Seamless Replacement of a DCS in a Large Wastewater Treatment Plant: Lessons Learned from the City of Fort Worth Village Creek Water Reclamation Plant

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ABSTRACT
Distributed Control Systems (DCSs) installed in the late 1980’s and early 1990’s have either been incrementally updated over the years or are long due for replacement, depending on the particular DCS product in question. Although the proprietary real-time operating system and programmed algorithms of a legacy DCS may work just fine, the hardware (controllers, workstations, servers, and network components) and general purpose operating systems (UNIX, Windows) that interact with them are likely beyond their commercial lifespan and are no longer supported. Unlike facilities which have regularly scheduled shutdowns that can provide an opportunity for full replacement of a DCS, a wastewater treatment plant runs 24 hours a day, seven days a week, and must meet permit requirements for effluent quality. There are four major areas that must be addressed in order to achieve a successful replacement of a DCS in a wastewater treatment plant; compliance with local, state, and federal regulations, operator acceptance of the modern DCS, stable and seamless transition of process control functionality, and comprehensive documentation.

This paper is a case study on how the four mentioned areas were successfully addressed for the replacement of a DCS in a large North Texas wastewater treatment plant. The project included DCS replacement, control room remodel, and update of the control area electrical infrastructure in the midst of other ongoing construction projects at the plant. Although the project involved replacement of a commercially obsolete proprietary DCS with a modern DCS (proprietary yes, but open to communication with other supplier components), many of the principles followed would apply to any effort to update a legacy control infrastructure. Mistakes and recovery activity will be discussed along with those items that executed as planned.

Introduction
The Village Creek Wastewater reclamation facility in Fort Worth Texas is a 166 MGD wastewater treatment facility featuring high rate clarification of influent, primary clarification, activated sludge processing, secondary clarification, digestion, and disinfection. The plant recently upgraded its facilities to permit use of digester and
landfill gas in a co-generation process that produces electrical power and steam for use in producing air for the activated sludge basins. The plant has won numerous awards; most recently the plant won the U.S. Environmental Protection Agency 2010 Sustainable Public Health Protection Award. Computerized process control has been an integral part of Village Creek operations for over 35 years, and the plant has had three generations of Distributed Control Systems (DCSs) installed from in the mid 1970’s to the present. This paper discusses aspects of the most recent generation, the Emerson Ovation Distributed Control System (DCS) commissioned in 2012. The paper discusses four areas that were addressed in the project to achieve the successful replacement of the legacy DCS: compliance with local, state, and federal regulations; operator acceptance of the new DCS; stable and seamless transition of process control functionality; and comprehensive documentation.

The legacy DCS in operation prior to 2012 was a 1990’s XL/System (XL/S) DCS manufactured by Johnson-Yokogawa. The XL/S was comprised of six controllers, known as Distributed Control Units (DCUs), a historical server, database server, operator workstations, and network components. The system featured over 200 sheets of Excel reports covering all aspects of plant operations, and having the built-in intelligence to flag circumstances where there was missing laboratory data or there were unique configurations of flow for short periods of time. Over the life of the XL/S, there have been several plant process upgrades that added or modified control strategies. In addition, several projects at the plant featured stand-alone Programmable Logic Controllers (PLCs) that were interfaced to the DCS system using Ethernet. Written documentation (in the XL/S O&M manuals) of changes to the legacy DCS after initial installation are of mixed quality, with some modifications being well documented and others being minimally documented.

**Compliance with Local, State, and Federal Regulations**

There are two aspects to regulatory compliance: meeting procurement regulations and meeting plant operating requirements so as to be in compliance with all regulations. Meeting the various procurement regulations in the execution of this project is a fascinating story but is outside of the scope of this paper. Meeting plant operating requirements so that there were no permit violations was a major criterion in all decisions associated with the project. Major decisions made once the particular DCS was chosen included:

1. Graphics and Control “look and feel” in the new DCS would be as near as possible to the “look and feel” of the legacy DCS.

2. Control logic in the new DCS would be patterned as nearly as possible to the logic in the existing DCS, with allowances for improvements in technology being offered in the new DCS.

3. Integrity of the data being sent to regulatory agencies was paramount. Reports would operate on the legacy DCS until all points had been cut over to the new DCS. This meant that a portion of the annual reporting cycle would utilize data residing in the legacy DCS and a portion would use data residing in the new DCS for the year 2012. After migration of all the points to the new DCS, the owner will then backfill data from the legacy DCS report into the new DCS report.

4. The plant would be transitioned to the new DCS in small segments that corresponded to specific processes, or by PLC units, rather than by legacy DCS groupings. These segments could have control strategies in
more than one DCS. The overall order of transition was presented in the Maintenance of Plant Operations (MOPO) plan.

5. Overall process stability, rather than speed of actual signal wire transition to the new system, was the goal of the transition plan. There were major physical relocations of process signals and marshalling locations when the legacy system was installed in 1992, and the system it replaced had several failing components. Therefore, the emphasis in 1992 was to move from the old system as quickly as possible, and fine-tune the control later. In 2012, the legacy system was not in danger of failure, the overall quantity of controls on the system was larger, wire relocation distances were minor, and efficient plant operations were strongly linked to the robustness of the process control strategies. Therefore, in order to minimize the risk of a plant upset leading to possible permit violations, it was decided that related process segments that had been transitioned to the new DCS would be fully tuned before moving to the next process.

Operator Acceptance of the new DCS

The key concepts of operator acceptance revolved around maintaining as much as possible the “look and feel” of the graphics, maintaining as much as possible similarity with the existing process control strategies. Operator acceptance of the reporting tool and manual data entry for laboratory data was also needed. The five steps taken in the application programming development to gain operator acceptance were: understanding the legacy DCS control strategies, understanding of the historical reports, methodical graphics application development, methodical controls application development, and careful application testing.

Deciphering Control Strategies and Preparing Control Narratives Submittal

While the legacy DCS did not support programming in any of the IEC languages, it did permit visualization of the logic in standard function block-like diagrams called strategy maps. Each strategy map was the size of an 8.5" x 11" paper with a limited number of the modules fitting onto the map. It could be produced as a printed sheet or PDF file. One process control strategy could span multiple strategy map pages. For the project team to properly review the legacy DCS strategy maps, they were drawn out by hand on an 11x17 paper using corresponding new DCS modules. This procedure consolidated multiple pages of the strategy maps into one sheet and had the benefit of educating the developer in how the legacy strategy operated. The hand-drawn maps facilitated easy review of the control strategies from the left (source registers) to the right (destination registers). An example of a hand drawn map is shown in Figure 1. Legacy DCS sequencer modules were drawn out using basic Boolean logic, arithmetic algorithms, and other control modules. An example of a sequencer module is shown in Figure 2, with its corresponding representation in function block-like logic shown in Figure 3.
FIGURE 1: Sample of a drawn out strategy map
FIGURE 2: Legacy DCS Sequencer module

Figure 3: Sequencer module representation in function block diagrams
The hand-drawn maps were thoroughly reviewed and compared to the existing control descriptions to make sure any process upgrades and strategy updates were documented. Any discrepancy found was documented as comments in the existing control descriptions. Tuning constants like timer presets, PID parameters, process clamps, and other constants were also vetted and discrepancies documented. The final document was sent to the owner as a controls description submittal for review.

After owner review, comment, and return of comments to the project team, face-to-face meetings were held to discuss review comments and resolve discrepancies. After incorporating the owner feedback and comments from the review meeting, the final control description narrative was completed. The replacement DCS was programmed based on this final control description. During the programming phase (a period lasting over a year), the owner maintained a strategy modification log to confirm that the new DCS incorporated any modifications that occurred after approval of the final control narrative.

**Historical Reports**

The legacy DCS had about 300 pages of reports in Excel format. Each page was an independent spreadsheet that collected raw data from the historical log. The initial step in duplicating the reports on the new system involved documenting all existing reports by name and listing the database points used in each report. A review document was put together listing each report and points associated with each report, and submitted to the owner for review. Because of the highly custom nature of each report, over the years nearly 100 reports had been created for special purposes and were no longer used. The owner identified which reports were obsolete and the updated final submittal only included the active reports for the new DCS.

**Graphics Application Development**

There were nearly 460 process monitoring graphics on the legacy DCS system, exclusive of control sub displays (popups). A three-step process was developed to convert the existing graphics into the new DCS graphics. VBA scripts were developed to convert legacy DCS process graphics to text files. These text files were in turn used as a starting point to generate the new DCS process graphic objects on process graphic screens. The objects were then located manually on the new graphics screens. This approach was taken because the new graphics builder application allows development of graphics with a text editor. Although a significant amount of time was spent developing and refining the scripts, the overall graphics effort proceeded quickly once the script files were executed. The use of VBA scripting of graphic objects minimized opportunities for human errors while developing the process graphics.

There was an additional graphics-related task of developing control pop ups. Operators use the control pop ups to enter process control set points and send process control commands to the controllers. In order to develop standardized control pop ups, graphic macros were used in developing the control pop ups. Graphic macros are standardized graphic subroutines that are built and thoroughly tested. Once they are proved to function correctly, they can be used in multiple control pop ups that differ only by the tag number of the device being controlled. This approach also helps to maintain the same look and feel throughout all pop ups and provides an easy means to the owner to create new graphics in case of a system upgrade.
Controls Application Development

As in the case of the graphics development, control macros were developed to standardize and speed the process of implementing strategy logic. Control macros are specialized controls subroutines that are built and thoroughly tested. Once they are proved to function correctly in all of the known permutations, they can be used throughout the DCS system. As with graphics macros, this approach provides consistency in the programs. The control macros were developed to mimic corresponding legacy DCS modules with respect to functionality. They were incrementally modified to take advantage of features present in the new system while maintaining the original module functionality and control intent.

The next step involved developing the new DCS database from the legacy DCS database. Several VBA scripts were developed to dynamically manage the database because it was changing as the project team proceeded with application development. With the initial database loaded into the new DCS, the next step involved entering the hand-drawn strategy maps. While entering the hand drawn strategy maps into the DCS, there was need to create new database points. The new points were created by closely following an already developed database point naming standards and conventions to maintain consistency in the system.

There were nearly 500 controlled devices and each required an equipment block programmed in the DCS. In addition to the equipment block in the controller, each device required an equipment control pop up at the graphics. The 500 equipment blocks were able to be developed and later linked with HMI graphics objects using eight templates. The templates were programmed in the DCS with generic tag names taking the format: EQUIP#XXXX; whereby EQUIP# is the equipment number as given in the legacy DCS and XXXX is a function code. If a function code did not exist, a name was provided with owner’s consultation. The new DCS control sheets with the programmed equipment block templates were exported out as text files. We then developed VBA scripts which used the separate databases to generate equipment block program in text file format and replace the generic tag names with actual tag names as given the DCS databases. The new DCS programs in text file format had to maintain the same text file structure as the originally exported templates. The generated programs in text file format were then exported into the DCS. Again, the use of simple programming tools greatly reduced the potential for human errors.

Application Testing

With the completion of the database, graphics, and control strategy configurations, the next step in achieving operator acceptance was application testing and demonstration to the operations personnel. Capabilities of the new DCS system facilitated this effort, in that the development workstation had full simulation capability. Strategy, database, and graphics could be tested simultaneously without the need for hardwired I/O connections. Comprehensive testing procedures for each control strategy were developed. A key aspect of owner acceptance was that the control strategy naming conventions and point naming conventions maintained the original DCS conventions. The new DCS easily accommodated these conventions and the practice maintained overall consistency with easy review against legacy strategies. Each control strategy was tested per the written testing procedures. After going through the initial testing in the lab, a formal witnessed application testing was arranged with the owner. The development system was shipped to the plant so that plant personnel could participate in the application testing. The goal was to collect as much feedback from plant staff
as possible and to produce an applications package that generated a high level of confidence on the part of operators and plant management.

**Stable and Seamless Transition of Process Control Functionality**

After formal witnessed testing on the development system was completed, the project was ready to begin the actual process of transitioning from the old system to the new system. In parallel with the software development effort, the overall DCS system had been designed and ordered, there had been a planning effort for physical construction, former office areas had been remodeled to accept the new DCS, the new DCS had been installed and energized, and a physical transition plan, called the Maintenance of Plant Operations plan, had been created.

**Maintenance of Plant Operations (MOPO) Plan**

A MOPO plan is a detailed document that provides guidance on how to proceed during commissioning with the goal of minimizing process interruptions. Development of a MOPO plan had been a continuous exercise from the time the project started. After completing applications testing, it was time to put different pieces together to come up with the final comprehensive MOPO plan to be used during the cutover/migration process of strategies from the legacy DCS to the new DCS.

The first step in putting together the MOPO plan was begun a year before the transition and focused on overall philosophy of the transition. Such items as work hours, contact lists, critical processes, preliminary transition order, maximum allowable manual operation time, and contingency planning were incorporated into the draft plan. Roughly a year later, after the applications testing, the entire set of strategies was analyzed to determine which strategy variables were shared between controllers. This analysis was essential so that a mechanism could be put in place to maintain the stability of process control calculations when a variable’s value was modified within a de-commissioned strategy. Determining shared points was accomplished by writing a VBA script that searched the legacy DCS database and logged every data point that was used in a particular controller but originated from a different controller. After gathering the list of shared data points, a cross reference was done in the new system programs to determine if the strategy utilizing a shared variable was critical or not. If the strategy was critical, then contingency measures to provide current values of the variable were devised to keep the strategy execution accurate. If the calculation was not critical (such as an informational calculation for display at the HMI), it was simply noted that it would be erroneous during the transition period.

The next step involved working with the plant’s process engineer and operations to update the order of migrating the strategies. The approach taken in the case of Village Creek was to mimic actual process flow so that upstream strategies were migrated first followed by downstream strategies. One unique aspect with the Village Creek plant is that in older areas of the plant, field signals (often related by a process) are terminated at a field junction box referred to as a Remote Termination Unit (RTU). The field signals are consolidated into multi-conductor cables that link the field terminations by discrete or analog function to a centralized Termination Facility (TF) cabinet near the control room. The benefit of this aspect with the MOPO plan is that it was frequently possible to move all signals associated with a process fairly quickly when the transition was executed and decommission the existing strategy. The legacy system initial installation of wire terminations in
1992 closely followed the RTU grouping. The drawback of this marshalling approach was that over the years many additional signals had been added to the RTU’s. Within the legacy system, they were then landed on whatever spare point was available using dedicated 2 or 4 pair wires. Care was needed to prevent accidental loss of control or monitoring when these isolated signals were part of an RTU bundle being transitioned. The MOPO plan prioritization focused on automatic control strategies and left flexibility for transitioning the non-critical strategies as circumstances permitted. The flexibility came from tracking all points from any particular RTU and providing guidance for when to migrate field signals not associated with automatic control strategies. In addition, the MOPO plan documented a list of field signals (ordered by source RTUs) that could be migrated any time during the cutover process. During times of testing the automatic strategies and tuning of PID loops, the electrician migrated the lower priority field signals. These signals would not compromise plant operations if they were unavailable for an extended period of time. Under this setup, it was possible to keep the transition effort moving forward while the automatic strategies were tuned. A sample of the MOPO plan is shown in Figure 4.

![Figure 4](image-url)  
*Figure 4: A sample of a MOPO plan with details on how to migrate DCS strategies*

Prior to commencing the cutover process, a program was developed that analyzed the legacy DCS PID tuning parameters and generated corresponding initial tuning parameters for the new DCS. The initial tuning parameters calculated in this program provided a reasonable starting point for tuning a PID loop with only one or two iterations. This approach reduced the amount of time needed to fully commission a new strategy that contained a PID algorithm. This approach contributed to operator acceptance of the new system by minimizing the time taken to decommission and commission a strategy and helped to prevent permit violations.
The first day of the cutover process, the project team did a dry run of migrating a strategy from the legacy DCS to the new DCS and back to the legacy DCS. This exercise was important to determine what it will take to revert a strategy to the legacy system in the event that unexpected problems were encountered. During the transition process there was an end of day meeting for discussion of strategies to be commissioned the following day. Concerns and precautionary measures were noted. A brief meeting was held the following day in the morning just before moving wires to confirm the planned activity with plant operations and get a “go/no go” decision for the day’s cutover activity. This level of communication was essential to maintaining operator acceptance of the daily cutover process.

The MOPO plan was followed during the cutover process with full tuning of a strategy being completed and approved by operations before initiating cutover of another strategy. The approach identified and dealt with transition issues as they arose and contributed to maintaining stable process control. Stable process control helped to prevent release of untreated wastewater and kept the plant in compliance with local, state, and federal regulations. It was known that as cutover process progressed, some strategies would be on the legacy system and some would be on the new DCS. In order to guide operators as to which system was in control, a visual method was developed to communicate which strategies had been migrated in addition to the recording the information in the shift log book. A migration data point was declared in the legacy system for each strategy and associated with a banner on each legacy graphic. This banner is animated by toggling the strategy data point from false to true after the strategy is migrated. Figure 5 shows a graphic in the legacy system that provided the means to set the migration data points. Figure 6 shows a graphic for a process area that had been migrated to the new DCS. The banner tells the operator to look to the new system. Figure 7 shows an overview graphic where only one process has been migrated to the new DCS. Therefore, the banner covers only that portion that had been migrated. By routing operations to the correct DCS using a graphics banner approach, minimal time was wasted when an operator needed to make an adjustment and helped contribute to acceptance of the new system.

Figure 5: Interface to set bits to dynamically route operations to the new DCS
Comprehensive Documentation

Over the life of the legacy DCS there have been several process upgrades which needed thorough vetting of the existing control descriptions to properly incorporate any changes in the system into the updated control descriptions. A major effort went into confirming operation of the existing reports on the new system. The Operator and Maintenance (O&M) manuals for the new DCS were completed after commissioning but were based on a thorough review of the legacy O&M to confirm they matched the current control strategies.

Operator and Maintenance (O&M) Manuals

Documentation is the solid bridge between the legacy DCS and the new DCS. A lot of effort was put to clearly document the many pieces of the application. These included, but were not limited to, graphic macros, control macros, application development standards and conventions, control descriptions, reports and more.
The emphasis put on the documentation was geared towards providing a firm guidance on future system expansion while at the same time providing information about the system.

The O&M was broken down into several sections to provide an easy way of accessing system information. For example, documentation related to standards and conventions was a standalone section with several subsections. In order to provide easy access to the O&M, the process control sheets have hyperlinks on them from which maintenance or the system administrator can easily call the document related to any particular control strategy. This form of online documentation is easy to update whenever a control strategy is modified as opposed to performing a physical change out of pages on hard copy manuals.

**Lessons Learned and Recovery Effort**

The MOPO plan provided crucial guidance during the cutover process. However, due to an oversight in not considering equipment accumulated runtimes while developing the MOPO plan, migrating the accumulated runtimes from the legacy system and reconciling it into the new DCS was not done during the cutover. Contingency measures were put in place after commissioning to backfill the accumulated runtimes and reconcile them into the new DCS. Also, while comprehensive in-house testing and final witnessed testing minimized time spent in commissioning the strategies, primary effluent (PE) control strategy complexities led to unexpected problems after cutover. Some of the problems involved strategy bumpless transfer from manual flow control to automatic flow control and PID loop tuning. The one day dry run to migrate a strategy to the new DCS and move it back to the legacy DCS proved to be a vital knowledge asset because we quickly followed the same steps to move the PE strategies back to the legacy DCS for further analysis and studying. After figuring out the solution, the strategies were migrated the following day successfully.

**Summary**

At the onset of the Village Creek DCS Implementation project, a comprehensive MOPO plan was determined to be an integral part of the project execution. The project team put a lot of effort to continuously refine and update the MOPO plan over the course of project execution. The final MOPO plan provided crucial guidance before, during and after commissioning the new DCS. By following the MOPO plan during the cutover process, we were able to minimize plant interruptions which in turn allowed the plant to avoid any permit violations. Working with the plant to maintain compliance to all local, state and federal regulation was one of the major deliverables. If in the future the plant experiences an unexpected catastrophic failure of plant operations infrastructure, the MOPO plan will remain a critical component to be used to determine the order with which to bring the system online.

After the final selection of the replacement DCS, a decision was made to utilize the additional capabilities of the new DCS while at the same time maintaining the same look and feel of the legacy DCS. This decision was meant to achieve the most operator acceptance of the new DCS which in turn will improve the plant’s ability to maintain exceptional effluent treatment standards. In order to achieve this goal, the legacy DCS standards were migrated; these included, but were not limited to, point tagging, graphic layout, color sequence and animation schemes, graphics navigation standards, etc. While the legacy DCS utilized sub displays to provide operators with an interface to enter process control set points, the capability of the new DCS was utilized which allowed control pop ups instead of the sub displays. With control pop ups, operators can view all set...
points on one graphic as opposed to the sub displays where they had to scroll through several windows in cases where multiple process set points were used.

In order to provide a stable process control, all strategies were thoroughly tested in house using detailed testing procedures. The owner was also given an opportunity to witness process control testing. This rigorous controls testing was facilitated by the capability of the new DCS to run the control strategies in virtual controllers that act and function like actual controllers. Due to the successes of the witnessed functional demonstration test, the effort of migrating the control strategies to the new DCS was reduced to loop tuning which in turn provided the most plant up time.

Finally, the effort to develop and maintain detailed O&M manuals yielded immeasurable benefits during commissioning and has remained a vital troubleshooting tool for the maintenance personnel. The goal from the project onset was to maintain an O&M that is representative of the system and the programmed control strategies.

List of Acronyms:

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>DCS</td>
<td>Distributed Control System</td>
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<td>MOPO</td>
<td>Maintenance of Plant Operations</td>
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<td>DCU</td>
<td>Distributed Control Unit</td>
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<td>PE</td>
<td>Primary Effluent</td>
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<td>RTU</td>
<td>Remote Terminal Unit</td>
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<td>TF</td>
<td>Termination Facility</td>
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<td>O&amp;M</td>
<td>Operator and Maintenance</td>
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Mr. Mogaru graduated from the University of Texas at Arlington with a B.S. Degree in Electrical Engineering. He is an automation engineer at CDM Smith specializing in applications software development. Mr. Mogaru has six years experience in project planning, control logic development for Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCSs), HMI graphic development, field commissioning and startups, project documentation, and operator training.

Second Author Name: John Robinson

Mr. Robinson has 30 years of experience developing and implementing instrumentation and control systems, 24 of which he has specialized in water and wastewater treatment. Mr. Robinson's experience includes project management, instrumentation specification, control logic development for programmable controller systems (PLC) and distributed control systems (DCS), application programming, field startup, troubleshooting, operator training, and pilot plant operation.

Third Author Name: Luke Matus

Mr. Matus has worked for the City of Fort Worth since May of 1988. His degree and background in Instrumentation has provided an avenue to be involved in the development and implementation of process control systems throughout the City of Fort Worth for both the Water and Wastewater Industries. He's worked on and maintained both PLC based architectures as well as DCS systems.