The Role of SCADA in Developing a Lean Enterprise for Municipal Wastewater Operations

by

Stanley J. Prutz

Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

Central to optimizing a wastewater system's operations is the collection of alarm and operational data from various remote locations throughout a municipality, hence the basic need for supervisory control and data acquisition (SCADA). The process of providing SCADA systems to municipal clients, from conception to implementation, is typically a cumbersome process involving a wide variety of stakeholders. Municipalities have historically been slow to change, often being among the last in adopting new processes and technologies. Municipal SCADA systems usually are deployed without considering how they will specifically create value for municipality end-users and without defining metrics to gauge their effectiveness.

Lean enterprise principals suggest a focus on the value stream can reduce waste and improve the value municipality end-users derive from SCADA systems. The author performs a lean analysis of the process of implementing SCADA within a municipal wastewater operation. The municipality's current systems integrator-centric model for SCADA delivery is examined. An alternate lean vision is proposed for the integrator's operations and their relationship with the municipality. This vision reduces SCADA implementation time and costs while improving the effectiveness of the SCADA solution.

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I am particularly grateful to my professor and thesis advisor Deborah Nightingale who introduced me to the world of lean enterprise and supported my research, assuring a return on my company's investment in an MIT education.

BIOGRAPHY

Stanley J. Prutz earned a bachelor's degree in Electrical Engineering from the Milwaukee School of Engineering in Milwaukee, Wisconsin. He has more than twenty years experience in the field of control and information systems integration as well as the project management of SCADA implementations in the water and wastewater treatment industry. He is a NSPE registered professional engineer in the area of control systems. His related publication in this field is "Best Practices for the Reduction of SCADA System Total Lifecycle Costs", AWWA 2004 Annual Conference Transactions, June 2004.

CHAPTER 1 - INTRODUCTION

Background

How does one improve the operational efficiency of a municipal wastewater operation?

With the globalization of the world economy, the majority of commercial and industrial enterprises have found it necessary to focus upon improving their competitive ability to ensure their survival. The requirement for these organizations to improve their operational efficiency naturally follows. The organizations best identifying and serving their customers' needs survive; those who are less efficient tend to be acquired or otherwise moved out of existence by market forces. As in the animal world, the market ensures that the "fittest" organizations survive and those less fit become extinct, providing a mechanism that assures continuous evolution of these organizations.

Municipal wastewater systems operate as monopolies, insulated from the evolutionary force of market demand. The need to transport a municipality's wastewater through a vast, costly network of underground piping, the economics of providing the required degree of treatment together with environmental regulatory agency discharge and reporting requirements serve to support a single wastewater processing supplier per municipality.

In the United States today, most municipal wastewater systems are publicly owned. While the vast majority of these installations are also publicly operated, a few municipalities have contracted with commercial firms to operate their systems, effectively "privatizing" system operation. Privatization has typically been chosen by elected governmental officials as a result of a funding crisis, with private firms sometimes offering attractive upfront terms. In practice, privatization has not always met expectations. As one example, capital improvements to the publicly owned infrastructure remain the responsibility of the municipality; lack of regular and proper preventive maintenance will increase capital costs, in the long term potentially negating the benefits sought from privatization.

The establishment of service levels within defined cost and business constraints has been proposed as the ultimate objective of good wastewater utility management (Urquhart & Sklar 2005). Lacking external market driven or privatization forces, the establishment by a municipality of service levels for its municipal wastewater operations is a way for it to internally provide an equivalent motivating force. Service levels thus become the performance goals of the utility, used to direct and measure the utility's improvement efforts.

A service level is a utility's stated commitment to deliver service at a specified level of quality and reliability. A utility's stated service-level targets help set appropriate expectations with customers, regulators, and key stakeholders and provide the basis for measuring the utility's performance. Reliability, customer service, quality, and regulatory service level goals have been proposed. Central to monitoring progress in achieving service level goals is the collection of alarm and operational data from various remote locations throughout a municipality, hence the basic need for SCADA.

Lean enterprise principals suggest a focus on the value stream can reduce waste and improve the value a municipality derives from its wastewater system. While the concepts of lean enterprise provide a framework for analyzing current operations, for establishing service level goals and the strategies for their implementation, this author focuses on improvement of the process by which SCADA (supervisory control and data acquisition) is implemented within a municipality.

A vision is offered for the implementation of SCADA systems employing lean principles within municipal wastewater operations that more efficiently coordinate the existing network of numerous stakeholders. This includes contractors, systems integrators, systems and engineering consultants, suppliers of software, communications and other data services bound together with a contractual model that supports establishing a long term mutually beneficial lean enterprise. There is particular emphasis on the systems integrator, who in this industry traditionally is contractually required to take the majority of the responsibility for the ultimate success of a major SCADA implementation.

Objectives

The specific goals of this research are to:

- Identify the stakeholders involved in a specific municipal wastewater SCADA implementation and their needs. Analyze how the present SCADA delivery organization is employed to support the value streams.
- Suggest an alternative method for SCADA delivery including specific changes for the systems integrator organization and related stakeholders to reduce waste, lower cost and improve efficiency by employing principles of the lean enterprise.
- Propose a transformation plan for transitioning the system integrator organization and related stakeholders from their current state to the suggested lean alternative state.

The overall intent is to provide insight into the design of future lean enterprises for the implementation of SCADA in municipal wastewater.

Approach

Methodology

A specific large wastewater utility located in the United States was chosen for analysis. This analysis was based upon the municipality's systems integrator-centric SCADA delivery method. The municipality's wastewater SCADA needs and current value stream were determined via individual meetings, conversations and correspondence with identified stakeholders.

Enterprise Value Stream Mapping and Analysis (EVSMA), a lean evaluation and planning process derived from the MIT Lean Aerospace Initiative (LAI), was used as a guide in structuring the analysis process.

Structure of Thesis

Transformation of the existing municipal wastewater SCADA implementation enterprise from its current state to the vision offered requires a thorough understanding of the concepts presented in this analysis. The upper management of all involved stakeholder organizations must drive this transformation. This thesis is thus structured to provide these managers with the required pre-requisite knowledge of the wastewater process, SCADA systems and lean enterprise principles.

Chapter 2 provides an overview of the wastewater treatment process, while Chapter 3 explains SCADA concepts. Chapter 4 includes an overview of lean enterprise concepts and a discussion of their application.

Given the background knowledge provided in earlier chapters, Chapter 5 progresses to an analysis of the subject municipality's SCADA implementation process, employing lean techniques to focus on stakeholder identification, their needs and an analysis of their system integrator current operations.

Specific results of the lean analysis are listed in Chapter 6. A discussion of the lean analysis results, including a proposed vision for the lean transformation of the SCADA implementation process is offered in chapter 7. Also included in this chapter are stakeholder suggestions concerning the transformation of the current enterprise to the future envisioned enterprise.

Chapter 8 offers a short discussion of future work remaining to be addressed regarding the role of SCADA in implementing a lean enterprise within municipal wastewater operations.

Chapter 9 concludes with an overall summary of recommended changes for the implementation of SCADA in municipal wastewater operations.

CHAPTER 2 – MUNICIPAL WASTEWATER OVERVIEW

Industry Size

The United States 1997 census identified 696 municipal wastewater treatment plants nationwide. With a census 6% historical growth rate, the census projects 1,111 facilities in the US in 2005. It is important to note that the census figures include only independent wastewater systems and do not include municipal systems that handle both water and wastewater, a relatively common occurrence. The industry research organization EPRI estimates there are 15,000 wastewater treatment plants in the United States. (EPRI 2004). Today, the water sector (as well as the directly tied wastewater sector) rides a wave of strong demand, with the World Commission on Water for the 21st Century expecting water use to increase 50% during the next thirty years. (WSJ 4/2005).

Wastewater facilities are predominately located in areas of 10,000 and greater population. The wastewater of smaller water systems is most often treated by individual septic systems. Nearly 75% of the nation's housing units dispose of their wastewater via public sewers (USCB, 2001).

Wastewater is defined as water which has been used and must be disposed of or treated. The volume of wastewater is then proportional to water usage, which depends on many factors. Household consumption, irrigation, industry, and many other uses result in wastewater. In the United States, the average per capita wastewater produced is from 75 to 150 gallons per day. Industrial consumption increases per capita quantities in larger cities.

Wastewater Types and Characteristics

Wastewater is generally classified into two categories, domestic and industrial. Domestic wastewater results from the use of water in the home, and includes both water after its use in the shower, sink or toilet and the material it carries such as body wastes, kitchen wastes, household cleaning agents, and laundry soaps and detergents. In contrast to the general uniformity of substances found in domestic wastewater, industrial wastewater shows increasing variation as the complexity of industrial processes rises. Because biological treatment processes are ordinarily employed in water pollution control plants, large quantities of industrial wastewater can interfere with the processes as well as the total load of a treatment plant. As a result, many industrial plants are required to pre-treat their waste effluent.

Characteristics of wastewater vary. The solid content is numerically low and can amount to less than 1 lb. per 1000 lbs. of wastewater. The character of these waste materials is such that they would cause significant degradation if discharged directly into the environment, and could spread waterborne diseases, notably typhoid and dysentery.

US Environmental Regulatory Requirements

Wastewater treatment in the United States is driven largely by Environmental Protection Agency (EPA) regulations. Why do we need to be concerned about wastewater?

Water pollution degrades surface waters making them unsafe for drinking, fishing, swimming, and other activities. As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters within the United States. Point sources are discrete conveyances such as pipes or man-made ditches. Municipal facilities must obtain permits if their discharges go directly to surface waters, which is almost always the case.

Effluent limitations serve as the primary mechanism in NPDES permits for controlling discharges of pollutants to receiving waters. When developing effluent limitations for an NPDES permit, a permit writer considers limits based on both the technology available to control the pollutants (i.e., technology-based effluent limits) and limits that are protective of the water quality standards of the receiving water (i.e., water quality-based effluent limits).

Properly designed, operated, and maintained sanitary sewer systems are meant to collect and transport all of the sewage that flows into them to a publicly owned wastewater treatment facility. However, occasional unintentional discharges of raw sewage from municipal sanitary sewers occur in almost every system. These types of discharges are called sanitary sewer overflows (SSOs). SSOs have a variety of causes, including but not limited to severe weather, improper system operation and maintenance, and vandalism. EPA estimates that there are at least 40,000 SSOs each year. The untreated sewage from these overflows can contaminate our waters, causing serious water quality problems. It can also back-up into basements, damaging property and threatening public health. (EPA 2005).

The Wastewater Treatment Process

Primary and Secondary Treatment Required

An important aspect of municipal wastewater is that it can be biologically treated. The biological treatment component of a municipal treatment plant is termed secondary treatment and is usually preceded by simple settling (primary treatment). Secondary treatment standards are established by EPA for secondary wastewater treatment plants. These technology-based regulations apply to all municipal wastewater treatment plants and represent the minimum level of effluent quality attainable by secondary treatment, as reflected in terms of 5-day biochemical oxygen demand (BOD5) and total suspended solids (TSS) removal. The EPA secondary treatment standards also provide alternative standards established on a case-by-case basis for treatment facilities considered equivalent to secondary treatment (trickling filters and waste stabilization ponds).

BOD is a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. BOD is used as an indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic waste. BOD is used by the EPA as an indicator of pollutant level, where the greater the BOD, the greater the degree of pollution.

TSS refers to the weight of particles that are suspended in water. Wastewater is passed through a filter and the amount of material captured is measured relative to the amount of wastewater filtered. Suspended solids in water reduce light penetration in the water column, can clog the gills of fish and invertebrates, and are often associated with toxic contaminants because organics and metals tend to bind to particles.

Treatment plants

The activated sludge process shown in Figure 1 is a prevalent form of treatment for municipal wastewater.

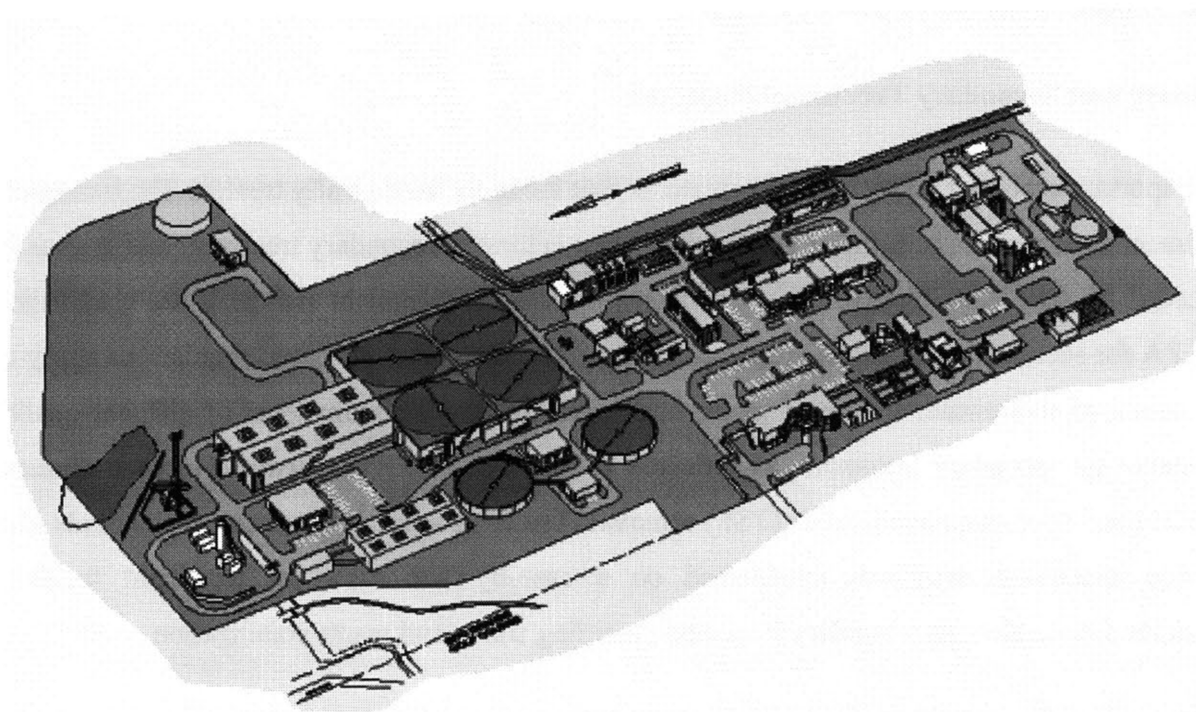

Figure 1: Activated Sludge Treatment Plant

Southern Regional Wastewater Treatment Plant, Hollywood, Florida

Screening

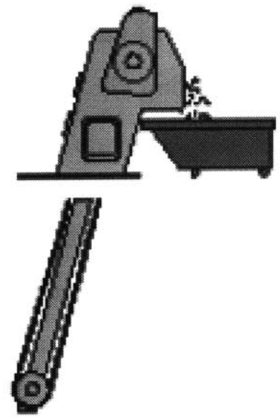

Figure 2: Bar Screen

Screening precedes all other treatment processes in a wastewater treatment plant. The removal of coarse solids achieved through screening provides protection to all equipment, pipes and channels in the treatment plant. Raw wastewater from the collection system enters the screen chamber. The wastewater then flows through a bar screen or similar device where large materials, such as sticks, rocks, and rags, are removed in order to protect the downstream equipment from being damaged. Screening facilities today are often enclosed in some manner so that the atmosphere can be continuously scrubbed for odor control.

A screen is a device with openings placed in a channel such that the wastewater flows through while the solids are caught on its upstream side. Screens consisting of parallel bars arranged in the form of a rack are known as bar screens (Figure 2). Flow of wastewater through a bar screen is generated by gravity. The bar screen is mechanically cleaned by a traveling rake which pulls the debris out of the channel and into a container. Screenings are periodically hauled by truck from the site for disposal by burial. Wastewater flows by gravity from the bar screens to the grit chambers.

Grit Chambers

Grit removal completes the preliminary treatment of the wastewater. In conjunction with screening, it provides protection to plant equipment, pipes and channels, and it enhances the efficiency of downstream wastewater treatment and sludge handling processes and operations.

The grit chamber is designed to remove sand, gravel, cinders, and other suspended inorganic materials having specific gravities substantially greater than those of the organic solids in wastewater. Grit chambers remove this material, protecting mechanical equipment from abrasive action; reducing the formation of deposits in pipelines, channels and conduits; and reducing the amount of inorganics entering biological process units and sludge handling facilities.

A grit chamber is a sedimentation tank where the horizontal flow velocity is slowed down just enough to allow the heavy inorganic material to settle out while maintaining the lighter organic material in suspension. The settled solids are raked by a mechanism to a sump. From this sump the collected solids are typically pumped through a cyclone where inorganic grit is separated from the water and organic material captured in the grit chamber sump. The grit is typically discharged into a rake classifier, where it is washed by water sprays and dumped into a container to await land disposal. The overflow from the cyclone and the classifier flows back by gravity to the grit chamber influent channel. As with the bar screens, it is common for grit chambers to be covered and their atmospheres continuously scrubbed for odor control.

The wastewater flows by gravity from the grit chamber, typically to an influent pump station.

Influent Pumping

With the completion of preliminary treatment, the next step involves the separation of suspended and dissolved organic material from the wastewater stream. This is accomplished through secondary treatment. To get the wastewater there, an influent pump station (Figure 3) is usually required to provide the necessary hydraulic energy required to enter the secondary treatment section of the plant.

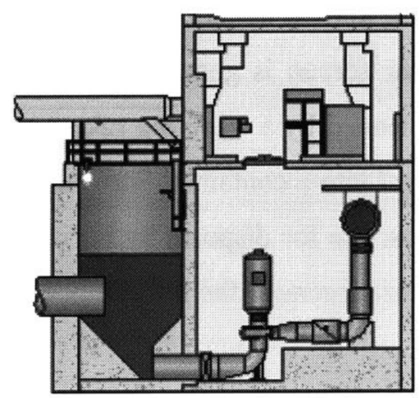

Figure 3: Influent Pump Station

An influent pumping system can consist of one or many fixed and variable-speed centrifugal pumps. Under normal operation in multiple pump systems, one pump operates as a lead or base pump, and the remaining are in backup duty if flow demands. The pumps automatically alternate by a programmable controller to change the order in which they are started, so as not to over use one pump.

Activated Sludge Process

The activated-sludge technique is a biological treatment process where aerobic (i.e., requiring free dissolved oxygen for their respiration) organisms are contacted with the wastewater in an environment suitable for their proliferation. The function of the activated-sludge unit process is to convert organic substances in finely divided, colloidal, and dissolved form into oxidized products and a settleable floc. This floc, known as "activated sludge", is later removed from the wastewater in the clarifiers leaving a high quality effluent (Figure 4).

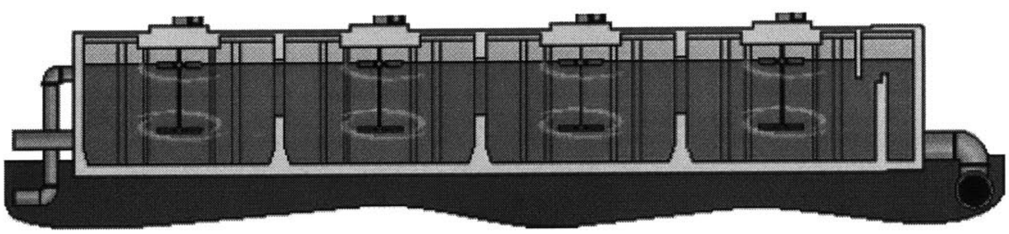

Figure 4: Activated Sludge Unit

Activated sludge is a living biomass that utilizes the organic substances in the wastewater as a food thereby removing these wastes from the wastewater stream. The biomass which make up the activated sludge are the workers in the treatment process. Large mixers are used to keep the solids in suspension and oxygen distributed.

The activated sludge units discharge to secondary clarifiers for separation of the effluent into its two main components, activated sludge and treated water. The sludge settles by gravity while the water flows out from the top. A portion of the settled activated sludge is recirculated back to the activated sludge units to be mixed with the incoming wastewater and provide a continuous process. There the biomass begins feeding all over again on the organic material in the wastewater, stabilizing it and creating new organisms. The remaining sludge is sent to the sludge handling facilities for dewatering and stabilization.

Secondary Clarifiers

Secondary clarification (Figure 5) has the function of separating the activated sludge and influent suspended solids from the treated wastewater stream by gravitational settling. The success of the process depends on liquid-solids separation because the solids must be recycled to the activated sludge basins to sustain the process, and any solids escaping separation will impair the quality of the effluent.

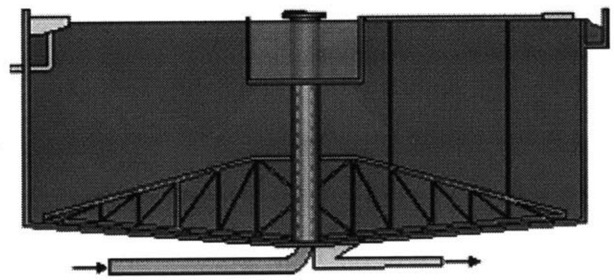

Figure 5: Secondary Clarifier

The effluent from the activated sludge units is distributed to the individual clarifiers where the activated sludge solids settle out and are separated by gravity from the treated wastewater stream. The bulk of the settled sludge is recirculated back to the activated sludge units where it mixes with wastewater, the remainder is diverted to the sludge handling facilities. The overflow from the clarifier is the plant's final treated effluent, which is chlorinated for disinfection purposes as it flows to the effluent pumping station. A scum baffle in the clarifiers prevents floating solids from overflowing the effluent weir. A scum skimmer moves these floatables to a discharge box. The floatables collected in the scum box flow to a wet well for disposal.

Chlorine Disinfection

Although the number of microorganisms is greatly reduced by treatment processes and natural purification, a disinfection process must be used to remove pathogenic (disease-producing) organisms. Typical waterborne bacterial diseases include typhoid, cholera, and dysentery. Many wastewater effluents are discharged to surface waters which are used as a source of public water supply, shellfish growing areas, for recreational purposes, or for the propagation of fish and wildlife. Therefore, removal of pathogenic organisms is required by EPA standards to minimize the health hazards.

As chlorine disinfects very well and is available at a reasonable cost, it is the primary disinfecting agent used in wastewater treatment. The clear effluent from the secondary clarifiers is chlorinated as it flows by gravity to an effluent pumping station.

Effluent Pumping Station

In most systems, effluent pumping is required to supplement the gravitational energy of the outfall, at least under conditions of high discharge head and/or peak flows (Figure 6). The treated wastewater flows via a pipeline from the effluent chlorine contact chamber, where it is chlorinated, to the station's wet well. The effluent pumping system consists of one or more fixed or variable-speed centrifugal pumps that are controlled similarly to the influent pumping station's pumps.

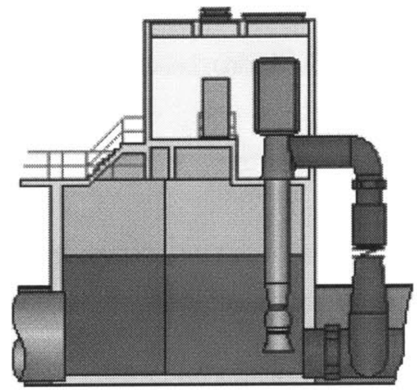

Figure 6: Effluent Pump Station

Sludge Handling

Waste sludge from the clarifiers is typically pumped to an equalization tank where variations in flow and concentration are equalized prior to processing. From the equalization tank, the sludge is pumped to belt presses where most of the remaining liquid is removed. This liquid is recycled back to the influent pump station to be treated. The "cake" that comes off the belt presses is transferred by conveyor and high pressure pumps to trucks for transport to a local landfill.

Alternate Secondary Treatment- Trickling Filters

Trickling filters (TF) are an alternative to activated sludge units for removal of organic matter from wastewater (Figure 7). The TF is an aerobic treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. These systems are known as attached-growth processes.

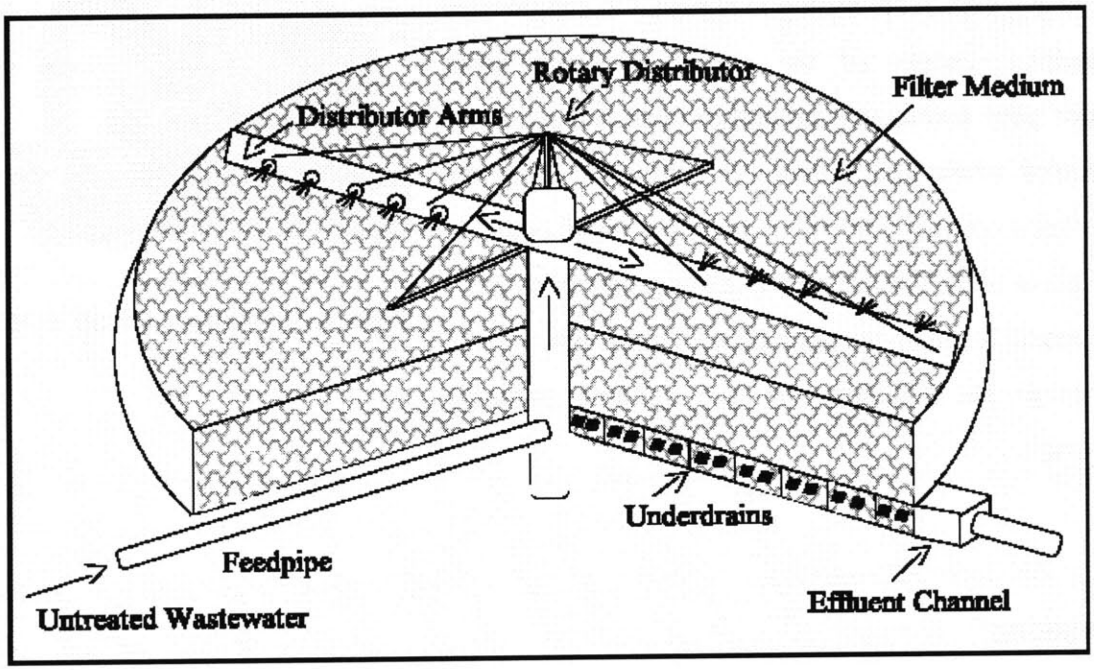

Figure 7: Trickling Filter

TFs enable organic material in the wastewater to be adsorbed by a population of microorganisms (aerobic, anaerobic, and facultative bacteria; fungi; algae; and protozoa) attached to the medium as a biological film or slime layer (approximately 0.1 to 0.2 mm thick). As the wastewater flows over the medium, microorganisms already in the water gradually attach themselves to the rock, slag, or plastic surface and form a film. The organic material is then degraded by the aerobic microorganisms in the outer part of the slime layer. As the layer thickens through microbial growth, oxygen cannot penetrate the medium face, and anaerobic organisms develop. As the biological film continues to grow, the microorganisms near the surface lose their ability to cling to the medium, and a portion of the slime layer falls off the filter. This process is known as sloughing. The sloughed solids are picked up by the underdrain system and transported to a clarifier for removal from the wastewater. (EPA 2000)

Wastewater Collection Systems

The purpose of a wastewater collection system is to convey wastes from the point of generation to the point of treatment or disposal. For municipal systems, collected wastewater is almost always conveyed by a piping system. The piping system may employ gravity, pressure or a combination of these.

Gravity Flow Systems

Gravity flow systems consist of a network of underground sewer pipes sloping continually downhill to the wastewater treatment facility. Gravity systems must incorporate lift stations in order to avoid deep excavation that would be required in a flat or undulating terrain. It is desirable that piping systems be designed to avoid the formation of septic conditions, i.e., the velocity of wastewater through the piping system must be maintained to avoid the formation of septic conditions. The result of septic conditions is the formation of hydrogen sulfide, which causes odor and may cause damage to the piping materials. Therefore, maintaining a minimum flow of fresh wastewater is an important consideration when formulating a piping collection system.

Force Main Systems

In some systems pumping of wastewater from the point of generation to the point of treatment or disposal is required. Pumping is necessary when gravity flow is not practical due to topography and/or economic considerations, when there is insufficient head for gravity flow through a treatment system, or when the plant effluent must be lifted into the receiving stream or body of water. Force main pressure systems can be either of a positive pressure or vacuum pressure design.

Pump Stations

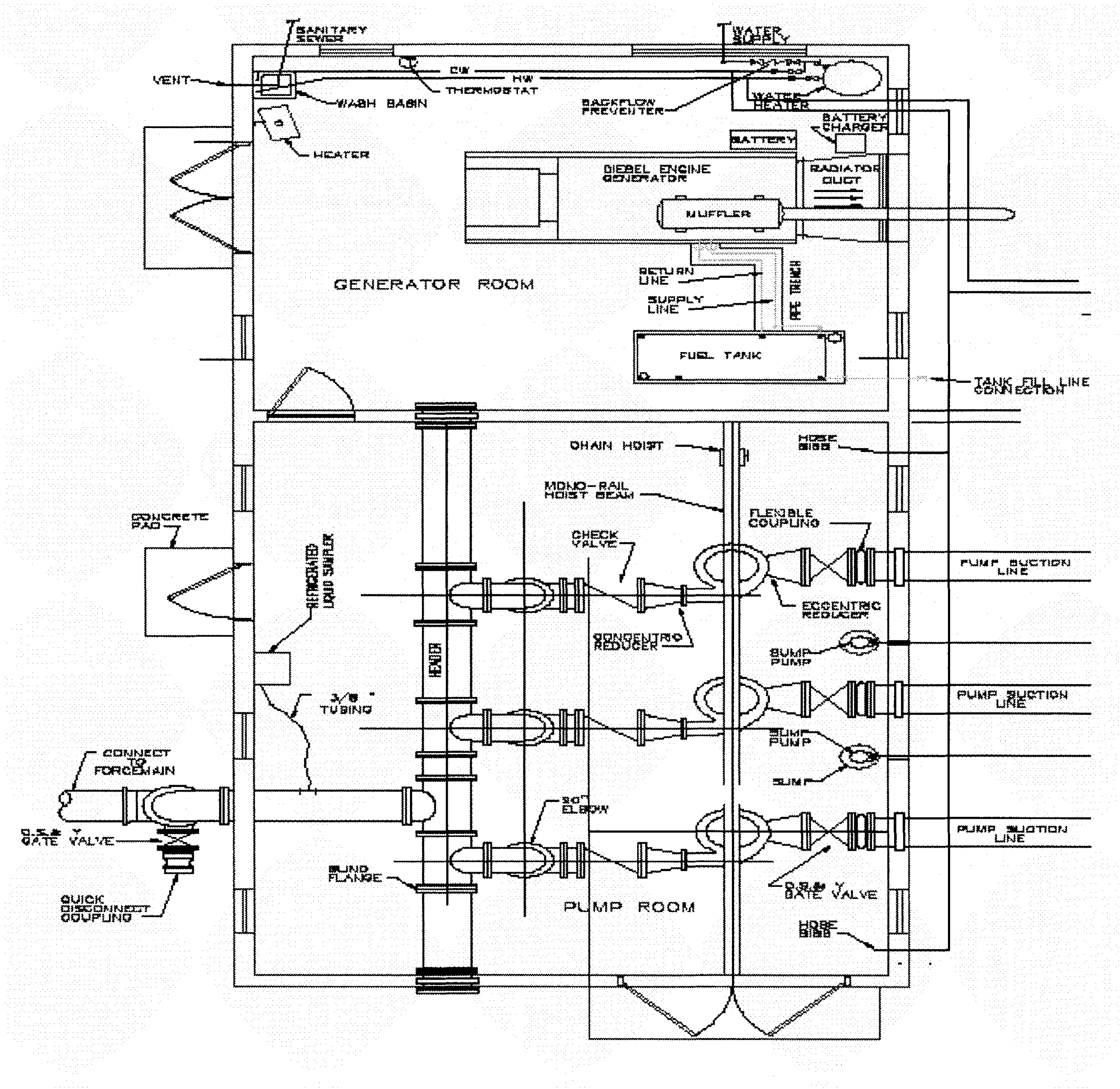

Figure 8: Typical Dry Pit Pumping Station

Numerous pumping stations are required in most gravity and force main wastewater collection systems. In a gravity system these are commonly referred to as lift stations, as wastewater drains by gravity to the station's wetwell, from which it is pumped into another gravity line at a higher elevation. Several stages of pumping may be required to reach some treatment plants. A municipality of 20,000 might have 25 such lift stations located throughout its service area while a population of 400,000 spread over a 20 square mile area can require over 300 lift stations.

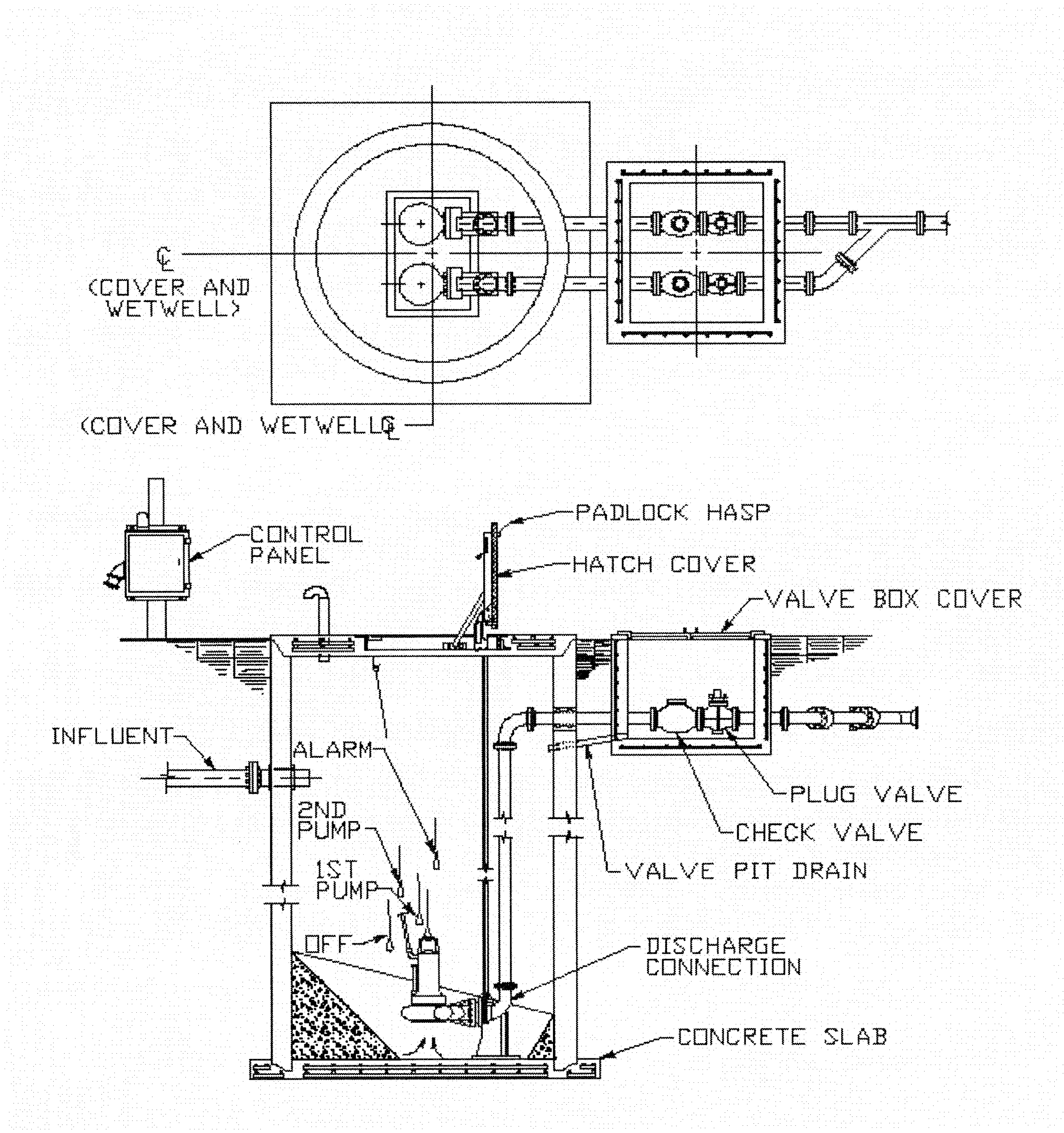

Figure 9: Typical Submersible Pumping Station Cross-Section

Most lift stations are equipped with two or more fixed or variable-speed centrifugal pumps which are controlled in a similar manner to an influent pumping station's pumps.

Pump stations can be either dry pit employing a non-submersible motor and pump (Figure 8) or wet pit employing a submersible motor and pump (Figure 9). A control panel is supplied to sense wetwell level, starting and stopping pumps automatically to prevent overflowing.

With a basic understanding of the municipal wastewater treatment process in hand, we move on to an overview of municipal SCADA hardware and software in Chapter 3.

CHAPTER 3 – MUNICIPAL SCADA OVERVIEW

The Need for SCADA

All wastewater utilities use some type of remote monitoring and/or control system to aid in proper and efficient operation. Control systems designed to monitor a process are referred to as data acquisition systems. If the system also allows remote control to occur based upon the acquired data, it is referred to as a supervisory control and data acquisition system, or SCADA system (Figure 10).

Older systems without SCADA capabilities may rely primarily upon local control and merely a remote indication of a single, non-specific station alarm. Newer SCADA-based installations make more information available both for local and remote control.

Dynamic processes like wastewater collection and treatment require continuous process monitoring and control to achieve minimum standards of cost, treatment regulations and safety. Many municipalities still rely heavily on expensive periodic visits by maintenance people to check on the status of equipment at lift-stations and treatment plants. A SCADA remote monitoring and control system can reduce the frequency of these visits substantially. Typically configured to consolidate operations at a central office, personnel can monitor and control virtually any aspect of the operations. A SCADA system can provide information in a real-time environment that identifies problems as they occur and can take corrective action when assistance is needed. Proper monitoring of equipment can maintain operations at an optimal level by identifying and correcting problems before they turn into significant system failures. Avoiding major problems has become more important as both federal and state regulatory agencies increase the economic consequences of improper discharges. (Motorola 1993)

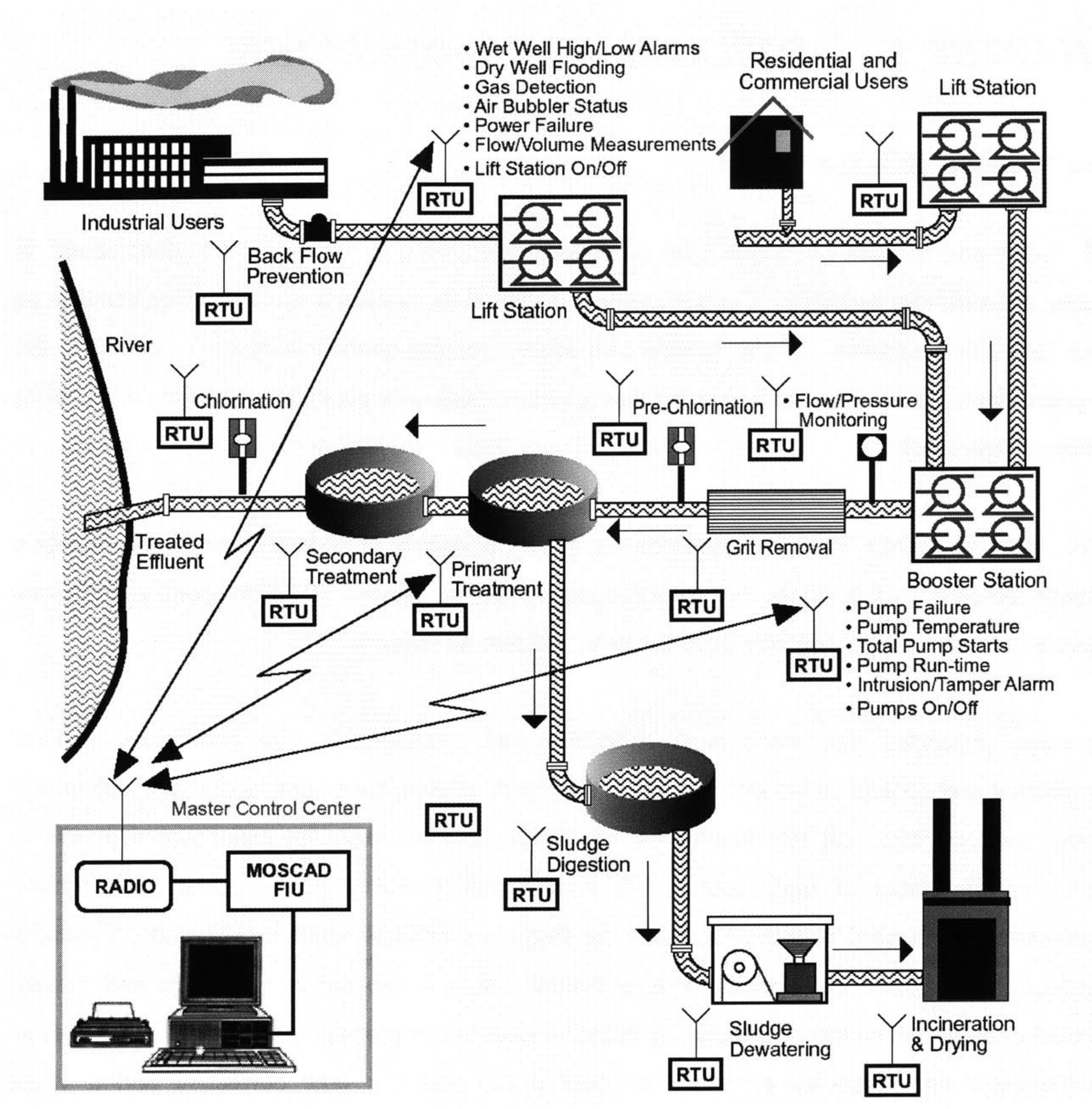

Figure 10: Traditional Municipal SCADA System Architecture

The primary hardware elements of a SCADA system are the operator interface, communication systems, remote telemetry units (RTU), instrumentation and controls. SCADA software and services include the operator interface software, historical databases, report generators, systems documentation and training.

SCADA Hardware

Central Operator Interfaces

Central operator interface hardware most often consists of standard PC computers and LCD monitors with appropriate desks and consoles (Figure 11). Medium and larger systems are normally built with redundant display capability with seating for two or more operator personnel. Report and sometimes alarm printers are also furnished. UPS hardware is normally provided to protect against power outages until backup generation can be placed on-line.

Figure 11: Typical SCADA Central Control System for a Large Municipality

Communication System

Traditional communication systems for SCADA involve dedicated radio systems operated on privately licensed frequencies in the VHF, UHF, 800 and 900 MHz bands (Figure 12). Unlicensed radio frequency bands have been designated by the FCC in the 900 MHz band for what are popularly known as spread spectrum radios. These radio systems operate in a frequency hopping mode, never locked into a particular frequency for very long, with retransmission algorithms built into the transmission protocol. Each radio in the system uses the same hopping sequence to enable communication with one another. Spread spectrum radios have the advantage of being unlicensed. The transmitted power of these radios is limited by the FCC vs. fixed frequency licensed radios, reducing their maximum range somewhat. In some parts of the US there are no available fixed frequencies to license; however, this has diminished since refarming by the FCC. Refarming refers to the FCC subdividing previously licensed 25 KHZ frequency bands into two 12.5 KHZ bands. This has been possible due to improvements in radio technology brought about by digital design. The FCC foresees further subdivision, assuring adequate radio spectrum will be available for municipal usage.

The most prevalent architecture for traditional radio systems is to assign one radio at a central location, normally the location of the SCADA operator interface computer, as the master for the system. This radio is setup with an omni-directional antenna so it can communicate with remote RTUs located in multiple directions. Remote RTU sites are most often equipped with directional yagi antennas that must be aimed within a few degrees of the master omni antenna for full signal strength.

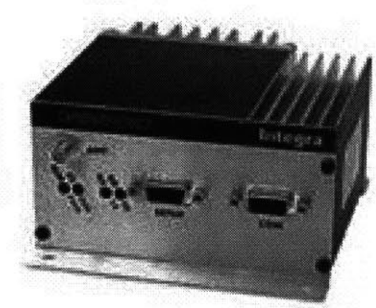

Figure 12: VHF/UHF Radio

Most commonly, the central SCADA computer through the master radio polls each remote slave RTU site in a round-robin fashion, reading and writing all device data assigned to that device each poll. This is the simplest to implement, but least efficient communication method. A more advanced protocol uses a write-by-exception technique whereby each remote RTU selectively operates as a master or a slave, sending data to the central SCADA computer whenever a change of data occurs at the remote site. These systems typically also allow polling from the central site on an occasional basis as a check of overall system health, or allow poll-on-demand by the operator from the operator interface.

Traditional radio systems are low bandwidth – typically 9600 baud devices – which is adequate for the limited amount of data that needs to be transmitted for pump station control. The additional bandwidth requirements of video surveillance or remote web access are not accommodated on traditional radio communication systems.

Alternatives to traditional radios include dedicated Ethernet spread spectrum radios and cell-based modems, which use the public cell phone tower infrastructure. Both of these methods allow the higher bandwidth connections required for video and web applications.

Remote Telemetry Unit (RTU)

A remote telemetry unit (RTU) is a control device that can sense the state of discrete events (such as an alarm or a pump run status) and/or analog events (such as level and pressure) and report this information back via a communication port to the communications system. In the past there was a distinction made between "dumb" and "smart" RTUs. While the dumb ones could be connected to discrete and analog sensors and devices, they couldn't act upon this information without a central controller "polling" or requesting data from the device. Microprocessor technology has made this category of RTU nearly obsolete – smart RTUs that can read and act upon values of discrete and analog sensor devices can be had for under $100 today. Where in past years the RTU function of delivering data to a central computer was separate from the control of the local equipment (such as a pump station), today these functions are often combined into one device. Figure 13 shows a mid-range RTU with control capability equipped with a radio, power supply and terminal blocks in an overall enclosure.

Recent RTU design focus has been on the ability of the unit to support multiple open communication protocols, such as Modbus, Modbus TCP, Ethernet IP, Profibus and DeviceNet. User friendly local human machine interfaces are also featured in many RTU designs that can operate independent of the central SCADA computer.

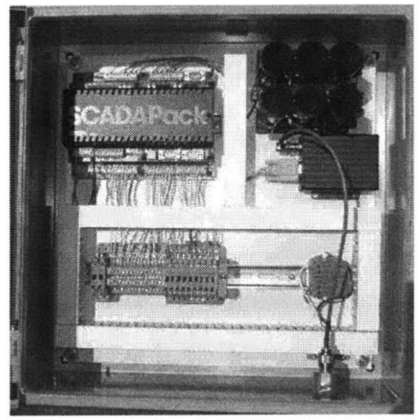

Figure 13: Basic Pump Station RTU

Pump Control Panels

Pump motors consume a considerable amount of electrical power which must be safely switched on and off. This switching is performed by either a separate pump controller or an RTU/controller combination unit such that the level in the collection well is automatically regulated. The pump panel contains motor starters, circuit breakers and protective devices required by the National Electric Code and third party safety certification agencies, such as Underwriters Laboratories (UL) (Figure 14).

Figure 14: Outdoor Pump Control Panel

Local Human Machine Interface (HMI)

RTU door-mounted operator interfaces provided at each RTU are optional but are becoming more common as their reliability has increased while their prices have dropped (Figure 15). They are convenient for monitoring levels, pressures and setting pumping and level setpoints. These configurable displays are flexible and often cost-effective replacements for multiple door-mounted discrete devices.

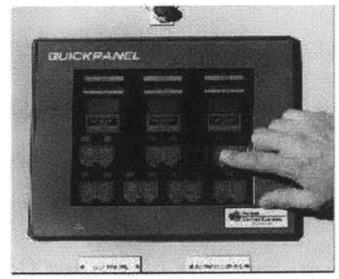

Figure 15: Local HMI

Instrumentation and Controls

Instrumentation (sensor) requirements are determined by the specific installation and operational environment. At a remote lift station, older systems had just a few status/alarm inputs, with pump control left to a local controller. Modern installations tend to make more information available, such as:

Wet well (dry well) - High/Low Alarms
Level/Flow - Bubbler (measures water level), Float, Submersible Pressure, Ultrasonic (Fig16)
Pump Status - Run, Fail, Number of starts, Run-time, Temperature, Vibration
Power monitoring - Current, Phase, Stand-by Generator
Station Conditioning - Security, Temperature, Gas

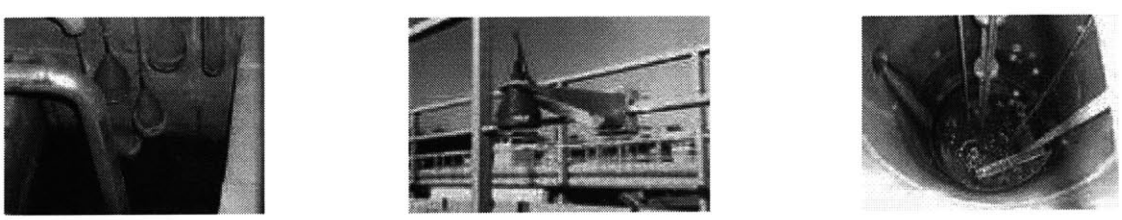

Figure 16: Float, Ultrasonic and Submersible Pressure Level Sensing

SCADA Software

Configurable operator interface software is available from dozens of companies, often marketed on a world-wide basis for general use in industrial, commercial and municipal automation. Such software is designed to run on standard PC desktop or industrially-hardened versions of these products. These suites of applications provide a graphical operator interface function (Figure 17) to monitor processes (the data acquisition of SCADA) with additional capabilities to create process control screens (Figure 18), which provides the supervisory control function of SCADA.. Additional configurable modules for alarm management, historical logging, trending and reporting are typically included with these application suites.

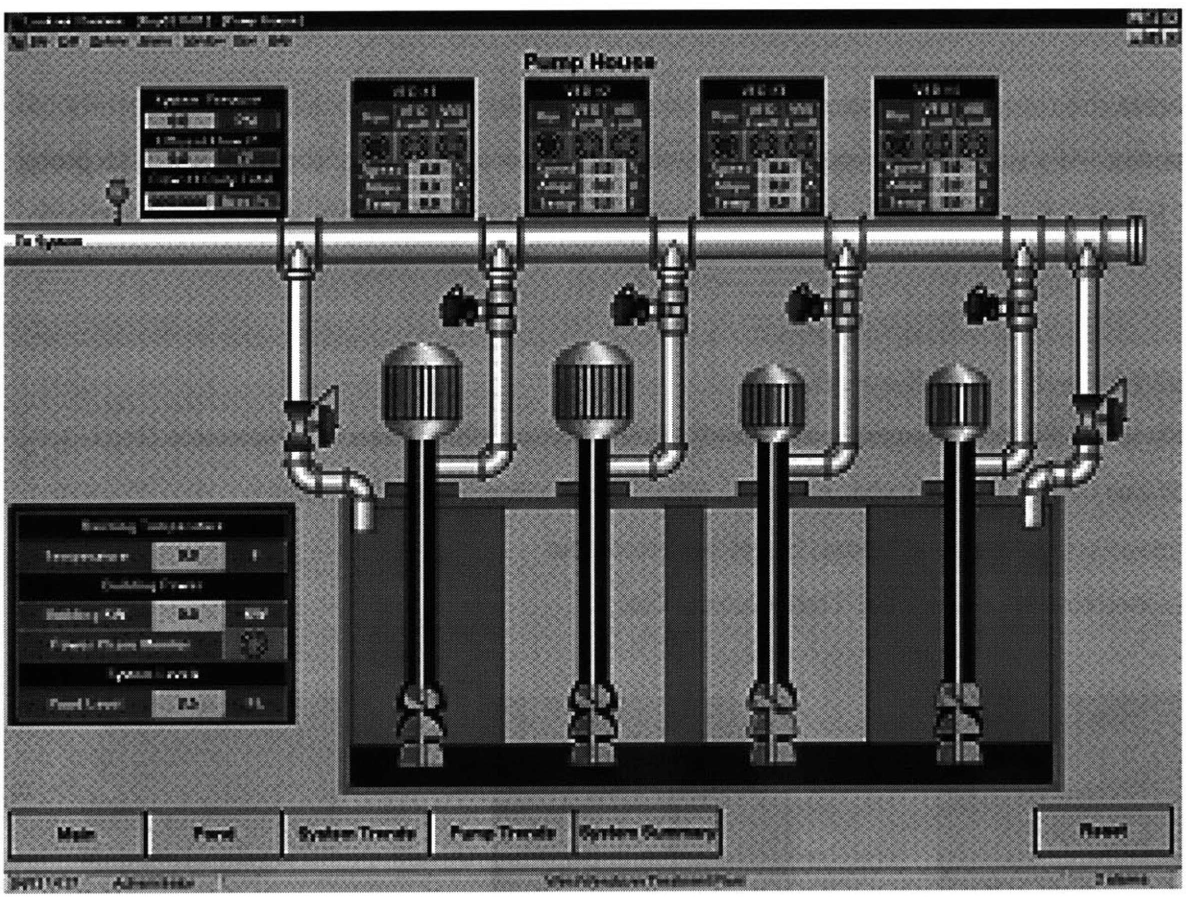

Figure 17: Typical SCADA Graphic for a Pumping Station

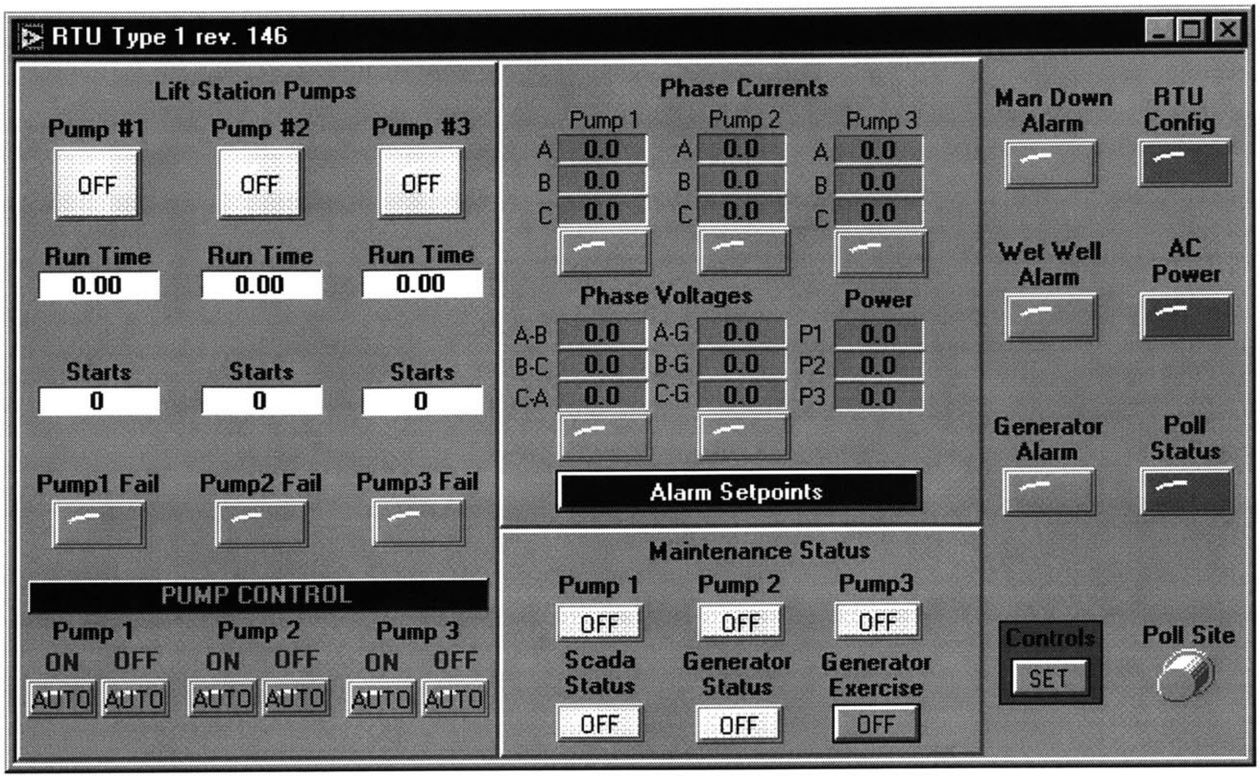

Figure 18: Typical SCADA Control Graphic for a Pumping Station

SCADA hardware and software are thus combined to provide the tools by which wastewater treatment personnel can monitor and control facilities located throughout a community. These systems are setup to acquire most routine data automatically and can also be configured to intelligently act upon acquired data to automate routine processes. Typical collection system automation would include pump station level control, pump alternation (to distribute wear between redundant pumps), automatic switching to a backup pump in the event a primary pump failed, and alarming to advise maintenance personnel of pump station trouble. Some systems provide an alarm notification function, distributing incoming alarms to specific maintenance personnel automatically via voice dialers, email distribution to cell phones or pagers.

With a firm understanding of the municipal wastewater treatment process gained in Chapter 2, together with an understanding of the scope and capabilities of a typical municipal wastewater SCADA system gained in this chapter, the author redirects to the issue of defining a lean enterprise in Chapter 4.

CHAPTER 4 – LEAN ENTERPRISE OVERVIEW

Lean Definition and History

Lean is a new approach to managing enterprises. It has been defined as "the process of eliminating waste with the goal of creating value for enterprise stakeholders" (Murman, 2002).

Lean thinking grew from the study of production methods used by the Japanese automotive industry, first popularized in the book "The Machine That Changed the World" (Womack, 1990). This book was the first to clearly illustrate the significant performance gap between the Japanese and western automotive industries. It described the key elements accounting for this difference in performance as lean production – 'lean' because Japanese business methods used less of everything – human effort, capital investment, facilities, inventories and time – in manufacturing, product development, parts supply and customer relations. This lineage is obvious from a review of commonly used lean terminology in Table 1 (Womack, 1996).

Flow	the progressive achievement of tasks along the value stream
Just-in-time	a system for producing and delivering the right items at the right time in the right amounts
Kaikaku	radical improvement of an activity to eliminate waste
Kaizen	continuous, incremental improvement of an activity to eliminate waste
Kanban	a system to regulate pull of products by signaling upstream production and delivery
Muda	Waste or an activity that consumes resources and creates no value
Poka-yoke	a mistake-proofing device to prevent a defect during order-taking or manufacture
Value Stream	the specific activities required to design, order, and provide a specific product

Table 1: Lean Terminology

Lean Thinking Principles

The first lean principle recognizes that only a small fraction of the total time and effort in any organization actually adds value for the end customer. By clearly defining value for a specific product or service from the end customer's perspective, all the non-value activities – the "muda" (waste) - can be removed. It is typical that in production operations only 5% of activities add value, 35% are necessary non-value adding activities and 60% add no value at all. Eliminating this waste is the greatest potential source of improvement in enterprise performance.

As few products or services are provided by one organization independently, waste removal must be performed throughout the entire set of activities across all the firms involved in jointly delivering the product or service. Often new types of relationships are required between companies and customers to eliminate inter-organizational waste and to effectively manage the value stream. Instead of managing the workload through successive departments, processes are reorganized so that the product or design flows through all the value adding steps without interruption, using lean techniques to successively remove the obstacles to flow. Activities across each company are synchronized by pulling the product or design from upstream steps, just when required in time to meet the demand from the end customer. Removing wasted time and effort represents the biggest opportunity for performance improvement. Creating flow and pull typically involves radically reorganizing individual process steps, but the gains can become significant as steps link together. As this happens more and more layers of waste become visible and the process continues toward perfection, where every asset and every action adds value for the end customer. In this way, Lean Thinking represents a path of continual improvement.

The Lean Enterprise

Lean thinking says a company needs to view itself as just one part of an extended supply chain, to think strategically beyond its own boundaries. It also says that because value streams flow across several departments and functions within the company, it needs to be organized around its key value streams. Beyond the company, some form of organization is needed to manage the whole value stream for a product, setting common improvement targets, rules for sharing the gains and effort and for designing waste out of future product generations. This collective group of companies is called a lean enterprise.

Lean Thinking in Wastewater

Lean thinking has been found to apply to any organization in any sector. Although its origins are in the automotive production environment, the principles and techniques are transferable. There are many case studies that back up this assertion. Lean Thinking (Womack, 1996) showed how firms in several industries in North America, Europe and Japan followed this path and have doubled their performance while reducing inventories, throughput times and errors reaching the customer by 90%. These results are found in all kinds of activities, including order processing, product development, manufacturing, warehousing, distribution and retailing.

Lean Toolbox

A number of tools and techniques have been developed to support lean implementation, to enable companies and other organizations to apply the ideas and implement change. Some of these include the Five S's (five terms beginning with the letter S utilized to create a workplace suited for visual control and lean production – see Appendix A), Kaizen (a process function to plan and support concentrated bursts of breakthrough activities) and Value Stream Mapping.

Value Stream Mapping

In their book *Lean Thinking*, Womack and Jones highlight the importance of eliminating waste from the value stream by making it flow continuously.

> A value stream map identifies every action required to design, order and make a specific product. The actions are sorted into three categories: (1) those that actually create value as perceived by the customer; (2) those which create no value but are currently required by the product development, order filling, or production systems; and (3) those actions which don't create value as perceived by the customer and can be eliminated immediately.

> **Making Value Flow Continuously.** Once the third type of wasteful actions along a value stream has been eliminated to the maximum extent possible, the way is clear to go to work on the remaining non-value-creating steps through the use of flow, pull and perfection techniques (Womack & Jones, 1996)

It follows that to use this lean tool to reduce waste in implementing SCADA in wastewater, we must value stream map the process to identify actions that do not create value.

Enterprise Value Stream Mapping

While value stream mapping focuses on delivering value to the customer, enterprise value mapping focuses on the broader issue of delivering value to all stakeholders. Beyond the municipality, the enterprise definition used in this analysis includes general and electrical contractors, systems integrators, systems and engineering consultants, suppliers of software, communications and other data services.

Enterprise value stream mapping also addresses lifecycle, enabling and leadership processes. Lifecycle processes are those processes in a business that contribute directly to revenue generation for the enterprise. Enabling processes include many of the traditional corporate support functions that are necessary but do not directly contribute to revenue generation. Leadership processes include strategic planning, managing business growth and the transformation management critical to implementing a lean enterprise. One reason why this distinction between process types is important is that a lean enterprise tends to focus its leadership processes on the task of eliminating waste, creating flow and pull in its life cycle processes and deploying enabling processes only as necessary to support these lifecycle processes. A listing of enterprise waste categories that can be examined to streamline lifecycle processes is provided in Appendix B.

Enterprise Value Stream Mapping and Analysis (EVSMA)

Enterprise Value Stream Mapping and Analysis (EVSMA) is a lean evaluation and planning process derived from the MIT Lean Aerospace Initiative (LAI) providing the methodology used by this author for analyzing the implementation of SCADA in municipal wastewater (Murman et al, 2002).

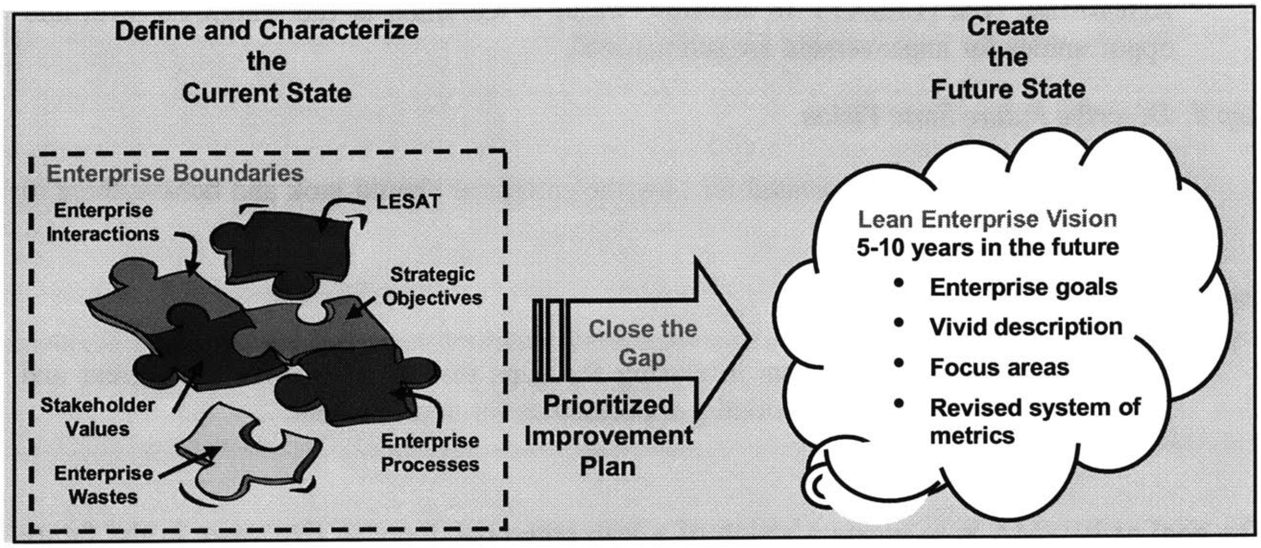

Figure 19: EVSMA Approach

The EVSMA approach shown in Figure 19 (Nightingale, 2004) employs a 6 step process to guide lean evaluation and planning (MIT, 2004):

Step 1: Define the Enterprise

This step relates EVSMA to the enterprise goals, provides a scope for the analysis and background information to ensure the team understands the motivation for change.

Step 2: Describe Stakeholders, Processes, and Metrics

The enterprise stakeholders, processes and high-level metrics are identified. Data collection occurs in this step.

Step 3: Construct Current State Perspectives

Based upon collected data, current state enterprise perspectives are created through analysis of stakeholder values, enterprise processes, high-level metrics, alignment and interactions within the enterprise.

Step 4: Identify Enterprise Opportunities

This step prepares for transition between defining the current state and creating the future state by assessing enterprise "leanness" through the Lean Enterprise Self-Assessment Tool (LESAT). In addition, waste is identified at the enterprise level and opportunities for improvement are summarized.

Step 5: Describe Future State Vision

Here a strategic vision is created for how the enterprise should look and behave three to five years in the future.

Step 6: Create Transformation Plans

The transformation plan assists in closing the gaps that exist between the current and future enterprise states by prioritizing opportunities for improvement.

The goal of EVSMA is to create a vision of a lean enterprise three to five years in the future which optimizes the enterprise value stream. This optimization of the enterprise value stream has the potential to achieve SCADA life cycle cost reductions, reduce the implementation time for SCADA and improve the service level efficiency of wastewater operations.

Thesis Methods, Results and Discussion Related to the EVSMA Process

The Methods chapter of this thesis incorporates EVSMA Steps 1 and 2 in which the existing SCADA implementation system stakeholders and process is defined and data is collected. The Results chapter incorporates the portions of Step 3 and 4 in which the collected data is analyzed using several EVSMA tools and a LESAT self-assessment of the organization. The Discussion chapter incorporates discussion of these analysis results. It includes Steps 5 and 6 where the results of the preceding steps are used to propose a revised lean process for SCADA implementation in municipal wastewater. Also included in the discussion chapter is a roadmap for conversion of the enterprise from the current to the proposed lean state.

With a firm understanding of the prerequisites of wastewater processing, SCADA systems and lean enterprise, the reader is properly prepared to review an actual EVSMA analysis of the SCADA implementation process in municipal wastewater, beginning in Chapter 5.

CHAPTER 5 - METHODS

Scope

This chapter deals with analysis of a specific municipality's wastewater SCADA implementation process, employing the EVSMA lean evaluation and planning process described in Chapter 4.

The municipality's wastewater SCADA needs and current value stream were determined via individual meetings, conversations and correspondence with identified stakeholders.

EVSMA Step 1: Define the Enterprise

Part A - Enterprise Description

The chosen value stream analyzed relates to a large US-based wastewater operation (the City) that provides wastewater services to the public.

The City's wastewater operations are extensive. Properly designed and implemented SCADA services are important to the efficient management of a number of critical functions:

- operation of (3) treatment plants
- operation of remote booster and pumping stations
- compliance to state and federal environmental regulations
- reporting to regulatory agencies
- response to general inquiries by the public
- response to trouble call-ins by the public
- maintenance of systems
- management of personnel resources

While the wastewater system has no competing supplier of wastewater services to its customer base, it is responsible to the individual sewer users who pay the monthly user fees that fund operations. The City has for the past 15 years been upgrading its wastewater system under various Consent Decrees and Administrative Orders that have been mandated by the Federal government. These programs have slowly increased sewer user fees. A significant additional improvement program is underway that is expected to double fees in the next few years. As a result, there is considerable political pressure to keep operating expenditures to a minimum.

The City's wastewater system was developed over the past 100 years and serves a population of over 400,000 located within a 20 square mile radius. Three main treatment plants process all wastewater, fed by a collection system comprised of gravity and force mains, including 2000 miles of pipes, two 15 mile pressurized pipelines, 12 booster stations and over 400 lift stations. There are more than 122,000 customers.

The City's aging wastewater system experiences numerous sanitary sewer overflows (SSOs), system back-ups and customer complaints. Because of the complex hydraulics of the system, it is difficult to know whether problems are the result of too much upstream flow, insufficient downstream capacity, or physical restrictions.

The extended enterprise responsible for the implementation of SCADA within the City's wastewater system includes general and electrical contractors, a systems integrator, project and electrical engineering consultants as well as suppliers of software, communications and other data services. As is typical for large municipal SCADA implementations, a SCADA specification is written by a consultant that transfers the responsibility for the SCADA implementation to a systems integrator. Consequently, there is particular emphasis on the processes used by the systems integrator, given their responsibility for project management and the ultimate success of the SCADA implementation.

Part B - Strategic Goals / Objectives

There are several forces within the City's wastewater system that are driving change:

- Environmental regulation compliance. The City's wastewater system has been operated under a Federal and State Consent Decree since September of 2001. This decree specifies permitted limits of 75% removal for BOD and TSS at each of the three treatment plants. These BOD and TSS limits are temporarily reduced from the normal 85% until the numerous in-process rehabilitation projects are completed to reduce infiltration into the collection system during rain events. To date, two of the three plants have met the 75% criteria. The largest plant, responsible for treatment of more than half of the total sewerage, has reached compliance targets at about a 50% rate. Mandatory fines are being levied by the EPA until this is corrected.
- Overflows. 47 Sanitary sewer overflows (SSOs) occurred due to pipe breakages, obstructed pipes and pump station failures in the last quarterly reporting period. The Consent Decree requires a detailed report be filed regarding each of these incidents with the EPA. Fines are stipulated if reports are not filed within 5 days.
- The trend toward privatization of public services has given new incentive for public entities to become lean.
- The call to utilities from their industry professional associations to establish service level goals.
- The trend toward improved automation and ERP. While the city has made a considerable investment in SCADA control systems for both the treatment plants and their collection systems, various issues have prevented these systems from reaching their full potential. These include personnel availability and training, fundamental design problems with the collection system SCADA and funding issues. The traditional process of delivering SCADA tends to be so onerous that it is all a municipality can do to get the system installed – and there it often sits, little applied to improving the ability of the municipality to deliver value to its clients.

While mission statements were developed by each department more than 5 years ago, there has been no overall goal setting or strategy planning resulting from this. For most of the past 5 years the focus has been upon meeting minimum regulatory standards as set forth in the EPA's consent decree. Operating budgets have been held even or have been allowed to increase a few percent during this period. Capital funds have not been available each year and a capital requests backlog exists for non-emergency equipment replacements.

EVSMA Step 2: Describe Stakeholders, Processes and Metrics

Part A – Stakeholders (with regard to SCADA implementations)

- End Customers for SCADA system
  - Electrical contractors
  - General contractors
  - City wastewater department
- End Users for municipal SCADA system
  - City's wastewater department
- Suppliers
  - Systems integrator
  - Major electrical suppliers
  - HMI software vendors
  - Instrumentation suppliers
- Systems Integrator Employees
  - Engineers
  - Shop personnel
  - Admin/financial/accounting
- Leadership
  - Wastewater administration
  - City project engineers
  - Consulting engineers
  - Systems integrator project managers
- Government
  - Federal environmental regulatory agencies (EPA)
  - State environmental regulatory agencies
- Society
  - The public served by municipalities

Part B - Processes

A high level overview of the wastewater treatment process is provided in Figure 20.

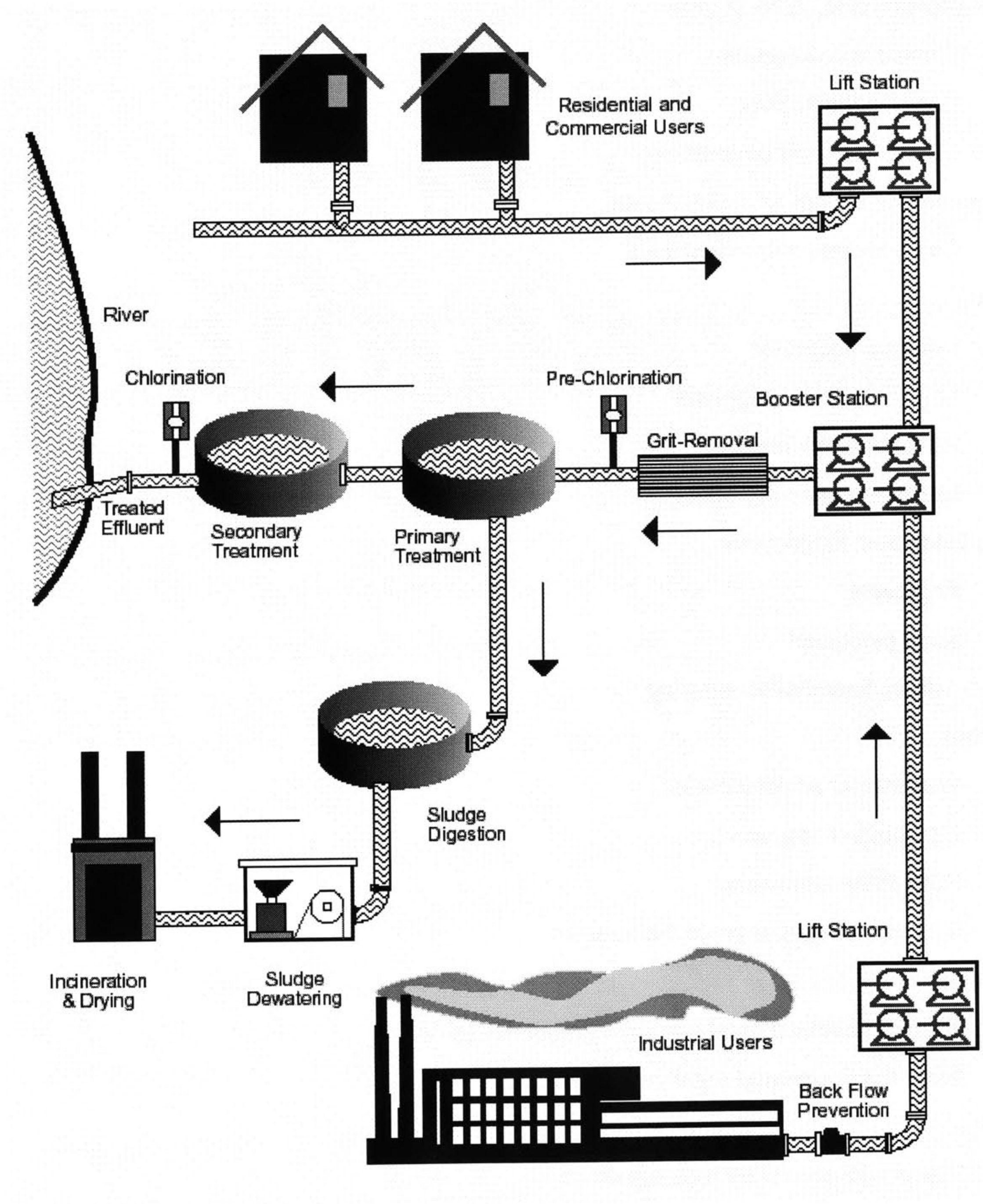

Figure 20: The Wastewater Treatment Process

Many sub-processes are required to assure this wastewater process operates reliably and efficiently. Some of these include:

- Monitoring operation of pump lift stations and treatment plants
- Dispatching of personnel in event of alarm/trouble conditions
- Reporting of alarms / trouble resolution reports
- Administering a preventive maintenance program
- Reporting on inspection of remote pump stations
- Handling customer service requests
- Reporting to EPA on SSO events
- Performing BOD and TSS sample gathering, testing and reporting
- Implementing control and information systems for the above

Particularly researched was the issue of *implementing* SCADA, as its control and information function contributes to the success of all other sub-processes. It is the usual case that large municipal wastewater SCADA system implementations be made the responsibility of a systems integrator. The SCADA implementation process of the City's system integrator was selected for evaluation. The process diagram of Figure 21 details the current process for SCADA implementation from the system integrators perspective.

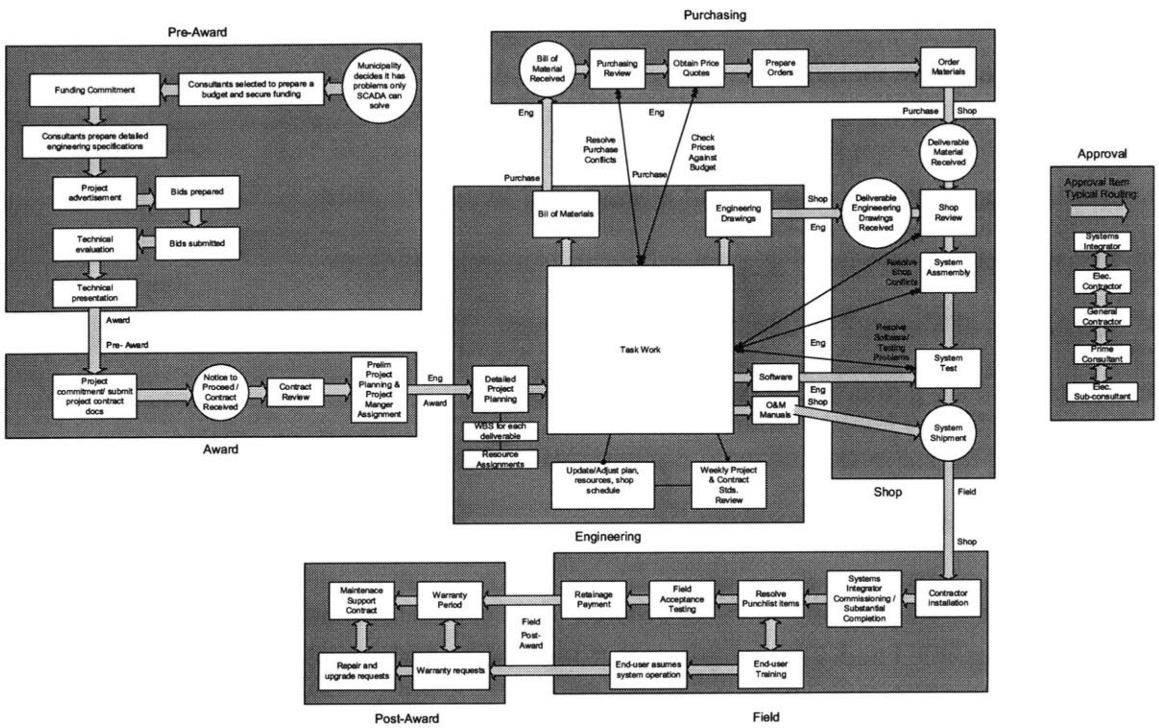

Figure 21: Current SCADA Implementation Process

This SCADA implementation process consists of 8 sub-processes (Figures 22 through 29).

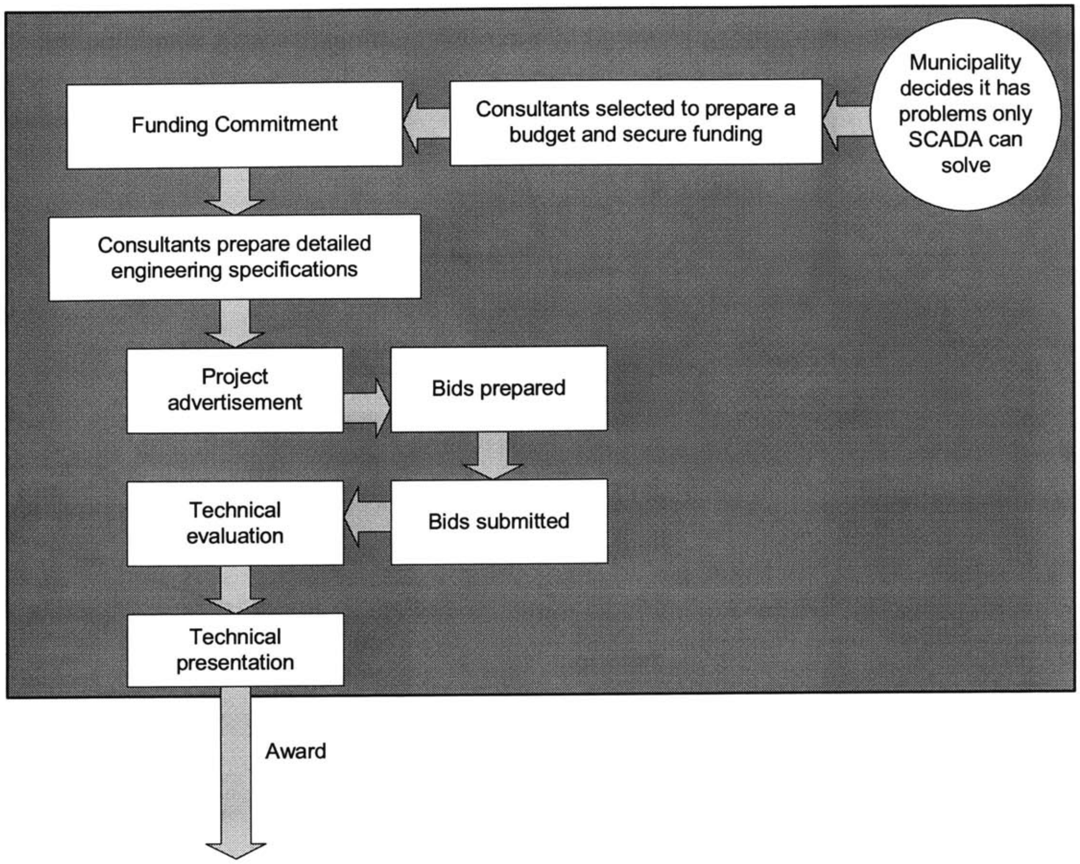

Figure 22: Current Pre-Award Sub-Process

The pre-award process assumes the utility uses a professional services or request for proposals process, which is commonly allowed for in the procurement of highly technical systems under special provisions of public bid law.

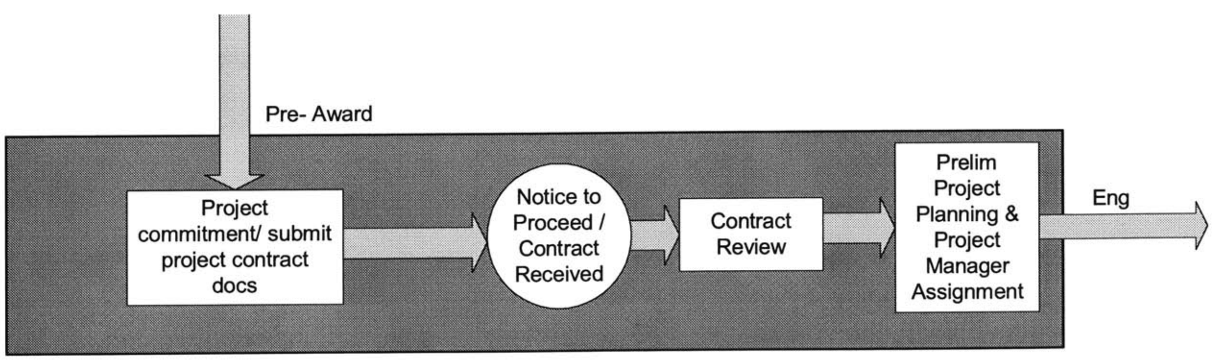

Figure 23: Current Award Sub-Process

The award process defines the actions required to establish a contract with a municipality.

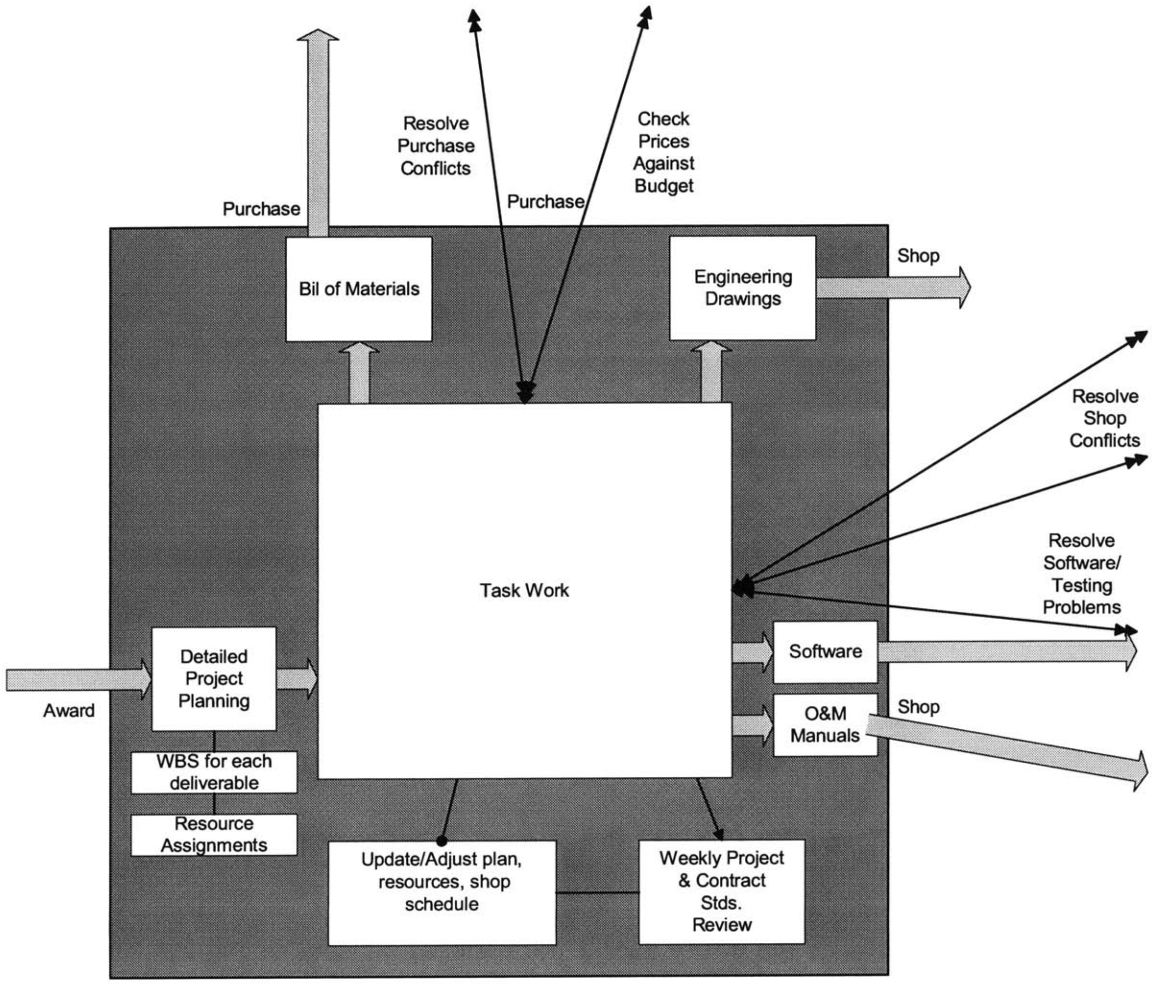

Figure 24: Current Engineering Sub-Process

The engineering process produces the detailed project plans, drawings, bills of material, software configuration, testing and documentation required for a SCADA system, coordinating particularly with the purchasing and shop processes.

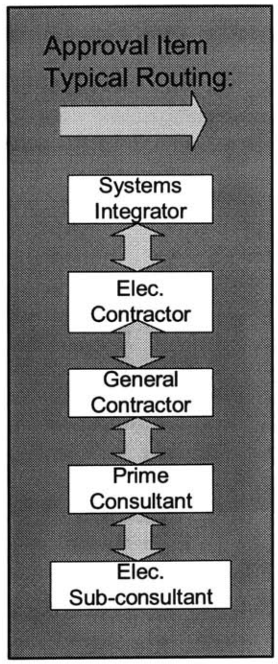

Figure 25: Current Approval Sub-Process

Approval items include bill of materials, engineering drawings and software. It is common for multiple technical submittals to be submitted, adjusted and resubmitted at least once before approval is given to release submittal items for manufacturing.

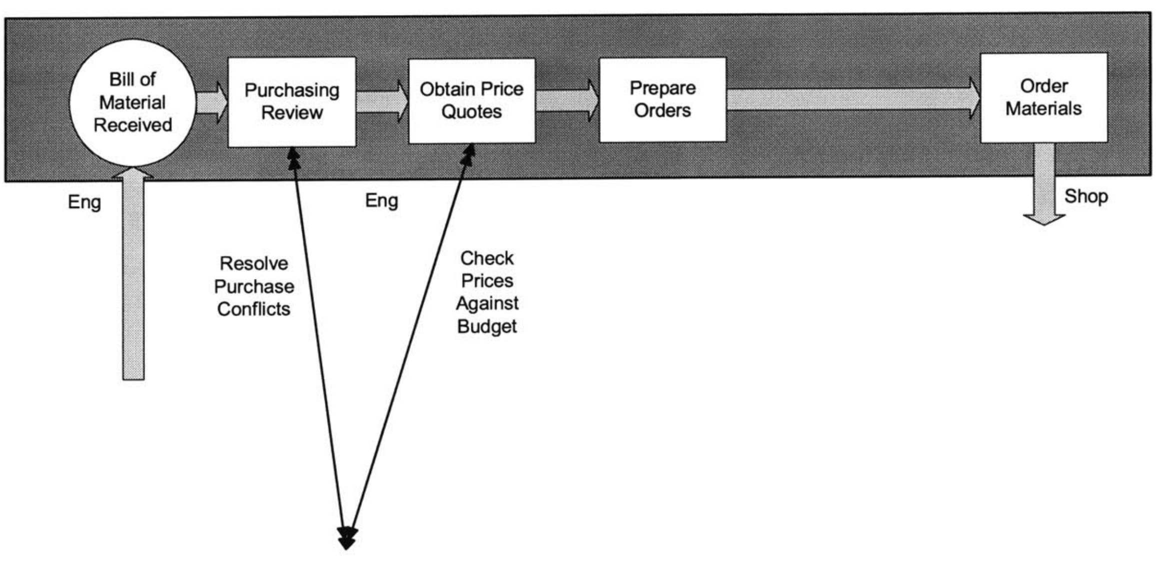

Figure 26: Current Purchasing Sub-Process

It is the responsibility of the purchasing process to order materials listed on submitted engineering bill of materials at a price within the job budget. Materials must be tracked to arrive in time for the shop process to begin at the planned build date.

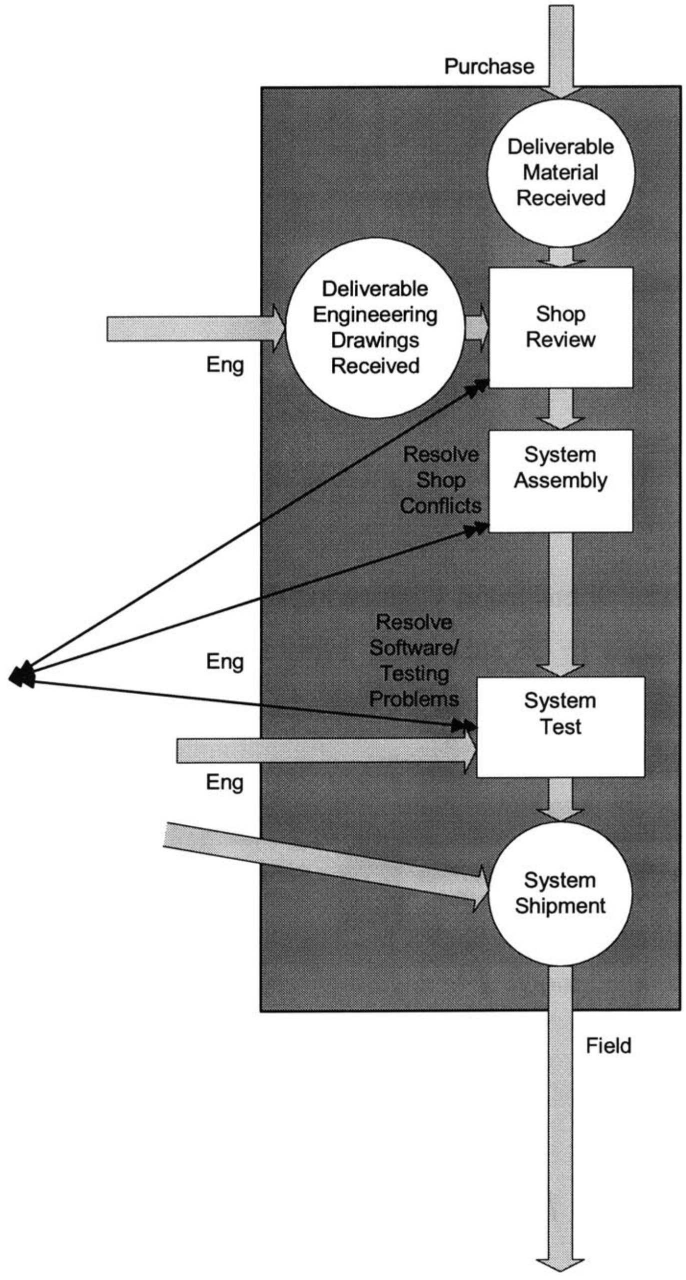

Figure 27: Current Shop Sub-Process

The shop process assembles RTUs, pump control panels, computer network cabinets and other related SCADA automation, in accordance with the engineering process's submitted drawings.

The shop process must closely coordinate with the engineering and purchasing processes to assure on-time assembly, reasonable design-for-manufacturing and for quality assurance testing of the system as a whole.

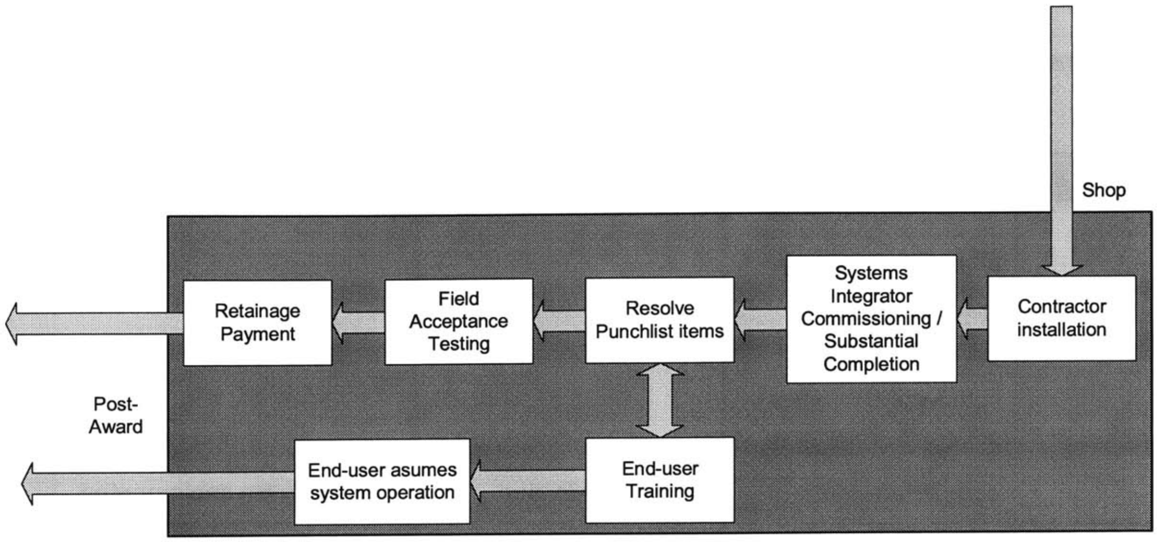

Figure 28: Current Field Sub-Process

The field process has the responsibility of commissioning items delivered from engineering via the shop process, supervising their installation, calibrating, field testing and performing final acceptance testing for the municipality and their designated consulting engineers.

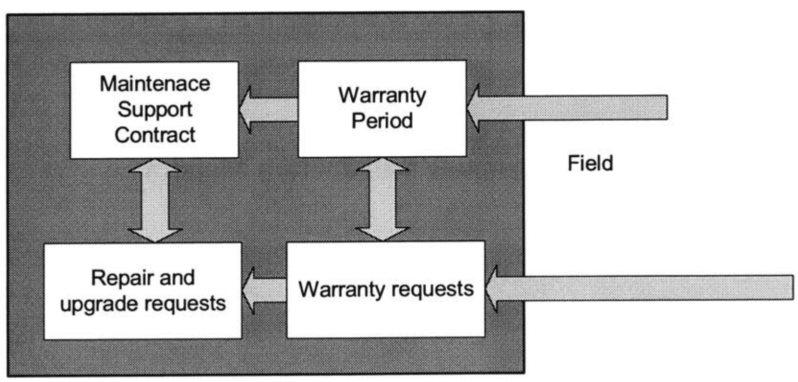

Figure 29: Current Post-Award Sub-Process

The post-award process begins once the SCADA system has achieved final acceptance. This is an on-going process for the life of the system.

Part C - Enterprise Metrics

A table of existing and potential metrics was developed to measure the system integrator's SCADA implementation performance (Tables 2 through 5).

Objectives	*Measures*	*Targets*	*Initiatives*
Customer survey score	3rd party surveying firm, uses email to solicit customer satisfaction info from clients work recently completed with	>90% satisfaction	Pilot program implemented
Complaints received	Tied to above	<1 in 25 responses complaints	Tied to above
Customer retention	Number of customers with repeat orders	4 out of 5 orders from existing customers	Use the above customer survey to better understand our customer's needs; add new services each year to remain a technical and service leader

Table 2: Customer Satisfaction Metrics

Objectives	*Measures*	*Targets*	*Initiatives*
Cost vs. Budget	Job estimate vs. actual costs recorded in accounting and labor billing systems	Actual costs below budgeted	Integrated project planning and time accounting; transferring job profit accountability to engineering using existing tools.
Headcount vs. Budget	To control overhead, set technical headcount with respect to gross sales	sales per engineer; sales per shop employee	Working to add another technical person

Table 3: Financial Metrics

Objectives	*Measures*	*Targets*	*Initiatives*
Profitability	% profit on gross sales	10% EBIT	Exceed industry average profitability; Goal: increase sales at current profit rate
Resource allocation	Technical personnel not heavily over or under utilized	90% - 110% utilization	Developed part time and temporary personnel workforce
New business pipeline	Maintain a quote backlog	quote backlog 3x target volume	Keep running log of potential jobs, their total value, updated weekly
Current business pipeline	Maintain a business backlog	Value of current order backlog 6 mo to 1 year of target volume	Keep running log of current jobs, their total value, updated weekly
Production Scheduling	Maintain on-time shipments; focus on getting billable work completed each month	Invoices each month > 2x fixed expenses minimum; target 1/12 of annual target	Monday AM weekly meetings to review priorities for week; set targets for billable work to be completed each month at beginning of month.

Table 4: Business Efficiency Metrics

Objectives	*Measures*	*Targets*	*Initiatives*
Training time	Improve skills of each employee each year	5% of time (2 weeks) training minimum annually; preferably taken during slow periods	Cross training of employees; manufacturer schools, OJT charged to job to learn new software/hardware or cross functional area
Product mix	New business needs to have content that meets resource allocation goals	Most jobs need a balance of engineering and shop content	Pursue OEM and pre-engineered business opportunities that can be used in leveling workload, continue to pursue longer term more flexible municipal work
Absenteeism	Maintain a reasonable level	Fixed number of sick and personal days allowed in company policy	Labor billing system to be used to track these days and give employees a daily tally regarding time remaining available to them
Turn over	Average length of employment of current personnel	>5 years	Currently > 5 years
Sustainability	Is any person indispensable to the business?	Personnel are cross trained & have backup, so no one person is indispensable	

Table 5: Growth and Development Metrics

Based upon the defined enterprise, the stakeholder analysis and collected data, Chapter 6 moves on to deal with tabulating the results employing a variety of lean process analysis charts and tables.

CHAPTER 6 - RESULTS

EVSMA Step 3: Construct Current State Perspectives - Results

In this step we analyze the information collected on stakeholders, processes, and metrics. As this paper concerns itself with the role SCADA and similar control and information systems play in developing a leaner wastewater enterprise, stakeholder interviews were conducted from this perspective.

Part A - Assessing Value Exchange Between Stakeholders and the Enterprise

The stakeholder groups identified in EVSMA Step 2 were interviewed to determine their values and contributions to the enterprise, with regard to wastewater SCADA implementations. The value exchanged between stakeholder groups and the enterprise is detailed in Tables 6 through 11.

Value Expected from the Enterprise	Stakeholders	Value Contributed to the Enterprise
• Working Product • Getting involved early in design • Good maintenance support • Redundancy of components • Low life cycle cost	**SCADA End-User** • The City's Electrical Maintenance Supervisor for pump stations	• Needs and requirements

Table 6: End-User Value Expected from and Contributed to the Enterprise

Value Expected from the Enterprise	Stakeholders	Value Contributed to the Enterprise
• Profit • Satisfied Customer • Happy Engineering company • Good Supplier partnership • Excellent relationship with everyone • quick resolution of problems • SCADA Expertise	**SCADA Customers** • Principal - General contractor • Field project supervisor - Electrical contractor	• Needs and requirements • Money (for products/services) • Prior experience, credibility and trust of engineers

Table 7: Customer Value Expected from and Contributed to the Enterprise

Value Expected from the Enterprise	Stakeholders	Value Contributed to the Enterprise
• Product Integration • Single Point of Contact • Cost of Ownership • Production schedules • Engineering Specifications	**SCADA Supplier/Partner** • Product manager for major electrical firm, Water and Wastewater Industry Systems	• Products and services • Applications expertise • Service support infrastructure

Table 8: Supplier/Partner Value Expected from and Contributed to the Enterprise

Value Expected from the Enterprise	Stakeholders	Value Contributed to the Enterprise
• Recognition for contributions • A fair wage Tools Expected: • Have necessary info. for decision making • Good communication • Cross functional training • Personal training	**Systems Integrator Employees** • Shop • Field • Administrative	• Time • Skills • Knowledge • Ability to develop professionally • Provide what customer asked for • Delegation of project assignments • Delivery of products on time

Table 9: Systems Integrator Value Expected from and Contributed to the Enterprise

Value Expected from the Enterprise	Stakeholders	Value Contributed to the Enterprise
• Customer satisfaction • Challenges • Good response to needs • Resource for the company	**Leadership** • Engineering • Administrators	• Project and budget management • Resource allocation • Strategic direction • Vision

Table 10: Leadership Value Expected from and Contributed to the Enterprise

Value Expected from the Enterprise	Stakeholders	Value Contributed to the Enterprise
• Environmental regulation compliance • Efficient, cost effective delivery of wastewater services	**<u>Society / Government</u>** • Municipality • Municipality citizens • EPA	• Tax base • Employees • Land • Environmental regulation benchmarks

Table 11: Society/Government Value Expected from and Contributed to the Enterprise

The relative importance of stakeholder values are charted in relation to the effectiveness of the enterprise in delivering value to the stakeholder as detailed in the following series of charts shown in Figures 30 through 38.

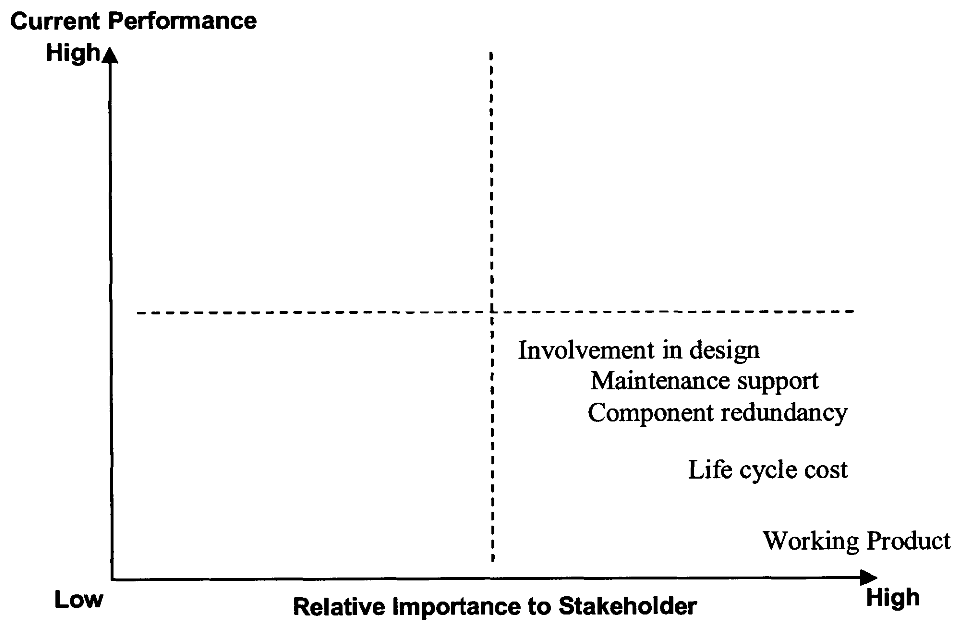

Figure 30: End-User Value Delivery

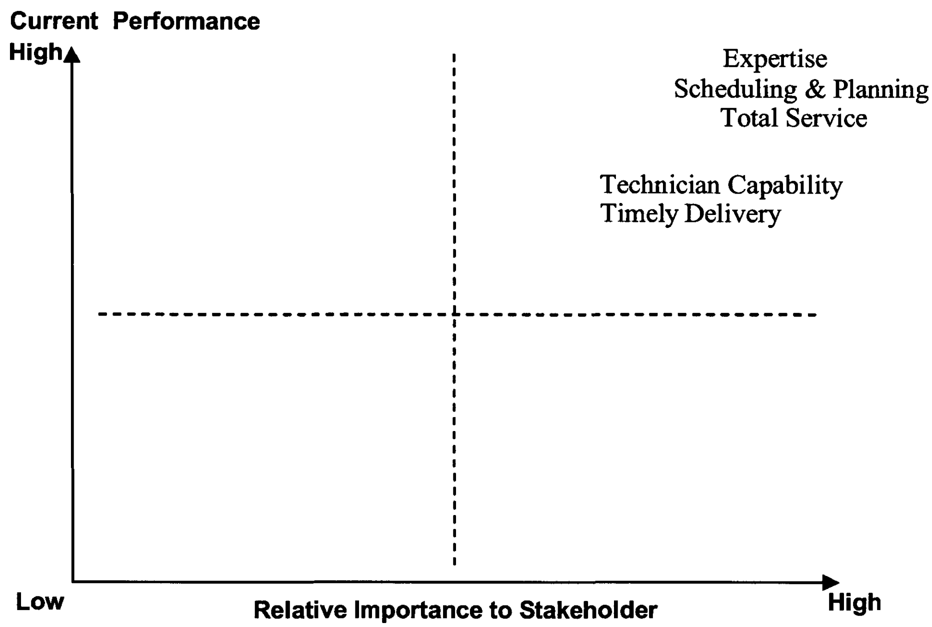

Figure 31: End Customer 1 Value Delivery

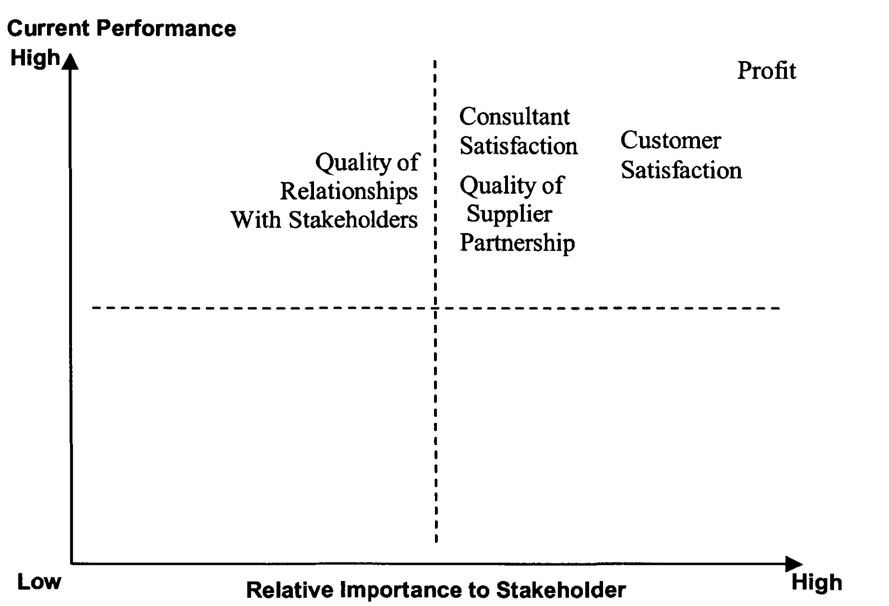

Figure 32: End Customer 2 Value Delivery

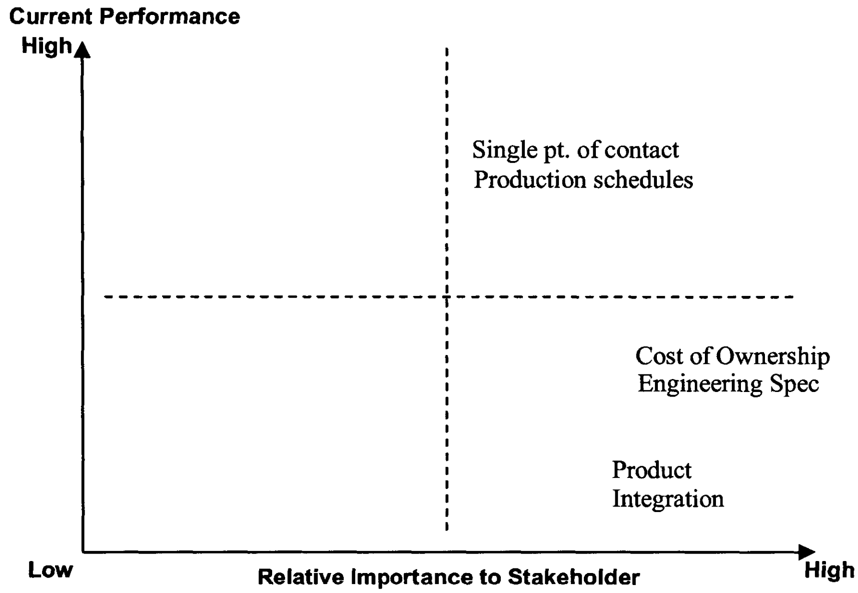

Figure 33: Supplier Value Delivery

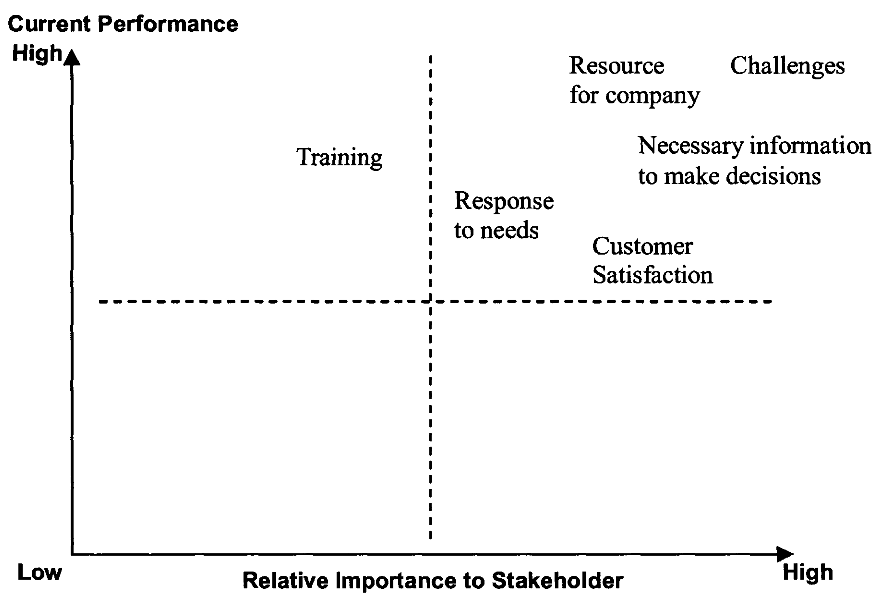

Figure 34: Leadership 1 Value Delivery

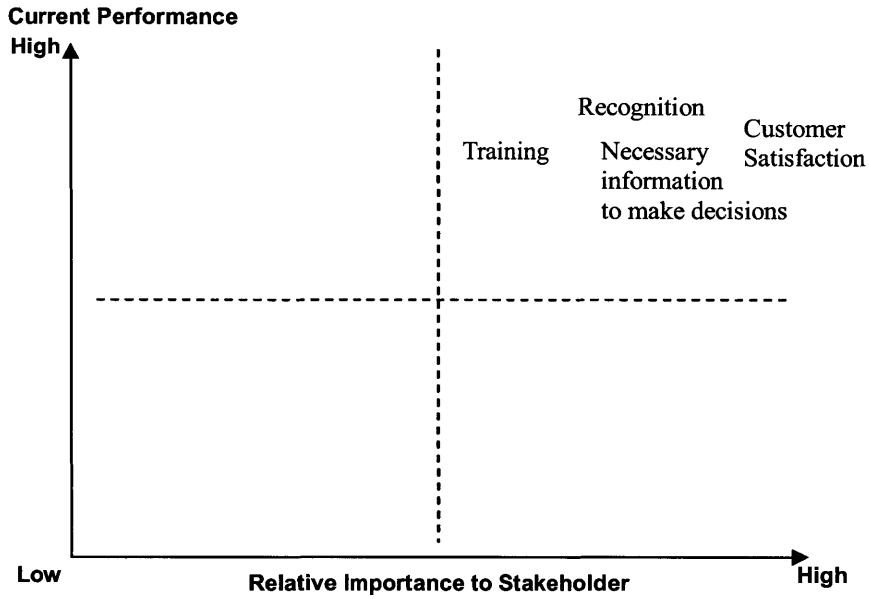

Figure 35: Leadership 2 Value Delivery

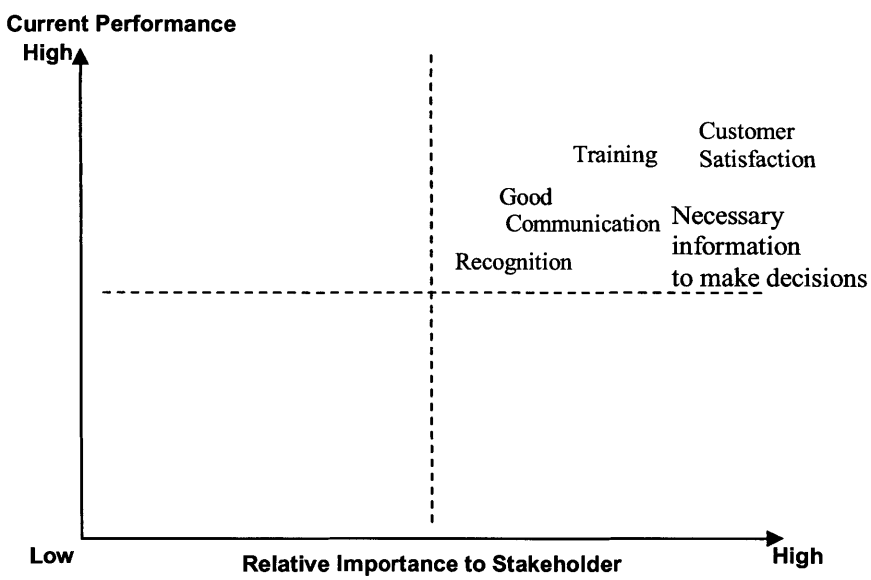

Figure 36: Systems Integrator Employee 1 Value Delivery

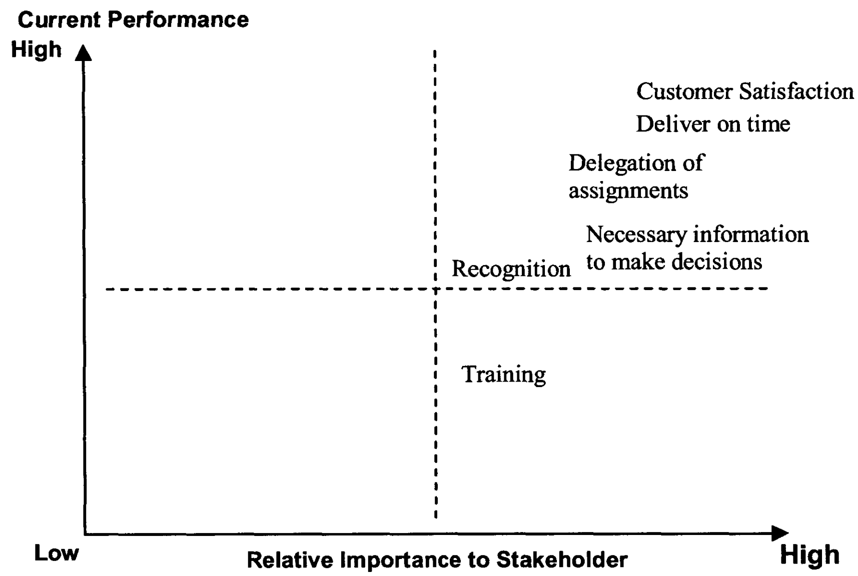

Figure 37: Systems Integrator Employee 2 Value Delivery

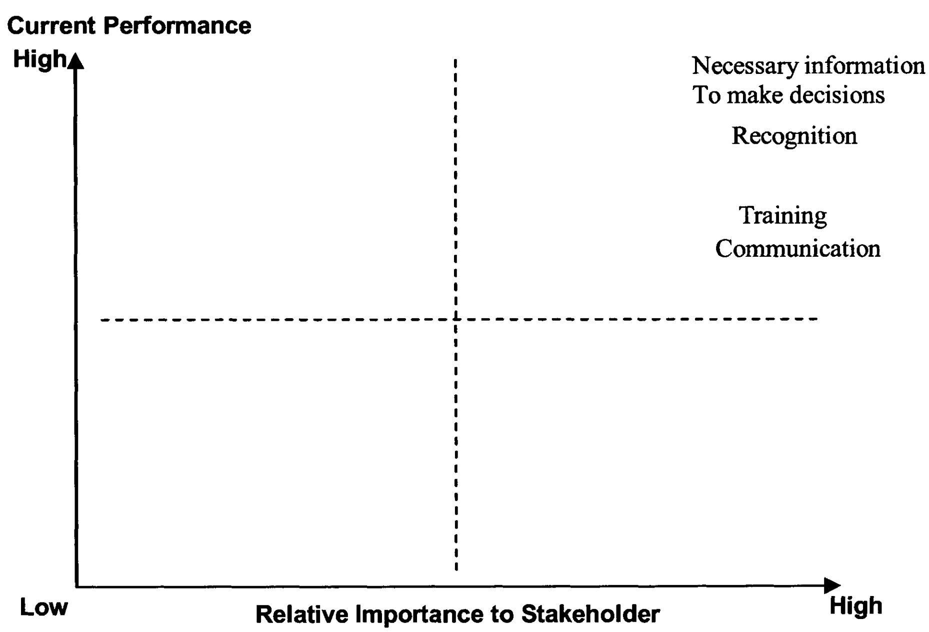

Figure 38: Systems Integrator Employee 3 Value Delivery

Stakeholders were compared according to their relative importance to the enterprise and relative value delivered to the stakeholder in Figure 39. The x-axis represents the stakeholder importance to the enterprise and the y-axis the value the enterprise delivers to that stakeholder. Stakeholders in the bottom left corner are those with least importance to the enterprise who receive the least value from the enterprise; the converse applies to the stakeholders in the top right corner. Stakeholders off the diagonal receive greater value than their relative importance or vice versa.

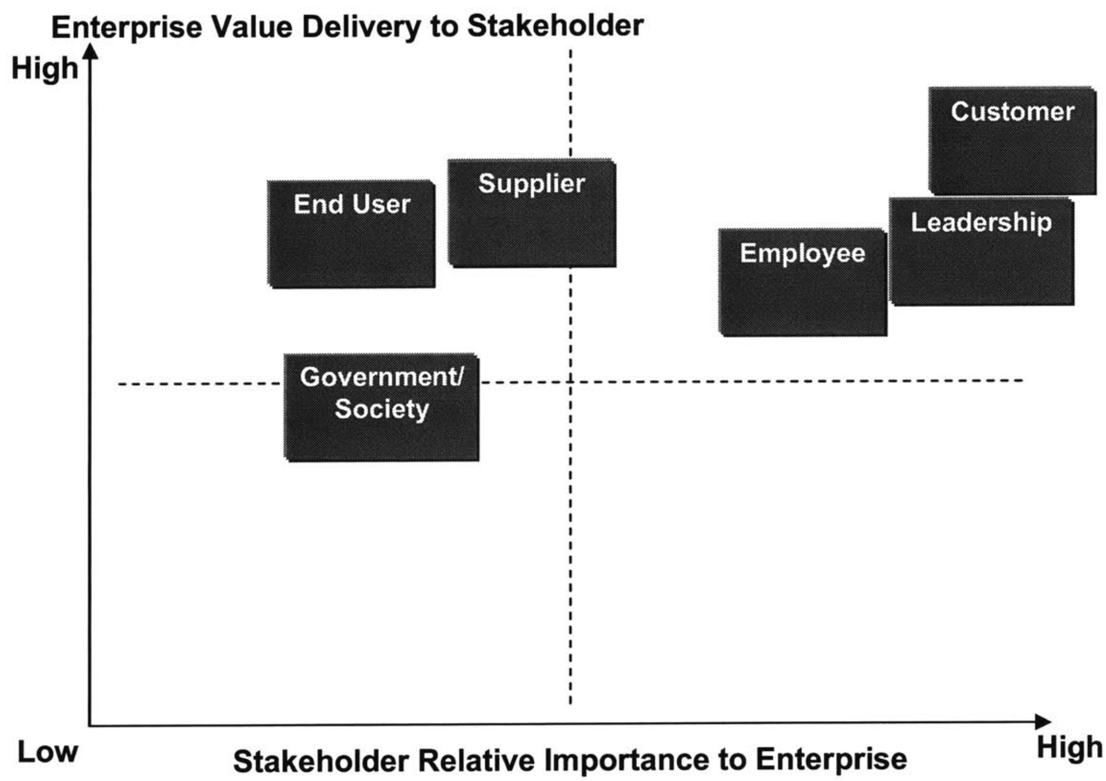

Figure 39: Stakeholder Value Comparison

Part B - Analyze Current Enterprise Process Performance

Table 12 indicates the approximate cycle time in days, headcount and percentage cost associated with each process identified in EVSMA Step 2 Part B in Chapter 5.

Process Data (Cycle times in days)		**Lifecycle Processes**			
		Engineering	Shop	Field	Post-Award
SCADA Systems	Total Cost	45%	20%	15%	3%
	Personnel Assigned	1	2	1	1
	Cycle Time	210	60	120	360

	Enablers		**Leadership**		**Total**
	Award	Purchasing	Pre-Award	Approval	
Total Cost	2%	5%	8%	2%	100%
Personnel Assigned	1	1	1	1	9
Cycle Time	60	30	180	120	1140

SUBTOTALS:

		Lifecycle Processes	Enabling Processes	Leadership Processes	Total
SCADA Systems	Total Cost	83%	7%	10%	100%
	Personnel Assigned	5	2	2	9
	Cycle Time	750	90	300	1140

Table 12: Lifecycle, Enabling and Leadership Process Cycle Times

Part C - Analyze the Enterprise Metrics

Tables 13 through 16 tabulate the results of the system integrator employee surveys.

Metric	Target	History	Current Status	On-Going Development
Customer Satisfaction	>90% satisfaction	~2 surveys sent out a few years ago	Very high except for late projects	Needs a company champion
Complaints	<1 in 25 responses complaints	Very few if any on quality; some complaints on schedule	Delays in bid process, submittal process, engineering, approvals, etc. make project "late" before it even starts On-time about 80%	none
Customer Retention	4 out of 5 orders from existing customers	On target	On target	

Table 13: Customer Satisfaction Results

Metric	Target	History	Current Status	On-Going Development
Cost vs. Budget	Actual costs below budgeted	majority below budget	Many above budget	Improvement in project and labor management systems continues
Headcount vs. Budget	specific sales per engineer; specific sales per shop employee	On target over last 3 years	On target over last 3 years	none

Table 14: Financial Results

Metric	Target	History	Current Status	On-Going Development
Profitability	10% EBIT	Large fluctuations month-to-month	Large fluctuations month-to-month	Transitioning to a % complete billing method
Resource allocation	90% - 110% utilization	Shop work has fluctuated significantly	This year<50% utilized some months, others 150% utilized	Working to cross train shop personnel; shop load expected more uneven next year
New business pipeline	Value of quote backlog 3x target volume	Not specifically tracked	>3x	Need to formalize reporting monthly
Current business pipeline	Value of current order backlog 6 mo to 1 year of target volume	On target	On target	Need to formalize reporting monthly
Even flow of Production/ Billings	Invoices each month > 2x fixed expenses minimum; target 1/12 of annual target	Dependent upon mix of orders, when approvals are received and when contract allows work to be billed	This year worse than last	Shop needs to review work in approval and do some before approval

Table 15: Business Efficiency Results

Metric	Target	History	Current Status	On-Going Development
Training time	5% of time (2 weeks) training minimum annually; preferably taken during slow periods	No specific goal, provided as needed	2% - 5%	Additional training
Product mix	Most jobs need a balance of engineering and shop content	Generally avoided bidding larger jobs that are lopsided in content	Understaffed in engineering; sometimes overstaffed in shop	Cross-train shop; shop under-staffs handled by temp employees; hiring engineers
Absenteeism	Fixed number of sick and personal days allowed in company policy	Up to 20 sick days/per person	3 sick days/per person paid out if not used	
Turn over	>5 years	Very low; Avg. 5.71 years	Very low; Avg. 5.71 years	Very low
Sustainability	All personnel are cross trained and have a backup, so that no one person is indispensable	Company built by present top management	Top management's over commitment restrictive to new growth & development	Find & train personnel to assume some of top management's responsibilities

Table 16: Growth and Development Results

Part D - "X-Matrix" Evaluation of Process/Stakeholder/Metric/Strategic Objective Interrelationships

An "X-matrix" was used to evaluate the interrelationships between each of these key areas. The two halves of this matrix are shown in Figures 40 and 41.

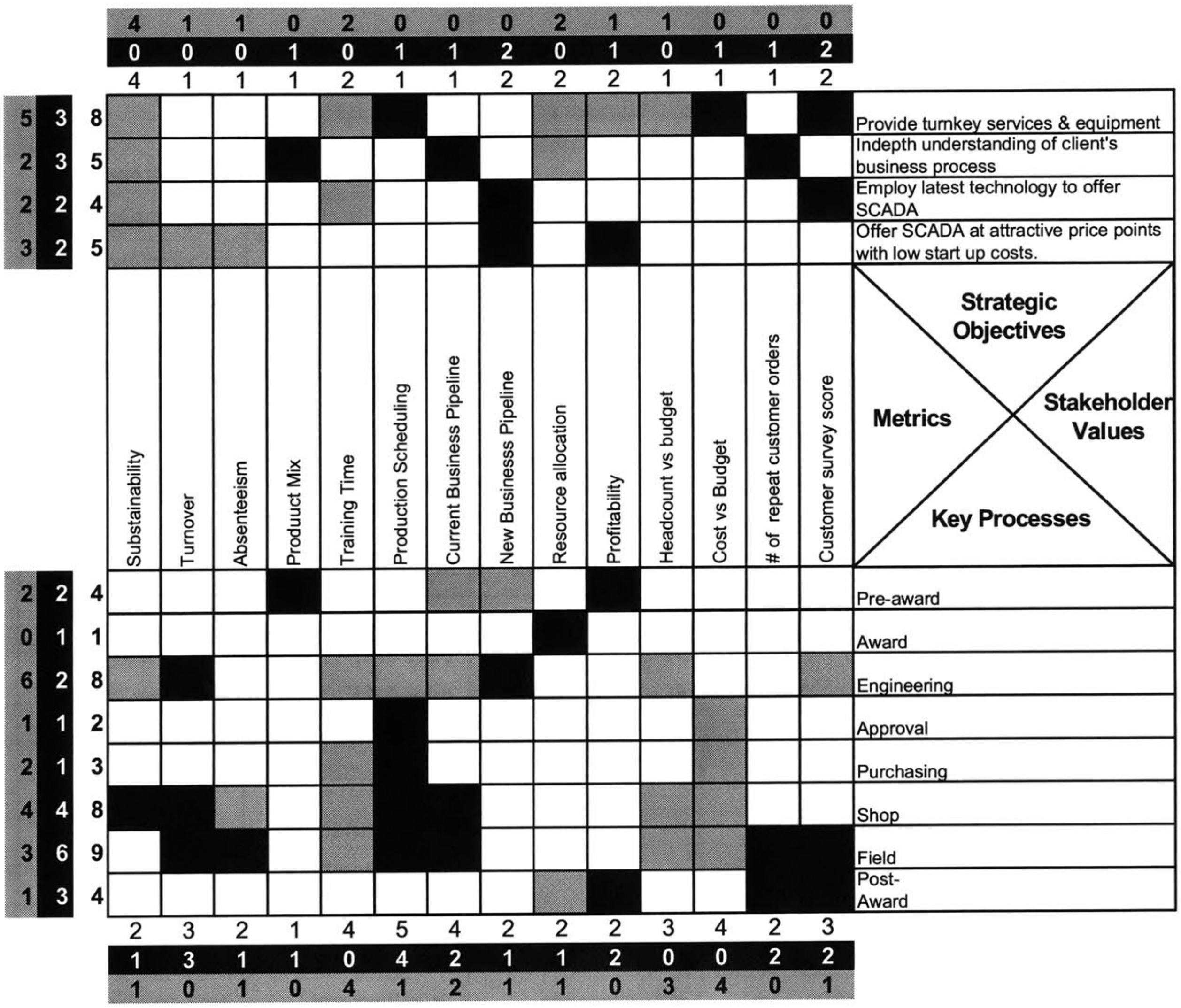

Figure 40: X-Matrix Relating Metrics to Strategic Objectives and Key Processes

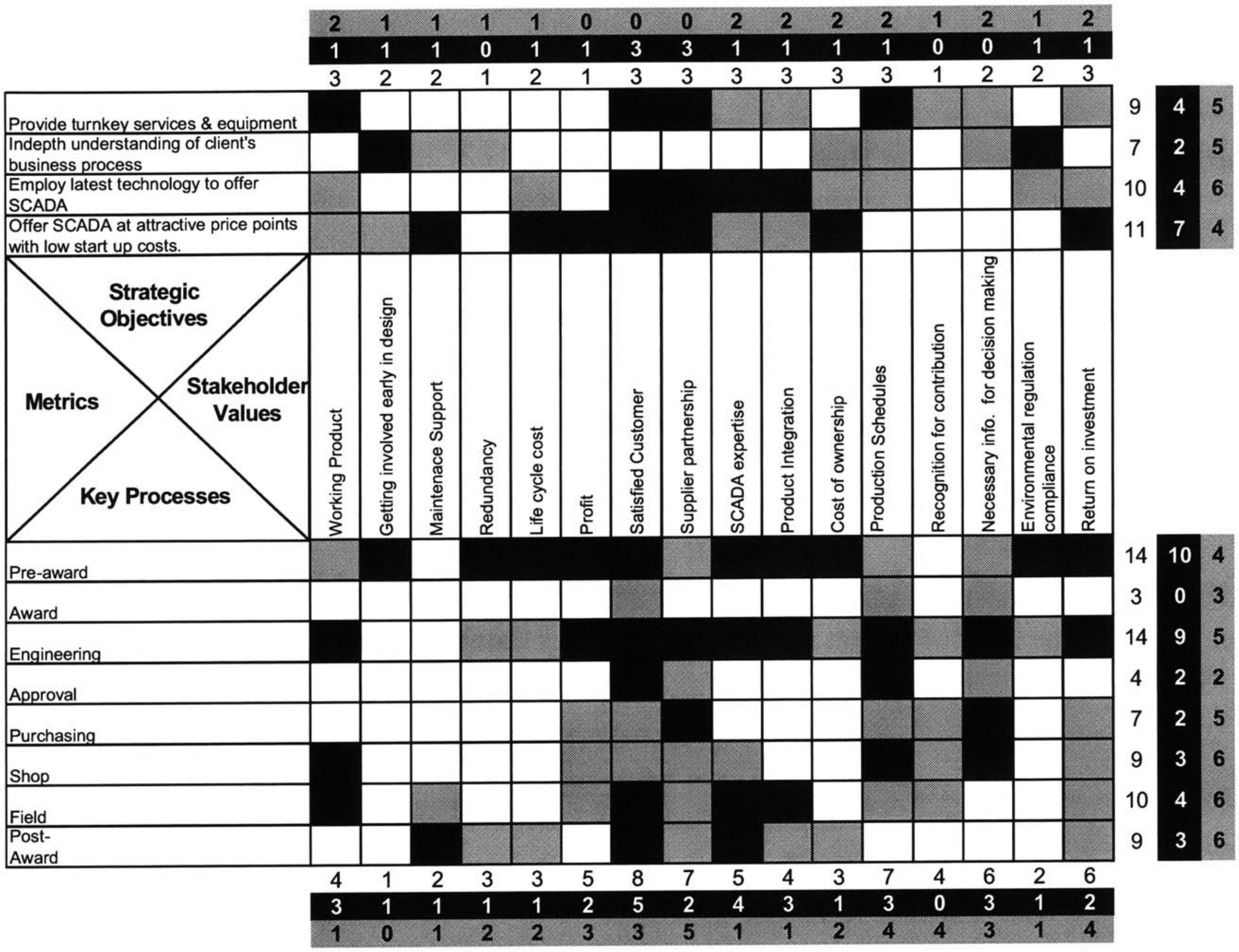

Figure 41: X-Matrix Relating Stakeholder Values to Strategic Objectives and Key Processes

EVSMA Step 4: Identify Enterprise Opportunities

Part A: LESAT Assessment Results

An organizational assessment of lean progress and "readiness to change" was conducted for the systems integrator using the Lean Enterprise Self-Assessment Tool (LESAT) (Murman et al, 2002). The LESAT Summary Sheets were used to record present and desired lean levels, focusing primarily on the "current" levels and then summarized using the LESAT calculator spreadsheet shown in Appendix C.

The LESAT was performed by the overall administrative and technical manager of the systems integrator. A summary of current state LESAT scores is shown in Table 17.

Current State - Overall LESAT Score			
	Mean	Variance	Range
Current	1.4	0.0	0.0

CURRENT STATE - LESAT Section Scores											
Section I - Lean				Section II - Life Cycle Processes				Section III - Enabling			
	Mean	Varianc	Range		Mean	Variance	Range		Mean	Varianc	Range
Current	1.2	0.0	0.0	Current	1.6	0.0	0.0	Current	1.9	0.0	0.0

Table 17: Current State LESAT Scores

A summary of the desired state LESAT scores is shown in Table 18.

Desired State - Overall LESAT Score			
	Mean	Variance	Range
Desired	2.7	0.0	0.0

DESIRED STATE - LESAT Section Scores											
Section I - Lean				Section II - Life Cycle Processes				Section III - Enabling			
	Mean	Varianc	Range		Mean	Variance	Range		Mean	Varianc	Range
Desired	2.6	0.0	0.0	Desired	2.7	0.0	0.0	Desired	3.0	0.0	0.0

Table 18: Desired State LESAT Scores

Specific gap scores indicating the difference between the current and desired LESAT scores is shown in Table 19.

GAP - Overall LESAT Score			
	Mean	Variance	Range
Gap	1.2	0.0	0.0

GAP - LESAT Section Scores											
Section I - Lean				Section II - Life Cycle Processes				Section III - Enabling Infrastructure			
	Mean	Variance	Range		Mean	Variance	Range		Mean	Variance	Range
Gap	1.4	0.0	0.0	Gap	1.1	0.0	0.0	Gap	1.1	0.0	0.0

Table 19: Gap Scores – Current vs. Desired

The chart in Figure 42 indicates the current lean predictive maturity state and gap between the current and desired states. This was compiled from the LESAT analysis.

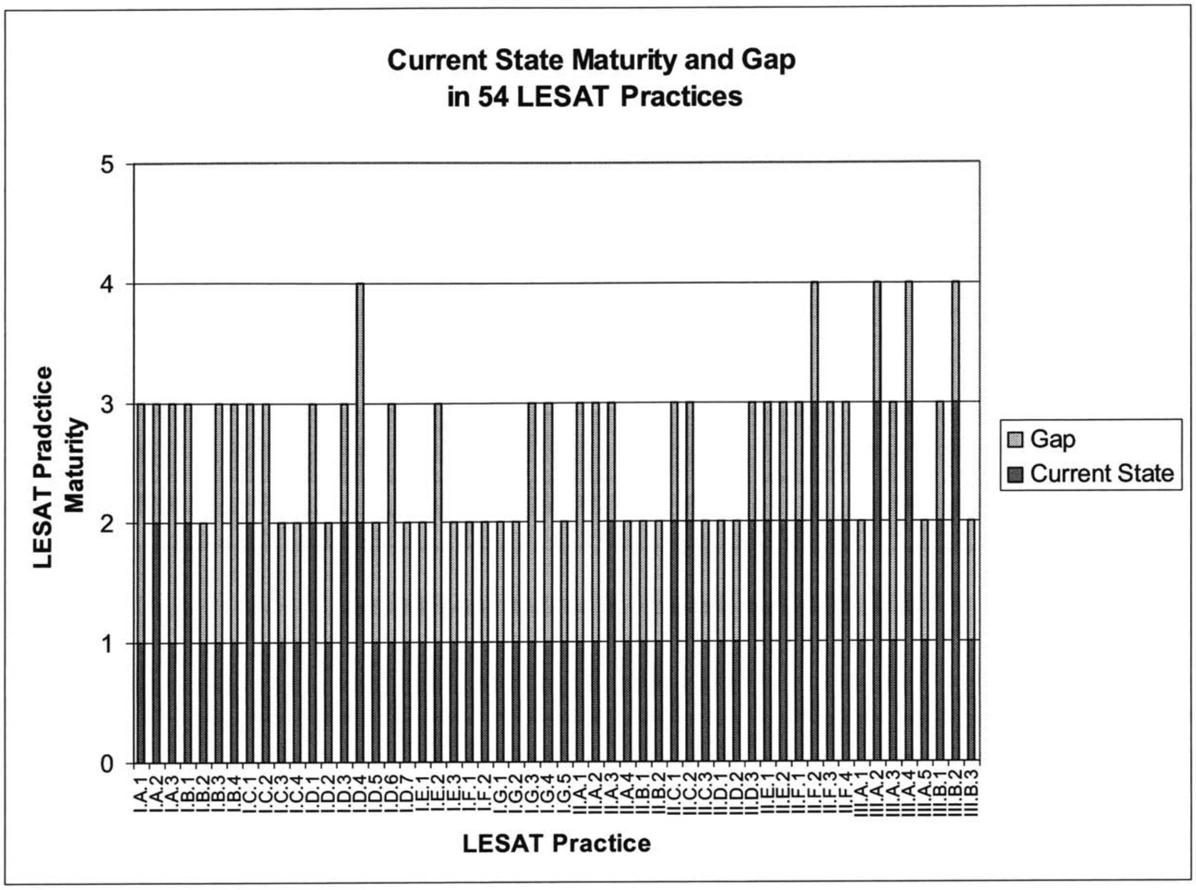

Figure 42: Current State Maturity and Gap in 54 LESAT Practices

A discussion of these analysis results, including a vision is for the implementation of an alternative SCADA implementation system employing lean principles is offered in the following chapter.

CHAPTER 7 - DISCUSSION

EVSMA Step 3 Discussion

Stakeholder Value Comparisons - Figure 30 thru 38

It is clear from Figure 30 that the municipality under study is not getting the necessary level of value from their present wastewater SCADA system implementation. Although the values "working product" and "life cycle cost" are ranked in importance in the top quartile, current performance is ranked in the lowest quartile. Maintenance support and component redundancy also rank in the top quartile of importance to the end user, yet current performance is ranked well below the median. This end user related that the public bid law at the time of their last SCADA implementation required that the contract be awarded to the lowest bidder. The municipality's experience was that the installation phase ran years past the original due date. The manufacturer was never able to achieve full performance, eventually defaulting on the contract to a bonding company. Post-installation equipment breakdowns, lack of manufacturer support and associated fines resulted in life cycle costs becoming much higher than expected.

In Figure 33 the supplier ranked "product integration" in importance in the top quartile while current perceived performance ranked in the bottom quartile. The supplier believes that because SCADA systems are implemented piece meal, often using the lowest bidder process, the municipality can receive components or products from various vendors which may experience compatible issues with one another. Product integration helps in reducing the life cycle cost as well as in establishing a single point of contact for the entire enterprise. Further discussions with the studied enterprise indicate they do demand product integration, within the confines of public bid law. Changes in public bid law now allow them to use a request for proposals process (vendors chosen on technical merit rather than price) for SCADA implementations. Their solution to product integration is to specify open protocols and place system responsibility on a systems integrator to assure the benefits of product integration while avoiding becoming "locked in" to a particular vendor.

Figures 31 and 32 indicate the electrical and general contractors represented as end user customers are relatively satisfied with the present value delivery system. Figures 34 and 35 indicate this is also true for the leadership of the enterprise. The front line system integrator employees generally supported this point of view in Figures 36-38, with some dissatisfaction in the area of training.

It is important to note that there were considerable differences in the values listed by the individual stakeholders, indicating that the enterprise does have a considerable number of values to service.

Stakeholder Value Comparison – Figure 39

This chart indicates that all the stakeholders are receiving equal or greater value proportional to their importance to the enterprise. The municipality end-user ranks below the median, however, in importance. It is believed that the design of the enterprise's contractual inter-relationships leads to a refocusing of implementers on plan and specification compliance, contributing to an after-award disconnect between the implementers and the downstream SCADA end-user.

Leadership, Enabling and Lifecycle Processes – Table 12

A significant problem this analysis reveals relates to how the systems integrator bids jobs. Bids are prepared based upon "billable" hours associated with the job within the engineering, shop and field lifecycle processes. A burden rate is applied to billable hours to account for the cost of administrative and general overhead, plus unbilled time (assumed at 10%) of billable personnel. The process analysis reveals that pre-award and award time invested amounts to 10% of the cost of a job, which is not being accounted for adequately in project cost estimates.

Another significant issue is the length of cycle times vs. the total engineering time actually bid. Cycle times are much longer than the billable times in the job estimates, indicating that there is much "dead" time typical in the process, during which time it is expected that personnel will be utilized on other billable jobs.

Municipal SCADA systems represent a low "clock-speed" market (Fine, 1999). There is not much concern among end user and engineering firm stakeholders in reducing overall project completion times. The systems integrator multi-tasks its engineers to reduce the impact of project start/stop intervals. The general and electrical contractors ARE directly impacted by the length of time they need to be mobilized on the jobsite, as their people are typically dedicated to a project until completion. In addition, general contractors are almost always subject to a "time is of the essence" clause in their contracts with municipalities, whereby stiff penalties are imposed for every day a project is late beyond the contract stipulated completion date. This difference in stakeholder values naturally contributes to the approval process extending longer than necessary, reducing the time available for completion of the final field process.

The largest cost process is engineering. This has also historically been the hardest one to estimate. To better distribute to the project team what time goals have been set for the various engineering components that make up a job, the systems integrator presently uses professional services time and billing software to track engineering, shop and field hours billed to jobs. This system is currently being two-way integrated with their project planning and scheduling software, allowing tasks created in project planning to be distributed and tracked by project team members via the professional services time and billing software and by project managers via the project planning software.

Systems Integrator Survey Tabulation – Tables 13-16

For the systems integrator, remaining profitable is largely dependent upon maintaining billable personnel at a high percentage of utilization. The tabulated data indicates maintaining an even flow of business is a significant issue, one that has been compensated for to some degree through cross-training of personnel in the shop and field functions.

The system integrator is dependent on certain employees for key business functions. While cross-training of personnel has been used to reduce this dependence, additional work remains, particularly in the areas of sales and general management.

X-Matrix Analysis – Figures 40 and 41

The systems integrator research indicated the company had an extensive usage of metrics. Fourteen metrics were identified that assisted the integrator in measuring company performance at least on an yearly basis. Various measures and targets for these metrics were established. The metrics primarily focused on the areas of Customer Satisfaction, Finance, Business Efficiency, Growth & Development and Investment in People.

Examining the key strategic objectives for the integrator and looking at the metrics they developed, a possible 14 (metrics) * 4 (objectives) = 56 interrelationships can exist. An actual 22 interrelationships exist of which 10 are strong and 12 are weak. A positive sign is that every metric the company has chosen to measure itself by is related to a strategic objective.

The system integrator's alignment of metrics to key processes is also positive, with each metric relating to one or more key processes. The system integrator's most important processes (engineering, shop and field) have the highest degree of interrelationship[with chosen metrics.

The system integrator should consider adjusting, adding to or subtracting from the metrics employed to monitor their progress toward strategic objectives. A goal in this consideration should be the elimination of wasted resources by spending time gathering data for metrics only when such metrics are well aligned with the key strategic objectives of the company as well as their key processes.

The systems integrator's strategic objectives are well aligned with the key stakeholder values, indicating the company has a good understanding of the needs of its stakeholders and has set its strategic objectives accordingly. Out of a possible 64 interrelationships, 37 existed. Room for improvement is suggested for stakeholder values like "redundancy" required by the end user customer and “recognition for contribution" suggested by the employee.

The linkage between key processes delivering value to the stakeholders at the systems integrator was also strong. Out of a possible 128 interrelationships between key processes and stakeholder values, there were 70 weak or strong relationships. The data indicates that the strongest linkages exist between stakeholder values and the key processes of pre-award and engineering, with the processes shop, field and post-award also ranking above the median.

EVSMA Step 4: Identify Enterprise Opportunities

Part A – LESAT Analysis Discussion

Since the LESAT was performed by one person, the variance and range numbers are not meaningful. The overall current mean for the company is 1.4, indicating the company is in the entry level stages of lean development.

The section scores in Table 17 indicate that the system integrator's enterprise infrastructure is its strongest asset in support of implementation of lean principles, practices and behaviors.

The company scored 1.6 in the life cycle processes section, which indicates it has begun implementing lean practices across life-cycle processes for defining customer requirements, designing products and processes, managing supply chains, producing the product, distributing products and services, and providing post delivery support.

The company scored lowest on lean transformation / leadership, indicating the first priority for the company will be to reconsider the major elements within the Transition to Lean Roadmap shown in Figure 43 (Nightingale, 2004), particularly creating and refining an implementation plan and implementing lean initiatives.

The overall desired mean for the company is 2.7, indicating the company management has stated a desire to move toward becoming a significantly more lean enterprise.

Bridging a gap of 1.2 between current and desired lean states is considered challenging but achievable. The largest gap exists in the section where the company scored the lowest on current lean maturity, which is the section dealing with lean transformation / leadership. The largest gaps in this section are in the area of enterprise strategic planning and adopting a lean paradigm.

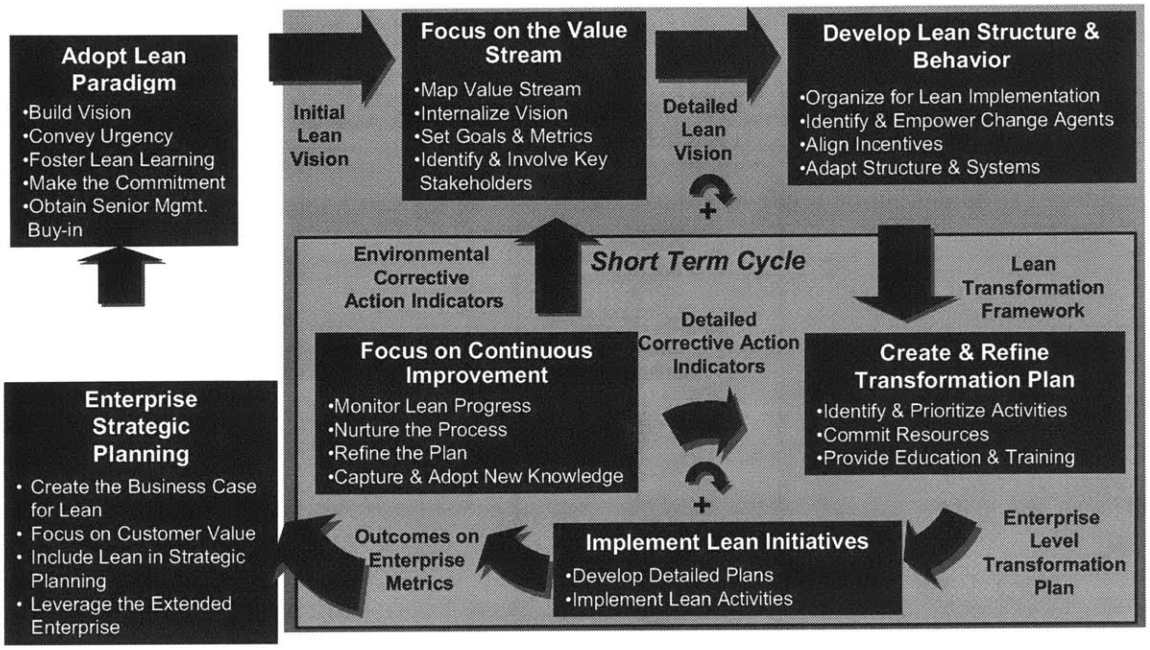

Figure 43: Transition to Lean Roadmap

Within the life cycle processes section, the largest gap exists in the area of business acquisition and program management.

In every category the company has expressed a desire for a higher lean maturity level, which can be expected given the current entry level state of lean development of the company.

Part B - Enterprise Waste

Sources of enterprise-level waste were identified using 9 enterprise waste categories (Appendix A). All results, including the LESAT assessment were considered in determining sources of waste. Several opportunities for improvement at the enterprise level were identified.

1. *Waiting* is idle time due to late decisions, cumbersome and excessive approvals, and unsynchronized enterprise processes.

One of the key processes of the enterprise is the Approval process. A typical approval process is depicted in Figure 44. The Approval process follows the Engineering Process in time sequence.

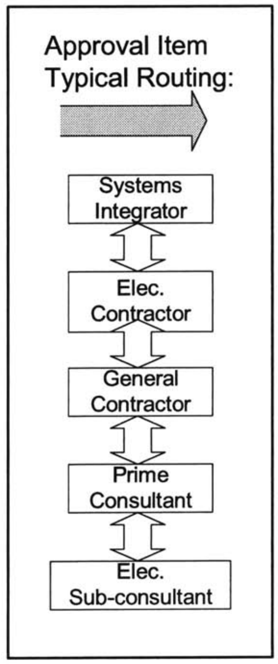

Figure 44: Wastewater Submittal Approval Process

Approval items include bill of materials, engineering drawings and software. The systems integrator submits to their customer, the electrical contractor. The integrator must go through the electrical contractor to the general contractor to the prime consultant to the electrical sub-consultant to get items approved, as this order represents the contractual relationships between the parties. Note submittals in this industry are still required in hard copy, so 8 sequential mailings are required to pass a submittal through this approval process one time. It is not uncommon for a submittal to get stalled at one of the 8 steps due to an individual being on vacation, out of town or just overloaded with work. Bypassing this order can involve significant contractual risks and lead to an unhappy customer for the integrator. If the integrator needs any clarification on the engineering specification, requests for information are submitted using this same routing. Prior to submittals being reviewed and returned marked "accepted" by the electrical sub-consultant, the integrator cannot safely place orders for materials and runs the risk of rework on any detail engineering completed prior to approval.

As the construction process is largely sequential, approval delays affect key downstream processes. Materials purchased late delay the shop and field schedules, likely delaying other projects while causing some personnel to be without billable work.

In our interviews with employee stakeholders, they reported experiencing a "wait and hold" pattern because of a lack of correct information or missing input from a key decision maker. This wait delayed key processes like Purchasing, Shop and Field services.

There are a number of other waiting delays in the enterprise process:

- Long lead times from receipt of customer request for quote (RFQ)/ request for proposal (RFP) to start of job. These include
    - Waiting for customer to deliver RFP/RFQ
    - Waiting for customer questions/additional info needed for RFP/RFQ
    - Waiting for customer to award bid (if awarded at all)
- If a contract is awarded, then there are additional waits before any work at the integrator commences:
    - Waiting for the award process to complete
    - Waiting for vendors to provide information (drawings, etc.)
    - Waiting for regulatory approvals
    - Waiting for funding approvals
    - Waiting for customer meetings
- Once work commences within the integrator, there are additional waits:
    - Waiting for all sub contractors to be available to start work
    - Waiting for engineering to deliver drawings for fabrication shop
    - Waiting for customer information (other vendors submittals, interface data)
    - Waiting for witness inspections
    - Waiting for functional specifications to be written, and then approved by customer
    - Waiting to find rework due to missed specifications, change in scope, etc.
    - Waiting for hardware & software delivery

    - Waiting for software programming & development to be completed
- There are additional miscellaneous waits as well:
    - Waiting for contractors to provide time sheets, W-2's, etc.
    - Waiting for integrator personnel to fill out time & billing information
- Waiting for the customer to pay invoice

***2. Transportation* is the unnecessary movement (including electronically) of administrative information and people; multiple approvals and handoffs.**

- Excessive mailing of specifications back & forth between the integrator, customer & sub contractors
- Excessive copies & electronic transfer of drawings & specifications within integrator departments (e.g., between engineering & fabrication).
- Unnecessary approvals by engineering and/or administrative management
- Delays caused by interoffice document and voice transfers
- Movement of people and resources between offices to complete a job or handle a service request

***3. Over-Processing* is effort expended that does not increase value to any of the enterprise's stakeholders. This can occur within the workforce, within management ranks, or across the entire enterprise.**

- Drawings rendered with more detail than is required by customer, or drawings completed beyond what was specified in the scope of the contract.
- Final testing of components that are rarely found defective, when systems integrator is responsible for startup and such problems can readily be corrected in field.
- Review of expenses, purchase orders, reports, etc. that does not result in more savings to the company than the time spent analyzing them.

***4. Inventory* is unnecessary levels of any enterprise resource: capacity, space, workforce, suppliers, information/data.**

- Multiple copies of drawings and software programs
- Un-utilized labor capacity
- Un-utilized shop capacity
- Operating at volume levels less than the facility design capacity (excess space and related overhead)

***5. Motion is* any human effort that does not increase stakeholder value.**

- Locating routine stock items near point of utilization and buying these items in bulk so motion is not expended repeatedly ordering, restocking and finding them
- Location and placement of shop tools so they are very near point of utilization and can always be found – Ex: dedicated place for each tool on portable caddy

***6. Defects/Rework* are erroneous results from defective enterprise processes and decisions.**

Employee stakeholder interviews indicated that if there is not good coordination between the Engineering and Shop processes, things may go wrong. Sometimes end user customers specify a particular way of fabricating or installing the product to engineering. If the Engineering process just passes to the Shop generic specifications and not the details, then the Shop process incorrectly manufactures the item. If this circumstance is not discovered prior to shipment, startups can be delayed and there is a risk of an unsatisfied customer. The Field process must expend unnecessary resources reworking such defects.

Other sources of defects/rework include:

- Software/programming bugs due to confusion on specifications or inadequate checkout procedures
- Unspoken customer requirements discovered late in development
- Vendor defects – hardware & software

7. Over Production **is any creation of enterprise outputs that does not increase stakeholder value.**

- Developing software features not specified by customer

8. Structural Inefficiencies **are waste resulting from inappropriate organizational structure, policies, business model structure, alignment, or strategies.**

- Inefficiencies in maintaining remote offices vs. centralized
- Administrative policies that cause employees unnecessary paperwork
- Business systems that require more effort to upkeep than they return benefit
- Business systems that require double entry of data (Ex: bill of material and purchase order – items entered twice)
- Business systems that do not make common tasks very easy to perform (Ex: fax from desktop)

9. Opportunity Costs **are wastes resulting from lost opportunities, e.g., untapped talent in the workforce.**

- Using engineering time to do drafting – control systems engineers are hard to come by – draftsmen are easy to come by and less expensive
- Using sales times to do engineering – you are missing sales when you are not out selling!
- Accepting an order for a low margin job when higher margin jobs are available and you are operating at capacity

Now that we have identified enterprise opportunities for lean improvements, we move toward the definition of a future vision for the enterprise in EVSMA Step 5.

EVSMA Step 5: Describe Future State Vision

In steps 1 and 2 we characterized the current enterprise for delivering SCADA implementations to the studied municipal wastewater utility. We defined "value" to the municipality and to the other key enterprise stakeholders. In steps 3 and 4 we performed a detailed analysis of the enterprise as it is currently constituted. We analyzed the customer and strategic requirements, metrics employed, cycle times, resource utilization, interactions, and sources of waste. This analysis provided a measure of the degree of "leanness" of the enterprise. In this step we create and describe our "Lean Enterprise Vision" for the enterprise as we believe it should look five years in the future.

The Future State Vision

The systems integrator will become a leader in providing professional services directing the implementation of lean operational processes within municipal water and wastewater systems. The systems integrator's current process of delivering SCADA systems will thus be "pull" redeveloped to place the focus on providing the professional service of directing the implementation of lean solutions for municipalities. As an enabler, the systems integrator will offer a pre-packaged, cost-effective, quick and easy-to-implement "simple" SCADA solution.

The diagram in Figure 45 details the future vision SCADA implementation process.

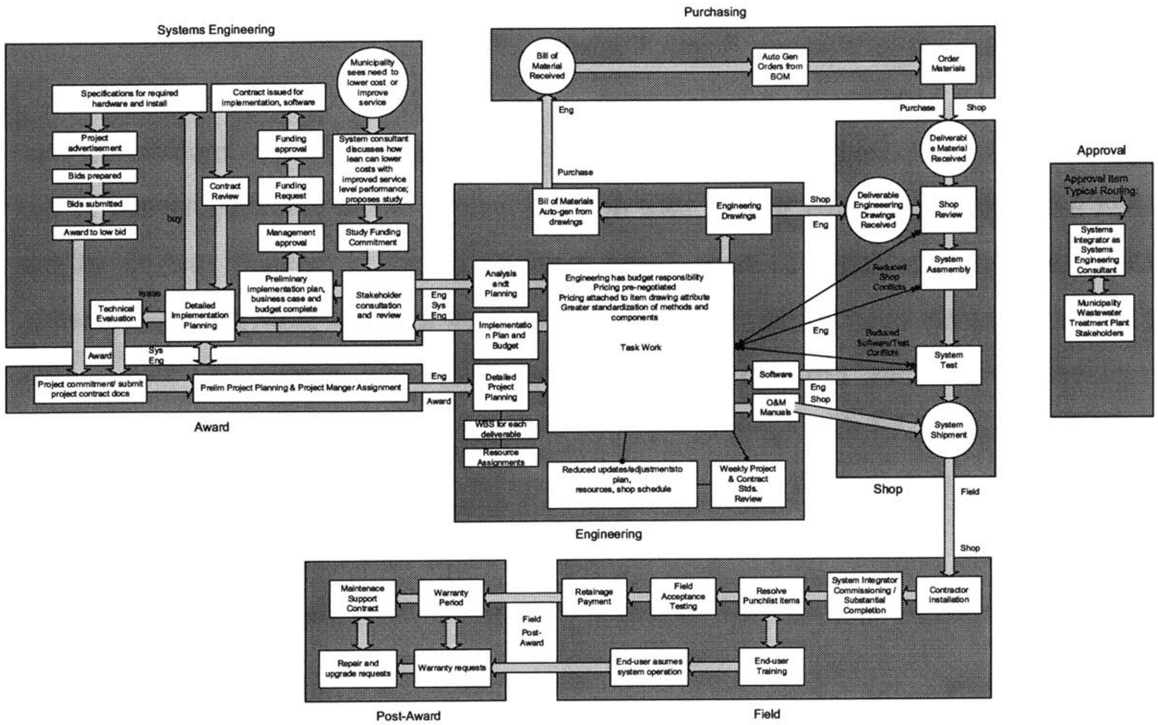

Figure 45: Future Vision – SCADA Implementation Process

A Change of Focus

SCADA implementation within the current enterprise is a primarily a "push" system directed by municipality contract engineering firms. These firms are predominately civil engineering oriented, with electrical and control work a small percentage of the total capital construction budget. Electrical and control work is, thus, most often relegated to electrical sub-consultants who tend to rely heavily on either their in-house (often well-aged) boilerplate or vendor provided specifications. The systems integrator responds to inquiries for new SCADA systems and dutifully provides them in accordance with plans and specifications.

The envisioned enterprise differs in that it is "pull" directed by system engineers with a focus on implementation of lean operational processes within the municipal enterprise. The former Pre-Award process is replaced by the Systems Engineering process (Figure 46). An enterprise analysis is performed (similar to Steps 1-4 of this exercise). A future vision is offered and agreed upon by consensus with municipality stakeholders. An implementation plan is then written. The system engineers direct the implementation over a period of several years, including directing installation of any necessary SCADA hardware and software, training and workflow implementations. This represents both a business process and business model transformation to lean.

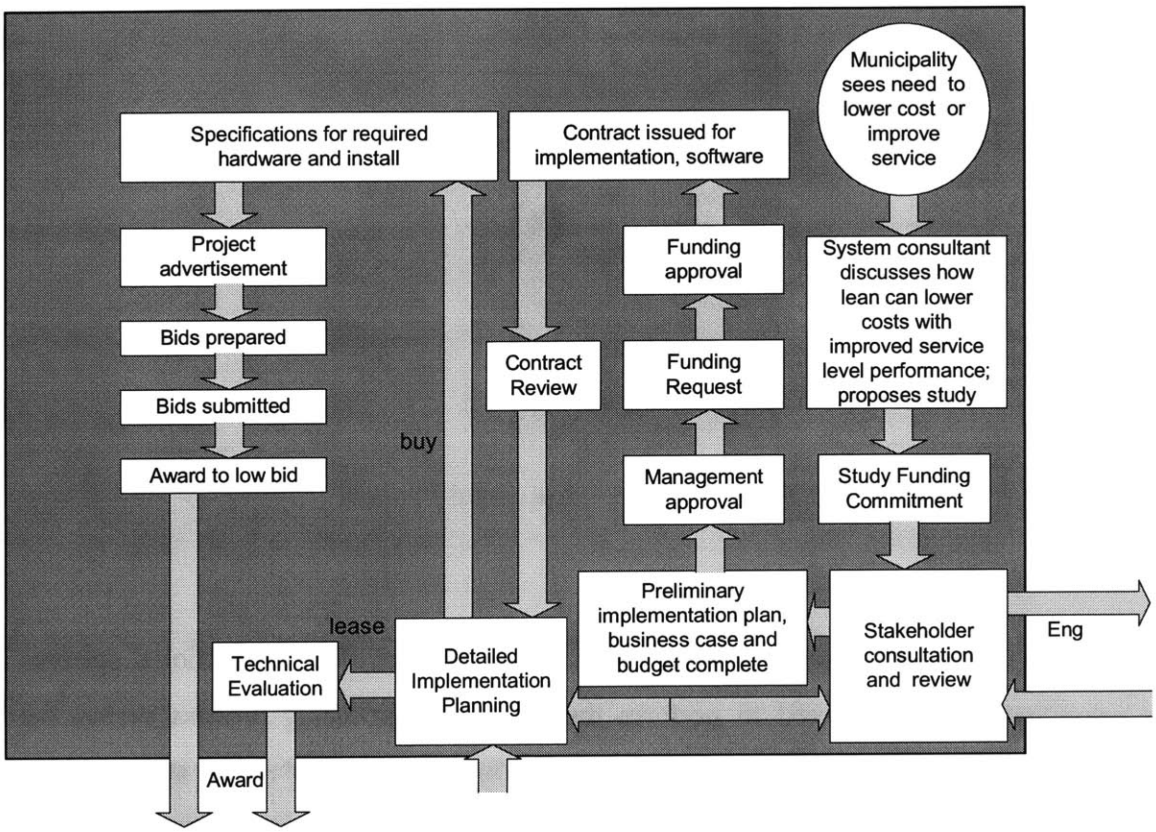

Figure 46: Future Vision – Systems Engineering Process

The Future Value Stream

Cycle times are estimated to be half of their current length, largely due to reduced wait times and coordination overhead. As witnessed by the revised approval process, the flow of information between the systems integrator and the end-user is minimized (Figure 47).

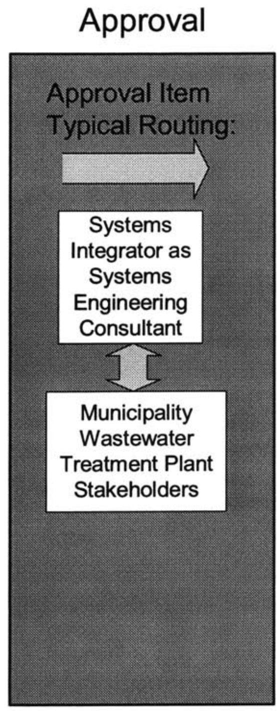

Figure 47: Future Vision – Approval Process

Reduced resources will be required to produce the SCADA product. While additional systems integrator resources will be required to perform the systems engineering process versus the current pre-award process, this will be offset by time reductions for other enterprise stakeholders, particularly contractors and consulting engineers. The largest savings will come from a systems engineering approach that chooses to set and monitor service level goals for the wastewater utility, using a toolbox of pre-packaged, cost-effective, quick and easy-to-implement "simple" SCADA solutions. This will greatly reduce the time and, thus, cost required for the enterprise to implement SCADA. The system integrator can standardize the supplied SCADA engineering, software and hardware components. Additional life cycle cost reductions can occur by employing standardized public wireless communication networks and hosted SCADA services. Contrast this with current enterprise procedures that require the systems integrator to customize SCADA engineering, software and hardware components for each installation.

Award Process (Figure 48)

Engineering project managers are given budget responsibility for jobs to be produced in accordance with a job budget. Job budgets are agreed upon early in the engineering design phase, in conjunction with sales. The key here is to give the project manager the tools to track the progress of the job with enough task detail and in near real-time.

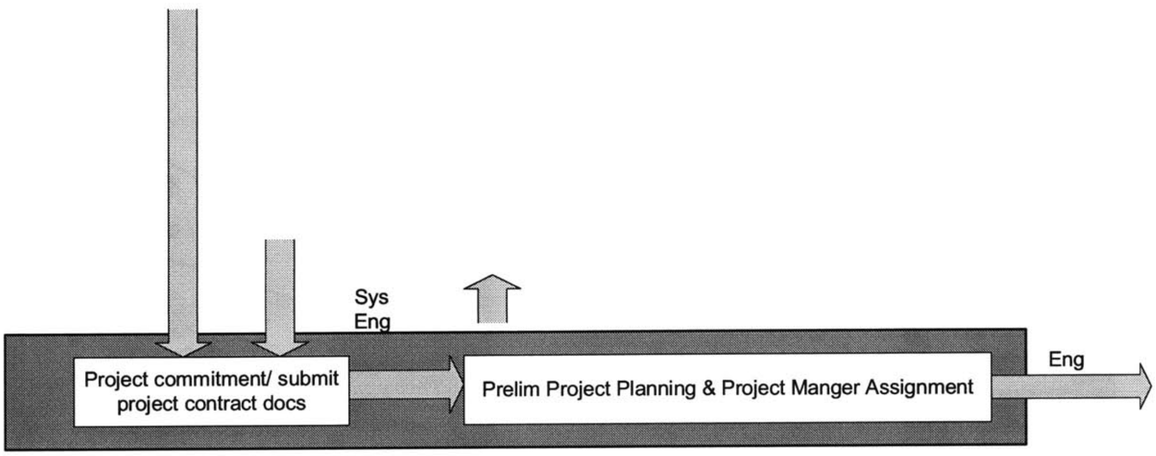

Figure 48: Future Vision – Award Process

Engineering Process (Figure 49)

Time required to obtain pricing from vendors is cut by reducing the number of vendors and having pre-negotiated pricing levels. These prices are placed in a database linked to drafting system objects.

Time is reduced to produce materials requirements by having bills of material auto-generate from the drawing object attributes.

The labor time billing and project management systems are integrated to the project task level. There is a reduction in the number of adjustments to project, resource and shop schedules that derives from an improved flow of information in near real-time to all project team members, which are now better informed regarding what the specific time and material budget is per task and how this fits into the whole.

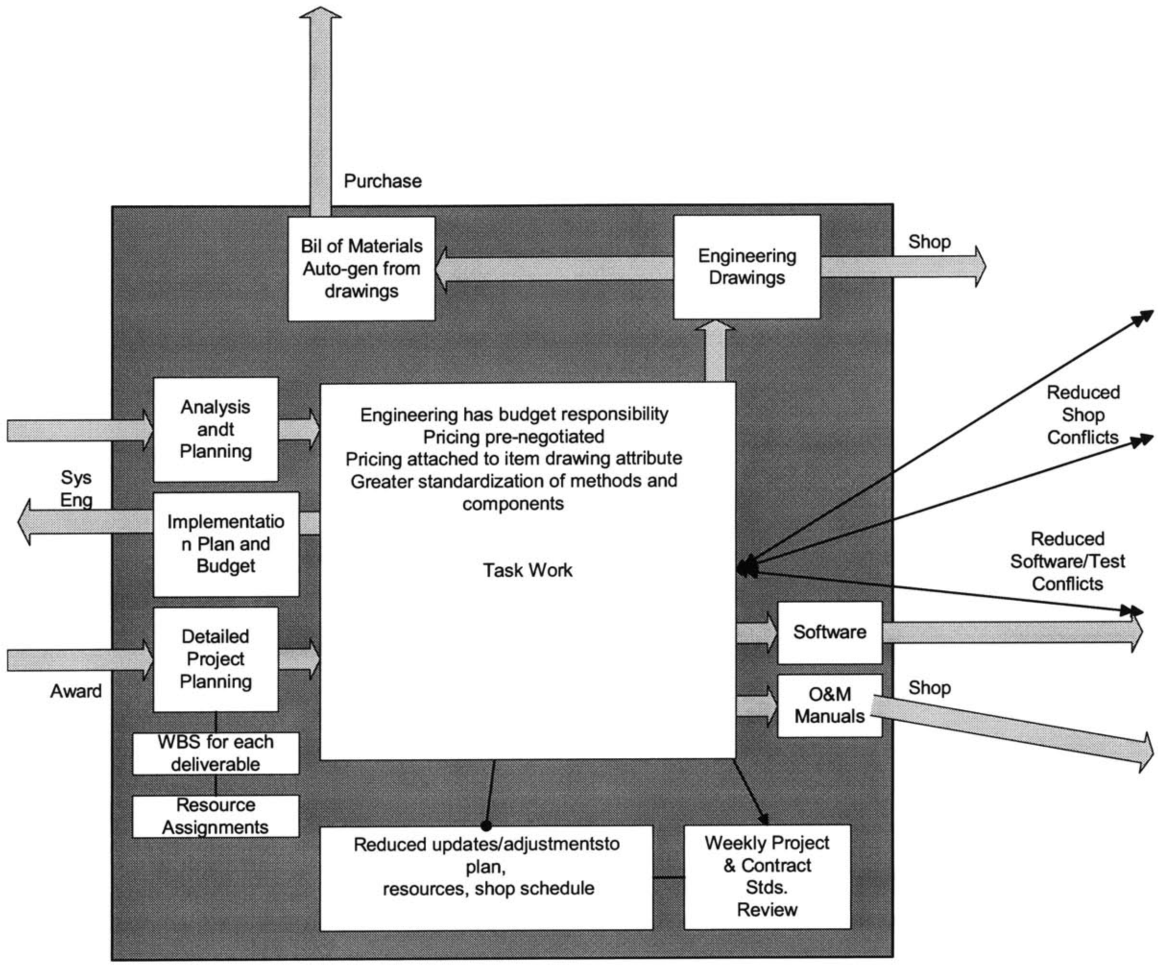

Figure 49: Future Vision – Engineering Process

Purchasing Process (Figure 50)

The purchasing review step is eliminated by having pricing issues resolved via pre-negotiated pricing and engineering direct negotiation of major item discounts. This allows purchasing to focus on the ordering and expediting of materials as they were first requested by engineering.

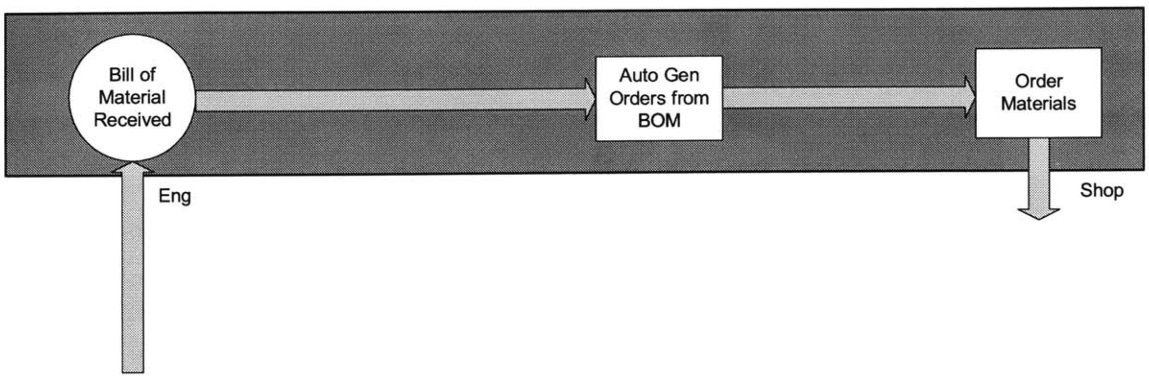

Figure 50: Future Vision – Purchasing Process

Shop Process (Figure 51)

Conflicts in shop review and system assembly will reduce resulting from more complete and accurate engineering drawings as well as more timely material flow into the shop.

The system integrator's historical experience is that the time required for a successful system test will reduce proportional to how well the preceding steps have been executed.

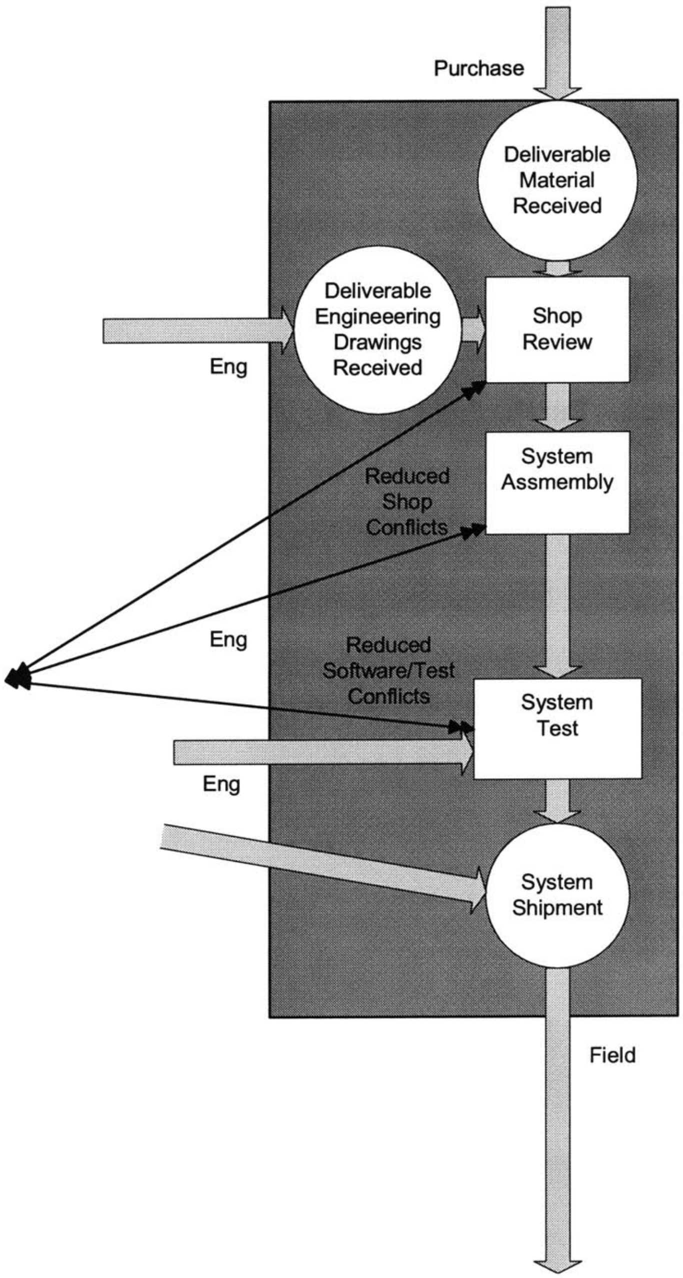

Figure 50: Future Vision – Shop Process

Field Process (Figure 52)

The field processing time is reduced due to standardization of SCADA hardware and software. There is a change in the character of this process, as the on-going systems engineering approach makes the completion of the field process more of an enterprise stakeholder beginning than an end.

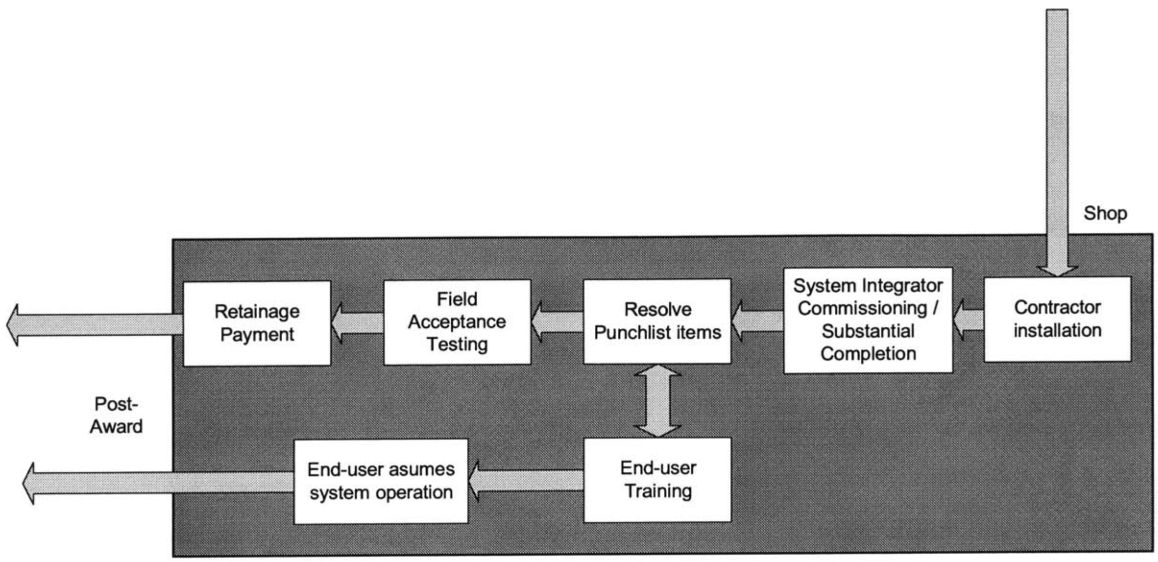

Figure 51: Future Vision – Field Process

Post-Award Process (Figure 53)

The future vision system engineer's implementation plan extends over a period of several years beyond the field process completion. The current character of post-award support is focused on SCADA hardware and software support. The future character of post-award support includes the necessary training, modifications and adjustments to assure workflows and reporting systems are implemented, all to support monitoring of progress toward the municipality's wastewater service level goals.

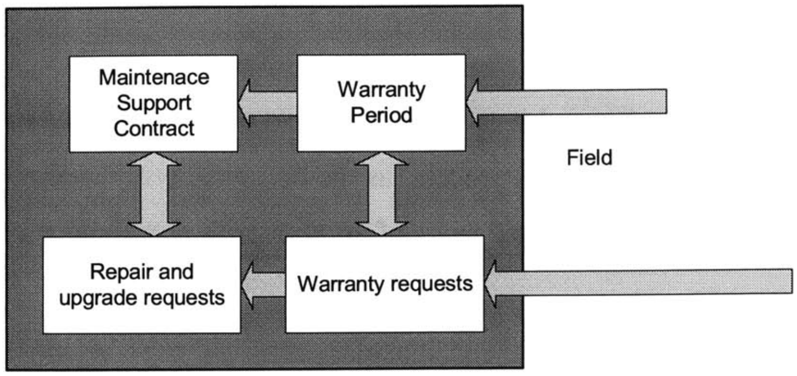

Figure 52: Future Vision – Post-Award Process

EVSMA Step 6: Create a Transformation Plan

In this step we describe how to get from our current state (Step 3) to our new enterprise vision (Step 5). A prioritized transformation plan is recommended, one that can be presented to enterprise senior executives as key recommendations regarding how the enterprise can be moved toward a lean architecture.

The general goal in transforming to lean is seen as refocusing the enterprise leadership on the desired end results within the municipal wastewater organization. Once these goals are identified, determine how SCADA may be used as a tool to achieve these results.

Transition Needs

Further discussion with the enterprise stakeholders was used to identify and prioritize the primary changes required for transition from the current enterprise structure to the new enterprise vision:

1. Develop a lean business case for the industry that can be tailored for presentation to specific municipalities. Establish metrics for measuring a municipality's current ability to serve its stakeholders that can also be used to assess the degree of success in implementing a lean transformation.

2. Develop a marketing capability for systems engineering. The systems integrator needs a software and systems engineering-experienced business development manager to focus in this area. It will be the responsibility of this marketing effort to introduce municipalities to service level goals, systems engineering and lean enterprise principles.

3. Establish a professional engineering services operating group to better promote the system integrator's control systems-oriented systems engineering consulting capabilities. It will be the responsibility of this group to conduct service level and lean enterprise

studies using established metrics. This group will also have the capability to produce the goal statements and specifications required to direct an actual SCADA installation.

4. Develop a promotional lean "mini-study" for municipalities that can estimate the benefits of a full lean implementation, with the intention of moving the municipality toward commitment to a detailed study and implementation.

5. Establish a systems integrator division to develop and offer standardized web-based SCADA system solutions. Install an initial web-based SCADA system at a medium to large size municipality, geographically near the systems integrator that can serve as both a test bed and showcase highlighting the benefits of this approach.

6. Provide additional "value added" deliverables such as maintaining downtime and efficiency metrics. In addition to calculating these metrics, the systems integrator can also develop standard metrics within the industry to help provide a common reference. Additional deliverables could include data mining and analysis contracts, auto-generation of EPA reports and an EPA reporting service.

7. Improve training programs. Evaluate managers based upon the time spent by their direct reports in training to ensure that management attention is properly focused on employee training. Require all employees to develop and submit a continuing education plan for approval.

8. Improve internal communications. One method might include posting a large and readily available bulletin board listing all current and future projects. It might contain, for example: RFP due date, proposal due date, estimated start date, estimated completion date status update, approximate work load. For current projects, indicate current bottlenecks & risks. Indicate time in each department, material being held up, etc. The intention is to better inform all employees of company goals and progress. Another method is further integration of the labor billing and project management systems, and further training of personnel on using this tool to communicate project goals and outcomes.

9. Establish a formalized cross-training rotational program in which employees work in other departments.

Project Plan

It is recommended that the systems integrator develop a high level project plan including a list of tasks to be performed, indicating resource assignments, task start and finish dates and dependencies to lead the enterprise's transition to lean.

Overcoming Obstacles

A number of potential obstacles were identified during stakeholder discussions in making this transition. These are listed below together with stakeholder recommendations for overcoming them:

1. Effects of alternate technologies
    - Design SCADA architecture to easily incorporate alternates
2. Inadequate funding
    - Bootstrap – sell concept first, then do detail development
3. General economic conditions
    - The municipal market historically transcends economic conditions
4. Expectations exceed reality
    - Clearly define scope in writing
    - Be careful not to over-promise until concept is proven
5. Poor project definition
    - Develop system specifications via in-house consulting group
6. Personnel being diverted to other projects
    - Continue hiring and training personnel
7. Under-estimating requirements
    - Add a significant contingency factor to estimates if unproven / first time

8. Lack of customer support
    - Minimize by remaining focused upon stakeholder values and service level goals
9. Committing to an unproven technology
    - Provide early systems with hybrid old & new technology to provide a "fallback" capability to the proven technology
10. Regulatory issues
    - Be aware of state public bid requirements
11. Customer acceptance
    - Write contracts to include on-going support after installation

CHAPTER 8 - FUTURE WORK

This author focused on the process of how to improve the systems integrator-centric process by which SCADA is delivered to one large wastewater municipality. While it has been the system integrator's experience that most medium and large water and wastewater municipalities handle implementation similarly in the region they are active in within the United States, a broader national and international study of SCADA implementations has merit and is left to future authors to pursue.

Another aspect of the role of SCADA in developing a lean enterprise for municipal wastewater, beyond the lean implementation of SCADA discussed here, is the lean *design* of wastewater operations. Performing a lean analysis of plant wastewater operations would suggest new uses and architectures for SCADA, service level goals and strategies for their implementation.

Most SCADA systems today are architected to automatically bring all system alarm and operational data to a central point in the municipality. From there, however, manual processes are commonly used to distribute the data to operations employees, to track exception conditions and to record the corrective actions taken. Municipal SCADA systems usually are deployed without considering how they will specifically create value for municipality end-users and without defining metrics to gauge their effectiveness.

Recently, new technologies for communicating data from remote sites have been introduced. Low cost public wireless communication networks are rapidly becoming available worldwide. IP-based computer networks supporting email and Internet connectivity have reached most municipalities. These developments suggest a new architecture that can move SCADA from serving as a centralized data store to a more distributed, accessible tool capable of directly empowering front-line workers. Such empowerment is a necessary tool for municipalities in their move toward the lean enterprise.

Lean principles can and should be applied to wastewater system design. The long system lifetimes and massive legacy infrastructure make this a lesser candidate for near term productivity and efficiency gains, however. Operations can be impacted relatively quickly and for those municipalities with existing SCADA infrastructure, a nominal capital outlay.

CHAPTER 9 – CONCLUSIONS

It was apparent from our current municipal SCADA enterprise analysis that consideration of stakeholder value requirements at the end-user level was a foreign concept. As a result, much effort is currently expended without proper consideration of what the return will be, or whether the return from the investment will be justified. While metrics exist for operations at the systems integrator level, it became apparent that SCADA end-user value metrics are largely non-existent. There are generally low or vague expectations by municipalities regarding SCADA returns vs. what would be possible if the full capability of the technology was employed in service of specific stakeholder needs. There is much room for improvement.

Once a decision to employ SCADA is made, there is significant time "muda" in the process of implementing a system. This process typically involves numerous stakeholders including engineers, contractors, integrators and suppliers, the coordination of which can extend the completion time of a project from what could be a few months to several years. We make several recommendations to reduce SCADA implementation time including employing systems engineering techniques to focus on municipality stakeholder values and reducing the number of stakeholders with a turnkey implementation process. The focus is placed on the process of satisfying stakeholder values and defining metrics to measure progress toward service level goals. SCADA becomes one component in the system supporting this process, a tool to be used to improve service levels rather than a project's primary objective.

With about a 10 year lag, the use of SCADA technology within municipalities appears to parallel the application of business desktop computers. In the 1980s, desktop computers were often purchased by business users with a limited understanding of their capabilities and a vague idea regarding how they would provide a return on their investment. There was much talk of enhanced productivity, reduced processing time, etc. but in the end this was more a hope than a concrete fact. Did PC users realize an urgent business problem (the stakeholder analysis) and then select the PC as the best solution from among the available tools (i.e. focus on obtaining the best solution to stakeholder needs)? The answers at that time was typically "no", but has increasingly become "yes" since that time. This may be due in part to the several generations of experience these users now have, which has lead them to understand better the capabilities and limitations of the technology. The appeal of the newness of the technology has worn off, the "hype" phase has passed. Users have progressed on the technology maturity curve to the point where we can more readily be objective and again focus on stakeholder analysis and choosing the tools to best solve stakeholder needs. We believe the time is coming near for municipalities to become seriously focused on stakeholder values.

Finally, we believe that municipalities are largely unaware of how the latest Internet and communication technologies can be leveraged to reduce both the time and expense associated with SCADA implementations. There are a number of firms offering such services today to SCADA users, some particularly focused on municipalities; yet, municipalities have been slow to adopt. What appears to be missing is a solution provider offering to use this newer technology as a tool, together with a systems engineered lean approach that focuses on reducing waste and providing customer value within municipal water or wastewater operations.

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APPENDIX A – THE FIVE S'S

The 5 S's represent habits of personal discipline and organization that make it easier to see waste.

1. *Seiri* (organization) = Straighten or Simplify: organize tools, accessories and paperwork

2. *Seiton* (neatness) = Simplify or Sort; remove all unnecessary items from the work area

3, *Seiso* (cleaning) = Scrub or Shine; repair, clean and keep clean

4. *Seiketsu* (standardization) = Standardize or Stabilize: establish and maintain controls and standards

5. *Shitsuke* (discipline) = Sustain or Self-Discipline: strive for continuous improvement

(Osada, 1991)

APPENDIX B - ENTERPRISE WASTE CATEGORIES

1. Waiting is idle time due to late decisions, cumbersome and excessive approvals, and unsynchronized enterprise processes.

2. Transportation is the unnecessary movement (including electronically) of administrative information and people; multiple approvals and handoffs.

3. Over Processing is effort expended that does not increase value to any of the enterprise's stakeholders. This can occur within the workforce, within management ranks, or across the entire enterprise.

4. Inventory is unnecessary levels of any enterprise resource: capacity, space, workforce, suppliers, information/data.

5. Motion is any human effort that does not increase stakeholder value.

6. Defects/Rework are erroneous results from defective enterprise processes and decisions.

7. Over Production is any creation of enterprise outputs that does not increase stakeholder value.

8. Structural Inefficiencies are waste resulting from inappropriate organizational structure, policies, business model structure, alignment, or strategies.

9. Opportunity Costs are wastes resulting from lost opportunities, e.g., untapped talent in the workforce.

APPENDIX C – LESAT FOR SYSTEM INTEGRATOR

SECTION 1 – LEAN TRANSFORMATION/LEADERSHIP

TTL LINK	Lean Practice		1
I.A Enterprise strategic planning	I.A.1. Integration of lean in strategic planning process	Current	1
		Desired	3
	I.A.2. Focus on customer value	Current	2
		Desired	3
	I.A.3. Leveraging the extended enterprise	Current	1
		Desired	3
I.B Adopt Lean Paradigm	I.B.1. Learning and education in 'lean' for enterprise leaders	Current	2
		Desired	3
	I.B.2. Senior management commitment	Current	1
		Desired	2
	I.B.3 Lean Enterprise Vision	Current	1
		Desired	3
	I.B.4. A sense of urgency	Current	1
		Desired	3
I.C Focus on the Value Stream	I.C.1. Understanding the current value stream	Current	2
		Desired	3
	I.C.2. Enterprise flow	Current	1
		Desired	3
	I.C.3. Designing the future value stream	Current	1
		Desired	2
	I.C.4. Performance measures	Current	1
		Desired	2

I.D Develop lean Structure and Behavior	I.D.1. Enterprise organizational orientation	Current	2
		Desired	3
	I.D.2. Relationships based on mutual trust	Current	1
		Desired	2
	I.D.3. Open and timely communications	Current	2
		Desired	3
	I.D.4. Employee empowerment	Current	2
		Desired	4
	I.D.5. Incentive alignment	Current	1
		Desired	2
	I.D.6. Innovation encouragement	Current	1
		Desired	3
	I.D.7. Lean change agents	Current	1
		Desired	2
I.E Create and Refine Implementation Plan	I.E.1. Enterprise level lean implementation plan	Current	1
		Desired	2
	I.E.2. Commit resources for lean improvements	Current	1
		Desired	3
	I.E.3. Provide education and training	Current	1
		Desired	2
I.F Implement Lean Initiatives	I.F.1. Development of detailed plans based on enterprise plan	Current	1
		Desired	2
	I.F.2. Tracking detailed implementation	Current	1
		Desired	2

I.G Focus on Continuous Improvement	I.G.1. Structured continuous improvement process	Current	1
		Desired	2
	I.G.2. Monitoring lean progress	Current	1
		Desired	2
	I.G.3. Nurturing the process	Current	1
		Desired	3
	I.G.4. Capturing lessons learned	Current	1
		Desired	3
	I.G.5. Impacting enterprise strategic planning	Current	1
		Desired	2

SECTION II - LIFE CYCLE PROCESSES	

TTL LINK	Lean Practice		1
II.A. Business Acquisition and Program Management	II.A.1. Leverage lean capability for business growth	Current	1
		Desired	3
	II.A.2. Optimize the capability and utilization of assets	Current	1
		Desired	3
	II.A.3. Provide capability to manage risk, cost, schedule and performance	Current	2
		Desired	3
	II.A.4. Resource and empower program development efforts	Current	1
		Desired	2

II. B. Requirements Definition	II.B.1. Establish a requirements definition process to optimize lifecycle value	Current	1
		Desired	2
	II.B.2. Utilize data from the extended enterprise to optimize future requirement definitions	Current	1
		Desired	2
II.C. Develop Product and Process	II.C.1. Incorporate customer value into design of products & processes	Current	2
		Desired	3
	II.C.2. Incorporate downstream stakeholder values into products and processes	Current	2
		Desired	3
	II.C.3. Integrate product and process development	Current	1
		Desired	2
II.D. Supply Chain Management	II.D.1. Define & develop supplier network	Current	1
		Desired	2
	II.D.2. Optimize network-wide performance	Current	1
		Desired	2
	II.D.3. Foster innovation and knowledge-sharing throughout the supplier network	Current	1
		Desired	2
II.E. Produce Product	II.E.1. Utilize production knowledge & capabilities for competitive advantage	Current	2
		Desired	3
	II.E.2. Establish and maintain a lean production system	Current	2
		Desired	3

II.F. Distribute and Service Product	II.F.1. Align sales and marketing to production	Current	2
		Desired	3
	II.F.2. Distribute product in lean fashion	Current	3
		Desired	4
	II.F.3. Enhance value of delivered products and services to customers and the enterprise	Current	2
		Desired	3
	II.F.4. Provide post delivery service, support and sustainability	Current	2
		Desired	3
SECTION III - ENABLING INFRASTRUCTURE			

TTL LINK	Lean Practice		1
III.A. Lean Organizational Enablers	III.A.1. Financial system supports lean transformation	Current	1
		Desired	2
	III.A.2. Enterprise stakeholders pull required financial information	Current	3
		Desired	4
	III.A.3. Promulgate the learning organization	Current	1
		Desired	3
	III.A.4. Enable the lean enterprise with information systems and tools	Current	3
		Desired	4
	III.A.5. Integration of environmental protection, heath and safety into the business	Current	1
		Desired	2

III.B. Lean Process Enablers	III.B.1. Process standardization	Current	2
		Desired	3
	III.B.2. Common tools and systems	Current	3
		Desired	4
	III.B.3. Variation reduction	Current	1
		Desired	2