# IMPROVING DREDGE EFFICIENCY AND PRODUCTION THROUGH AUTOMATION

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## ABSTRACT

With energy costs soaring and spoil areas shrinking, transporting dredge slurry at the optimum flow rate and concentration is paramount. In years past, dredge operators would vary the dredge pump speed, cutter speed, and swing speed to achieve acceptable dredge production with little risk of pipeline plugging or equipment over-loading. Survey engineers constantly checked the dredge position, movement, tide, and spoil area to certify that the dredge was producing what and where it was expected.  Additionally, maintenance and operating crews serviced and monitored the dredge for continuous operation and any signs of problems.

Today, many dredges employ flow control systems that vary the dredge pump speed based on the slurry flow rate and density. This type of automaton can greatly reduce energy usage while insuring a fairly consistent production rate. Often, slurry dilution automation is combined with pump speed control to allow the dredge operator the ability to maximize the dredge excavating system. Cutter/swing speed control systems are also installed to try to optimize the excavation rate. GPS positioning and digital pre, current, and post survey maps are used to assist the operator and survey engineers to control the excavator position and spoil area throughout the dredging project. Control systems also log equipment faults, alarms, and hours to assist maintenance personnel in keeping the machine operating at peak efficiency.

However, this type of automation is only the beginning of what is currently under development. With addition of a few sensors, cameras, software, and the integration of current pump speed, swing and cutter speed, GPS positioning and predictive maintenance, the dredge is being re-created as an intelligent machine that can "learn" from its environment and assist the crew in making decisions that further optimize production and reduce operating costs.

**Keywords:** Dredge, Efficiency, Production, Automation, Intelligent

## INTRODUCTION

Dredge automation employs the use of a control system to reduce the need for human intervention and labor and to increase the safety, productivity, and accuracy of the work performed. In the 1950's, the canning industry became the first group to install automation equipment to enhance their processes; this technology was used on high speed lines to rapidly fill containers, seal and label them, reject defective products, and sort and bundle them. The result was a much higher throughput, greatly reduced labor cost, and a more consistent product. Shortly after, automation equipment was incorporated into the automotive and other manufacturing industries with similar results.  In the 1990's, automation was incorporated into dredges to reduce wiring runs and to add inexpensive safety interlocks. As the control systems and networks became more powerful and less expensive, the more laborious dredging tasks were automated to increase productivity and decrease down time.

Much of the increase in productivity and efficiency of automated dredges over human controlled dredges is due to the rapid data collection and processing. Additional improvements are gained by operating closer to or at optimum efficiency points of the installed equipment. As an example, the average response time of a NHRA drag racer is 0.500 seconds; the measured reaction time is far smaller since the driver can anticipate the half second time for the light to change from amber to green. When conditions cannot be anticipated and there are multiple stimuli, like in dredging, the typical human reaction time is between two and four seconds. When conditions deteriorate rapidly and higher levels of decision making are involved, human reaction time can extend to 10 or more seconds. Reaction time can be further degraded because the information being provided to base a decision on was not received or received late, as often happens when an operator cannot directly see what he is doing and must rely on instrumentation.

Automation and its related instrumentation and process piping are typically shown on piping and instrument diagrams, or P&ID's; Figure 1 depicts a typical automated booster P&ID. From this simple diagram, all of the

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equipment, interlocks, controls, and instrumentation are shown. Logic diagrams are also used to depict the range of possibilities and options for a given automation system.
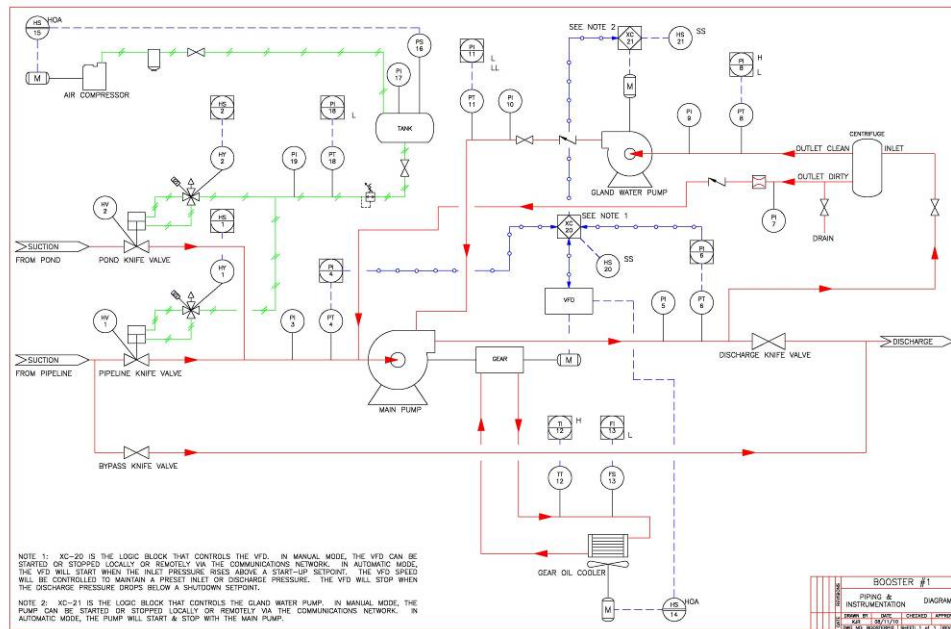


**Figure 1. Typical automation piping and instrumentation diagram.**

This booster is similar to the ones that are referenced in the simulated case study towards the end of this paper. As shown on this diagram, this is a variable speed electric unit with pneumatic valves to by-pass and isolate the pump for servicing.

## AUTOMATION COMPONENTS

The dredge control system consists of a multitude of components that accumulate data, process data, and perform tasks based on that process.

### Central Processing Unit

The heart of the dredge automation system is a Central Processing Unit, or CPU; the CPU receives information and data from the operator, dredge sensors and switches, and other intelligent processing units, processes that information, and then sends data and commands to the dredge equipment and user interfaces. PLC's, programmable logic controllers, and PC's, personal computers are most commonly used for automated dredge control.
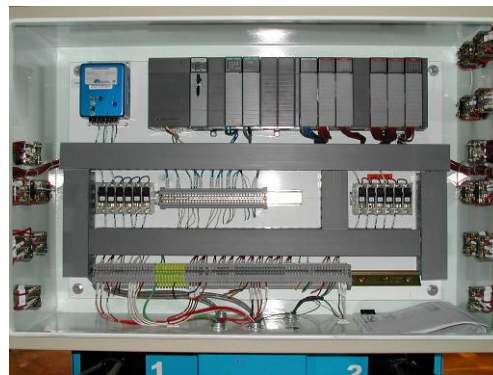


**Figure 2. Typical PLC arrangement.**

Figure 2 shows a typical PLC installation. PLC's differ from PC's in a number of ways. First, PLC's operate a specific program or set of instructions that are provided by the equipment manufacturer and are not normally subject to modification by the purchaser or end user. Spreadsheets, word processors, video games, screen savers, internet browsing, etc. are typically not included; the advantage is that the PLC is less likely to encounter crashes due to viruses, processor overloading, and tampering; the disadvantage is that the system is more rigid and requires a programmer to make requested changes and enhancements.  Secondly, PLC's are designed to operate in severe conditions such as moisture, heat, cold, dust, and vibration where PC's are usually not. Lastly, PLC's do not usually handle permanent file storage or support graphics directly, where this is common on PC's.

**Operator Interface**

The operator interface includes all of the displays, gages, buttons, switches, joysticks, etc. that the dredge operator or leverman uses to control the machine.  This interface is also referred to as an HMI, human machine interface, or an MMI, man machine interface. On an automated dredge, this is usually an operation screen with digital gages such as flow, vacuum, pressure, etc. and the hand control that the leverman typically uses such as swing, ladder, spud, carriage, cutter, etc. controls. GPS maps and radar images are also part of this interface.



**Figure 3. Interface dredge human machine interface.**

Figure 3 illustrates the dredge lever room and HMI of small portable dredge. The touch screen provides the operator with a customizable set of gages, control buttons, and control loop set points.

**CPU Programming**

The CPU programming can be as simple as electronically mimicking the operator's motion while displaying alarms and warnings and keeping and recording maintenance schedules to as complex as robotically operating the dredge

and its process. The actual automation programming language will either be Function Block Diagram, Ladder Diagram, Structure Text, Instruction List, or Sequential Function List.

Figure 4 is an example of Ladder Diagram programming, the most common PLC programming language. Each horizontal line is referred to as a rung; only one rung is processed at a time, from the top rung to the bottom rung; each rung in computed from left to right.
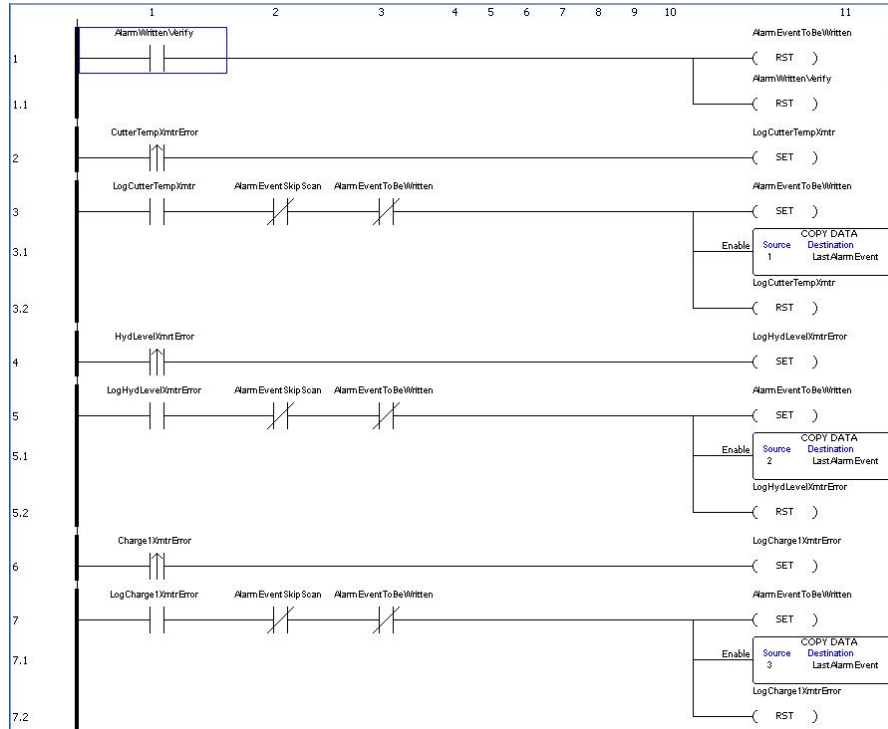


**Figure 4. PLC ladder diagram.**

## Analog Inputs and Outputs

In automation, analog refers to signal that is variable between a low and high value; transmitters are current varying analog devices and transducers are voltage varying analogue devices. A 0 to 414 kPa (0 to 60 psi) pressure transmitter will output 4 ma of current at 0 psi and 20 ma of current at 414 kPa (60 psi). Any pressure between the ends causes a linear current output between 4 and 20 ma. Since CPU's only compute numeric values, analog input cards convert the signals into digital numbers and analog output cards convert digital numbers into currents or voltages. The precision of the conversion is dependent on the sensor, its wiring, and the conversion card. Using the 0 to 414 kPa (0 to 60 psi) pressure transmitter as an example, a 12-bit processor card (low resolution) will break the electrical signal into $2^{12}$ discrete numbers (0-4095) or a resolution of 0.101 kPa (0.01465 psi), which is more precise than is normally needed for dredging. Most hydraulic speed automation is done by analog control.

## Digital Inputs and Outputs

Digital, or binary, refers to an on or off state. Buttons, switches, and contacts are examples of digital signals. Digital I/O is the low technology side of automation, but is invaluable for when a simple yes or no is required. Hydraulic directional valve control automation is accomplished by digital outputs.

## Communication Networks

Communication networks allow vast amounts of data to be transferred between connected devices. There are a number of industry accepted controls and communication networks currently being used some of which are: Ethernet, Modbus, Profibus, Canbus, HART, SAE J1939, and DeviceNet. These communication networks are how field devices, drives, engines, PLC, PC's, etc. communicate to one another and to the operator. Networks can be radio based, wire based, or fiber optic based depending on the specific conditions required. Because many

manufacturers use their own proprietary networks, network bridges are often required to pass data from one device to another.

**Field Devices, Engines, and Drives**

There are a growing number of devices used in the automation industry that can communicate with PLC's and PC's to transfer data and to accept commands. These devices typically pass and receive digital numbers that correspond to sensor readings and operating status, replacing numerous analog and digital IO's. AC drives and DC drives can be fully monitored and controlled using one or more of the communication networks listed in this paper. Modern electrical switchgear has options for digital control and monitoring as well. Any modern diesel engine can be monitored through the SAE J1939 network. The engine throttle position, start, stop, and E-stop must be controlled by digital or analog outputs. Network controlling these devices greatly reduces the wiring requirements and related cost and provides almost limitless data monitoring and polling.

**Control Loops (P, PI, PID)**

Most PLC's and control PC's have provisions for also operating as a loop controller. A loop controller is essential in optimizing automated performance by varying the control output, like speed, based on a process value, like pressure, using up to a three-parameter equation. This is where the real "intelligent" automation comes into play; with control loops, the control system can make flexible choices other than yes or no or on or off. The letters in the term PID stand for proportional, integral, and derivative. All P, PI, or PID loops attempt to minimize error, which is the difference between where you are and where you want to be. The proportional portion of the equation depends on the present error, the integral portion is computed from the accumulation of past errors, and the derivative portion is a prediction of future errors. With respect to the dredging processes, flow, density, and load loops typically use the proportional portion of the equation (P) because the conditions are so inconstant that past or future errors predictions are futile. PI and PID loops are often used on position or temperature processes that are more repeatable. For example, a PI loop is often used for spud carriage position; the loop controller will rapidly accelerate the carriage, reduce the error (its desired position minus its current position), and then reduce the speed as it approaches the end of its travel to eliminate jarring or over-running.
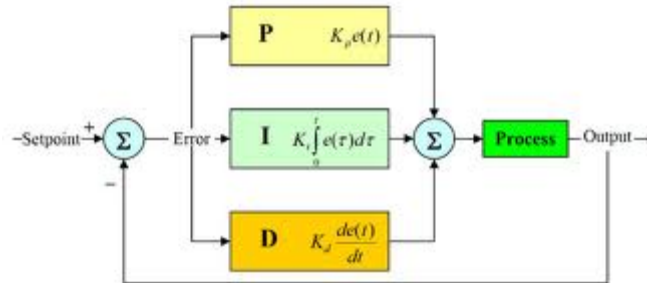


**Figure 5. Typical PID controller functionality.**

Control loops must be tuned to operate efficiently, and tuning a loop is more of an art than a science. Control loops can be updated several times a second, however, averaging values over a second or two and filtering known erroneous data improves the loop response.

## DREDGE AUTOMATION CONTROL

Different combinations of the automation components listed above can and are used to automate dredge functionality. In the simulated case study below, the benefit of automating as many redundant tasks as possible becomes evident. Starting with the front of the dredge, the current and developing automated controls will be discussed.

**Cutter head speed automation**

Cutter head speed automation is achieved by using a proportional (P) control loop using the swing speed as a controlling variable. The cutter speed is normally set to rotate at a low speed with no swing winch movement to help feed material into the suction mouth when abundant material is available. As the swing speed increases, the cutter

speed increases as well to keep the slice thickness at a desirable level. The main benefits of this automation are reduced cutter head wear due to over speeding and a decrease in required power. This automation is not very common, but is very inexpensive to implement on a PLC or PC equipped dredge.

**Suction mouth restriction monitoring and automation**

A suction mouth or cutter head clogged with clay or debris adversely affects dredge production, but can often be difficult to detect by an operator with limited instrumentation; the operator sees an elevated vacuum and assumes its due to slurry moving into and up the suction pipe. Several different automated solutions are available to alert the operator of this condition and assist in correcting it. The most common approach is to have a device monitoring the slurry in the pipeline; if the vacuum is high but the density is low, a clog likely exists. Most density meters average over time so there can be a delay up to 30 seconds in reporting. A faster method of detection is the addition of a second vacuum transmitter just behind the suction inlet. If a high vacuum is present and there is only a slight deviation between the two transmitters, the suction mouth or cutter is restricted. Another method involves monitoring the prime mover load and determining if dense slurry is present. Upon detection of a clog in a clay-laden deposit, jetting water can be automatically directed into the suction mouth and cutter head to assist in clearing it. Many mining dredges have separate digging jets to liquefy clay strata in the bank to relieve the cutter head. By simply starting this pump and redirecting its flow, the problem can be quickly corrected without a shut down. When clay is less frequent, the dredge service water system may suffice in remedying the problem. This automation is not very common, but is only moderately expensive to implement on a PLC or PC equipped dredge; it increases effective dredge time and reduces power consumption by eliminating the pumping of only water or light slurry.

**Dredge ladder dragging monitoring and automation**

Ladder dragging can occur from several different conditions: over advancing the dredge, creating a grade that is too steep for the dredge geometry, and from a bank cave-in. An indication that this condition exists is when the dredge swing load is high and the dredge cutter load is low; this is a common occurrence when a new dredge cut is being established. Electronic monitoring of the swing and cutter loads can inform an operator that this condition exists. Spud carriage, convectional spud automation, or stern wire automation as mentioned below can eliminate the over-stepping condition. With an automated loop employed to control the ladder lowering depth based on dredge advance, the dredge grade can be controlled. This control scheme can also monitor the swing, ladder, and suction loads and have the dredge determine if a cave-in has likely occurred. Meeting the programmed criterion for this, the dredge is commanded to step back and perform a sweeping operation. This automation improves the dredge cycle time, eliminated wear on the ladder and suction pipe due to dragging, while reducing the need to return to improperly dredged cross-sections at a later date. The cost for this automation is low as most of the monitoring devices are already on a modern dredge.

**Suction slurry dilution automation**

Surry dilution is the most common automated control on dredges today; it is marketed by a number of manufacturers under trade names like: Maximizer, ConVac, Hoffer, and Pearce. The principal behind this system is simple: a "tee" of port is placed in the suction line of the dredge pump. A control valve is installed in the branch leg of the "tee" or port; the opposite side of the valve is screened and plumbed to a site that is beyond the probable cave-in depth. Combinations of the dredge suction, discharge, flow rate, and density are monitored. In the least complicated schemes, a condition higher or lower than a set point triggers the valve to begin opening, allowing ambient water to flow into the suction pipe thus reducing the incoming slurry density. The valve continues to open as long as the set point is exceeded; when that condition ceases, the valve begins to close. In this scheme it is important to size the valve and its speed to prevent a rapid drop in the mouthpiece velocity, which can cause plugging prior to the valve. More complicated control schemes open the valve a controlled amount using a P or PI control loop for each process variable monitored. Slurry dilution automation helps keep the dredge pipe line flowing during cave-in and cutter and mouthpiece plugging; additionally, it gives the operator added confidence to excavate at a higher level, knowing that the slurry will be diluted if it becomes viscous. Figure 6 is a picture of a slurry dilution valve with a submerged vacuum transmitter.

**Figure 6. Slurry dilution valve with vacuum transmitter.**

**Dredge pump speed automation**

The second most common automation scheme on modern dredges is dredge pump speed automation. The most direct control is to vary the dredge pump speed with a proportional (P) control loop to maintain a constant flow rate regardless of slurry density; a uniform flow rate is crucial when slurry is being directly processed as in a dewatering application. When the process does not require a uniform flow rate, as in navigational dredging, slurry density, prime mover load, and discharge pressure can be used as process variables as well. The result of this scheme is controling the flow rate to transport slurry at the lowest energy cost per volume. Obviously, the loop structure here is fairly complicated and must vary as the nature of the slurry varies. Booster pumps use similar speed automation, but typically automate on the incoming and outgoing pressures, especially if the dredge has flow rate speed control automation. Combined with automated clutching, declutching, and system monitoring, unmanned booster operation is now common. The benefit to cost ratio of pump speed automation is the highest of all the dredge automation systems as higher densities can be carried at lower flow rates with less chance of pipeline plugging. This both decreases the energy cost and increases the dredge throughput and uptime.

**Dredge pump status monitoring**

Comparing the dredge pump's current performance against its new or theoretical (manufacturer's performance curve) performance can be used to gage the condition of the pump. Automating this monitoring requires that the suction and discharge pressure, flow rate and pump load be monitored during initial prime up and pump acceleration with clear liquid prior to dredging. With the addition of an accelerometer near the dredge pump, out of balance wear as well as impeller vane plugging can rapidly be diagnosed. Typically, a performance report will be generated and emailed to the personnel in charge of maintenance and the management team. This type of automated reporting is inexpensive and its key benefits are in reducing downtime and power consumption by strategic replacement.

**Swing speed/production automation**

The dredge excavation rate is generally controlled by adjusting the dredge slewing rate, or swing speed, across the cut. This rate is primarily dependant on four factors: swing load, cutter load, vacuum or suction load, and overall project production limit. The swing speed is automated by use of the minimum control loop output of a swing load loop proportional loop, a cutter load proportional loop, a suction control proportional loop, and a production proportional loop. Swing speed automation is inexpensive, but requires some skill in tuning the loops to reduce rapid acceleration and deceleration of the swing winches. This automation primarily increases dredge throughput by maximizing the excavation and acquisition systems of the dredge.

**Hydrographic survey automation**

Hydrographic survey automation is simply the real time updating of the project survey based on the actual cutter head longitude, latitude, and depth. This updating can also be enhanced with the installation of a stern-mounted fathometer to check for material running in behind the dredge cut. This automation requires a GPS system and an

accurate pre-dredging mapping and the desired post-dredging mapping. This automation can provide management with additional tools for predicting and enhancing production, since the system can tag areas of low production or of high downtime. WinOps, DredgePack, and Prospector are some commercially manufactured products that provide this level of automation. The cost varies greatly both on the hardware and software side. Most public dredging jobs now require these types of systems to generate reporting to the owner.

**Swing position automation and anchor position monitoring**

If hydrographic survey automation is installed, the dredge swing can be automated to operate within the confines of a cross-section. A PI position loop is used to reduce the swing speed near the ends of the cut and to reverse the swing direction at the end of the cut. This automation is best used when used with cross-section contour and either spud carriage, conventional spud, or stern wire automation. With the combination of these, the dredge will continue until the desired depth is met and then step forward into the next cut automatically. Swing position automation is inexpensive when hydrographic survey automation exists.

**Cross-section contour automation**

In addition to keeping the dredge within the desired XY coordinates, cross–section contour automation controls the ladder depth to excavate the dredge cut into the appropriate shape. Contouring requires a PI control loop on depth where the depth is updated based on the dredge position. Additionally, the swing speed may need to be reduced if drastic shape changes are required. This type of automation relieves the operator of the difficult task of cutting grades and over or under dredging. The key benefit with this type of automation is the increased swing rate that can be utilized and the reduced chance of having to redo or clean-up a section. Both of these benefits increase the overall dredge production rate.

**Spud carriage automation**

A spud carriage can be automated using a PI or PID loop to automatically advance or retract the dredge a chosen distance. A linear encoder is often used as an analog input to show the carriage's exact position relative to the dredge. Additionally, automation can be added to reset the carriage at the end of its cycle, including raising and lowering of the carriage spud and setting spud. Because the spud carriage is usually located behind the operator in poor view, the operator is slow to set and reset the carriage. Automated carriage resetting can be as much as four times faster than manual resetting. This automation scheme can be called by other automation processes, like the cross-section contouring for seamless spud advancing. Increased average slurry density due and greater positional accuracy are the primary benefits to this type of automation.

**Conventional spud automation**

Conventional spud automation can be installed to increase the spud setting and lifting cycle speed. Since manual conventional spud manipulation can be much more time consuming than manual spud carriage manipulation, automating the spud setting can dramatically increase dredge productivity. When the setting is tied to other automation, like swing position automation, highly accurate steps can be made. This type of automation is simple and increases dredge position accuracy and slurry pumping time.

**Stern wire or wires automation**

Operating a dredge on a single stern line of a Christmas tree (three stern lines) can be useful in deep mining, high sea states, or wide cut conditions. Mechanically paying out the correct amount of cable to step ahead is tedious and difficult. This process can be automated by simultaneously releasing holding brakes, while hoisting or paying out metered amounts of cable. The metered cable can be measured by drum RPM, time, or GPS location. This type of automation is simple and inexpensive when other automation packages are used in conjunction with it. Like the spud automation, increased production and positional accuracy are the primary benefits.

**Service water speed automation**

Service water or gland water speed control is often automated to provide the correct dredge pump packing gland flow and pressure. A proportional control loop that monitors the service water and dredge pump difference varies the pump speed just enough to properly seal the dredge pump, increasing packing life and reducing power consumption of the service pump. On smaller dredges, the service water can be a significant power draw.

**Equipment monitoring, diagnostics, and maintenance scheduling**

With a PLC or PC controlling dredge operations, the running time for every piece of controlled equipment can be accurately kept. With a service schedule input, the dredge can notify maintenance of upcoming requirements, which reduces over servicing and extends equipment life. Any equipment with analog connections or a control network can be monitored for proper operation and life, similar to how the dredge pump status monitoring works. Monitoring is usually included with any automated dredge and increases efficiency through predictive servicing.

**Remote viewing and control**

With dredge projects getting more complex due to contaminated material, smaller, more remote spoil areas, increased boat traffic, etc. management needs timely information and updating of production, changing events, and downtime. PLC's and PC's can be easily controlled remotely, via fiber optic, wireless, cellular, and satellite networks. All of the dredge data, both historical and real-time can be viewed and updated if the dredge is connected into one of these networks. Ethernet cameras are often added to provide additional information about the surroundings. In secluded areas, like sand and gravel mines, the entire dredge operation can easily be controlled remotely by employing an operator only for safety and service reasons.

## SIMULATED CASE STUDY

**Project Background**

To demonstrate the benefits of some of the automation control schemes listed in this paper, a dredge project with an automated dredge and booster system has been modeled. A simple time and motion study has been performed on the dredge operating fully automated and completely manual for comparison.

Imagine a dredge reclamation project for a three thousand acre contaminated lake in the northeastern United States. The project is divided into three different zones based on contamination level. Zone one, shown in yellow in Figure 7, requires removal and disposal of the lightly contaminated layer; since these areas are located near the shoreline, they will be cleaned with land based and floating excavators. Zone two, shown in green, requires removal and treatment of the contaminated layer and transport water, and zone three, illustrated in orange, requires removal and treatment of just the upper portion of the contaminated level and transport water followed by capping with uniformly sized sand, pre-sized gravel, an active carbon, more uniformly sized sand and a protective stone cover. A hydraulic dredge will remove the material for both zones two and three. The total contaminated area to be remediated is about 1.5 million cubic meters (2 million cubic yards), over 101 hectares (250 acres), most of which is shallow and requires a great deal of stepping. Since this project is monitored by local, state, and federal organizations, all dredge systems and treatment plant operations must be continually monitored and displayed on a remote web site. The lake has been surveyed and detailed hydrographic maps exist in digital form for dredge operation.

**Figure 7. Example lake project.**

**Dredge System Description**

On the lake, an automated diesel-powered hydraulic dredge with a submerged pump and spud carriage barge will be the primary dredge. This dredge has ample power and head to transport contaminated sediments from any point in the defined regions to a booster pump network located on the shore. The dredge is equipped with a commercially available GPS package that includes the digital survey and the mine plan to be followed. The dredge has the following automaton packages installed: cutter head speed control, ladder dragging, slurry dilution, dredge pump speed, dredge pump status, swing speed, swing position, cross-section contour, spud carriage, service water speed, equipment monitoring, and remote viewing and control. The booster network consists of four automated, variable speed, electrically powered booster units, three of which are along the lake shoreline. The boosters have dredge pump speed, dredge pump monitoring, equipment monitoring and remote viewing and monitoring automation installed. The plastic pipeline, shown in red in Figure 7, covers approximately 6096 meters (20,000 feet) with an elevation increase of nearly 30 meters (100 feet) near its termination at the treatment plant. The treatment of the sediments and water is complex and a uniform flow rate and density is required for optimal processing. The dredge communicates its operating data to the booster network through an industrial wireless Ethernet system; the booster units are connected by a fiber optic system to the processing plant. At the processing plant, a web server receives the dredge system information as well as the treatment plant operation and places the information on the Internet to be viewed by the public.

**Automated Dredge Operation**

With the dredge on location as per the mine plan, the dredge operator starts the dredge auxiliary diesel engine and then the dredge pump engine. While the engines are warming up, the dredge control system performs system checks on all its instrumentation using the equipment monitoring automation and polls the booster network indicating that it is ready to start operating. The dredge can operate with a single person, but on this job, due to safety concerns with the contaminated sediment, an assistant is employed. The dredge signals a successful system check to the lever man and he depresses the "Start" button to commence dredging. The control system raises auxiliary engine speed up to its defined speed and starts the dredge service water pump. The service water pump supplies water to the dredge pump packing gland and jetting water to clean the cutter head when stiff clay is encountered. The dredge now swings to its port most swing position and lowers the dredge ladder to a few feet above the lake bottom using the swing position and contour automation. The dredge pump is clutched in and begins to slowly increase in speed using its speed automation; the submerged dredge pump allows immediate priming of the dredge pump. The main engine pauses its speed increase at several points throughout to compare the differential pressure (vacuum), discharge pressure, flow rate, and engine load with known set points in the dredge PLC dredge monitoring section of the program. The dredge system can predict pump wear during this test and any degradation in performance is immediately emailed to the maintenance supervisor and the project manager. The dredge controls now bring the dredge pump to a speed that matches the desired dredge flow rate. At this point, the dredge has been in the start mode for less than three minutes; the water in the pipeline has traveled about a half a mile which is about half of the way to the first booster. The dredge control system starts the dredge cutter and lowers the ladder onto the lake bottom using the automated cross-section contour. As the dredge cutter touches the bottom the cutter load jumps slightly and the control system compares the last hydrographic data recorded with this depth using a tide gage to correct for varying water levels; this is to ensure that there was not a cave-in or re-deposition of material since the last dredging operation. The survey and the actual bottom match, so the dredge is commanded to lower the cutter to the required depth, or the maximum depth based on cutter load, whichever is shallower; another fifteen seconds has expired. All during this time, the main engine is increasing its speed to keep the flow at the desired rate. The dredge starboard swing winch now begins to turn moving the dredge to the right. The swing speed is automatically controlled by the systems swing speed loop; it is controlled by the dredge vacuum, swing winch load, cutter load, and dredge throughput; the control system will increase or decrease the swing speed until one of these conditions is maximized, producing the optimal swing speed for the anchor placement, sediment stiffness, and production rate. The dredge cutter head speed is also varied with the swing speed to help reduce wear from over speeding using the automated cutter speed control. The cutter head height is adjusted across the cut for variations in the desired profile. The material here is soft and the face is shallow, so the dredge swings fairly fast. The GPS system monitors the current cutter head position and updates the survey map in real time. The GPS also reports to the dredge how far from the end of the cut it is. With the dredge approaching the end of the cut, the starboard swing winch slows to a smooth stop at the end. Because the bottom profile is so critical on this job, the dredge is pre-programmed to make a quick clean-up cut back to the port side. The port swing winch now begins to hoist and quickly propels the dredge across the cut back to the starting point. Again the GPS slowly brings the port swing to rest at the other end of the cut; the main engine has been slowly and steadily increasing its speed throughout this process to maintain the required flow rate. The hydrographic survey is updated across the entire dredge cut to show the area dredged.

At this point, the water is just reaching the first booster pump. The pump senses the rising incoming pressure and increases its speed automatically to maintain a set rate using its automated pump speed control. The booster performs a pump wear check during this phase just like the dredge did. None of the booster pumps are manned while the communication network is operating properly. The booster pump packing gland uses dredge slurry that has been de-sanded by a cyclone as not to dilute the solids concentration. The booster service water pump is variable speed as well and it constantly changes its speed to provide just enough pressure to the packing gland.

With flow now past the first booster, the dredge pump speed is varied less frequently and in smaller increments, just enough to maintain a constant flow in the line as the density varies slightly in the cut corners and on the back swing. The dredge now advances forward on its spud carriage a cutter head length using spud carriage automation and the entire swing cycle is repeated.

As each subsequent booster pump detects dredge water then slurry flow, they follow the start-up procedure and checks described above. The dredge and each booster stay in constant contact with the web server located at the

treatment facility. As slurry reaches the plant, the plant begins to relay data about its status back to the dredge and boosters so that a solids and slurry balance can be maintained.

Throughout the dredging cycle, dredge and booster status and the remaining service interval hours for individual components are constantly updated by the control system. After the third set on the spud carriage, the dredge control system will lower the setting spud and raise the carriage spud. The carriage will then reset itself to the retracted position. At the duration of the swing, the carriage spud will be lowered and the setting spud will be raised. The dredge will then set ahead a cutter head length on the carriage. As the dredge continues to advance forward, the GPS system will alert the operator and the dredge maintenance crew when the dredge swing anchors need to be repositioned and a location that is appropriate.

## Dredge Operation with an Upset Condition

A number of upset conditions can be encountered during the dredging process, particularly on this job with such a long pumping distance. The dredge automation system is designed to respond to many of these automatically. Some of these conditions are cave-ins, the loss of a booster pump or the dredge pump, and a loss in communication. The simulation accurately predicts how the dredge and system will respond in an automated state, but no data is available on how 6 individuals will perform under pressure.

## Anticipated Performance With and Without Automation

Table 1 displays the key simulated data from this project with a manual and automated operation. In the simulation, it was assumed that the operator would respond with three seconds to a normal dredge task like swing to port or raise the ladder. Additionally, the dredge operator's efficiency at loading the dredge excavation and acquisition system is assumed to be 80%. There was no loss of time or efficiency calculated for the manual booster operations, equipment downtime without predictive maintenance, etc.

**Table 1. Conventional and automated dredge example comparison.**

| | Without Automation | With Automation |
|---|---|---|
| Time for 3 complete swing cycles | 17.2 minutes | 16.0 minutes |
| Time for 3 carriage advances | 0.55 minutes | 0.25 minutes |
| Time for 1 carriage reset | 1.02 minutes | 0.27 minutes |
| Total time | 18.77 minutes | 16.52 minutes |
| Production rate | 161 meter$^3$/hour (210 yard$^3$ / hour) | 228 meter$^3$/hour (298 yard$^3$ / hour) |
| Power consumption | 1474 kilowatt (1976 horsepower) | 1617 kilowatt (2168 horsepower) |
| Power consumption per production | 9.16 kilowatt/meter$^3$ (9.41 horsepower / yard$^3$) | 7.09 kilowatt/meter$^3$ (7.28 horsepower / yard$^3$) |
| Personnel required | 6 | 2 |

## CONCLUSIONS

Dredge automation is one of the most cost effective methods of increasing hydraulic dredge production and efficiency. PLC's and PC's are capable of making thousands of calculations and corrections a second, whereas the normal reaction time of an operator is seconds per correction. Automated controls also allow the machine to operate closer to its optimum levels without fear or emotions about a plugged line, over-digging, under-digging, etc. The cost to fully automate an electrically controlled modern dredge is comparable to a dredge operator's salary.

From the lake simulation example above, the automated dredge completes the job in 6,711 pumping hours, whereas the manually operated dredge requires 9,523 hours. The automated dredge and boosters consume 10,701,139 kilowatt-hours (14,549,500 horsepower-hours), while the manual dredge and boosters use 13,840,248 kilowatt-hours (18,817,500 horsepower hours). Lastly, the automated system operates with a dredge operator and a laborer, while the manual system requires six people in total. No benefits for predictive maintenance or increased dredging accuracy were computed.

All of the automation features listed in this paper are currently available on new dredges. The lake example is based on an actual job that will commence in 2012.

**CITATION**