Purified Water SCADA System and Network Infrastructure Upgrade To a ArchestrA Virtual Platform

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Abstract *— Pharmaceutical Manufacturing Industry struggles between maintaining a low cost manufacturing, meeting strict regulations and avoiding obsolescence in their systems. Implementing upgrades to the existing systems in order to avoid obsolescence and meet regulations represents cost and time challenges. This project is about to the upgrade of a Purified Water Supervisory Control and Data Acquisition System (SCADA) and its related Network Infrastructure from an isolated network and obsolete hardware/software platform to a centralized Manufacturing Network System based on ArchestrA and Virtual Platform. The methodology of Flawless Project Execution was used to implement the best project leadership and management practices in order to deal with the constraints in time and budget. The approach used during this implementation represented a cost avoidance of approximately $24,800, implementation time reduction of approximately six (6) weeks, and power consumption reduction of 1,025 watts per hour due eliminated activities related to hardware.*

Key Terms *— Control System Upgrade, Flawless Project Execution, SCADA, Virtual Platform.*

Background Information and Problem Statement

The original hardware architecture was based on a four-generation old Hewlett Packard I/O and Terminal servers connected to a main console, Ethernet Switch, dedicated printer, and Programmable Logic Controller (PLC) located in a very restricted space within the Purified Water Control room. PLC is a microcomputer based device that uses stored instructions in programmable memory to implement logic, sequencing, timing, counting, and arithmetic control functions through digital or analog input/output modules for controlling various machines and processes [1]. PLC was able to control automatically all the Purified Water System operations without intervention of supporting personnel. Ethernet Switch provided connection to the two Thin Clients located at first and second floors of Purified Water Rooms. A thin client as described by 2X Software Ltd, is a device that relies on a server to operate. It provides a display device, keyboard and mouse and basic processing power in order to interact with the server. A thinclient device contains no moving parts such as fans or hard drives (in the case of a dedicated thinclient device). It does not store any of the data locally – it is very thin in features and functionality – hence the term ‘thin client’ [2]. Thin Clients (SCADAs) were used for routine maintenance such periodic sanitization, and monitoring activities of the Purified Water System performed by Engineering Personnel. The SCADA is a computerized system that gathers data, monitors and controls equipment, instrumentation and other devices of the Purified Water System. Terminal Server ran the Wonderware Intouch SCADA application and provided terminal services to the associated Thin Clients.

The I/O server was used to provide Water Process system reports, and allowed communication access between the Purified Water SCADA applications to all programmable control instrumentation. See Figure 1.

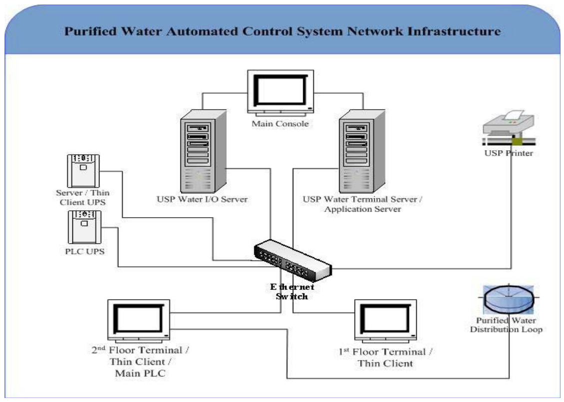

Figure 1
Original Purified Water Automated Control System Network Infrastructure

SCADA system of the Purified Water ran under an obsolete Microsoft Windows 2000 platform. This operating system was not longer supported by MICROSOFT Company and by design, the Microsoft Server Terminal CAL license expired; therefore, licenses were not available in the market. This provoked that Terminal Server restricted routine maintenance application activities from the Thin Clients used by Engineering Personnel. For security and safety purposes the system was designed to prevent engineering activities to be executed directly from the server. As consequence maintenance operations were delayed since the server had to be rebooted constantly.

The other challenge presented by the original architecture is that since the system was isolated from the Manufacturing Network, all administration services, such as backup and restore, applications version controls, antivirus checks, user access control and others services needed to be manually executed.

METHODOLOGY

Two alternatives were evaluated to address the instability issues due to obsolescence of software and hardware components of the system. The first option (Option A) was to maintain the original isolated network infrastructure and replace the Terminal Server and the I/O server by new models. In addition, upgrade the applicable software/ operating system, such as the Wonderware Intouch SCADA version 8.0 to version 10.1 and the Microsoft Windows 2000 to Microsoft Windows XP. This option will require Computer System Validation and the obsolescence in other components would not be addressed. Network troubleshooting, monitoring, administration, backup and restore activities had to be manually executed. The implementation time would be approximately of 22 weeks and the estimated cost will be $106,800.

Second alternative (Option B) consisted of the integration of the Purified Water Control System to the existing Manufacturing Network which runs in a virtual based platform. Major change would be in terms of software upgrades without altering the current functions of the Purified Water system application, either PLC program. The following activities would be required:

- Update to the software applications and related system licenses: Microsoft Windows XP Operating System, WonderWare InTouch 10.1, Wonderware Application Server 3.1 based on ArchestrA platform, Cristal Reports (to access reports from the web) and Wonderware active factory version 9.2 for trending reports (to access reports from the SCADA system).
- Integrate the USP Purified System to the Manufacturing Network servers under the Isolated Computer Environment (ICE) and to latest administrative technologies such as Backup Server, Antivirus system, Security Patches and Domain Controller to enhance Purified Water Control system architecture design by migrating SCADA to platform of ArchestrA Galaxy, Historian, and Virtualization infrastructure in order to address the same system functionalities of data access servers, data historization, reports and human machine interface, but increasing system reliability and efficiency. To create a business case for virtualization environment is important as presented by Brocade Company, built on benefits such as reduced capital and operating expenses because organizations need fewer

physical servers, making the server infrastructure less costly and easier to manage. With fewer machines, companies also have reduced power, cooling and data-center footprint requirements while improving security. Virtualization also improves the availability of applications and services, as enterprises can more easily recover virtual machines (VMs) from failure [3]. Despite of the benefits that virtualization platform can provide to business operations, enough documentation and adequate training to the support personnel should exist to assure proper management and understanding of the system.

ArchestrA™ is the next generation architecture for supervisory control and manufacturing information systems. It is an open and extensible system of components based on a distributed, object-oriented design [4]. The advantage of this platform is that it is capable of providing support to different programming languages, reduces complexity and facilitates administration activities due to common platform for all applications.

The following servers require configuration to run and manage the Purified Water System applications:

- Virtual WonderWare Industrial Application Server (IAS) 3.1. It is where the WonderWare Purified Water System application will reside. This environment is based on objects that represents physical equipment and include I/Os definitions, logic, scripting configuration, security, access control and alarms/events configurations that are stored in the virtual Integrated Development Environment Server (IDE). SCADA tags description needs to be updated as per ArchestrA Galaxy format (objects). Tags are usually designed for a specific or single function and specific hierarchy that makes difficult and time consuming any modification. In the other hand, as explained by Steven D. Garbrecht, in object-based SCADA applications, application objects contain aspects or parameters associated with the asset they represent. For example, a valve object can contain all the events, alarms, security, calculations, data collection, integrations, communications and scripting associated with the asset [5]. This allows that the same object can be used for similar devices and saves time and effort for configuration several functions for the same object.
- The IDE Server is used as the repository of all application objects. It is also configured to load and initialize the operating system without external intervention (bootstrap).
- Virtual Sever Historian in SQL 9.0 provides for real-time and historical database. This server is made-up of subsystems for configuration, data acquisition, data storage, data retrieval and event management; these subsystems work together to manage data flow.
- Pano Manager Sever provides virtual desktop interface, allowing the user to access to the virtual machines, without PC hardware, by using a zero access client. Pano devices are installed instead of workstations, servers or clients. Their power consumption is approximately of 5 to 6 watts per hour versus 80watts of a PC or 400watts of a server. Three zero access clients would be implemented to serve as two HMI thin clients for the first and second floors and one for Main Utilities Control Room.
- Domain Controller Server provides for the user's authentication through the Windows XP Operating System in addition to the security levels provided by the Purified Water Application. Security roles are defined by groups that allows for user verification at time of login. Login Screen of the Purified Water System would need to be modified since security services will

be provided by the Domain Controller Server of the Manufacturing Network.

- Process Control Monitoring System (PCMS) provides for the applications change control and version control. This virtual server is divided in two major areas: Management and the Scheduler. The Management is for the administration of control system application source codes. This includes the check-in, check out, audit trail and any modification to the applications. The Scheduler is responsible to schedule verification, auditing and reporting of the application source code of the SCADAs and PLCs. Validated backups are stored in the PCMS system. See to Figure 2 for the new network architecture.

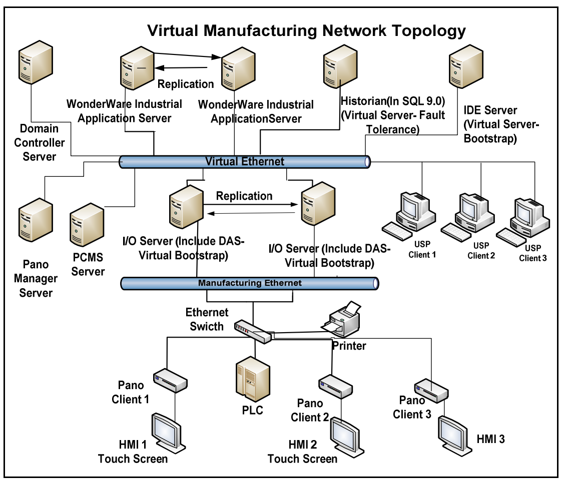

Figure 2

Purified Water Automated Control System Integrated to Manufacturing Network Infrastructure

The implementation time would be approximately of 16 weeks and the estimated cost will be $82,000.

The option B was selected based on that it provides the overall business objectives. This option eliminates the need of acquiring new hardware server/PC components, saves physical space in the control room and addresses the issues of the obsolete software performance. This alternative also requires Computer System Validation but some of the testing can be leveraged since the Manufacturing Network was already validated. Hardware requisition, documentation generation and approval, lead time, and installation to maintain the original infrastructure represented an approximately cost of $24,800 and additional project duration of approximately six (6) weeks. Option B offers the following benefits:

- Administration tasks will be performed automatically for System Application backup, antivirus verifications, control version monitoring.
- System Redundancy for all clients since they are virtual machines and can be easily duplicated.
- Reduce operations downtime related to computer hardware/software failure.
- Increase system reliability and enhance performance executing same current functions.
- Enable the capability for proactive maintenance by monitoring real time clients performance and provide team notifications.
- Reduce the costs related to PC lifecycle like power consumption, and hardware inventory.

RESULTS AND DISCUSSION

To deliver project objectives with the minimum duration and resources as possible, it was used the Flawless Project Execution (FPX) Methodology developed by Johnson & Johnson. This methodology was adjusted to fit the project complexity. FPX involves the following major phases:

- To establish Project Leader, Team Structure and Governance
- To align Team, Kick off Meeting and Development of Key Deliverables Matrix
- Development of Execution Plan and Risk Assessment
- Execute Best Practices and Project Close Out

Establish Project Leader, Team Structure and Governance

When an initiative needs to be deployed, it is time to form the team that will develop and execute the plan aligned to the business need. Selection of the Project Leader, Project Sponsor, and Core Team members is critical for the success of the project. Project Leader is the individual who is fully accountable for leading a team that will deliver the Final Project Objectives [6]. The Project Leader is responsible for the communication outside the team, establish the roles and responsibilities for the core team members, motivate the Core Team, facilitate the meetings, and formally close the project once all deliverables have been completed. The Project Sponsor is responsible to gain alignment of the Senior Management and Stakeholders on business expectations and secure the funds required for the implementation. The sponsor should eliminate the road blocks that the Project leader and core team are confronting. This person should be available for the Project Leader. Core Team member can manage sub-teams or ad-hoc members as required based on project complexity. Members to be included are the ones responsible for the key deliverables and not necessarily the ones that will be performing the task. The team members can be responsible for areas outside of their usual functional area. The core team members should have the empowerment to take decisions regarding their area and they need to have ability and expertise to identify resources and activities required to complete the deliverables under their responsibility, and provide support to the other core team members.

For the Purified Water SCADA and Network Infrastructure Upgrade to a ArchestrA Virtual Platform, Core Team was composed of four members, one from Information Technology, which was responsible for the technical aspects of the upgrade in terms of the Network Infrastructure and applications, one represented the System Owner that was responsible for Purified Water system, one from Quality Assurance, responsible for the compliance and regulatory aspects and one from Commissioning & Qualification responsible for leading the validation deliverables. Other ad-hoc members include Manufacturing Area and logistics that provide input in terms of Purified Water usage requirements and any anticipated Water System interruptions.

Align Team and Kick off Meeting

The team needs to be aligned in order to move forward to the Final Project Objectives (FPOs) with the purpose of avoiding misunderstanding and unnecessary redundancy of activities, this also helps to assure clear communication within and outside the team and reduce the risk of uncontrolled scope changes.

As part of team alignment and Kick off meeting, the project definition, FPOs, Timeline and Team Roles and Responsibilities are completed. During the Kick off meeting, the Project Leader presents a draft Project Definition, which is discussed and updated with the team members to obtain team commitment to the project. Project case covers “why” the project is important and “what” will be delivered by the team. Refer to Figure 3 for the project definition used for this initiative.

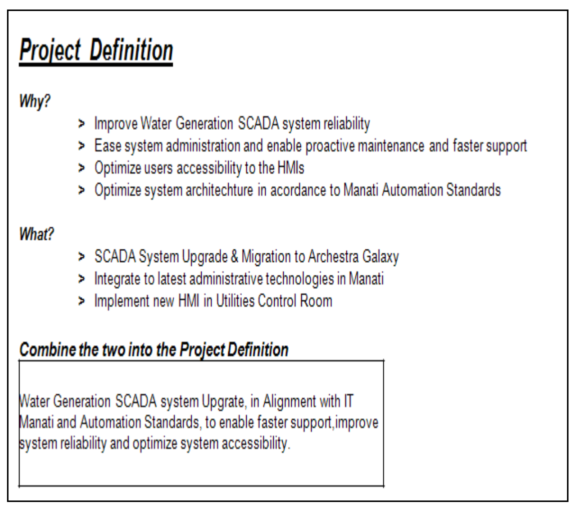

Figure 3
Project Definition

Based on the Project Case, the Team defines the Final Project Objectives (FPOs). These are the common goals that define the project success and guide the decision making. Figure 4 presents the FPOs defined for the Purified Water SCADA System and Network Infrastructure Upgrade to ArchestrA Virtual Platform.

FPOs

List Elements of FPOs from list below, or create new ones for your project

Schedule
Budget
Technical Capability
Customer Service
Sustainability

Write specific FPOs for each of the above

- > Implementation of SCADA system upgrade and migration as part of this project, completed no later than **1st Qtr 2012**.
- > Provide the required technical skills to IT Operations Team to support upgraded system.
- > Do not exceed budget of **$150K** on capital
- > No manufacturing impact (delays or deviations) associated with system upgrade and migration from execution to implementation.
- > Allow a stabilization time in which should maintain a maximum monthly average of 2 incident in 2 months after implementation.

Figure 4
Final Project Objectives

Timeline, roles and responsibilities are defined under Key Deliverables Matrix. This tool is used to track the progress of the project and covers the major phases or milestones and due dates. Usually, it is divided in four major phases presented in form of columns in order that it can be leveraged for other similar projects within the organization. Detailed tasks are covered under specific action plans provided by the core team members and not in the Key Deliverables Matrix. Refer to Figure 6 for the project Key Deliverables example.

Key Deliverables Matrix Document												
Project Name: Purified Water SCADA Migration												
Project Phases	A			B			C			D		
	Strategy and Timeline			Negotiation & Equipment/ Sortware Acquisition			System Upgrade Implementation			Technology Sustainability & Project Close Out		
Core Member	Criteria	Due Date	Status	Criteria	Due Date	Status	Criteria	Due Date	Status	Criteria	Due Date	Status
Project Leader	Provide support on the proposed implementation strategy	11-Oct	Done	Bidding Process			Follow up on deliverables execution on time			Close Change Control		
	Facilitate Kick-off meeting			Coordinatates Team Meetings			Coordinates Installation Activities			Complete all FPOs		
	CAR Approval			Update drawings			Coordinate PW Use Points monitoring					
Information Technology				Design upgrade and provide costs requirements			System Upgrade Configuration			Provides Training to Operations		
				Obtain licenses			System Upgrade Execution			Execute Retirement Activities for old infrastructe		
							Install and qualify client computer			Approve Final Report		
							Qualify client computer for Backup/Restore Server			Monitor system		
							Create User Accounts					
							Execute Functionality Confirmation					
CSV Specialist	Define requirements for Implementation Strategy						Develop Validation Documentation			Generate Final Report		
	Evaluate Current SDLC and Design Test Cases						Execute System Qualification					
QA Specialist	Provide support for development implementation Strategy						Approval of system documentation and Qualification Reports			Approve Final Report		
							Ensure system implementation Comply with Regulatory					
System Owner (Manufacturing)	**Provide Support for design of test cases**						**Provide resources for test cases execution**			**Approve Final Report**		
	Provide support on strategy to maintain water supply for other projects											

Figure 5
Key Deliverables Matrix Example

This tool is monitored during recurring Core Team Members meetings. Once an activity is completed, it is highlighted with a specific color in order to focus on activities not completed or that might be at risk. All activities are linked to a team member and they have to be understandable to the all team members. Duplicity of the activities between team members should be avoided unless it is required by a procedure or specific need, for example documentation approval. Core team member may have sub-teams or ad-hoc members based on project complexity.

Development of Execution Plan and Risk Assessment

After Key Deliverables Matrix is completed, all Core Team Members prepares their Action Plans to identify the required resources, materials and personnel to support the project within the timeline schedule and budget. They should recognize the interactions and dependencies with other projects, team members, processes, equipment, facilities and utilities. Team members should be able to identify if deliverables are achievable as estimated. Potential risk should be escalated to the Project Leader and if the Project Leader understands that the issue is out of his/her control, the Project Leader should escalate the situation to the Project Sponsor.

Execution Plans were developed for the Information Technology technical aspects and for the qualification exercises of this project.

Risk Assessment allows fast identification of potential project risk, evaluate the impact and develop a mitigation plan or alternatives to overcome issues. In addition; it serves to anticipate potential funds required for project associated risk management. In general, exits three types of risks. First are the known risks that are managed through the project plan, the second ones are the potential unknowns managed under risk management plan, and the third ones are the unexpected unknowns managed under regular team meetings and team communication plan. Risk Management Plan for the Purified Water SCADA System and Network

Infrastructure Upgrade to ArchestrA Virtual Platform project was documented under FPX Risk Register. This is a table that includes the risk description, the risk owner, probability of occurrence, impact, FPO affected, Mitigation description, Mitigation Owner, Probability of Mitigation, cost and time impact. Refer to Figure 6.

Risk Register												
Project: Purified Water SCADA Migration						Date of Review: 29-Nov-11						
>Identify Major Risk to your plan >Describe the risk that are not yet mitigated >List Mitigations included in your plan >Describe risk that cannot be mitigated												
TIMELINE RISK					FPO Affected	MITIGATION						ACTION ITEMS/COMMENTS
Risk #	Risk Area	Risk Owner	% Prob.of occurrence	Impact (weeks, OEE points, etc)	(See FPO Tab)	Mitigation	Mitigation Owner	% Prob. Post mitigation	Impact (weeks, OEE points, etc)	Incremental Time to implement	Cost Impact ($M)	
4	Define requirements for 2 phase strategy	T.D	H	H	Schedule	Document strategy on Work Order (1st Phase)	R.C.	H	N/A	TBD	TBD	Release Requirements are part of the Qualification Deliverables. The functional test will be documented on a Work Order.
6	Project Resources / Execution Conflicts with Project C	R.C	H	H	Schedule	Coordinate a projects alignment meeting with Leaders and inform results to core team members.	R.C.	M	2 weeks	TBD	TBD	1. Evaluate alternatives to provide water to Project C 2. Confirm USP SCADA qualification timeline
7	Does any water release activity is required?	T.D	H	H	Schedule	Justify that the release is not required by the fact that the project does not impact the water quality.	TD/AJ	M	TBD	TBD	TBD	Meet with Micro and QA to confirm requirements and update plan

Figure 6
Risk Register Example

Execute Best Practices and Project Close Out

During this phase, project execution is initialized using the tools previously discussed. Information Technology action plans started in a virtual development and testing environment to avoid interruptions to Manufacturing Process. Action plans execution included the virtual infrastructure development and certification, creation of virtual clients (servers and thin clients), hardware installation (related to new HMIs and PANO devices), applications migration and testing.

Approximately 2,500 existing Wonderware Intouch tags were manually created into ArchestrA 3.1 Galaxy as objects. Limitation of number of users that can be connected to the development and testing environment made difficult the process of ArchestrA objects verification. To address the issue, the objects were exported to Excel using a tool provided by the system. Export process was verified by taking a random sample of 125 objects based on ANSI/ASQC Z1.4-2003 methodology and comparing the exported objects characteristics in Excel against the objects in the system. In this way, the tester only needs to be connected in the Testing Environment for the 125 objects review. The remaining objects verification was performed using the Excel printout against the expected results.

Functions related to the SCADA and new Virtual Infrastructure were verified in the testing environment but the functions related to the PLC responses could not be tested in this environment. For this upgrade, no change to the PLC code was performed; the only modification to the PLC was IP address. Purified water system functions were not modified, for this reason; no impact in the system operations and or water quality was expected. As preventive action, team decided to perform a test of connecting the Purified Water system's PLC and SCADAs to the new infrastructure over a weekend and perform some functional testing while monitoring online critical Purified Water parameters.

Computer System Validation strategy included the update of Purified Water System Development Life Cycle documentation, leverage of Configuration and Functionality Verification package performed by IT Department and the execution of a generic pre-approved protocol. Functionality Verification Package covers virtual clients qualification performed as per a standard procedure and form. Test cases specific to the Purified Water System upgrade were generated and integrated to the generic protocol. Testing executed encompass comparison of the SCADA displays versus instruments display, objects functionality within the screens, infrastructure drawings accuracy, components verification, servers redundancy verification, procedures verification for operation, administration, backup and restore, environmental conditions verification for hardware (Panos devices and HMIs), software applications and PLC versions verification, Objects verification, communication verification, alarms challenge, reports accuracy and printing functionality.

During the testing related to the alarms, it was noticed that in case of a communication failure between the PLC and IAS, a critical alarm is generated that lead the system to fail into a safemode where purified water recirculation is stopped and it has to be manually re-activated. This would be an issue if the system is not continuously monitored (twenty four hours per seven day a week.)

A second issue found during the implementation is that a single Data Acquisition Service within the I/O server was dedicated to several areas in the plant. This resulted in DAS overload and intermittent communication failures of microseconds which generated that some objects do not update information in a timely manner. Decision making for engineering activities might be jeopardized since the current information might be delayed. Response of other supporting/control systems might be impacted due to outdated information. To address the situation, two corrective actions were implemented: the first one consisted on creating a DAS per system within the I/O server and the second one was to change the setup configuration to "Optimize for Read" option, in order to improve workload of the I/O server.

During the implementation process, Purified Water temperature reached out of limits, due to a configuration error. For this reason, Purified Water system was sanitized and all sample points were monitored per three consecutive days. Results were within the acceptable limits. Project could be officially closed after all applicable documentation was approved and all the FPOs were completed.

The project also included retirement activities of the old hardware and isolated network infrastructure. I/O Server, Terminal Sever, and thin clients were retired and disposed according to applicable procedures. Backup, restore and administration procedures for the original design were made obsolete.

Conclusion

This project demonstrates that using interdisciplinary functions and team collaboration approach, challenges related to obsolesce in systems can be addressed maintaining quality standards and budget constraints. Purified Water SCADA System was successfully upgraded to ArchestrA Virtual Platform and integrated to the Manufacturing Network. Upgraded System runs under a continuously monitored platform that provides a centralized administration, security, backup and restore tools. This platform allows for engineering and information technology support in a more efficient and fastest way.

The FPX methodology used during this project was a key element for the completion within time schedule and budget and to overcome issues arose during the process.

Finally, this implementation opens a window to create new ways of testing virtual environments and to recreate and simulate potential issues such as communication interruptions of microseconds. Testing software might be developed to provoke these interruptions and to understand responses of the system without putting at risk the real infrastructure and or systems.

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