gloves and other protective equipment.

It is entirely practical to assume that with a bit of development AR will be accurate, reliable and secure. The key is directed development that is focused on this topic. I predict that we'll see "hybrid sensing systems" that combine the strengths of depth sensing and optical recognition. The problem we are experiencing today is in a commercially driven market the major developers are relying on the technology they developed or invested in and trying to make it do everything. The team recommends remediating these challenges through the formation of collaborative alliances with technology vendors and academia to refine industrial requirements and cooperatively develop pathways to implementable, sustainable, and scalable AR/MR solutions for shipbuilding manufacturing. Specifically, the team recommends that Navy ManTech continue to support AR development/implementation by funding one or more of the projects described in the pilot plans included in Section 6 of this report. To do so will (A) make focused progress on breaking down specific technology barriers and (B) strengthen the industry collaboration in the areas of Augmented Reality.

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