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Applied Operations Research: Operator's Assistant

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ABSTRACT

NASA operates high value critical equipment (HVCE) that requires trouble shooting, periodic maintenance and continued monitoring by Operations staff. The complexity of the automated HVCE and amount of data and information required to maintain and trouble shoot HVCE to assure continued mission success as paper is voluminous. Training on new HVCE is commensurate with the need for equipment maintenance. Therefore, given this complex equipment and maintenance support NASA and the LaRC Research Directorate has undertaken a proactive approach with research to support Operations staff by initiation of the development and prototyping an electronic computer based portable maintenance aid (a.k.a Operator's Assistant, or OA). Portable maintenance aids are ubiquitous in commercial industry and Department of Defense. This applied operations research established a goal with multiple objectives and developed a working prototype operating within the existing NASA computer enterprise system and an industrial work environment. The research helped to identify affordable solutions; constraints; opportunities for improving knowledge management; demonstrated use of commercial off the shelf software; demonstrated use of the US Coast Guard Electronic Performance Support Solutions maintenance solution; demonstrated use of NASA Procedure Representation Language for use as an electronic Standard Operating Procedures capability; and the identification of computer system architecture strategies; where these demonstrations and capabilities support the facilities, Operator, and HVCE maintenance. The results of the applied research and prototype development revealed validation against measures of effectiveness and overall proved a substantial training and capability sustainment tool to support Operation's staff. The research indicated that the OA could be deployed operationally at the LaRC Compressor Station with an expectation of satisfactorily results and for use to obtain additional lessons learned prior to deployment at other LaRC Research Directorate Facilities. Further, the OA research revealed projected cost and time savings for operation of HVCE.

I. Introduction and Background

NASA's Langley Research Center (LaRC) Research Directorate (RD), Marshal Space Flight Center, and Ames Research Center owns and operates high value critical equipment (HVCE) in support of the national and commercial aerospace programs. The critical nature of this HVCE in support of these programs requires a high level state of readiness to support mission requirements. Recognizing the need to support and improve readiness, upgrades to existing equipment in the form of automation and selective replacement of older HVCE mandates Operations staff to attain a higher level of maintenance intensity and retain accessibility to an increased amount of maintenance and operational data and information. Further, Operations staff must be enabled to perform increasing levels of maintenance resulting from predictive maintenance data; trouble-shooting; parts identification, failure and replacement; system diagnostics; monitoring real time equipment operating data; with a system that could be expandable for future computer applications such as augmented reality (AR).

To facilitate closing a gap for use of electronic portable maintenance aids with HVCE, a prototype Operator's Assistant (OA) was deployed with four strategic goals and corresponding objectives identified, Table 1. The research was conducted in an existing industrial environment at the LaRC Compressor Station, Building 1247E. This LaRC location provided an ideal test bed for the prototype OA and evaluation.

The HVCE at the LaRC Compressor Station includes:

- Reciprocating Compressor #4 driven by a 4,000 HP synchronous motor installed circa 1960 that produces high pressure air up to 6,000 PSIG, and operated by a push button Motor Control Center

- Reciprocating Compressor #5 driven by a 4,000 HP synchronous motor installed circa 1973 that produces high pressure air up to 6,000 PSIG and was recently automated in 2015 to include programmable logic controllers linked to an Industrial Computer system consisting of an Allen-Bradley Historian™ and Factory Talk View™.

- Reciprocating Compressor #6 driven by a 4,000 HP synchronous motor installed circa 1995 that produces high pressure air up to 6,000 PSIG and operated by a push button Motor Control Center

- Two future commercial-off-the-shelf (COTS) combination centrifugal and reciprocating compressors where each is to be fully automated. These combination compressors are to be installed 4^{th} quarter FY'17 and FY'19 respectively and capable of producing high pressure air up to 6,000 PSIG. Compressor #4 will be replaced by one of these two new combination compressors.

As a test bed, the LaRC Compressor Station is similar to many of NASA's industrial operating schemes where an intensive industrial work environment is exhibited. The LaRC Compressor Station produces high pressure air with continuous operations servicing multiple customer's demands daily within the Center and this utility support operation is coupled with continuous infrastructure improvements. A complement of six Operations staff are resident, where two are required to operate an individual piece of equipment during start-up, operation, and shutdown. Comprehensive written Standard Operating Procedures are used and routine continuous monitoring of equipment must be performed. Aggressive trouble shooting is normal for each of the Compressors 4, 5 and 6 where each of these HVCE represents approximately 10,000 individual parts and must be actively maintained. The first floor of the facility (Operations Area), Break Room and Office Area was only recently equipped with Wi-Fi for access to the Langley Research Center network (LaRCNet). All areas of the facility basement are not covered with Wi-Fi reception.

Table 1
Strategic Goals – Operator's Assistant

Strategic Goal	Objective / Detail	Success
1	**1.2 Achieve efficiencies in providing IT services**	

	• Windows 7™ tablet access to Windows Office, email, VPN to LaRCNet
	• Access to Center's LaRCNet via Wi-Fi
	• IT support (via ACES)
	• Access to existing LaRC servers
	  ⅄ Center Operations Directorate (1247E Folder)
	  ⅄ LaRC Contractor: Construction, Management Operations and Engineering (CMOE)
	  ⅄ MAXIMO™ (CMMS software by IBM and operated by CMOE)
	  ⅄ CMOE Electronic Contract Management System (ECMS)
	  ⅄ Electronic Drawing File (EDF)
	  ⅄ Configuration Management On Line (CMOL)
		✓

2	**1.4 Provide enterprise applications that support the Agency's business and information needs**	
	• Windows 7™ Hewlett Packard Elitebook PC Tablet was readily available within ACES • Adaptable to other Center's IT architecture (MSFC, and ARC) • Demonstrated COTS CMMS Software (e.g. MAPCON™, used at NASA White Sands Space Harbor) deployed on the Operator's Assistant. Helped determine feasibility for use of bar code for equipment recognition, parent-daughter relationships, and facilitation of computerized maintenance management methodologies • Demonstrated COTS software: Acrobat™, Project Planner™, and suitability of Windows 7™ system to allow use of hand-held bar code scanner, Procedure Representation Language, and JAVA™ for use with CMMS software	✓
3	**1.5 Enhance mission success by providing efficient and effective access to enterprise information and collaborative functionality**	
	• OA can be configured to accept Input/output from diagnostic systems, or input from an Asset Condition Based Monitoring system (equipment health monitoring systems e.g., Sentinel™/Mhealth™) or show Real Time Operational data from Allen-Bradley Factory Talk View • Successfully installed USCG Electronic Performance Support Solution (EPSS) which demonstrates high value training capabilities based on use of a COTS software, e.g. Adobe RoboHelp 10™ • Successfully installed NASA's Procedure Representation Language (PRL) for use with facility's Standard Operating Procedures	✓
4	**3.1 Develop architectural roadmaps that reflect future mission requirements and guide selection of new IT**	
	• Operator's Assistant capable to run and operate on multiple NASA systems, LaRC RD, COTS software, and 3D models. • Augmented Reality requires "mapping", model development, and configuration • System approach to Augmented Reality (AR) initialized with an AR Roadmap	✓

Complementary objectives in this effort included: (1) integration of this work with LaRC RD Strategic Initiatives research to expand use of a prototype OA; (2) establish identification of critical high value equipment components using barcode tags with COTS barcode recognition software; (3) verify effectiveness of COTS software for equipment component recognition as deployed to provide equipment ID, identification of potential field problems associated with barcode recognition as installed on the equipment, determination that software is suitable for equipment information/data, and maintenance history reports; (4) resolve a recommendation identified in a NASA Safety Center Report, titled: *LaRC Compressor Station Reliability, Maintainability, and Availability Independent Assessment*, 2011, "to develop better maintenance data practices and data-gathering information for systems and components"; and (5) through Peer Reviewer's (Ames Research Center, Marshall Space Flight Center, US Coast Guard) collaboration identify industry best practices, understand commonality of industrial systems, identify OA software and hardware architecture that accommodates NASA's needs, and identify opportunities for strategic AR applications.

II. Approach

In this research, the OA was conceived to operate solely within the existing NASA enterprise computer system. This configuration would maximize the effectiveness and the integral support required of the system. Selection of the electronic computing device to be fielded as a prototype would also be limited to current offerings of personal computer models in the NASA ACES contract inventory. Capabilities for what is typically used and needed by an Operator were considered and a list was generated believed pertinent to a field deployed operating system in a portable maintenance aid. A comparison of capabilities with three operating platforms are presented in Table 2.

Table 2
Capabilities – Operator's Assistant

Item	Capabilities	Win 7	Apple	IOS, Android
1	Operator's familiarity with computing device function	✓	✓	✓
2	Microsoft Windows Office products i.e. WORD™, EXCEL™, Project Planner 10™	✓	X	X
3	Adobe Acrobat 9™, Reader DC™	✓	✓	X
4	Bluetooth™	✓	✓	✓
5	Operate with HTML, Apache-Tomcat™, JAVA™ for use with NASA's Procedure Representation Language (PRL)	✓	✓	X
6	Portability (3.8 Lbs.)	✓	✓	✓
7	Touch screen	✓	✓	✓
8	Read bar code (Onboard camera)	X	✓	✓
9	Virtual Private Network Access, Email	✓	✓	✓
10	COTS software configuration and support	✓	✓	X
11	Printing, battery life, Webcam, display screen, system backup	✓	✓	✓
12	Internet Access	✓	✓	X
13	Security (DAR, Smart Card, Updates)	✓	✓	✓
14	Expandability for future 3D modeling, Augmented Reality	✓	✓	X
15	Connectivity to LaRCNet Wi-Fi for CMOL, MAXIMO™, NX™, time sheets, newsletters, cafeteria lunch menu, other servers located on the LaRC network	✓	✓	X
16	Live system support, trouble shooting, updates	✓	✓	X
17	Access to peripherals, keyboard, USB Input	✓	✓	X
18	Memory, processing speed, RAM,	✓	✓	X

Based on an evaluation of the capabilities listed, access to and full editing capability for Microsoft Office software products was determined to be of higher priority for an Operator at this level of prototype development rather than use of onboard Webcam for reading equipment bar code.

Although there exists open source software that allows the use of Windows 7™ Webcam to read bar code, such as bcWebCam™, ByteCcout, and Zbar, the open source software Zbar could not be made functional. To gain a capability for reading bar codes with a Windows 7™ operating system, a handheld

Bluetooth enabled Socket Mobile™ Model: CHS 7Di, 1D, Durable; laser bar code scanner was used and found successful for use with Windows 7™ operating platform.

The OA used as a prototype in this research was a personal computer tablet Hewlett Packard Elitebook 2760p, pen and touch input screen, 32 Bit, 298 GB disk capacity, 8 GB RAM, Intel® Core™ CPU at 2.5 GHz, and 10.5" x 6.5" screen, 3.8 lbs, equipped with a docking station CD disk player, and ports for peripherals. A screen shot of the OA appears in Figure 1.

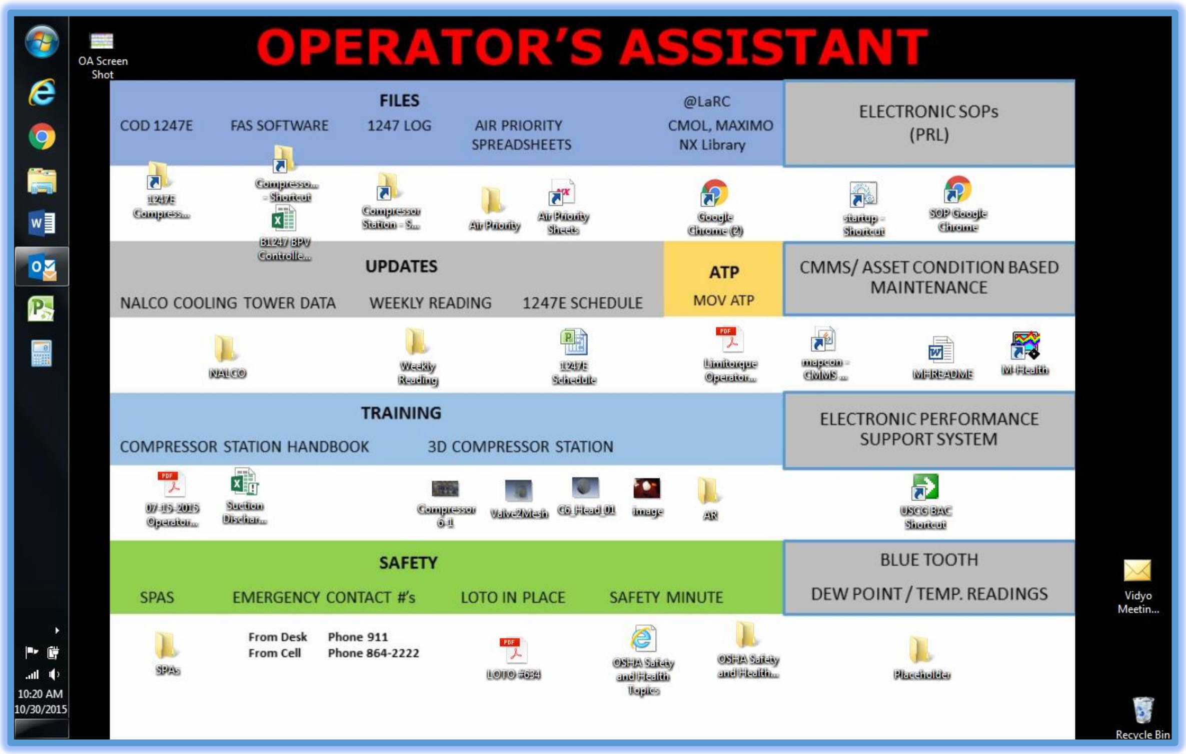

Figure 1. Screen Shot - Operator's Assistant

Software applications, servers and files identified as significant capabilities that are typically used and anticipated to be used by Operations Staff were incorporated into this OA research, identified in Table 3.

Table 3
Applications - Operator's Assistant

Item	Description	Support Area
1	WORD™, EXCEL™, Project Planner 10™	Operations, Training, O&M Support
2	USGS Electronic Performance Solutions (EPSS)	Training
3	CMMS (Mapcon™)	O&M Support
5	Air Priority Spreadsheets	Operations
6	CMOL, COD 1247E, NX™, FAS Software, MAXIMO™, Compressor Station maintenance Log, NALCO™ Cooling Tower Data	O&M Support, Operations
7	Compressor Station Handbook,	Training
8	NASA's Procedure Representation Language (Electronic SOPs)	Operations
9	Safety Plan of Action (SPA)	Operations
10	Bluetooth Compressor 5 Stage 1A, Suction and Discharge Valve Temperatures(1)	O&M Support
11	Bluetooth Dew Point (Hygrometer) Data(1)	O&M Support
12	MHealth™(2) (Asset Condition Based Monitoring)	O&M Support
13	Lock Out Tag Out (LF 495)	Operations
14	Safety Minute, Weekly Reading	Training
15	1247E Schedule	O&M Support, Operations
16	Emergency Contact #'s	Operations
17	Acceptance Test Plan (MOVs)	O&M Support
18	3D Compressor Station(3)	Training, Future AR as O&M Support

Notes:
(1) Scheduled to be completed by November 2015
(2) Not functional
(3) Work by Old Dominion University, Cooperative Agreement, NIA2A92, 2015

III. Challenges

Multiple challenges were identified in the prototype development. None of the challenges identified diminished the OA potential. The challenges could be resolved with further development during subsequent system deployment. The challenges are presented in Table 4 along with their impact and respective possible resolution.

Table 4
Challenges – Operator's Assistant

Item	Challenge	Impact/Resolution
Tablet PC		
Tablet Log In	Time out	Increases time/No foreseeable resolution
Tablet Weight	Unit used for Prototype 3.8 Lbs.	Operator fatigue/Tablets now have hand straps weigh 1.5 Lbs
Touch screen	Glove unfriendly	Touch screen ineffective with most work gloves/Gloves are offered now with touch screen pads
Screen size text/ icons	Text / Icons too small	Eye strain/Increase text and icon size
Training		
Training Priorities/Format	Priorities for training and format need to be established for each industrial area	Direct Staff Support/Increase training support similar to USCG EPPS
Budget	Inconsistent budget complicates HVCE training and method of delivery	Quality compromised, no capability sustainment/Executive imperative to resolve
Computer System Architecture		
Facility Wi-Fi Access	No Facility Wi-Fi for access to LaRCNet	No field communications/Wi-Fi installed
Industrial Computer System	The industrial loop of control PLCs and development computers must be independent of the business enterprise	Potential security/ operational issues/ Implement proposed computer system architecture See Figure 1
Lock Out Tag Out		
Electronic LOTO	No budget was available to evaluate electronic LOTO software capability	Lost time/Implement electronic LOTO software for evaluation See Figures 2 and 3
Asset Condition Based Monitoring (ACBM)		
Existing ACBM	Exist ACBM nonworking	Equipment condition cannot be evaluated effectively/Replace ACBM system
COTS ACBM	COTS ACBM providers supply 2D solutions	COTS 3D AR system not available/ System to accommodate future 3D AR
CMMS		
Access by Operator's	Operators are constrained by number of MAXIMO™ seats available to them	Use and function not fully exploited/ Provide seats as needed
Bar Code Tag (BCT) Placement	BCT provided NPR 4200.2B as paper tags – not suitable for high heat applications	Bar code tags ineffective for long term use/Develop cost effective solution
Bar Code Reading	Exist. Window 7™ platforms do not normally use of WebCam for reading bar code	Freeware such as Zbar ineffective/ Use handheld bar code scanner
Bar Code Running Parts	Running parts for COTS equipment do not receive a bar code tag	Inventory incomplete/Develop cost effective solution
Field Application	CMMS unavailable to Operator's in the field	
Integration		
Effort strategies	Begin OA use in small increments to obtain lessons learned	One system does not fit all/Learn basics and apply what we know that works
PRL strategies	14 LaRC RD facilities utilize approximately 881 paper copies of procedures for operation of equipment	Lost time/ Implement PRL for use with Electronic SOPs
Operator "Buy In"	Operator's must give "Buy In"	Operator complacency/deploy OA with Operator's obtain their input
PC Reliability	PC's reliability in the field	Non-use of OA/Continue PC support
Computer architecture	Computer system architecture must be expandable	System bottlenecks/Research computer system architecture to assure adaptability

Of the challenges identified in Table 4, three were explored in further detail. The first of these was the Industrial Computer System and a proposed system architecture proposed for use at the Compressor Station. This included identification of the existing system components and those planned for future implementation in the future as shown in Figure 1.

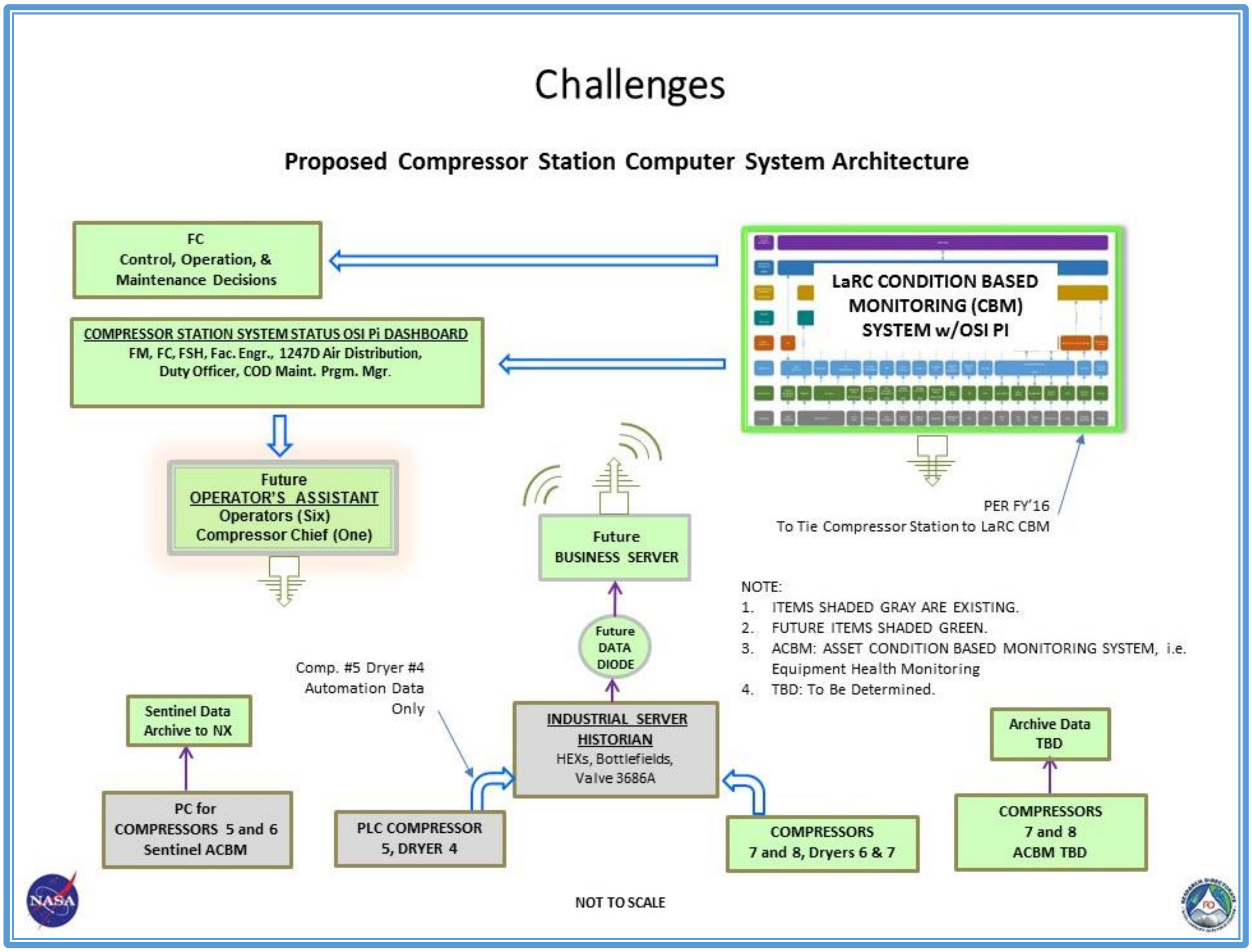

Figure 1. Proposed Compressor Station Computer System Architecture

The proposed Compressor Station Computer System Architecture, Figure 1, sequesters the Industrial Server while communicating status and operational condition of the HVCE. This arrangement for separating the industrial operations from the business operations seeking equipment status is common in many commercial enterprise operations and could be applied to LaRC RD Facilities to obtain multiple benefits including allowing capability for use of future AR applications.

The second challenge identified included used of Electronic Standard Operating Procedures in lieu of paper copy SOPs with handwritten entries. Electronic SOPs in effect are applied where NASA Procedures Representation Language (PRL) are used in operation of equipment. A work flow process analysis was conducted where paper copies were used versus an electronic SOP installed on the OA. The analysis revealed an estimate of at least two hours of time could potentially be saved by an Operator during the operation of the HVCE. Additional efficiencies for use of electronic note taking and recovery of documents was identified however, no time savings was identified for these attributes. Figure 2 compares the current and proposed work flow processes.

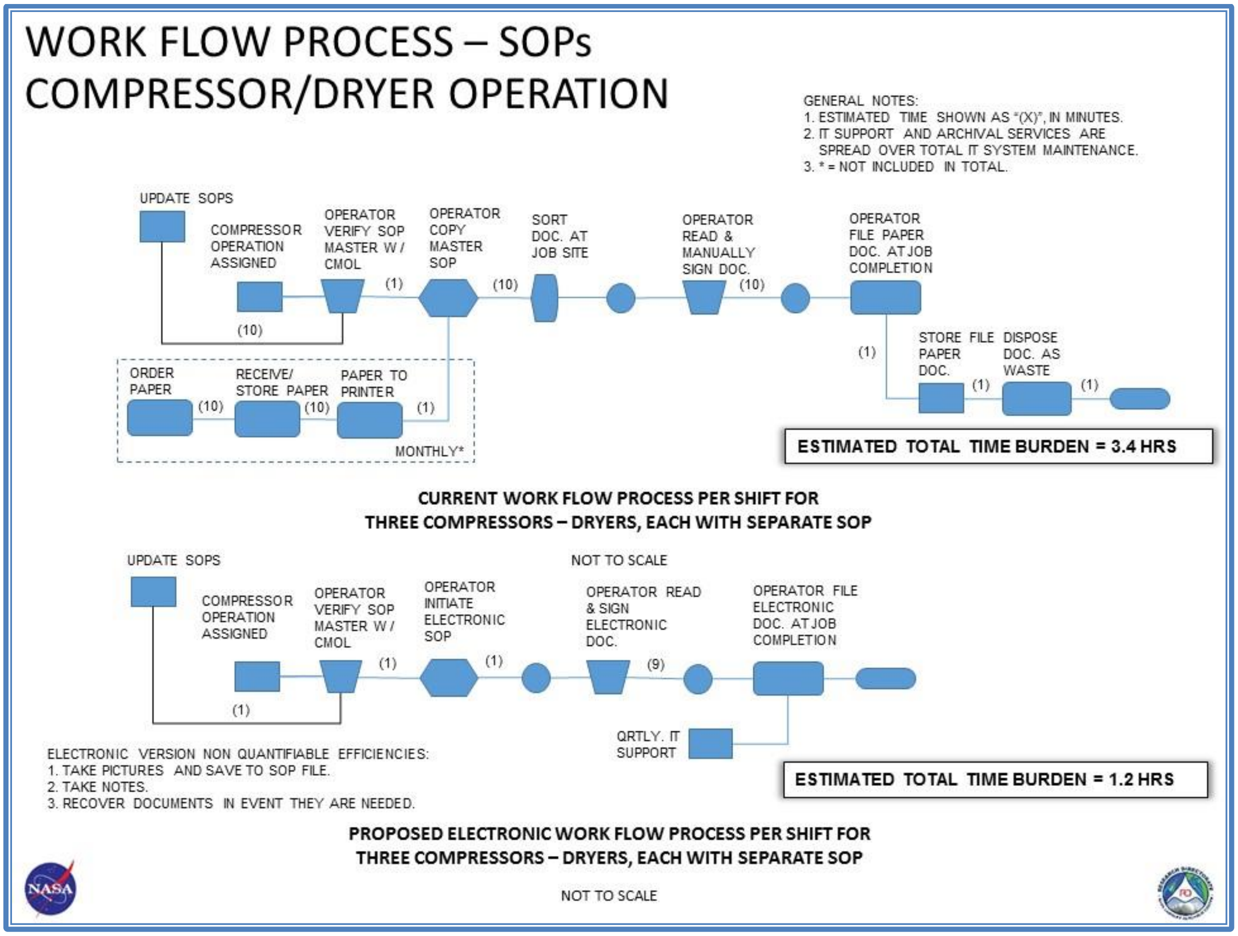

Figure 2. Work Flow Process -
Comparison of Existing SOP Operation of HVCE Using Hardcopy SOPs versus Electronic SOPs

The third challenge identified included use of an electronic Lock Out Tag Out (LOTO) system. Although the electronic LOTO software could not be evaluated in this research, a work flow analysis was conducted where paper copies were used versus an electronic software installed on the OA. The analysis revealed that an estimated four hours of time could potentially be saved by Operations staff during the initiation, preparation, and execution of a LOTO as shown in Figure 3.

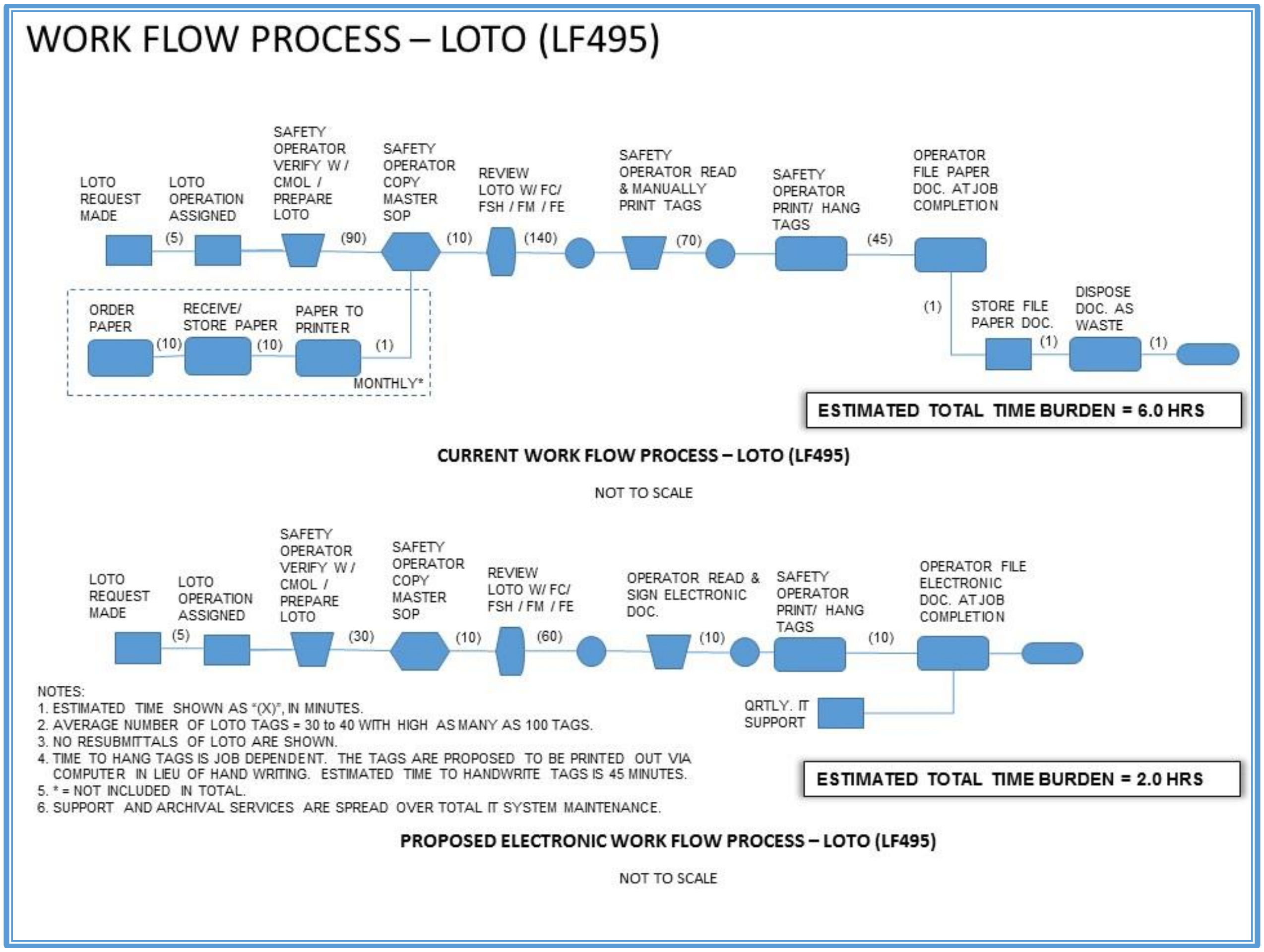

Figure 3. Work Flow Analysis – Comparison of Hard Copy LOTO Preparation versus Use of Electronic LOTO Software

IV. AR Applications

Augmented reality is the overlay of computer generated information, data, or graphics onto the real world view. The goal for use of AR in an industrial operating environment is to provide an Operator a real time capability to diagnose HVCE status, its operational condition, and support the Operator just in time data or information to assure the HVCE is within normal operating parameters. The OA was originally conceived first as an electronic device that could be accessed by an Operator to retrieve multiple sources of information, maintenance and equipment data. The progression of the OA capability with AR can exponentially improve the Operator's situational awareness of HVCE status, provide and indispensable aid to maintenance, and provide a higher level of training and learning.

The human machine interface (HMI) of information to the Operator complemented by AR and how it is accessed can be varied. Currently, AR applications in the commercial market in both hardware and software continue to be in the development phase and the HMI such as heads up display hardware changes rapidly. The strategic use of AR in an industrial environment however cannot be understated and will be fundamental to NASA's capability sustainment initiative and future HVCE maintenance and operation. Augmented Reality capabilities are mostly work still to be done, as that solution space rapidly evolves.

V. Results

The estimated technology readiness level (TRL) for the OA at start TRL 1, and at completion of this research was TRL 3. The OA should support all of NASA's operation and maintenance of HVCE and 14 Technology Areas as it pertains to training, operation, and documentation.

Operators were provided demonstration and then consulted at different times on the use and effectiveness of the OA. Comments by Operators indicated substantial acceptance. A desk top validation of the OA was performed to confirm that the system structure meets capability and operational expectation of the customer, users, and Operators. Measures of effectiveness are identified and evaluated in Table 5.

Table 5
Measures of Effectiveness

Measure of Effectiveness	Results
Information/Knowledge Management Resource	Satisfactory
Training Platform	Satisfactory
Accessibility to Existing Servers/Portals	Satisfactory
Use of Existing IT Infrastructure	Satisfactory
Use of Existing IT Support	Satisfactory
Integrate OA to Existing LaRC CMMS and read equipment bar code	Satisfactory

The OA was evaluated to be an evolutionary technology pull. It represents a technology that supports or enables specific functions, capabilities or performance levels, for a defined mission, ones that are not achievable by proven, existent approaches. Pull technologies are motivated by the specific needs for missions, where the missions are developed by enterprise organizations to satisfy long-term strategic goals.

An estimate for routine time and cost savings was prepared using work flow analysis. The use of the OA at the LaRC RD Compressor Station could potentially save up to an estimated 3,690 hours annually, and result in a Benefit Cost Ratio of approximately $10.21 savings and benefits generated for each dollar invested over an eight year period.

The results of the research indicate that the OA should be exploited as an affordable means to support Operator's training and HVCE operation and maintenance. Support to Operator's as a recommended solution will be by deployment to the Compressor Station operations staff where the following benefits and opportunities will be realized:

- Start small to obtain Lesson's Learned
- Migrate the OA into the Compressor Station first, then to LaRC RD, Centers, and NASA wide
- Continuously improve its use and capability to sustain connectivity, and Knowledge Management
- Initiate Electronic Standard Operating Procedures using NASA's Procedure Representation Language to save staff time
- Initiate training capability similar to the USCG Electronic Performance Support Solution
- Investigate use of COTS electronic LOTO software to save staff time
- Support and continue advances made in Augmented Reality Research to improve operation and maintenance posture, and increase the level of training required commensurate with the complexity of the HVCE

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Appendix A

Acronyms:

ACBM	Asset Condition Based Monitoring
ACES	Agency Consolidate End-User Services
a.k.a.	Also known as
AR	Augmented Reality
ARC	Ames Research Center
BCT	Bar Code Tag
CD	Compact Disk
CMMS	Computerized Maintenance Management System
COD	Center Operations Directorate
CMOE	Center Maintenance, Operations, and Engineering
CMOL	Configuration Management On Line
COTS	Commercial Off The Shelf
CPU	Central Processing Unit
CTO	Chief Technologist Office
Doc.	Document
ECMS	Electronic Contract Management System
EDF	Electronic Data File
EPSS	Electronic Performance Support Solution
Fac. Engr.	Facility Engineer
FAS	Facility Automation System
FC	Facility Coordinator
FE	Facility Engineer
FM	Facility Manager
FSH	Facility Safety Head
FY	Fiscal Year
GB	gigabyte
GHz	giga hertz
HEXs	Heat Exchangers
HP	Horse Power
HRS	Hours
HTML	Hypertext Markup Language
HVCE	High Value Critical Equipment
IOS	Internetwork Operating System
ISS	International Space Station
IT	Information Technology
JSC	Johnson Space Center
LaRC	Langley Research Center
LaRCNet	Langley Research Center Network
Lbs.	Pounds
LF	Langley Form
LOTO	Lock Out Tag Out
Maint.	Maintenance
MOVs	Motor Operated Valves
MSFC	Marshal Space Flight Center

NASA National Aeronautics and Space Administration

NTRS NASA Technical Report Server

OA Operator's Assistant

O&M Operations and Maintenance

PC Personal Computer

PLCs Programmable Logic Controllers

PSIG Pounds per Square Inch Gage

Prgm. Mgr. Program Manager

PRL Procedure Representation Language

RAM Radon Access Memory

RD Research Directorate

SOPs Standard Operating Procedures

SPA Safety Plan of Action

STI Scientific and Technical Information

TBD To Be Determined

TM Technical Memorandum

TM Trade Mark

T&I Technology and Information

TRL Technology Readiness Level

US United States

USCG United States Coast Guard

VA Virginia

W/ with

WBS Work Breakdown Structure

Wi-Fi Wireless Fidelity

Win Windows

2D Two Dimension

3D Three Dimension

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14. ABSTRACT
NASA operates high value critical equipment (HVCE) that requires trouble shooting, periodic maintenance and continued monitoring by Operations staff. The complexity HVCE and information required to maintain and trouble shoot HVCE to assure continued mission success as paper is voluminous. Training on new HVCE is commensurate with the need for equipment maintenance. LaRC Research Directorate has undertaken a proactive research to support Operations staff by initiation of the development and prototyping an electronic computer based portable maintenance aid (Operator's Assistant). This research established a goal with multiple objectives and a working prototype was developed. The research identified affordable solutions; constraints; demonstrated use of commercial off the shelf software; use of the US Coast Guard maintenance solution; NASA Procedure Representation Language; and the identification of computer system strategies; where these demonstrations and capabilities support the Operator, and maintenance. The results revealed validation against measures of effectiveness and overall proved a substantial training and capability sustainment tool. The research indicated that the OA could be deployed operationally at the LaRC Compressor Station with an expectation of satisfactorily results and to obtain additional lessons learned prior to deployment at other LaRC Research Directorate Facilities. The research revealed projected cost and time savings.

15. SUBJECT TERMS
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