PRACTICAL EXPERIENCE WITH STATE-OF-THE-ART TECHNOLOGIES IN SCADA SYSTEMS

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ABSTRACT

A Supervisory Control and Data Acquisition (SCADA) system is a powerful tool which, when implemented properly in irrigation districts, can lead to improved water delivery service to farms, more effective operations, reduced spill (and therefore reduced diversions), and in some cases a reduction in costs (less labor, less energy, etc.). However, widespread adoption of SCADA and automation technologies remains a technical and financial challenge for most irrigation districts. In spite of many good hardware and software products available on the market now, putting all the pieces together requires specialized expertise. Nevertheless, by following some straightforward strategies and rules of good practice, combined with advanced control techniques, even very complex automation systems have been successfully implemented. These implementation steps are briefly outlined with a focus on lessons learned. Updated implementation costs for typical system components are given to aid in project planning.

INTRODUCTION

This paper provides an overview of experience implementing SCADA systems. By investing in advanced communications and electronics technologies, agricultural water districts are striving to benefit from reduced operations costs, improved system performance, and increased responsiveness from a management standpoint. In practice, many engineers face challenges in each step of the project-cycle that mean achieving these benefits is far from automatic.

The California Polytechnic State University Irrigation Training and Research Center (ITRC) has worked with water districts in the western U.S. to put an increasing number of SCADA systems into operation. In this paper the authors relate recent experiences with implementation of SCADA and automation projects. The relevant lessons discussed in this paper can be summed up as follows:

- When beginning a project, explore whether a non-SCADA solution makes the most sense.
- Districts themselves can be the weak spot in a SCADA project, especially if they do not dedicate adequate budget and staff time.
- SCADA is different from typical engineering projects and involves special issues that affect the design, specification, and implementation of systems in districts.

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- ISaGRAF[3] has proved to be a valuable tool that benefits the entire SCADA team.
- The actual implementation costs for a "typical" SCADA site are anything but typical. However, the real costs for a site – if it is done properly – are much higher than most engineers realize.

KEEPING THINGS IN PERSPECTIVE – SIMPLE WATER CONTROL SOLUTIONS WITHOUT SCADA

SCADA systems are high-visibility projects within a water district because of their significant cost and, to a certain degree, the apparent 'magic' of the information technology involved. Indeed, the temptation of publicized SCADA technology is too much for some engineers to resist. At trade shows, in industry publications and during sales calls engineers are being exposed to advanced technologies that were unthinkable a decade ago. Unfortunately, this can lead to some expensive regrets when the same engineers try to implement them. In fact, the best solutions for improving water control often do not involve SCADA or PLC[4]-based automation.

The authors estimate that at present less than 5% of the existing canal control infrastructure (check gates and pumps) in California's agricultural water districts has some type of automation. At first glance this would seem to illustrate the very large potential for SCADA development in the future. Due to a variety of internal and external drivers, there will continue to be more SCADA projects in the coming years as districts invest in infrastructure upgrades. However, while ITRC provides technical assistance to perhaps 10-20 irrigation districts every year that are undertaking modernization efforts, only a few of these end up implementing a SCADA program, at least at first.

Solving water control problems in canal and pumping systems is a complex multi-disciplinary enterprise. Strategizing the proper control approach requires engineering expertise, ability to comprehend practical and complicated hydraulics, familiarity with modern water control designs, collection and analyses of relevant field data, and other knowledge gained through experience. When the proposed solution involves any type of PLC-based automation, the level of complexity increases by several orders of magnitude.

Still, we are extremely confident in the benefits of SCADA and ITRC has been involved with a large number of successful automation projects in the U.S. ITRC has a strong track record and has accumulated an unmatched expertise in implementation of canal automation. Enroute, we have also struggled at times and participated in some painful lessons dealing with SCADA and automation. Some of these lessons have been well-illustrated at previous USCID conferences (for examples refer to Norman and Khalsa, 2005; Perkins and Styles, 2007).

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[3] ISaGRAF is an industrial automation control software supporting IEC61131-3 PLC languages: Ladder Diagram (LD), Function Block Diagram (FBD), Sequential Function Chart (SFC), Structured Text (ST), and Instruction List (IL), plus Flow Chart (FC).

[4] Programmable Logic Controller

Fortunately, there are some practical solutions available such as the long-crested weir and ITRC flap gate, which both have well-deserved reputations. Both of these are automatic control structures, but neither one requires any SCADA at all (i.e., no electronics, no PLCs, no sensors, no programming, etc.). When a district's infrastructure is analyzed, we are always asking ourselves if a non-SCADA solution is possible. We only consider canal or pump automation when several prerequisite conditions are met (these conditions are outlined later in this paper). The reasons are simple – SCADA is expensive and can easily become problematic.

On the other hand, long-crested weirs are straightforward and have few problems. They are inherently safe structures, with few maintenance and labor requirements once they are in place. Of course, coming up with a good design requires experience and good judgment, and construction techniques can vary widely. For example, we have seen and designed long-crested weir structures that cost as low as several thousand dollars. But we are also aware of long-crested weirs in medium-size canals that approach $50,000 just for construction.

Figure 1. A long-crested weir being constructed with surplus K-rails (Banta-Carbona ID)

Of course, there are many, many control and monitoring situations where the physically simple solutions are impractical or too expensive.

PRACTICAL APPROACH TO MODERN SCADA FOR IRRIGATION DISTRICTS

Armed with some basic knowledge, districts have a better chance at getting a SCADA system that meets their performance objectives and stays within the allocated budget. The authors take for granted that it is (nearly) widely accepted now that SCADA systems should, among other things:

- Utilize only off-the-shelf, industrial-grade hardware
- Be provided by a qualified and experienced integrator
- Be commissioned with extensive hands-on training and thorough documentation

- Employ open architecture systems (i.e., it can easily be worked on in the future by another integrator)
- Have room for future expansion (scalability)

This section supplements some of these hard-learned lessons with new considerations.

<u>Turning the Tables – What are a District's Obligations and Responsibilities?</u>

In previous papers the authors have noted that the weak link in SCADA projects was typically the integrator (e.g., Piao and Burt, 2005). This can still be the case, although ITRC has worked successfully with a handful of integrators who had to meet pre-qualifications that ensure the selected firm has the track record, in-house technical expertise and sound financial health to support the project after it is finished. However, based on recent experience on some large canal automation projects, we have identified a new weak spot in SCADA projects that we did not initially suspect: the districts themselves.

The problem is not that districts lack expertise with SCADA. After all, this lack of in-house expertise is why districts hire consultants and integrators. It is unreasonable to expect most district engineers to fully understand all the ins and outs of successfully implementing a SCADA project. However, all districts will have had some experience with implementing at least some type of capital improvement project or infrastructure upgrades. In many ways, the steps in a SCADA project are similar to other "standard" engineering projects. Common steps include:

1. Identifying the problem, formulating options, and justifying the preferred solution
2. Preparing plans and cost estimates
3. Getting approval from management and the Board of Directors to proceed
4. Developing project specifications
5. Selecting vendors and engineering consultants
6. Finalizing design and specifications
7. Construction
8. Training and documentation

So what makes a SCADA project different? What special steps are involved? Enough examples are available now to expand upon both questions in detail. But what should happen <u>before</u> a district embarks on a SCADA project, before any significant planning or engineering is done? Is it possible to know in advance whether a SCADA project is likely to fail? If so, then consultants would be well-advised to steer a district away from SCADA as a solution for the time being.

Our experience has shown that it is worthwhile at the very beginning to focus on to what extent a district or other agency meets the conditions listed below. The authors are even considering ways to formalize these "pre-conditions" into some type of pre-project agreement that the district would have to sign before ITRC gets on board with them in a SCADA project. Our proposed SCADA pre-conditions include:

- A project manager. The district must appoint a project manager with sufficient authority to make decisions in a timely manner about budgets, schedules and commitments. The project manager has to be able to work across different departments (IT, engineering, administration, operations, etc.). The project manager must have a "can-do" attitude, construction experience, at least limited budget authority, and a willingness to learn new things.

- Sufficient budget to overcome the unexpected hurdles. Every SCADA project costs more than managers and the Board of Directors initially expect. With good planning and well-prepared specifications – not to mention hiring the right integrator – cost overruns can be minimized. But being reluctant to spend money when it is warranted can lead to even more problems down the road. The authors recommend that districts be prepared to budget an extra 10% to 20% beyond the initial project costs just to cover the inevitable unknowns.

- Commitment to be a team player. This is a sensitive area for obvious reasons. The district is ultimately the primary decision maker because they are the customer and the one paying for it all. Where the authors have run into trouble is when one or more of the following happens:

    - District staff from one department not sharing information with every member of the team (e.g., the classic problem of the left hand not knowing what the right hand is doing)
    - Districts being over-reliant on vendors and not checking with the consultants supposedly in charge of certain parts of the project prior to hardware or software selections being made.
    - District being reluctant or unwilling to direct sufficient resources to regular inter-action with the team. This is related to the budget issues mentioned above – meetings take up staff time and therefore cost money.

- Involvement of operations personnel. It is all too common for professional engineers to avoid involving the operations staff who will ultimately have to use the SCADA system. This is a common situation in irrigation districts, in which a gulf may exist between the engineers who dream up (from an operator's point of view) projects and the operators who have to live with the engineers' solutions. Operators should be involved in every step of the process. There is a huge learning curve and time is needed for acceptance; early buy-in and involvement is critical.

- Compliance with assigned tasks on a well-planned schedule. This is a difficult one to call a pre-condition per se, but there has to be a good understanding upfront by the district about how much is actually involved with supposedly simple tasks like furnishing and installing electrical conduit (plus all the day-to-day project management tasks involved with a SCADA project). Specific tasks are assigned between the district, the integrator and other consultants in the project specifications. Since there are always other projects already going on in a district at any one time – just consider how much regular maintenance is usually done in the off season when many SCADA installation tasks also take place – a well-planned schedule is essential.

Implementation Experience with ISaGRAF Control Software

Several years ago ITRC made a major shift in its approach to canal automation projects (see Piao and Burt (2005) for background about this decision). Prior to this ITRC had been handing over to integrators large, complicated (non-executable) flow charts of control logic. Integrators would then use the flow charts to create a ladder logic diagram for each PLC. This approach had several problems including a lack of understanding of canal control theory by integrators, susceptibility to programming bugs when the flow charts were converted into ladder logic, plus the fact that every new project had to basically start over with programming. As a result, ISaGRAF control software, consisting of six IEC 61131-3 programming languages in an integrated application environment, was selected by ITRC for PLC control programming.

Reasons that ITRC decided to use ISaGRAF included:

1. Cross-platform support among PLCs from different manufacturers
2. A clear line of responsibilities between ITRC and the integrator (i.e., the assigned PLC registers)
3. Compliance with international standards and open architecture
4. Ability to write control modules (e.g., upstream control with a radial gate, flow control with a sluice gate, etc.) that do not have to be rewritten for every job
5. Standardized programming interface, support for unlimited I/O, and sufficient flexibility for logic and arithmetic functions
6. Debugging features that aid examination of the code in simulation mode
7. Reasonable license fees

The authors' experience to-date with ISaGRAF has indeed validated most of the above reasons. As a result, the entire process of control logic development has become more efficient and reliable. Hassles and finger-pointing that used to occasionally arise when PLCs malfunctioned have been largely eliminated. Now ITRC handles all the PLC programming using an ISaGRAF approach that has been incrementally improved with each automation project.

Several issues have arisen, however, which merit discussion. First, ISaGRAF is not quite as universal as initially thought. This means that even though major PLC manufacturers (e.g., Allen-Bradley, Control Microsystems, Modicon, etc.) do provide ISaGRAF support, each one has its own customized libraries and extensions. In general ITRC does not utilize these manufacturer-specific features. However, there is still some extra programming that is required in order to take an ISaGRAF code programmed for one particular PLC and transfer it to a PLC from a different manufacturer. The ISaGRAF coding for the control logic is the same, but interaction with a particular manufacturer's firmware, communications ports, local displays, radios, etc. requires some special PLC-specific instructions also written in ISaGRAF. ITRC has not done a systematic evaluation of various manufacturers but our experience indicates that the time involved may vary from a few hours to a few days per PLC.

A second consideration is that very few integrators working in irrigation districts have any experience with ISaGRAF. It is likely this will change in the future as the popularity of ISaGRAF spreads due to its advantages (see the list above). On the one hand, since ITRC is responsible for the PLC programming there is no need for integrators to know about ISaGRAF. However, in practice some level of understanding of how the program works is required because of the teamwork nature of troubleshooting. It also matters because ISaGRAF opens up special possibilities for how the HMI can be used to interface with field sites.

One direct benefit of ITRC's approach using ISaGRAF is that the software kicks out the list of tag names and registers as part of the control programming. Therefore, an integrator knows what to bid on. However, this also means that ITRC has to develop the PLC code before the integrator is selected.

A minor consideration is the near universality of ladder logic. In large districts that have already implemented earlier generations of SCADA, there can be a hurdle involved with getting people to accept something they've never heard of. Usually, it is a matter of explaining the good reasons for using ISaGRAF. Furthermore, our approach means that it would be extremely rare for anyone at a district to ever need to edit a control program written in ISaGRAF (note: the same rule applies to the integrator as well).

Irrigation SCADA – Why Is It Different?

SCADA systems designed and installed for irrigation districts are different from other industries. While irrigation SCADA involves process control, there are some unique features. For a start, the "people" factor looms large. Already mentioned is the fact that districts lack in-house exposure to SCADA and trained technicians to operate and maintain a sophisticated computerized system. Often, operators in the field are being exposed to these technologies for the first time.

Another aspect of human organization is that fact that districts have to assemble a specialized team for SCADA projects. In other industries, large engineering and construction firms often view SCADA as simple – it's sort of an afterthought. However, in irrigation systems, designing a SCADA system first involves formulating a strategy for how water is going to be controlled and managed. Control options have to be weighed against objectives for improving water delivery service, conserving water, reducing energy costs, etc. This necessitates consultants dealing extensively with district staff from operations, engineering, administration, construction, and others. Then during implementation the district has to coordinate the work of various consultants, the integration firm, construction contractors (frequently multiple companies doing different parts of the job), as well as in-house electricians, construction/maintenance crews, etc. An experienced civil engineering firm that serves as a central coordinator for construction management can greatly benefit a district implementing a large project.

Other distinctive features of control systems for irrigation districts, such as lag-time, limit the involvement of integration firms who are used to industrial applications. In canal systems, things don't happen right away everywhere. For example, a change in flow rate made at a reservoir by remote control may not show up at another control point for several hours. Without proper tuning of the control algorithms based on hydraulic simulation modeling, resonance waves can be created (and get out of control) between automated gates. The selection of the correct control gate hardware, pump configuration, flow measurement device, etc. has to specific to each project and to control strategy being implemented. For these and other reasons, the required infrastructure and SCADA system have to be designed together, requiring consultants and integrators with specialized expertise.

CURRENT SCADA IMPLEMENTATION COSTS

A paradox: At the same time that the prices of the electronics hardware used in SCADA systems are going down – due to competition in the marketplace, cheaper components, newer models being brought out that target our industry, etc. – our cost estimates for a SCADA system are going up. What is the reason? Are SCADA systems really more affordable (or more expensive) than they were a few years ago?

Looking back at the proceedings from previous USCID conferences, one can find estimates for remote monitoring sites as low as a few thousand dollars. The authors would like to share some recent experiences that have convinced us the "typical" costs for a *properly-equipped* SCADA site are actually much higher than what was previously thought. For example, we used to tell districts that setting up a base station at their headquarters office would run around $30,000 to $50,000. Even then we would often get startled expressions from district staff members who were interested in SCADA but had no idea it would cost so much. Now, we will tell an interested district that they should count on spending at least $80,000 to $100,000 for a properly-equipped base station.

Part of the reason for rising costs is rising expectations. Districts are no longer satisfied (or won't be satisfied for very long) with just having one computer on somebody's desk that serves as the sole access point to the SCADA system. People want to be able to get into their SCADA systems from their homes, from laptops mounted in their service vehicles, and even from their smartphones while they are away. Managers and other office staff also want to have access to various summaries of the data on their own computers. This desire for 24/7 access by the whole organization comes with a significant cost. Computer server networks have to be set up with the necessary secure access, laptops have to be purchased and configured, extra software licenses have to be bought, etc.

Table 1 provides some updated cost estimates of various types of SCADA system components.

Table 1. Updated estimated SCADA system costs for irrigation districts (2009)

Item	**SCADA***	**Additional Construction Costs**	**Estimated Sub-total**
Base station	$80,000-$100,000	---	$80,000-$100,000
Remote monitoring of a ultrasonic flow meter in a canal	$40,000	$20,000-$60,000‡	$60,000-$100,000
Automating a check structure with 2 radial gates for water level control	$70,000	$20,000-$50,000‡	$90,000-$120,000
Automating a pump station with a VFD controller†	$100,000	$50,000-$300,000‡	$150,000-$400,000

* Includes written specifications, SCADA hardware, control programming and testing, model simulation, HMI software, commissioning and documentation.
† Does not include new pumps
‡ Rough order of magnitude costs for enclosures, power service, infrastructure modifications

Another factor raising the cost of SCADA systems is that office computer networks are becoming more sophisticated and complicated – firewalls, web servers, antivirus software, continuous version updates, functional creep, etc. For example, ITRC is working with several districts that are implementing new billing software at the same time they are expanding their SCADA systems. Both efforts require extensive involvement of IT professionals because ultimately the systems have to run on the same office-wide computer systems. However, while it is tempting to think of one centralized database managing data from both the SCADA and billing systems, the IT costs involved, not to mention complexities, make it impractical. Therefore, the authors strongly recommend that as much as possible, different databases should not be integrated with each other.

Equipment costs bring up further issues. For automation projects in particular (versus for example just monitoring a single sensor for water levels), ITRC insists on only very high-quality industrially hardened equipment. It is possible to buy PLCs for only a few hundred dollars, but these are totally inadequate for running sophisticated automated control routines. The same rule applies to all the other components that go into a Remote Terminal Unit (RTU). It is a critical fact that a SCADA system is only as reliable as its weakest component. Does it make sense to spend thousands of dollars on a good PLC and then try to save a few dollars on a relay or switch? The answer is no.

In addition, early generations of SCADA systems may have consisted of a relatively simple RTU mounted on a pole. For newer systems districts usually require small buildings to securely house all the equipment, on-site interactive displays, etc. Many old systems had 15-minute query times with very simple control. Minimal information had to be transmitted to the office. Now, systems require high-speed transfer, storage and display of large amounts of data. This is especially useful for troubleshooting. A modern automated site can involve over a hundred PLC tags that interact with the office HMI.

Finally, another reason that the cost estimates in Table 1 are higher than what is typically published is that they include more than just the integrator's and consultant's bills. When one considers the amount of staff time that goes into working with consultants who help design the system, prepare specifications, collect field data, etc., the actual cost to the organization can be an additional one-third to one-half of what an integrator will charge for implementation. What about the costs to modify or replace older gate motors or demolishing existing but obsolete measurement equipment? In addition, for canal automation, surveying work is required, along with hydraulic simulation modeling, tuning the control algorithms, commissioning and field testing, etc. These costs all have to be put into the budget.

FUTURE TRENDS

SCADA systems will continue to evolve. Automation will be implemented with greater regularity as water districts transform themselves into modern service utilities. Here's a brief take on some likely future trends:

- A growing emphasis on security vulnerabilities
- Electronics getting smaller and smaller. For example, in the future, an electric motor may have a VFD controller built into its terminal box.
- Widespread use of wireless sensors
- Web-based interfaces and data access becoming the norm
- Mobile (remote) access
- Ethernet-enabled PLCs, radios and sensors (IP-based systems)
- Intelligence close(er) to the point of control. For example, some flow meters may eventually include built-in control algorithms to move a valve in order to control a flow rate, with supervision from the SCADA system.
- Integrated packages that combine PLCs, displays, radios, etc. into a single component
- Ultra-fast communications
- Smaller-scale SCADA systems at the farm level

SUMMARY

Experience to date with SCADA systems continues to prove there are significant benefits to irrigation districts that implement them. Risk of failure and costs can be minimized by following an approach that recognizes the distinctive features associated with SCADA implementation in irrigation districts. However, districts must be prepared to adequately fund a project and realize they have special obligations to make it succeed.

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