



Final Project Report

Digital Twin Testbed for Process Manufacturing	
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I. EXECUTIVE SUMMARY

This project had, at its core, a desire to implement and see the benefits of digital twin and mobile worker technologies. This project set out to accomplish this by upgrading existing industry practices, standards and systems to digital industry 4.0 level where they exist (historians, standard operational procedures, process control systems, etc...) and to insert digitalization where technology gaps exist (mobility, breaking down data silos, digital twinning, AI, AR, etc...).

Using a simplified model such as a process test bed skid allowed for an interesting and visual way of showing what is available in the above-mentioned ways for the digital transformation of continuous process manufacturing. DMC, in collaboration with Siemens, developed a physical skid and a virtual software layer specially fitted and tailored to MxD’s space and purpose to address the requirements set by RFP MxD-19-04. This system was based on similar work performed by Siemens at Process Automation World in Karlsruhe, Germany.

In order to guarantee a seamless experience for both top floor and shop floor professionals in continuous manufacturing we applied mobility on top of the existing good practices of data historians and integrated control and safety systems plugged into digital networks and smart devices.

The use cases addressed by this project were answered with a full stack of hardware and software from the Siemens product catalog mated to a custom designed tank system.

Siemens process control hardware was paired with the PCS neo DCS to create a mobile enabled instrumentation and control platform. This system provides the baseline skid functionality to enhance and explore control system concepts on. In addition to baseline process control functionality, a software stack was implemented to provide the MES, digital twin, and mobile worker functionality.

The challenges of pulling together this many disparate components into a single installation were numerous. Each of the components would be a relatively large integration effort when taken individually and the interoperability is a project in and of itself for each of these items. The system, as assembled provides a solid foundation for future demonstration of the possibilities and development towards easing the integration challenges faced by future efforts to create an integrated mobile worker solution in industry.

II. PROJECT DELIVERABLES

The following list includes all deliverables created through this project. These deliverables will be referenced throughout this final report and can be accessed on the membership portal in accordance with the rights defined in the Membership Agreement.

#	Deliverable Name	Description	Deliverable Type
1	Project Immersion Workshop	Face to face meeting with Pilot Manufacturer including stakeholders from key business units to review project transition plan and define pilot requirements	Meeting



2	Siemens Software Platforms	Software resulting from the testbed development, necessary to run the testbed demonstrations, and to operate and maintain the testbed post-project. Inclusive of licenses for all software components involved in the system such as PCS neo, IMATIC IT, COMOS, regulatory control software for process control, and IIoT integration platform for capturing sensor data.	Software installed on skid
3	Mobile Worker Smart Devices	Industrial tablets and smart glasses for access to the above software and Augmented Reality.	Physical devices
4	Technical Data Package	Piping and Instrumentation Diagrams (P&ID), Floor Plans, CAD models (if applicable), BOM, Instrumentation Specifications, Software Documentation (Siemens)	Documents
5	Playbook for Testbed Digital Integration	Playbook for explaining steps and considerations for integration of digital technology for a process testbed	Document
6	System Architecture & Integration Framework	Documentation of the system architecture and integration framework including approach and diagrams	Documents
7	Network Architecture	Documentation of the network architecture including approach, diagrams, and considerations for compliance and security	Document
8	Mobile Worker Software Tool	All project-developed software including source code, executables, and APIs	Software
9	Test & Validation Report	Technical report on testing results for the physical testbed and digital technology developed and implemented	Document
10	Technical Demonstrations at MxD	Demonstration of technical research and development outcomes in MxD's factory	Meeting
11	Testbed Operation Training	Training for testbed operation and maintenance for MxD representatives and member representatives identified by MxD; includes training needed for testbed reconfiguration for future experimentation	Meeting
12	Mobile Worker Research Report	Report of end-user interviews and gap analysis for the mobile worker solution	Document
13	Mobile Worker Operator Training Curriculum	Curriculum for training manufacturing operators how to use the mobile worker solution	Document



14	Mobile Worker Solution Training (Trainers)	Training for at least 5 trainers from MxD’s manufacturer members on how to teach operator training curriculum	Meeting
15	User Manuals	Includes user manuals for all modes of operation; also includes installation instructions and operation and maintenance manuals	Documents
16	Transition Plan	Written plan for successful transition of project outcomes after period of performance including technology integration, educational distribution, and potential commercialization	Document

III. PROJECT REVIEW

USE CASES & PROBLEM STATEMENT

This project targeted the following key use cases:

The following use cases were implemented to represent the internal and external organizations found at industry sites, simplifying a team of managers, supervisors, specialists and technicians into six different mobile personas, each with their specific sets of tasks and responsibilities:

- **Mobile Use Case 1: Factory Manager:** Operations Intelligence (OI) Dashboard on an industrial tablet connected not only to the process sensors through the Industrial Internet of Things (IIoT), but also to Enterprise Resource Planning (ERP) and Business Intelligence (BI) systems. Allows for flexible and timely command of the factory operations and field operators.
- **Mobile Use Case 2: Continuous Process Manufacturing Operator:** Brings the traditional Human Machine Interface (HMI) from the control room to the hands of the operator, independent of the location of the operator.
- **Mobile Use Case 3: Digital Asset Reliability Engineering:** View the operational data and get Artificial Intelligence recommendations on timing equipment inspections, maintenance and replacements. Has access to digital twins from asset design and process engineering as well as equipment, automation, process and plant simulations in order to gain the capability to contextualize and to drill down on the specific technology applications.
- **Mobile Use Case 4: Maintenance:** Receives maintenance orders on an industrial tablet from any of the above mobile worker colleagues. Access design digital twins for process, electrical, power, and utility information. Checks work permission and previous work orders and the Bills of Materials of the relevant assets.
- **Mobile Use Case 5: Installation Services:** Consults the Electronic Work Instructions of the relevant asset, such as a pump or a motor, for how to mount, put it together, connect, install and validate the installation on the industrial tablet and through Augmented Reality glasses layering the virtual world with the physical world. Used in workforce training as well as during standard operations.
- **Mobile Use Case 6: 3rd Party Assisted Service:** Subcontracted industrial service professional comes to the site and connects with a tablet and Augmented Reality while



guided by off-site specialist on inspection and calibration on instruments. IIoT connection and Artificial Intelligence used for planning and scheduling the on-demand condition based predictive service calls.

SCOPE & OBJECTIVES

This project aimed to enable the use cases of this project with a physical skid capable of being a baseline on which to both demonstrate the use cases described above, but also to provide a playground in which new concepts could be tested. This physical system was paired with a software infrastructure to execute the above use cases.

- PCS neo
 - Process Control System
- Opcenter Execution Process
 - Manufacturing Operations Management
- Opcenter Intelligence
 - MES/MOM Monitoring App
- Opcenter Formulation
 - Quality control software
- TeamCenter Project Lifecycle Management
 - Web based, mobile worker enabled
 - Visualization server for 3D model rendering
- NX CAD
 - Machine design, product used in digital twin functionality
- COMOS Plant Engineering Software
 - Walkinside 3D visualization
 - Smart P&ID and instrumentation information
- SimCenter FloMaster
 - Real time calculation of a virtual sensor based on simulation
- SIMIT
 - Digital twin of control hardware
 - Non-physics based simulation for virtual commissioning
- XHQ & Mindsphere Mendix
 - Executive dashboards
- Asset Performance Suite
 - StoreIQ
 - Tank farm visualization dashboard
 - SimoticsIQ
 - Vibration condition monitoring
- SIPIX
 - Remote assistance software with Epson AR graphics

Project Objectives:

- Operational Physical skid that met both physical size and safety considerations
- Operational stack of software to handle MES, mobile worker, digital twin, and dashboard functionality.

TECHNICAL APPROACH

Task 1 – Skid

The skid was designed in collaboration with the machine builder, DAPR, and the project team. The operational concepts and P&ID were created as a collaboration with the team. The core need of the basic process was that it needed fit a shop footprint, be “impressive”, show basic process control operations, and provide visibility to the control components for MxD visitors.

The physical design was also developed collaboratively with aesthetics in mind.



Task 2 – Digital Twin

The skid was designed in 3D CAD from the beginning and delivered in Siemens NX format. The industry standard for models provided by manufacturers is to provide “fitment models”. This CAD model was used in COMOS Walkinside training visualization tool and inside RE’FLECT augmented reality maintenance system.

NOTE: The RE’FLEKT tool was used to guide the user through a pump replacement while wearing a Microsoft HoloLens. However, the RE’FLEKT platform was shut down prior to delivery of this project.

Physics based digital twin functionality was implemented with SimCenter Flomaster where sensor data was read into a physics based simulation engine to create a virtual flow meter. This virtual flow meter was then displayed on the PCS neo DCS screen.

Virtual commissioning digital twin functionality was implemented with SIMIT. This provided a virtual controller with basic responses to allow basic functionality tests prior to downloading to the controller on the skid.



Task 3 – Mobile Worker Solution

The mobile worker solution consisted of a number of components that were targeted towards allowing all elements of the workforce to be mobile.

The control system, MES system, and dashboards were all designed with tablet use and mobility in mind. In addition, the SIPIX system with Epson glasses was designed to allow remote support of maintenance technicians while providing ultimate freedom to work where the problem exists.

PLANNED BENEFITS

This system is expected to provide the following major benefits at the end of the period of performance:

- Visual appeal on the MxD shop floor.
- Demonstration of modern process control solutions
- Demonstration of an integrated full stack implementation from control to manufacturing operations
- Demonstration of the potential of a mobile worker solution
- Demonstration of digital twin functionality
- Demonstration of modern cloud enabled analytics functionality

The future benefits of this solution are:

- Instrumentation and piping base for experimentation with open process control concepts
- Platform for testing of digital twin and mobile worker concepts

IV. KPI'S & METRICS

The table below outlines the key performance indicators and metrics used to evaluate the success of the project outcomes in comparison to the current state and proposed goals.

Metric	Baseline	Goal	Results	Validation Method
Operational test skid	No process system at MxD	Process skid deployed at DMC and able to meet functionality requirements.	Operational	Skid in operation at MxD since ribbon cutting in July 2021
PCS neo deployment	No DCS/PCS system installed at MxD	Operational skid.	Operational	Skid in operation at MxD since ribbon cutting in July 2021
Full stack mobile worker deployment	No full stack instrumentation to business integration solution with mobile worker enablement at MxD	Mobile operators are able to view data about the skid and operate it as a cohesive system.	Operational	Ability for the system to operate according to the Master demonstration script as provided by Siemens.



V. TECHNOLOGY OUTCOMES

TECHNOLOGY DELIVERABLES

#	Deliverable Name	Description	Format of Delivery
1	Physical Skid	Physical system of pipes, wiring, instrumentation, and superstructure.	Physical system delivered to MxD
2	PCS neo	Process control System	Software and configuration installed on skid
3	Opcenter Execution Process	Manufacturing Execution System/Manufacturing Operations Management. Used to create work orders.	Software and configuration installed on skid
4	Opcenter Intelligence	Operations Dashboard -Availability of system provided in a dashboard. Utilizes Mindsphere capabilities as an IIOT OS	Installed in MxD Mindsphere tenant
5	Opcenter Formulation/RD&L	Quality control system	Software and configuration installed on skid
6	Teamcenter	Products lifecycle management, plant data aggregation	Software and configuration installed on skid
7	NX	3D model and model generation software	CAD file in SharePoint, software installed on skid
8	COMOS	Plant engineering software. Handles record of P&ID, instrumentation, and maintenance work instructions.	Software and configuration installed on skid
9	COMOS Walkinside	3D digital twin viewing for operator training	Software and configuration installed on skid
10	SimCenter Flomaster	Physics based digital twin used to create a virtual flowmeter on the PCS neo screen.	Software and configuration installed on skid
11	SIMIT	Virtual commissioning software	Software and configuration installed on skid
12	XHQ	Operations dashboard	Software and configuration installed on skid
13	Mindsphere Mendix	Intelligent app platform and dashboard	Installed in MxD Mindsphere tenant
14	StoreIQ	Tank farm visualization software	Installed in MxD Mindsphere tenant
15	SimoticsIQ	Vibration condition monitoring for motors	Installed in MxD Mindsphere tenant
16	SIPIX	Physical tablet and smart glasses plus remote assistance software	Physical devices delivered to MxD



SYSTEM OVERVIEW

The MxD 19-04 project created a process demonstration skid (PDS) at the MxD facility in Chicago. This skid is accompanied by a full software stack designed to demonstrate the use of modern mobile technologies. This effort condensed a full stack of software designed to operate billion-dollar facilities into an accessible platform that helps develop understanding of the use and implementation of these new technologies.

From bottom up the system consists of the physical process, the process equipment, and the control devices, such as pressure, level, temperature, wireless temperature/vibration sensors; drive controls, control valve actuators; cables, switches, CPU, field units and architecture that feeds the servers and software on the plant bus level. There is an automation station, process historian and process device management maintenance station completing the traditional operational technology (OT) space.

On the information technology (IT) space there is a wide software stack serving design and optimization needs for the project, but also for improving the operations and maintenance relevant efficiencies. The software stack includes tools for 3D model authoring, 2D/1D authoring, validation and dynamic simulation of the process equipment, emulation of the control devices, manufacturing operations management, asset and process health monitoring, product lifecycle management, asset & operations dashboarding, operator and technician training, including for execution of installation, inspection, and maintenance tasks.

With two exceptions, the originally intended functionality was delivered.

The first exception was the original intention to install a Bluetooth sensor to measure a process variable. On investigation, it was determined that all such devices of this type were built to work with in manners not compatible with the goals of this project. Most, if not all, of these devices were designed to integrate with a proprietary cloud service and were not designed in a manner to integrate with third party devices.

The second exception was Augment Reality functionality. This feature set was built on top of RE'FLEKT and functionality was, effectively completed. The platform was purchased by PTC and slated for shutdown in June of 2022. As a result, this feature was removed from delivery. Siemens is in the process of working on a replacement system and will work with MxD once that system is ready for implementation.

SYSTEM REQUIREMENTS

As a partially Siemens funded effort, this system was designed as a full stack Siemens solution operating a physical skid. The demonstration script and training materials provide the needed information to perform demonstration of the skid and mobile worker solution.

For longer term research around mobile worker concepts, there are opportunities to interface with the system.

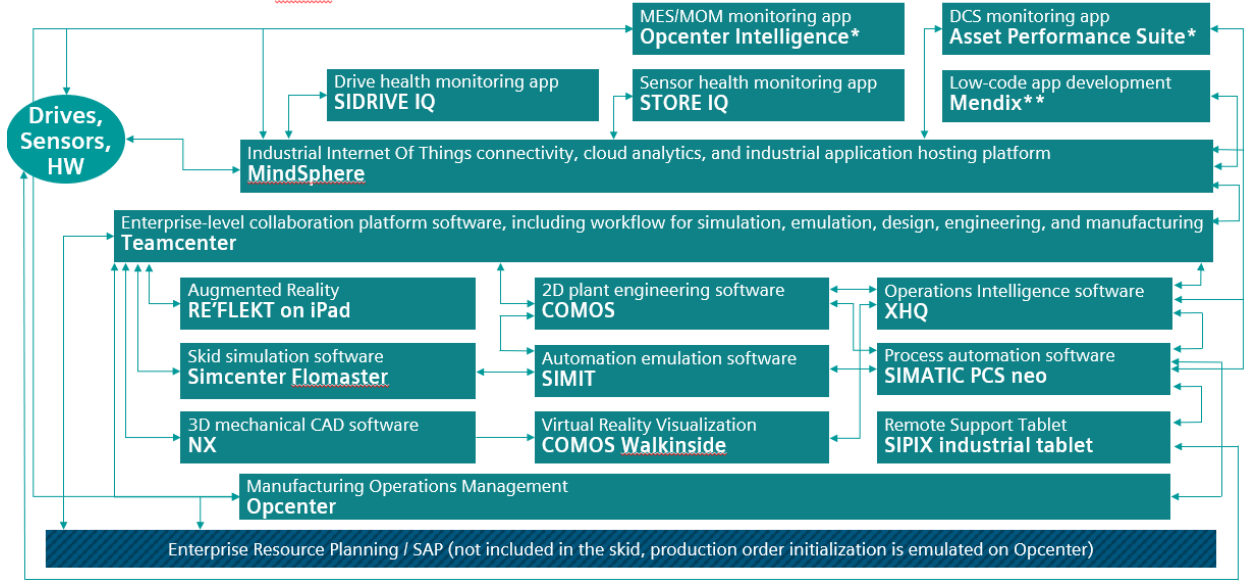
- PCS neo exposes data through OPC UA. Where data is already exposed, integration is simply connecting through the existing exposed tags. Where modification is needed, PCS neo can easily be modified to expose necessary tags.
- The device layer is ProfiNet and Profibus. All Profibus devices are connected to a ProfiNet aggregator. That means that any controller that can utilize the ProfiNet protocol and interface with profiNet devices can be integrated in place of the PCS neo controller directly through the ProfiNet network.

SYSTEM ARCHITECTURE

The diagram below represents the system software system architecture for the process demonstration skid.

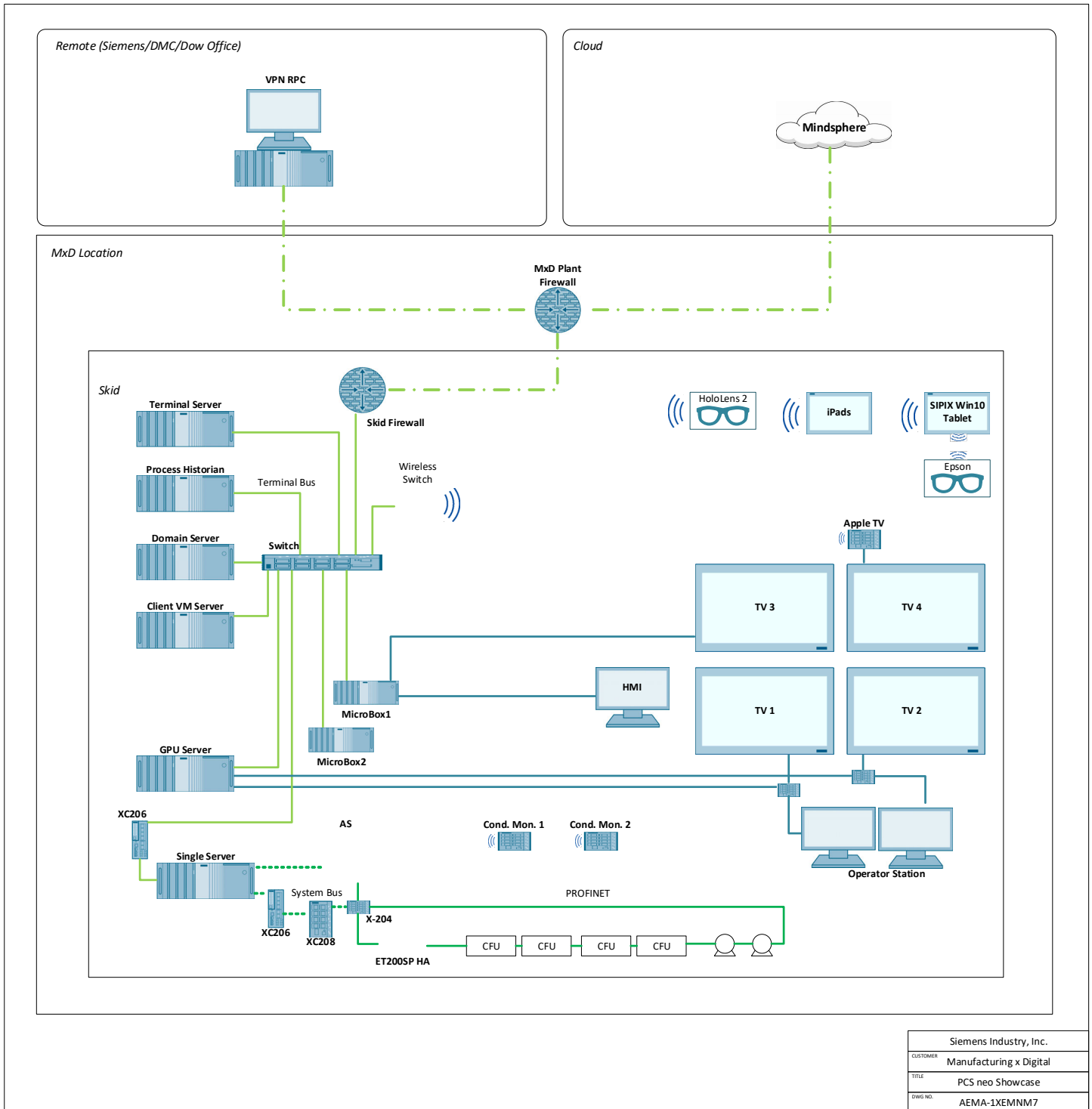


Product names of MxD skid software



*requires later version of PCS neo with batch support **with Siemens DISW Timeseries

The diagram below represents the physical computing infrastructure for the system.



	Siemens Industry, Inc.
CUSTOMER	Manufacturing x Digital
TITLE	PCS neo Showcase
DWG NO.	AEMA-1XEMNM7



FEATURES & ATTRIBUTES

Feature	Feature Provider
Physical system of pipes, wiring, instrumentation, and superstructure.	Physical Skid
Process control System	PCS neo
Manufacturing Execution System/Manufacturing Operations Management. Used to create work orders.	Opcenter Execution System
Operations Dashboard -Availability of system provided in a dashboard. Utilizes Mindsphere capabilities as an IIOT OS	Opcenter Intelligence
Quality control system	Opcenter Formulation/RD&L
Products lifecycle management, plant data aggregation	Teamcenter
3D model and model generation software	NX
Plant engineering software. Handles record of P&ID, instrumentation, and maintenance work instructions.	COMOS
3D digital twin viewing for operator training	COMOS Walkinside
Physics based digital twin used to create a virtual flowmeter on the PCS neo screen.	SimCenter Flomaster
Virtual commissioning	SIMIT
Operations dashboard	XHQ
Intelligent app platform and dashboard	Mindsphere Mendix
Tank farm visualization	StoreIQ
Vibration condition monitoring for motors	SimoticsIQ
Augmented reality remote assistance	SIPIX



TARGET USERS & MODES OF OPERATION

Feature	Factory Manager	Process Operator	Digital Asset Reliability Engineer	Maintenance	Installation Services	3rd Party Assisted Service
3D Model	X	X		X	X	X
Skid Control System	X	X				
Process Control Automation Simulation		X				
Quality and Laboratory	X	X	X			
Integration with ERP	X	X				
Work Order Instructions (Opcenter)	X	X				
Operations Dashboard Availability, utilizes Mindsphere OS	X	X	X	X		X
Operations Dashboard	X	X				
IIOT	X	X	X	X	X	X
3D Digital Twin Viewing	X		X			X
Maintenance Instructions (COMOS)				X	X	
AR Maintenance Instructions				X	X	X
Product lifecycle management	X	X	X	X	X	X

SOFTWARE DEVELOPMENT/DESIGN DOCUMENTATION

The software skid is a complex interconnection of the software components listed elsewhere in this document. Please refer to the Developer Documentation Report, Mobile Worker Specification, Skid Specification, Skid Operation, Training Videos, and user documentation deliverables submitted with this report.

VI. INDUSTRY IMPACT

The manufacturing and process industries are undergoing a period of significant transition. The technology gap between traditional IT and OT technologies is shrinking as control systems and industrial software gain ever increasing capabilities. This provides the opportunity to leverage mobility, cloud technologies, and levels of interoperability which were not available to the industry before. These technologies have been given the label of “Industry 4.0”

Industry 4.0 is still in its infancy and most companies are just beginning to explore how these technologies might be useful to them. This is compounded by the fact that industrial product lifecycles can be measured in decades as opposed to the single digit years of many IT assets.



This system provides an opportunity for potential adopters to see an operational full stack solution and explore the potential benefits to their organization without performing the expense and time commitment of a proof of concept at their own facility.

The second expected impact of this system is the ability to trial new concepts, such as open process control, in a safe environment against real process equipment. This safe playground provides an unprecedented opportunity for academic and research users to test concepts against a live system outside of simulation allowing for evaluation of functionality in the real world.

VII. TRANSITION PLAN

TRANSITION CHART

The transition chart provides a catalog of all of the project deliverables and their respective transition route. Deliverables can transition through deployment at an industry member’s site, as an educational reference or through a commercialization effort. Each of these transition routes are detailed in the Transition Summary section below.

#	Deliverable File Name	Technology Integration	Education	Commercialize
1	Testbed Hardware at MxD	X		
2	Siemens Software Platforms	X		
3	Configuration Code	X		
4	Mobile Worker Smart Devices	X		
5	Technical Data Package		X	
6	Playbook for Testbed Digital Integration		X	
7	System Architecture & Integration Framework		X	
8	Network Architecture		X	
9	Mobile Worker Software Tool	X		
10	Test & Validation Report		X	
11	Technical Demonstrations at MxD		X	
12	Testbed Operation Training		X	
13	Mobile Worker Research Report		X	
14	Mobile Worker Operator Training Curriculum		X	
15	Mobile Worker Solution Training		X	
16	Developer Documentation		X	
17	User Manuals		X	
18	Final Technical Report		X	

TRANSITION SUMMARY

Deliverable 1- Testbed Hardware at MxD

- MxD and Dow will deploy the testbed hardware, “the skid”, at MxD’s Future Factory in order to provide a foundational process manufacturing platform for future research and development purposes (e.g. testing of new solutions and digital twin use cases) through MxD projects and MxD Member-driven projects.

Deliverable 2- Siemens Software Platforms

- Siemens will deploy their software platforms at MxD’s Future Factory on the process skid in order to demonstrate a framework for collecting, processing and analyzing data from process manufacturing, enabling digital twins before manufacturers may deploy and scale aspects of the complete solution in their own factory environments.



Deliverable 3 – Configuration Code

- DMC will configure the digital solutions and any configuration code that is deployed will be available for MxD and MxD members to use and modify for future experimentation with the testbed.

Deliverable 4 – Mobile Worker Smart Devices

- Dow and MxD will deploy the mobile worker smart devices (including tablets and AR technology) at MxD's factory in order to provide educational demonstrations and training for end users (plant managers, process operators, and maintenance engineers) such that they can take the learnings back to inform their day-to-day jobs and improve familiarity and trust with these digital technologies.

Deliverable 5 – Technical Data Package

- The Technical Data Package will be used to educate MxD staff, the 19-04-03 project team, and members about the skid specifications, engineering designs, instrumentation, and software packages used on the project in order to inform future development and research that will build upon or modify the testbed.

Deliverable 6 – Playbook for Digital Testbed Integration

- The playbook will be used by Dow and other manufacturers and system integrators to learn about the steps and considerations for integration of digital technology for a process manufacturing application. This playbook will provide a guide for realizing value through each step of the transition through the digital transformation journey for brownfield and greenfield applications.

Deliverable 7 – System Architecture and Integration Framework

- The system architecture and integration framework documentation will be used by Dow, MxD, other manufacturers and system integrators to understand how and what data was connected into the digital twin so that the audience can replicate this method in their own factories and use it to inform future development that builds on the testbed.

Deliverable 8 – Network Architecture

- The network documentation will be used to educate MxD, Dow, and future R&D teams about the network architecture design including approach, diagrams, and considerations for compliance and security in order to inform MxD's cybersecurity initiatives and future R&D related to cybersecurity.

Deliverable 9 - Mobile Worker Software Tool

- Siemens will deploy a compilation of digital tools that encompass the Mobile Worker Software Tool at MxD's Future Factory in order to provide educational demonstrations and training for end users (plant managers, process operators, and maintenance engineers) such that they can take the learnings back to inform their day-to-day jobs and improve familiarity and trust with these digital technologies.

Deliverable 10 – Test and Validation Report

- The test and validation report will be used by MxD and Dow to ensure factory and system acceptance testing has been completed and that requirements have been met in order to mitigate post-project system failures and ensure handoff to MxD for operational use is successful.

Deliverable 11 – Technical Demonstrations at MxD

- The technical demonstrations of the testbed will be conducted in order to educate MxD staff, Dow, and MxD members about the new factory asset's functionality and purpose. A focus of the demonstration should be in garnering awareness of opportunities and plans for future use by MxD members.

Deliverable 12 – Testbed Operation Training

- Testbed operation training will be used to educate MxD staff and member representatives identified by MxD about day to day operation and maintenance of the testbed, delivery of all pre-developed demonstrations, and options for reconfiguration and expansion of the testbed capability for future use.



Deliverable 13 – Mobile Worker Research Report

- The Mobile Worker Research Report will be used to educate the project team and MxD members about the pain points experienced by the target end users (plant manager, process operators, and maintenance technicians) in order to prioritize features during design review and align the team on measurable success criteria for the project.

Deliverable 14 – Mobile Worker Operator Training Curriculum

- The Mobile Worker Operator Training Curriculum will be programming documentation used to educate Dow and other manufacturers' target users (plant managers, process operators, and maintenance technicians) on how to use the mobile worker solutions through interactive demonstrations in order to understand how the target users will interact with this technology and provide positive digital experiences that will increase adoption of similar technology on members' factory floor.

Deliverable 15 – Mobile Worker Solution Training

- The Mobile Worker Solution Training will be a “train-the-trainer” training used to educate instructors from MxD, Dow, and other members on how to deliver the mobile worker operator training curriculum in order to formally prepare personnel who will lead delivery of this curriculum on an operational basis (MxD tours, programming, and specific member engagements)

Deliverable 16 – Developer Documentation

- Developer documentation will be used to educate future researchers, developers, and system integrators from MxD or other members about the software development, configuration, and any known bugs/issues in order to inform modifications or reconfiguration necessary to complete future R&D projects.

Deliverable 17 – User Manuals

- User manuals will be used to educate Dow, MxD staff, and other members about all modes of operation, maintenance instructions, any software installation instructions, and any other information necessary to support the solution and use it for future research purposes.

Deliverable 18 – Final Technical Report

- The Final Technical Report will be used to educate Dow, MxD staff, and other members about what was implemented and how, the reasoning for technical decisions, lessons learned, and how the audience can use the final outcomes.

RECOMMENDED SEQUENCE OF USE

Technology Adoption

- It is recommended that all users first consult the Final Technical Report and Mobile Worker End User Report to understand the problem landscape and purpose for the testbed.
- It is best to then see the testbed demonstrations facilitated by a trained instructor.
- If a user is interested in potentially adopting pieces of technology from the testbed, the playbook for digital integration should be reviewed.

Training and Demonstration



- There are no prerequisites to receiving trainings and engaging in demonstrations related to the testbed, so it is encouraged that MxD members participate in these trainings to see the capability of the digital twin testbed.

R&D Use

- Prior to using the testbed for future R&D work, users must receive the operations training and other appropriate training from MxD needed to work in the MxD factory.
- Developer documentation, Technical Data Packages, and User Manuals should be consulted prior to initiating any development work with the testbed.

NEXT STEPS & CHALLENGES

The primary initial step is to provide access and visibility of the system to MxD members and other interested community members. This includes MxD, Siemens, and Dow tours and hands-on sessions with the equipment.

Several mid-term goals are:

- Implement and test an open process control system against the skid
- Enhance and improve the cloud data acquisition elements of the system
- Analyze the cloud and historian data for areas where data analytics are useful.

VIII. WORKFORCE DEVELOPMENT

Direct workforce development was not a major goal of this effort. However, this platform is an excellent opportunity for companies considering adoption of this technology to give their entire staff a hands-on experience with the technologies and gather feedback in preparation for an implementation.

IX. CONCLUSIONS & RECOMMENDATIONS

Rapid industry advancement is beginning to allow tighter integration of entire processes with the “next generation technologies” represented by the various concepts of digitalization, digital twin, IIOT, and more. These concepts are still quite immature in the industrial space and much work remains to be done to truly realize the offered benefits.

The system delivered as part of this project are implemented with the current state of the art in these technologies and are a beginning of what is achievable with this technology. The emerging nature provides opportunities to enhance the system and explore new concepts in the coming years.

The mobile worker capability demonstrated by the skid shows the state of what's possible. The current state of this technology is mature enough that utilizing mobility as part of a system is easily attainable. The challenges lie more in how to represent, display, and interact with systems in a small screen and touch orient interface paradigm. The skid and its associated systems provide a baseline on which to experiment with these quantities and explore better ways to engage with the system than just putting existing UI/UX on a tablet.

X. LESSONS LEARNED

Integrating this level of software stack is extremely challenging, even in a well-controlled environment like this. Even when products are designed to be interoperable, they may not comply with the same subset of standards. For example, even though data interchange was accomplished via OPC UA, different products required different parts of the standard to operate and neither supported the full stack required by the other



product. This required working with the support and engineering teams of the products to implement patches that allowed true interoperability.

Digital twin functionality requires a dramatic increase in design and data fidelity over that normally generated for systems.

For the 3D model digital twin, we learned that most models provided by manufacturers are fitment models. They are designed to be used in CAD used for system layout and assembly. Building up an AR electronic work instruction likely means building your own model which includes the inner workings of the system to be utilized in the EWI.

Even the most well-designed system will have variances when built. This is irrelevant in most cases as the variances are minor and consist of slight differences in positioning or routing. However, AR systems are generated from the CAD model. This means that the CAD must be updated to match the as-built and adds extra engineering time.

XI. ACCESSING THE TECHNOLOGY

The skid and its infrastructure are quite accessible. The necessary knowledge to operate it in its demonstration mode is quite modest and can be instructed by MxD staff as needed.

Further research into operation, such as the potential open process control or data mining of cloud data, would require reviewing design documentation, product user manuals, and may require formal training in the Siemens technologies to have the background to truly engage with the system on a research level.

XII. DEFINITIONS

What follows are a set of definitions, terms, and acronyms used in this document. These definitions were gathered from various source including the internet, reference papers, standards organizations, and the authors of these documents.

- **AR** – Augmented Reality
- **VR** – Virtual Reality
- **MES/MOM** – Manufacturing Execution System/Manufacturing Operations Management
- **CAD** – Computer Aided Design
- **Skid** – The physical process installed on MxD's shop floor
- **PCS** – Process Control System
- **DCS** – Distributed Control System (Often an alias for PCS)
- **EWI** – Electronic Work Instructions

XIII. APPENDICES

NONE