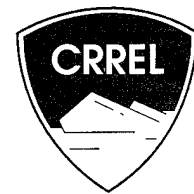


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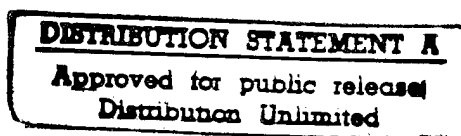
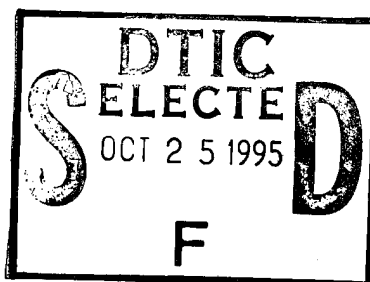


Improvement of Operations and Management Techniques Research Program

Automation Opportunities at Corps of Engineers Locks and Dams

Kevin L. Carey

September 1995



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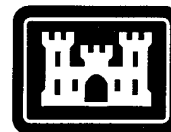
Abstract

In an investigation to determine the feasibility of automating some of the operations at navigation locks and dams of the Corps of Engineers, a scheme of five categories composed of seventeen characteristics was developed to evaluate candidate automation measures. As a result of both a survey of Corps water resources projects and field visits to seven lock and dam projects, 43 navigation project functions that could be automated to varying degrees are identified and described (24 associated with lock operations, 15 associated with dam operations, and four related to navigation operations). The 43 project functions are assessed according to the evaluation scheme, and presented in a matrix format. The matrix can be used for selections, comparisons, sortings, or rankings of the various project functions and automation alternatives. The matrix is readily adaptable to a database when and if it grows larger. Thus, an initial framework has been established for evaluating operations and functions commonly occurring at navigation locks and dams offering opportunities for automation. This framework should prove useful for operational planning and management decision-making.

For conversion of SI units to non-SI units of measurement consult *Standard Practice for Use of the International System of Units (SI)*, ASTM Standard E380-93, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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**US Army Corps
of Engineers**

Cold Regions Research &
Engineering Laboratory

Improvement of Operations and Management Techniques Research Program

Automation Opportunities at Corps of Engineers Locks and Dams

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PREFACE

This report was prepared by Kevin L. Carey, Research Hydraulic Engineer, of the Ice Engineering Research Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). It derives from an investigation conducted for Headquarters, U.S. Army Corps of Engineers (HQUSACE) under the Improvement of Operations and Management Techniques (IOMT) Research Program, as part of CWIS Work Unit 32722, "Navigation and Lock & Dam Automation Alternatives."

IOMT Coordinator for the Directorate of Research and Development, HQUSACE, was Jesse A. Pfeiffer, succeeded by David Mathis, and the Technical Monitors are James E. Crews and Robert M. Daniel. The IOMT Program Manager is Robert Athow, Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station (WES).

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Automation Opportunities at Corps of Engineers Locks and Dams

KEVIN L. CAREY

INTRODUCTION

The navigation lock and dam facilities of the Corps of Engineers encompass a wide range of designs, ages, conditions, traffic levels, and operating characteristics. This examination of adapting or extending automation to such a diverse population of facilities must necessarily be quite general. It will be the task of future studies to apply the general findings of the present study to the specific facilities found in a particular division or district or on a given waterway.

While a broad program to adopt automation measures could eventually result in the need for fewer operating personnel, the most important outcome of such a program would be to better utilize the skills of existing operating personnel. Personnel resources are much more valuable and productive when applied to overall surveillance of the safety and efficiency of operations, rather than to the tweaking of machinery components involved in the operations.

Important parts of this study were a survey of Corps projects to identify automation systems and needs, and visits to several lock and dam projects to examine automation systems and assess automation applications to project operations. The survey of Corps projects is the subject of Appendix A, and Appendix B contains accounts of the field visits.

AUTOMATION CHARACTERISTICS

For the purposes of this report, automation is considered to be any measure or equipment employed to control a procedure or operation with some degree of planned or programmed function. As such, automation is meant to relieve

operating personnel from continuous observation, visual feedback, and consequent adjustment of the control of the process being conducted. The purpose of automation is to achieve consistent, safe, and dependable operation of lock and dam facilities.

Automation measures can fall within an extremely wide range in terms of complexity, immediate purpose, cost, etc. While this study must remain generalized, there still needs to be a set of characteristics or criteria by which various measures can be described or distinguished within this wide range. These characteristics can be used, then, to discriminate among various levels of complexity, utility, cost, etc., and thereby form judgments concerning automation implementation.

To codify or categorize candidate automation measures, there is need for a scheme of criteria or determinative characteristics by which any particular measure can be described or evaluated. This study has developed a scheme comprising five categories to describe an automation measure. These categories are 1) type or level of automation measure, in terms of the complexity or sophistication of the measure; 2) the purpose for which the automation measure may be adopted, expressed in terms that have significance for operational management decisions; 3) the qualitative difficulty of installing or implementing the automation measure; 4) the relative (qualitative) cost of the measure; and 5) the degree by which operating with the new automation measure departs from operations using present methods. This latter category may give a rough indication of anticipated personnel acceptance of an automation measure.

The scheme of evaluation categories and the

Table 1. Evaluation categories and characteristics of automation measures.

Category	Symbol	Characteristic
Level	A	Fully programmed control with a high degree of interlocked operation, remote control and readout, emergency override
	B	Programmed operation with remote readout; may have some degree of interlocking, and would have manual override
	C	Remote readout and programmed control, remote control, or some combination
	D	Local installation for programmed control; would require manual initiation of operation
Purpose	a	Safety
	b	Simplification
	c	Staff reallocation
Difficulty of implementation	H	High
	M	Medium
	L	Low
Cost of implementation	H	High
	M	Medium
	L	Low
Departure from existing operational procedure	H	High
	M	Medium
	L	Low

determinative characteristics associated with each category are presented in Table 1. In the following paragraphs the evaluation categories and characteristics are described in detail.

Later in the report the candidate automation measures that have been identified in this study are described or labeled by these categories and characteristics in a matrix format.

Level

The wide range of automation measures has been divided into four levels based on the complexity of the measure or the degree of automated operation that the measure would provide. *Level A* is the most ambitious degree of automation, representing measures that have a large number of individual steps incorporated into a programmed sequence that includes "interlocking" or coordination with other simultaneous functions occurring at the navigation project. In plain terms, a Level A automation measure would require an operator to simply push a button and an entire operation normally requiring several actions on the operator's part would take

place automatically. Moreover, due to interlocking, the program would ensure that any necessary but separate conditions, normally verified by the operator, are fulfilled during the operation being conducted. For example, an interlock could be verification that a lower miter gate is closed before an upper miter gate is allowed to open. An automation measure at this level would be expected to be employed remotely if desired, and provide remote readout or status reports. Although capable of manual override, a Level A measure would normally require this only in emergency situations.

A *Level B* measure is less comprehensive than Level A in that it would control a smaller number of steps or operations, and have correspondingly fewer interlocks. Remote operation and readout would be present, but manual override would be used only in rare cases.

At *Level C*, only one step or operation would be controlled (or two closely related steps), and remote control or remote readout or both would be present. Manual override capabilities would be used more frequently due to normal variations in operating conditions (weather, stages, day vs. night, traffic, etc.).

The simplest form of automation, *Level D*, would have no remote features when deployed by itself (i.e., when not in combination with other automation measures), and would always require operator initiation for the process being conducted. This level contemplates close supervision by an operator, but frees the operator from making adjustments in the middle of an operation, because the automation measure would monitor the condition(s) adjusted for and make the adjustments according to a program inherent in the equipment. To put this in familiar terms, a Level D system might control and vary the speed at which a gate opens, and bring the gate to a stop at the end of its travel without overloading the machinery to a point that limit switches are invoked.

Purpose

Three distinct purposes for adopting automation measures at navigation projects have been identified. A measure may be desirable for more than one reason or purpose. However, the use of the three purpose characteristics will allow for ranking or sorting to aid in planning and decision-making.

Safety is labeled *Purpose a*. Safety is considered to apply broadly to project operating per-

sonnel and to users of a navigation project, as well as to capital equipment making up the navigation project. One of the great promises of automation is the reduction of mishaps due to operator error or inattention. Through the use of interlocks in programs, the conditions under which accidents happen should be substantially reduced in number.

Simplification of procedures is designated as *Purpose b*. This means, for example, a reduction in time needed for an operator to accomplish a procedure, or a reduction in the operator's surveillance of the procedure. It could also apply to a reduction in skill necessary to carry out certain operations.

Purpose c is staff reallocation. This may mean a reduction in the number of personnel needed overall or for a particular operation. It could also involve the reassignment or redistribution of tasks to personnel.

Difficulty of implementation

Three qualitative levels of difficulty of implementation of any proposed automation measure are defined, namely high (*H*), medium (*M*), and low (*L*). Difficulty of implementation involves several factors, such as the extent of construction needed, the accessibility of locations where components or equipment need to be installed, the length of time needed for installation of equipment, the degree of interference with customary operations during installation, the technical difficulty of personnel training, etc. The Level (*A*, *B*, *C*, or *D*) of the automation measure, as defined earlier, is likely to correlate roughly with the level of difficulty, but there are definite exceptions to any such correlation.

A high level of difficulty corresponds to an automation measure that would likely be implemented only during original construction or during a major rehabilitation or reconstruction, due to the extensive amount of component installation expected or the complexities of the navigation project that would be affected by the installation.

A medium level of difficulty would be characterized by construction activities less extensive than project rehabilitation, and would generally affect only a limited portion of the project's facilities. For example, automation implementation that would involve only work on gate lifting machinery, or only on filling and emptying valve machinery, might be termed *M*.

Implementation rated low in difficulty would

require no interruption in operations, and would include minor procedures, such as the simple replacement of components in a limited area, or the running of wires through existing, easily accessed conduit ways or chases.

Cost of implementation

As with the difficulty of implementation, three relative levels of cost of implementation of any proposed automation measure are defined. Again, these are designated as high (*H*), medium (*M*), and low (*L*). The cost of implementation may depend on many of the same factors as the difficulty of implementation, but there are additional factors, such as the complexity and sophistication of the actual automation components, the cost of training necessary for personnel, and possibly such factors as the need for system support personnel. The cost of implementation may correlate roughly with the difficulty of implementation, but again there would be exceptions.

While the cost category must remain qualitative in this study, costs can still be expressed in terms that are relative to customary practice. Therefore, a high cost level is one for which the cost of implementation of an automation measure is estimated to be more than twice the cost of non-automated equipment (e.g., relay-based rather than programmable logic controllers), along with the installation and training required to control and conduct the same operation(s). At the medium level, the cost would be estimated to fall between one and two times the cost of the corresponding non-automated approach, and at the low level, the automation measure is estimated to be less expensive than the non-automated alternative.

Departure from existing procedure

The four levels of departure from existing procedures are defined as high (*H*), medium (*M*), low (*L*), and none (*N*). These are highly qualitative indicators of such matters as the actual work patterns of operating personnel (e.g., remaining at one station vs. moving among several stations to accomplish an operation), the acceptance of automation measures by operating personnel (who may have reasons to fear or oppose automation), the ease with which automated procedures can be adopted to replace or supplant present techniques (e.g., can the change be transparent to navigation project users, or will they have to learn new practices?), and the dura-

Table 2. Lock operations identified as candidates for automation measures.

<i>Filling and emptying</i>	<i>Gate opening and closing</i>	<i>General machinery operation</i>	<i>Debris and ice control</i>
Timing and monitoring valve movements	Controlling rate of gate motion	Monitoring and controlling hydraulic systems	Programmed operation of pneumatic debris or ice flushers and screens
Controlling valve opening and closing rates	Latching gates in their recesses	Establishing and operating an alarm system	Interlocks between components of pneumatic debris control or ice control systems
Varying valve operation as a function of chamber stage	Interlocking gate operation between upper and lower gates	Monitoring and controlling sump pumping equipment	Temperature-triggered operating programs for ice control systems
Balancing flows between chamber sides	Interlocking gate operation with filling and emptying valve operation		Warning system for ice accumulation on barge bottoms at entrance to chamber
Programming valve operation for various vessel types	Interlocking gate opening with gage readings on both sides of a gate		
Establishing and remotely resetting limit positions of valves	Interlocking gate operation with vessel position in chamber		
Interlocking valve operation with upper and/or lower gate operation	Monitoring and controlling gate skew		
	Controlling closure of miter gates needing a specific sequence		
	Establishing and remotely resetting limit positions of gates		
	Programming sector gates to achieve optimum flow-through		

tion of training necessary to enable operating personnel to employ the automated measures.

The assignment of these indicators has been based on many observations of operations at a variety of navigation projects. It has been a judgmental process, and no further discrimination between the four levels is attempted.

NAVIGATION LOCK AND DAM FUNCTIONS SUBJECT TO AUTOMATION

Based on the survey of Corps navigation projects and the visits to selected locks and dams, as well as prior familiarity, the functions common to the great majority of lock and dam projects have been identified with a view toward adaptation to automation. Not all functions are present at every navigation project. Discussed below are these functions and the elements of each that invite consideration of automated control.

Lock operations

The various lock operations that may be considered for automated operation are discussed below and are shown in Table 2.

Filling and emptying

There are many different designs of filling and emptying systems. All of them, however, have certain considerations in common that contribute to optimum operation. These include keeping stresses and loads on the operating machinery within acceptable limits, and minimizing adverse currents and turbulence in the lock chamber during filling and emptying.

Timing and monitoring valve movements. For most lock projects the position of filling and emptying valves is shown by mechanical or servomechanical indicators, if it is shown at all. These indicators are usually located only at the lock stands and have no remote readouts elsewhere. Automation equipment on the filling and emptying valves would allow valve position information to be delivered to any desired location at the project, and would allow valve movements to be monitored so as to be input into programs for other related operations, and vice versa.

Controlling valve opening and closing rates. At most locks the opening and closing of the filling and emptying valves must be performed carefully to avoid too-abrupt variations in flow rates; otherwise, the loading and hydraulic ef-

fects on the gates, gate operating components, culvert walls, and intake screens may become excessive. Also, the transition from stable to varying water stages in the lock chamber must be accomplished gradually to minimize turbulence and oscillation in the chamber. This is of particular importance for certain older lock designs that have the filling/emptying system only on one side of the chamber. Automated mechanisms on the gate operating machinery could be programmed with the optimum rates for valve opening or closure, based on experience or experimentation.

Varying valve operation as a function of chamber stage. At most locks the stage in the chamber is varied more rapidly by the lock operator during the middle of a filling or emptying operation than near the beginning or the end of the operation. In other words, there is a stage-dependence for the maximum allowable flow rate into or out of the chamber. With automated control of filling and emptying valves, the amount of valve opening (and thus the flow rate) could be governed or moderated, according to a program, by feedback of chamber stage differential compared to upper or lower gages.

Balancing flows between chamber sides. Irregular and turbulent flows in the lock filling or emptying processes can result from significant flow differences between the filling/emptying systems on each side of a lock. These may result, for example, from inherent differences in the efficiency of the intakes or outlets of the systems, or from differently regulated filling/emptying valves, etc. The consequence is that excessive turbulence and adverse currents can exist in the chamber. This condition can place vessel mooring lines under undue loads and can make small recreational craft difficult to control. With the flows balanced automatically by means of flow measurement sensors giving feedback to the operation of the filling/emptying valves, all operating according to a program, the possibility of adverse unbalanced flow effects should be eliminated.

Programming valve operation for various vessel types. Larger vessels, such as tows, can tolerate more rapid filling or emptying of the lock chamber than smaller craft, such as recreational boats. Also, the number of recreational boats in a chamber influences the rate at which an operator will fill or empty the chamber, based on the idea that the closer the boats are to each other, the greater the danger for contact in stronger cur-

rents set up during the filling or emptying process. For these reasons, filling and emptying valves that are operated according to pre-established programs can be made to function according to two or more programs of different durations, adapted to various vessel types and their responses to the rate of change in lock chamber water levels.

Establishing and remotely resetting limit positions of valves. Limit switches are vital safety features on filling and emptying valve mechanisms for protecting components from damaging overloads. It is likely that these electromechanical devices would be employed as separate backups even with fully automated operation of filling and emptying valves. The setting or adjustment of limit switches is often troublesome due to difficult accessibility and the need for fine tuning. Remote setting of limit switches could be accomplished by relatively simple automated means. This would facilitate setting of limit switches, but especially would allow ease in changing the settings to meet temporary needs imposed by such conditions as worn or damaged machinery components or foreign material (debris or silt) interfering with valve operation.

Interlocking valve operation with upper and/or lower gate operation. At almost all lock projects it is the operator's responsibility to ensure that the lock gates are fully closed before filling or emptying operations are begun. Serious accidents and equipment damage are possible if filling or emptying operations are attempted prematurely. By having automated equipment monitoring the operations of the lock gates, operational programs can be designed to prevent filling or emptying operations from being attempted until a specified condition or position is achieved at the lock gates.

Gate opening and closing

While there is a variety of lock gate designs in use at Corps projects (e.g., miter gates, sector gates, lift gates, guillotine gates, tainter gates), the operation of them is critical to the efficiency of lock operation. Some operational concerns apply to all types of gates, while others apply only to certain gate types.

Controlling rate of gate motion. Operators control the speed of motion of most types of lock gates. Motion is begun and ended slowly, and in the middle ranges of motion the lock gates are generally permitted to move at maximum speed, barring any unusual conditions that would require

slower motion. Gate motion could be programmed so that the acceleration and deceleration would take place identically every lockage cycle without operator input (other than initiating the motion). Gate motion would thus become dependent on gate position within its range, according to a program.

Latching gates in their recesses. Some locks have latches for the lock gates that must be secured when the gates are in the opened position and before lock traffic is permitted. Some of these projects also latch the gates when passing ice over submergible bulkheads, to ensure that the gates are not damaged by the flow through the chamber. Latching is a manual procedure, or an automatic mechanical procedure; unlatching is manual in all cases. Latching and unlatching can be automated by programming latching to occur at a certain gate position and unlatching to occur at the beginning of gate closure motion. Automated latching/unlatching could also be chosen as an interlock condition for other programmed operations.

Interlocking gate operation between upper and lower gates. In ordinary operations, the upper and lower gates are never open at the same time. The closed gate must be fully closed before the other gate is opened. Usually this is verified visually by the operators, and may be done with or without reference to indicators in the lock stands. A mistake by an operator could be quite damaging to the gates and the lock. Automation equipment on the gate operating mechanisms will input gate position information to a program, and it would be an easy matter to create an interlock in the program that requires one gate to be fully closed before the other can be opened.

Interlocking gate operation with filling and emptying valve operation. One of the potentially most hazardous and damaging operator errors that can occur at a lock is to begin opening an upper gate before the chamber is substantially filled, or to begin opening a lower gate before a chamber is substantially emptied. The gates are vulnerable to damage, and if they were to become inoperative, there could be an uncontrolled flow situation through the lock. This is essentially the same problem that was stated earlier under filling and emptying operations, but in this case from the point of view of operating the lock gates. Thus, by having automated equipment monitoring the operations of the filling and emptying valves, operational programs

can be designed to prevent lock gate movement until a specified condition or position is achieved at the filling or emptying valves.

Interlocking gate opening with gage readings on both sides of a gate. At some locks it is difficult for the operators to observe when the chamber water level matches the upper pool stage at the end of a filling operation, or when it matches the lower pool stage at the end of an emptying operation. They want to have the stages match quite closely before opening the gate. For example, it is good to avoid the opening of miter gates against a head of water, or to avoid a surge of water past the gate upon opening. With water level monitors installed on each side of the gates, information could be fed to a program requiring a match of stages before gate opening could be accomplished, thus preventing the problems encountered with moderate head differences. This situation is the continuation of the condition stated immediately above, but it occurs closer to the end of the filling or emptying process.

Interlocking gate operation with vessel position in chamber. Certain designs of lock gates are vulnerable to damage by vessels such as towboats or barges if they are too close to the gate during chamber filling or emptying. For example, an accident once occurred in which a vessel in the chamber was too close to its upper end, and upon chamber filling the vessel hooked the underside of the upper gate structure (a tainter gate) and destroyed it. Another accident occurred when a submerged upper lift gate was raised inadvertently while a tow was entering the chamber. These occurrences could be prevented by sensors installed in the lock chamber and in the upper and lower approaches that determine whether a vessel or tow is clear of the gate areas before the gate would be allowed to move. This would be an interlock condition that would have to be satisfied to proceed with programmed gate operation.

Monitoring and controlling gate skew. Guillotine gates, and to a lesser extent tainter gates, are subject to skew because separate operating machinery is used to move each side of the gate. In some cases there are skew indicators that an operator must monitor to keep skew within tolerable limits, and there are also limit switches that will stop the lifting machinery if skew becomes excessive. What is suggested here is automated equipment that will use skew information as input in order to feed back adjustments to the lifting equipment to correct or minimize skew, thereby freeing per-

sonnel from monitoring skew, and ensuring gate movements that are uninterrupted.

Controlling closure of miter gates needing a specific sequence. The design of some miter gates or their seals requires that the gate be closed in sequence, e.g., left before right. Current manual procedures could be eliminated if gate movements were automated, since the closure sequence could be made a part of the program.

Establishing and remotely resetting limit positions of gates. As with filling and emptying valves, limit switches would continue to be used as backups with automated operation of lock gates, but their setting or adjustment might be annoying due to accessibility problems and fine tuning. Remote setting of limit switches could be accomplished by relatively simple automated means, facilitating the setting of limit switches, and allowing ease in changing the settings to meet temporary needs imposed by such conditions as worn or damaged machinery components or foreign material (debris, silt, or ice) interfering with gate operation.

Programming sector gates to achieve optimum flow-through. The flow between sector gates as they open is a function of head differential and the width of the opening. Since the rate of change of the width of the opening is dependent on the speed of the sector gates' movement, programming speed variations into the initial stages of gate opening could be employed to achieve optimum flow velocities for the benefit of minimizing hydraulic forces on waiting vessels and their mooring lines.

General machinery operation

There are several categories of equipment associated with a lock to support the overall operation. These include hydraulic systems, drainage systems, etc. The operation of these systems and equipment can lend itself to automation that will contribute to the best utilization of personnel.

Monitoring and controlling hydraulic systems. Many locks have hydraulic systems for powering part or all of the lock machinery. The hydraulic systems may range widely in age and sophistication. Most of these systems do not have automated monitoring and control, but automation could be added to many to make them easier to operate and more foolproof.

Establishing and operating a machinery alarm system. Most lock machinery is equipped with alarms to indicate malfunction or out-of-range operation. Without automation, an alarm usually requires a response from an operator and the op-

erator's intervention in other ongoing procedures affected by the alarm condition. An automated alarm system would be designed to stop, modify, or adjust ongoing procedures without operator response, increasing safety and reliability. Equipment to monitor and control gate skew, as described earlier, would be an example of an automated alarm system.

Monitoring and controlling sump pumping equipment. Sump pumping equipment is just one category of general lock machinery, but it is highlighted here because it is usually a constant operational task to maintain. Automation of such equipment, with monitoring and alarm provisions, would therefore contribute to an important reallocation of personnel resources.

Debris and ice control

Virtually all locks have systems for the control of debris and/or ice. These systems are deployed on an as-needed basis, which for some projects means infrequently.

Programmed operation of pneumatic debris or ice flushers and screens. Pneumatic systems ("bubblers") for controlling debris or ice are usually made up of several individual components. They are usually not designed to operate simultaneously, because this would require unnecessarily large compressor capacities. However, certain designs are intended to be operated in specific sequences, now under manual control. For example, cross-chamber air screens are operated to create an ice-free area upstream of miter gates, and then gate-recess air flushers are operated to remove ice from behind the opening gates, with the ice moving into the area just developed by the operation of the cross-chamber screen. The sequences could readily be programmed into automated controls to allow operational personnel to give greater attention to monitoring system performance rather than actual operation.

Interlocks between components of pneumatic debris control or ice control systems. As noted above, certain components of pneumatic debris and ice control systems are not usually operated together. Programmed operation could provide for interlocks to prevent the operation of selected components together.

Temperature-triggered operating programs for ice control systems. Under many winter conditions the operation of ice control systems could be optimized if they operated frequently for short periods, but operating personnel are generally too busy to follow such schedules. Thus, automated

and programmed operation, triggered for example by air temperatures, could allow such pneumatic or heating systems to produce beneficial results when otherwise they might be underutilized.

Warning system for ice accumulation on barge bottoms at entrance to chamber. Some locks experience groundings of barges in winter, either on the lock chamber floor or over gate sills, due to the buildup of ice on the bottom surface of barges. It is usually impossible to determine if a barge is so affected until a problem arises. Experimental systems have been developed for detecting this ice by remote-sensing means. These techniques could be further perfected to be part of an automated detection and alarm system that would signal the problem before the barge entered the chamber, in time for the barge to be removed from the queue.

Dam operations

The various dam operations that may be considered for automated operation are discussed below and are listed in Table 3.

Gate operation and control

There is a wide variety of gate designs and operational sequences. Gates at many Corps dams have some degree of remote operation and/or position indication, but any significant level of programmed operation would call for greater degrees of automation.

Remoting of gate position information and gate operation. As indicated above, many dams already have this minimum level of automation. It is a virtual necessity wherever a project's operations are part of coordinated basin management under a water control center. Options that may serve overall automation objectives involve choices as to where remote operation may be conducted, such as only at the local project's control room, at one project for a number of nearby projects, or at a water control center for most or all projects in a basin.

Controlling rate of gate motion, including provision for variable rates. With gate movement controlled by programmed automation equipment, it would be possible to choose rates of gate movement and select gate speeds to achieve hydraulic or environmental objectives. For example, very gradual gate movements could eliminate surges that might increase the risks of bed scour below the dam, or might affect water quality for fish.

Table 3. Dam operations identified as candidates for automation measures.

<i>Gate operation and control</i>	<i>Coordination with navigation</i>	<i>Operation of fish facilities</i>	<i>Debris and ice control</i>
Remoting of gate position information and gate operation	Interlocking selected gates with lock operations	Automating the operation of fishway weirs	Automated periodic debris passage or scavenging
Controlling rate of gate motion, including provision for variable rates	Interlocking selected gates with vessel operations	Programming and controlling the operation of traveling fish screens	Programmed operation of pneumatic debris or ice flushers and screens
Maintaining upper pool gage level automatically			Interlocks between components of pneumatic debris control or ice control systems
Programming gate opening sequences for water-quality or scour protection purposes			Temperature-triggered operating programs for ice control systems
Monitoring and controlling gate skew			
Alarm generation for gate overload, skew, etc.			
Establishing and remotely meeting limit positions of gates			

Maintaining upper pool gage level automatically. Most pools or reservoirs are maintained at the desired stage (or raised or lowered) manually. In other words, the operators consult a pre-established gate-sequence plan to determine which gates to operate, and then make the gate movements needed to maintain or achieve the chosen stage. Automated control of upper pool stages is possible by means of gage inputs to a program that contains the gate sequences and that issues commands to the gate operating mechanisms. A program such as this can provide for various levels of tolerance to suit particular conditions.

Programming gate opening sequences for water quality or scour protection purposes. There may be times when customary gate opening sequences need to be varied to meet special needs relating to scour protection downstream or water quality criteria. These occasions may arise due to extreme temperatures, abnormal contaminants (e.g., a hazardous chemical spill), prior flows at unusually high or low discharges, etc. With automated dam gate control, several alternative gate opening sequences could reside in the operational program, and the appropriate program could be selected by the operators or directed by the water control center to meet current needs.

Monitoring and controlling gate skew. Large tainter gates may suffer distortion or problems such as torsional "windup" if they become skewed during operation. As with certain designs of lock gates, automation could provide

a means to overcome this problem. Refer to the earlier discussion of this topic in connection with lock gates, on page 7.

Alarm generation for gate overload, skew, etc. System alarms for abnormal conditions could be automated to correct certain alarm conditions (e.g., skew) and return the equipment to normal status. For other conditions, automation could rely on interlocks to prevent other operations that should not be undertaken until the alarm condition is corrected, to prevent adverse consequences that might arise if an alarm is ignored. See also the discussion on page 7 concerning machinery alarms.

Establishing and remotely resetting limit positions of gates. This is the same matter that was presented earlier on pages 6 and 7, but dealing here with dam gates. Please refer to those discussions.

Coordination with navigation

Lock operations are sometimes affected by flows past navigation dams. Where this occurs it is necessary to meet the needs of the lock operation by modifying the dam operation, or vice versa. Presently this is entirely initiated by operations personnel.

Interlocking selected gates with lock operations. At some navigation projects, and for certain pool stages, flow rates, and magnitudes of dam gate opening, there can be adverse currents or outdrafts that cause difficulty for vessels entering or departing lock chambers. These conditions may

make it difficult for a tow to maintain an alignment in the lock approach areas, leading to potentially hazardous situations. With automated programmed gate operation, there could be a built-in alternative gate operation scheme that would be invoked only when lockages occur. This alternative scheme would reduce or stop flows past appropriate dam gates, and perhaps compensate by initiating or increasing flows through other gates, in order to reduce the adverse currents or outdrafts. Such an alternative gate scheme would be used only for the duration of a tow's approach, lockage, and departure, and it would require operations personnel to initiate and terminate the process.

Interlocking selected gates with vessel operations. It has been proposed from time to time that, at certain critical locations on the inland waterways, vessel monitoring systems should be developed and operated to promote safe and efficient waterborne traffic management. If these proposals were to be implemented, vessel movements could be used as the initiating and terminating actions for use of the alternative gate operational schemes discussed in the foregoing paragraph. (See the discussion of automated vessel monitoring on page 11, under Navigation operations.)

Operation of fish facilities

Certain Corps dams have facilities for the passage of anadromous fish. Generally the operation of these facilities is operator-initiated and controlled. There are patterns of operations that are adaptable to programmed operation.

Automating the operation of fishway weirs. The setting of the height of fishway weirs is generally done as a function of stage, but it is done manually and intermittently. Providing automated weir machinery driven by stage variations would be a fairly straightforward matter.

Programming and controlling the operation of traveling fish screens. These screens capture fish in the draft tubes of generators at hydroelectric facilities, and deliver the fish safely to the down-

stream side of the dam. Their operation is controlled manually. Automation would tie the operation of the screens to the operation of the related generators, so that when a generator goes on or off line, the fish screen would begin or end its operation.

Debris and ice control

This is closely related to the same topic under Lock operations, and the functions are largely similar.

Automated periodic debris passage or scavenging. Debris passage or scavenging systems at dams are operated manually on an as-needed basis. They could be operated automatically on schedules developed through past experience. Operational schedules could be driven by time, river stages, precipitation events, etc., according to local conditions.

Programmed operation of pneumatic debris or ice flushers and screens. Such systems serving dams are not usually made up of as many components as those at locks. The use of a diagonal air screen across the upper approach to a lock diverts ice or debris toward the adjacent dam gates. Programmed operation could consist of operating diverting air screens in conjunction with the nearby gate operation.

Interlocks between components of pneumatic debris control or ice control systems. The discussion on page 8 applies equally here.

Temperature-triggered operating programs for ice control systems. See the discussion on page 8.

Navigation operations

The various navigation operations that may be considered for automated operation are discussed below and given in Table 4.

Coordination with locks

Vessel movements and status conditions govern lock operations and vice versa. Some of the communications involved in this coordination could be accomplished automatically.

Table 4. Navigation operations identified as candidates for automation measures.

<i>Coordination with locks</i>	<i>Vessel monitoring</i>	<i>Information</i>
Sending automated messages, instructions, or signals to vessels	Vessel position monitoring with automatic messages and alarms as required	Automated trip, cargo, and lockage information for the Lock Performance Monitoring System (LPMS)
	Automated vessel speed monitoring, with automatic warning messages to vessels and/or alarms at projects	

Sending automated messages, instructions, or signals to vessels. Many of the communications between lock operators and vessels are repetitive and predictable, based on the status of the lock and the vessel position. These communications could be triggered automatically. For example, when a tow reached a certain point in approaching a lock, a message reporting the lock status could be broadcast automatically, or upon the vessel's use of an inquiry code. The message content would vary according to whether the lock is in use, ready for upbound lockage, ready for downbound lockage, etc. General cautions about temporary conditions could be included in these transmissions.

Vessel monitoring

Knowledge of vessel positions and movements is essential to lock and dam operators. Presently this is reported via voice communications, but automated monitoring would remove the inherent weak links in a voice-based system, especially under irregular or emergency conditions.

Vessel position monitoring, with automatic messages and alarms as required. Where river traffic is heavy and conditions are difficult, safe and efficient waterborne traffic management by means of a vessel monitoring system may be attractive. Such a system already exists in the Louisville area on the Ohio River, where it is termed the Vessel Traffic Service (VTS) system. Elsewhere in the United States, VTS systems exist at certain saltwater ports, where they may include the Vessel Movement Reporting System (VMRS). Functioning similarly to an aircraft traffic control system, a vessel monitoring system would display vessel locations, speeds, directions, etc. With a sufficient level of sophistication, such systems could automatically generate messages to vessels to announce lock status, approaching traffic, fixed hazards, etc. Such a monitoring system would operate under the direct observation and with the interaction of traffic control personnel. Thus, it would be more descriptive to term it a semi-automated system. Acting as a supplement to onboard radar, a vessel monitoring system would be particularly valuable in bad weather, or during congested periods.

Automated vessel speed monitoring, with automatic warning messages to vessels and/or alarms at projects. A vessel monitoring system could calculate vessel speeds and issue warnings directly to

vessels and to navigation projects that may be at risk. Restricted speed zones could be enforced, rather than in effect be merely advisory, as at present.

Information

Vessel and tow activity generates large amounts of data that are passed through lock personnel. These processes are very good candidates for automation.

Automated trip, cargo, and lockage information for the Lock Performance Monitoring System. Lock personnel have the task of collecting trip and cargo information from passing traffic, and also recording the physical details describing each related lockage. This information is essential input to the Lock Performance Monitoring System (LPMS) and the broader Inland Navigation Systems Analysis (INSA) Program. Currently the trip and cargo information is collected from vessel crew members and, along with lockage details, entered manually into the district's computer network. This can be a large commitment of time for lock personnel. After editing at the district level, the data are entered monthly into the LPMS library by the district. Much or all of this process is open to automation, reducing the collection, editing, and maintenance tasks now performed by lock and district office personnel. Cargo and trip information could be entered into the automated system by vessel operators, maintained up-to-date as barges and cargos vary during the course of a trip, and keyed to barcodes on barges and towboats scanned as each tow transits the lock. The corresponding lockage information could be input automatically as the lockage is accomplished, assuming the lock operation is controlled by automated means. Ideally, the edit process at the district level would be eliminated, and data would flow directly to the LPMS in real time.

GUIDELINES FOR CHOOSING AUTOMATED FUNCTIONS

Forty-three navigation project functions that could be automated to varying degrees have been discussed in the preceding section; 24 of these are associated with lock operations, 15 associated with dam operations, and four related to navigation operations. There is a very broad range of complexity and utility in the automation opportunities for the functions discussed.

Some could be adopted easily, while others would involve large expenditures and ambitious construction or rehabilitation programs. Moreover, since there is such a wide range of navigation project ages, conditions, traffic levels, functional designs, and operating equipment, a project function that would be straightforward to automate at one project could prove complicated to automate at another project. These distinctions cannot be addressed in detail in this report.

However, a portrayal of the candidate automated project functions is needed that allows them to be described according to the automation characteristics (level, purpose, etc., described in Table 1). Therefore, Table 5 has been prepared to present the navigation project functions and their associated automation opportunities in a matrix format along with the determinative characteristics that have been judged to best describe each of the 43 potential automation measures. The judgments used in assigning the determinative characteristics to each automation measure have been based on analysis of the automation survey and on the information collected during project visits. These judgments could change as further studies are performed.

It is important to emphasize that the judgments made in developing Table 5 are general. When a specific navigation project is considered, a different profile of characteristics is likely to emerge from the same judgmental process, due to that project's unique set of features.

The matrix format of Table 5 allows selections, comparisons, sortings, or rankings to be made among the project functions and automation alternatives. These processes can be done on a global basis for developing general Corps of Engineers policy and guidelines for operations and management. Or, on a project-specific basis, the selections, comparisons, sortings, or rankings could be performed after development of a new project-specific matrix modeled after Table 5. Results of the project-specific approach would provide decision support for an automation plan for that particular navigation project.

Some examples will illustrate the uses of the matrix of Table 5. For the first example, assume that it was decided to consider a program of automation at navigation projects involving only those automation measures that were judged low in difficulty of implementation and also low in cost of implementation. A sorting of the contents of Table 5 on these two characteristics re-

veals that the following measures are selected for consideration:

<i>Automation measure</i>	<i>Level</i>	<i>Purpose</i>	<i>Departure from existing procedure</i>
Controlling the opening and closing rates of lock filling and emptying valves	D	b	N
Latching lock gates in their recesses	C	a	M
Interlocking lock gate opening with gage readings on both sides of the gate	C	a	L
Controlling closure of miter gages needing a specific sequence	D	b	L
Monitoring and controlling sump pumping equipment at locks	B	b	L

As another example, suppose a proposal for automation was desired that was based primarily on improving the safety of operations, and yet would represent little or no departure from existing operating procedures. A sorting of the data of Table 5 for Safety in the Purpose category, and for L or N in the Departure from Existing Procedure category, would yield the following automation measures for consideration:

<i>Automation measure</i>	<i>Level</i>	<i>Difficulty of implementation</i>	<i>Cost of implementation</i>
Balancing filling and emptying flows between lock chamber sides	A	M	M
Programming filling and emptying valve operation for various vessel types	A	M	M
Interlocking lock gate opening with gage readings on both sides of the gate	C	L	L

At present, the data contained in Table 5 are not extensive enough to place in a database, and the sortings of the foregoing examples were done manually. However, if additional lock, dam, or navigation functions are identified as amenable to automation in the future, or if new determinative characteristics are developed for more thoroughly evaluating automation measures, the development of a database is indicated. This would permit more versatile use of the automation matrix for planning and management purposes and for decision support.

Table 5. Matrix of navigation project automation alternatives.

<i>Navigation project function</i> <i>Automation measure</i>	<i>Level</i>	<i>Primary purpose</i>	<i>Secondary purpose</i>	<i>Tertiary purpose</i>	<i>Difficulty of implementation</i>	<i>Cost of implementation</i>	<i>Departure from existing procedure</i>
Lock operations							
<i>Filling and emptying</i>							
Timing and monitoring valve movements	C	b	a		L	M	L
Controlling valve opening and closing rates	D	b	a		L	L	N
Varying valve operation as a function of chamber stage	A	b	a		M	M	L
Balancing flows between chamber sides	A	a	b		M	M	N
Programming valve operation for various vessel types	A	a	b		M	M	L
Establishing and remotely resetting limit positions of valves	B	b	a		M	M	L
Interlocking valve operation with upper and/or lower gate operation	A	a	b	c	H	H	H
<i>Gate opening and closing</i>							
Controlling rate of gate motion	D	b	a		L	M	L
Latching gates in their recesses	C	a	b		L	L	M
Interlocking gate operation between upper and lower gates	A	a	b	c	M	M	H
Interlocking gate operation with filling and emptying valve operation	A	b	a		M	M	H
Interlocking gate opening with gage readings on both sides of a gate	C	a	b		L	L	L
Interlocking gate operation with vessel position in chamber	B	a	b	c	M	H	M
Monitoring and controlling gate skew	D	b	a		L	M	M
Controlling closure of miter gates needing a specific sequence	D	b	a		L	L	L
Establishing and remotely resetting limit positions of gates	B	b	a		M	M	L
Programming sector gates to achieve optimum flow-through	D	b	c		L	M	L
<i>General machinery operation</i>							
Monitoring and controlling hydraulic systems	B	b	c		L	M	M
Establishing and operating an alarm system	B	b	a	c	M	M	L
Monitoring and controlling sump pumping equipment	B	b	c		L	L	L
<i>Debris and ice control</i>							
Programmed operation of pneumatic debris or ice flushers and screens	B	b	c		M	M	L
Interlocks between components of pneumatic debris control or ice control systems	C	b	c		M	M	L
Temperature-triggered operating programs for ice control systems	C	b	c		L	M	L
Warning system for ice accumulation on barge bottoms at entrance to chamber	B	a			M	M	H

Table 5 (cont'd). Matrix of navigation project automation alternatives.

<i>Navigation project function Automation measure</i>	<i>Level</i>	<i>Primary purpose</i>	<i>Secondary purpose</i>	<i>Tertiary purpose</i>	<i>Difficulty of implementation</i>	<i>Cost of implementation</i>	<i>Departure from existing procedure</i>
Dam operations							
<i>Gate operation and control</i>							
Remoting of gate position information and gate operation	B	c	b	a	H	H	H
Controlling rate of gate motion, including provision for variable rates	B	b	a		L	M	N
Maintaining upper pool gage level automatically	A	c	b		H	H	H
Programming gate opening sequences for water-quality or scour protection purposes	B	c	b		M	M	H
Monitoring and controlling gate skew	D	b	a		L	M	M
Alarm generation for gate overload, skew, etc.	B	a	b	c	M	M	M
Establishing and remotely resetting limit positions of gates	B	b	a		M	M	L
<i>Coordination with navigation</i>							
Interlocking selected gates with lock operations	A	a	b		H	H	M
Interlocking selected gates with vessel operations	A	a	b		H	H	H
<i>Operation of fish facilities</i>							
Automating the operation of fishway weirs	C	b	c		M	M	L
Programming and controlling the operation of traveling fish screens	C	b	c		M	M	L
<i>Debris and ice control</i>							
Automated periodic debris passage or scavenging	A	c	b		H	H	M
Programmed operation of pneumatic debris or ice flushers and screens	B	b	c		M	M	L
Interlocks between components of pneumatic debris control or ice control systems	C	b	c		M	M	L
Temperature-triggered operating programs for ice control systems	C	b	c		L	M	L
Navigation							
<i>Coordination with locks</i>							
Sending automated messages, instructions, or signals to vessels	C	a	c	b	M	H	H
<i>Vessel monitoring</i>							
Vessel position monitoring with automatic messages and alarms as required	B	a	c	b	H	H	H
Automated vessel speed monitoring, with automatic warning messages to vessels and/or alarms at projects	A	a	c	b	H	H	H
<i>Information</i>							
Automated trip, cargo, and lockage information for the Lock Performance Management System (LPMS)	A	b	c		L	H	M

CONCLUSION

An initial framework has been established for evaluating operations and functions commonly occurring at navigation locks and dams that may offer opportunities for automation. This

framework, presented in a matrix format, offers a straightforward method for describing and evaluating candidate automation measures in terms that are useful for operational planning and management decision-making.

This study has been largely qualitative in nature. Future efforts could further develop the study in a quantitative direction. In particular, it was hoped that this study would develop methodologies for evaluating automation costs and effectiveness, but this objective proved too elusive, given the level of generalization that had to be maintained. This objective may never be achievable on a general scale, and may be practical only on a project-specific basis.

It is important to add the final comment that, if any degree of automation and programmed

operation at navigation locks and dams is going to become common, whether in the near or distant future, an essential step toward that end is to adopt the requirement that all control functions be accomplished by programmable logic controllers (PLCs). In other words, electromechanical relays should be phased out in existing facilities and not specified for new facilities or for rehabilitation projects. Even without any significant level of automation, PLCs offer sufficient advantages over relay-based controls to warrant this policy.

**APPENDIX A: AUTOMATION SURVEY OF CORPS OF ENGINEERS
WATER RESOURCES PROJECTS**

The present study was a companion to another study titled *Automation Alternatives for Hydraulic Structures and Flood Control Projects*, also conducted under the Improvement of Operations and Management Techniques (IOMT) Program, and under the direction of Dr. Frank Neilson of the U.S. Army Waterways Experiment Station. The two efforts cooperated in the management and analysis of the automation survey described in this appendix, but otherwise were conducted separately.

The initial task facing the principal investigators of this study and the companion study was

to collect information about the current use of automated procedures at Corps water resources projects. At the same time, views were to be solicited regarding the need for new or additional automation at the Corps projects. The means chosen to obtain this information was a questionnaire or survey, intended to reach the level of the local lockmaster or project manager.

Dr. Neilson and Mr. John Rand of U.S. Army CRREL, the initial principal investigator for this study, collaborated on the design of the survey, a sample of which is provided below. It was distributed with a Headquarters, U.S. Army Corps

SURVEY OF EXISTING CORPS PROJECTS
TO IDENTIFY EXISTING AUTOMATED SYSTEMS

Purpose: To determine the potential of automated applications at Corps projects. The information you provide will encourage practical solutions through the Improvement of Operation and Management Techniques (IOMT) Program.

Our definition of an automated system: Any system that either provides information or allows some action to take place remotely. For example, river stage reading, gate control from central location, automated pumps, alarms for equipment, deicing equipment activation, etc.

PROJECT Name: _____
 Type: _____
 Location: _____
 River: _____ Mile: _____

NEW SYSTEMS: What can be automated at this project?
 (Your suggestions will be appreciated!)
 Physical description of system (its function): _____

Possible value (the economics or safety factors): _____

General comments you care to make: _____

EXISTING SYSTEMS: Are there existing automated systems at this project? _____

Is there documentation available? _____

PROPOSED SYSTEMS: Are there any systems currently being automated by your District? If so, identify the system(s) and please provide a point of contact: _____

Name, address, and telephone number of person completing this survey: _____

Please return survey to either of the persons listed below:

- * John H. Rand, USACRREL, 72 Lyme Road, Hanover, NH 03755
 Tel: 603-646-4309 Fax: 603-646-4477
- * Frank Neilson, CEWES, 3909 Halls Ferry Road, Vicksburg, MS 39180
 Tel: 601-634-2615 Fax: 601-634-2818

of Engineers cover letter from the Chief of the Operations, Construction, and Readiness Division in August 1991 to field elements throughout the country. As the cover letter directed, each receiving Operations Office was to distribute copies of the questionnaire to all lockmasters, dam operators, operators of other hydraulic structures, and other pertinent personnel. No replies were sought from the division level. Replies were received through November 1991.

Survey response data

Considering only the 49 states exclusive of Hawaii, and treating the New England Division as equivalent to an Engineer District, the survey brought replies from projects and elements within 28 districts. This is out of a possible total of 37 districts, for an overall reply rate of 76%.

From among the 28 responding districts, replies to the survey were received from a total of 235 Corps water resources projects.* In some cases more than one reply was received from a single project. This usually involved replies from one or more of the following elements: lock and dam operations, hydroelectric generation, natural resources management, mechanical maintenance, electrical maintenance, etc. When these multiple replies were tallied, they were considered as a single detailed reply from a single project. Table A1 is provided to show both the districts with responding projects and the number of projects responding from each.

Of the 235 projects that generated replies to the survey, 94 (or 40%) are lock and dam navigation projects. This number (94) should be compared with the 239 lock sites[†] owned and/or operated by the Corps of Engineers, translating to a survey coverage of 39% of all U.S. lock and dam navigation facilities. This response rate is considered quite satisfactory for providing a good overview of present automation techniques in use at navigation projects, as well as for gleaning opinions from personnel at the operating level concerning future automation directions.

*A small number of what are termed "extraneous" replies are not included in this 235 number. Extraneous replies came from office personnel addressing needs such as office management systems, improved uses of Corpsmail or fax, or administrative report transmission over computer networks. Also in this category were replies from repair facility and floating plant personnel concerned with floating plant systems such as pumps and alarms.

[†] *The U.S. Waterway System—Facts*, USACE, November 1991.

Table A1. Automation survey responses by district.

<i>Division/District</i>	<i>Project replies</i>	<i>Division/District</i>	<i>Project replies</i>
LMVD		ORD	
Memphis	1	Huntington	28
New Orleans	13	Louisville	19
St. Louis	5	Nashville	20
Vicksburg	NR	Pittsburgh	25
MRD		SAD	
Kansas City	7	Charleston	NR
Omaha	7	Jacksonville	NR
NED	NR	Mobile	9
NAD		Savannah	3
Baltimore	NR	Wilmington	3
New York	NR	SPD	
Norfolk	1	Los Angeles	5
Philadelphia	4	Sacramento	2
NCD		San Francisco	NR
Buffalo	1	SWD	
Chicago	1	Albuquerque	1
Detroit	1	Fort Worth	7
Rock Island	17	Galveston	NR
St. Paul	23	Little Rock	13
NPD		Tulsa	5
Alaska	NR		
Portland	6		
Seattle	5		
Walla Walla	3		

Note: The number of projects replying to the automation survey within each district is shown, grouped according to divisions. Also shown are the districts in which none of the projects responded (NR).

Survey findings

Considering the 94 responses from lock and dam navigation projects as the entire field for analysis with respect to the present study, the following statistics summarize the results that were found:

- 74% (70 projects) have some form of automation of lock and dam operations already in place;
- 26% (24 projects) report that there are plans for new automation or additional automation at their projects;
- 65% (61 projects) provide suggestions for new or additional automation at their projects, generally unrelated to any automation that is currently planned.

Specific findings of the automation survey are not enumerated here. The general findings of the survey, along with the results of the several field visits to lock and dam projects (see App. B), are principally expressed in the Matrix of Navigation Project Automation Alternatives, which has been developed using these information sources.

The word "automation" was interpreted widely by the survey respondents. While the in-

terest of this study has been the essential operational procedures necessary to carry on navigation lock and dam activities, several other additional, more or less separate, activities were the subject of some of the comments given in the returned questionnaires. In other words, activities that are not unique to lock and dam operations were mentioned as already being in place, or planned, or suggested for future installation. While no further examination of these uses of automation was conducted, examples of these uses were a) security or surveillance systems (e.g., remote control of entrance gates, cameras), b) facilities management systems (e.g., routine maintenance scheduling, CAD drawings, property inventories, FTE forecasting, historical data), c) lawn watering systems, and d) fax servers.

Another outcome of the survey that was peripheral to the study objectives, but bears mention

nonetheless, is the attitude or reaction that personnel may have concerning the automation subject. A few negative reactions to both automation and the solicitation of the opinions of field personnel were revealed by remarks such as the following:

- "Possibility of replacement of 'people' with 'machines' has a negative connotation within management circles."
- "People, not machines!"
- "No one would listen anyway."
- "I believe that very little attention is paid to an operator's input."

It is clear that any initiatives to introduce automation to navigation lock and dam projects on a broad and comprehensive scale will have to address attitudes that may be uninformed and hostile. Important as it is, this subject was not dealt with in the present study.

APPENDIX B: FIELD VISITS TO CORPS LOCK AND DAM PROJECTS

Seven Corps of Engineers navigation lock and dam projects were visited in support of the automation study. The purpose of these visits was to examine existing automation installations and learn about their successes and shortcomings, and to examine a wide variety of lock and dam designs of various ages to better assess the applicability of future automation techniques. The first two sites visited served to fulfill mainly the first portion of the stated objective. Correspondingly, the findings of those visits are given in greater detail.

Marseilles L&D, Marseilles, Illinois

This project on the Illinois Waterway was visited on 22 July 1991, because it has automated functions that are operated remotely. The interest under the study, therefore, was to become familiar with these automation systems.

In recent years the dam at Marseilles was rehabilitated, and new submergible tainter gates were installed. This dam is about two miles upstream from the lock, and it had an on-site operator before rehabilitation. In an effort to reduce manpower requirements and consolidate the management of operations, the rehab included installation of dam operating equipment that allowed for the remote automated control of the dam from the lock operating building, two miles away. This equipment was designed to automatically operate the tainters based on inputs from water-level gages, thus maintaining a specified upper pool elevation. Alternatively, manual operation, either from the lock control building or on-site at the dam, is possible. The system was accepted by the Rock Island District in the spring of 1990.

The system was designed by an outside consultant, under contract to the Corps. The current lockmaster had about ten years of previous service at Marseilles, so he witnessed the planning and execution of the rehab and the automation, and is the single person on the lock crew most acquainted with the system. However, he felt his acquaintance was not sufficient.

There are two separate but parallel operating systems, each having separate underground

fiber-optic data lines running from the dam to the lockhouse. Thus, one system backs up the other. One of the operating systems is made up of a large control panel in the lockhouse, displaying gate and gage information on digital readouts, indicating equipment status by means of lights (e.g., gate moving, up or down, fully closed, etc.), and having manual switches to conduct dam operations. The other system is composed of a keyboard and monitor; various menus and screens on the monitor mimic information on the control panel of the first system.

As explained, at the time of the visit the system was not fully usable as designed or intended. Remote manual operation is generally possible and free of serious problems. However, the automatic operation is not reliable because the upper gage information used by the system for control of the gates is not always accurate. As a result, automated operation is allowed to occur only during the day shift, Monday through Friday, when there are enough persons on duty to keep an eye on the system and be sure it does not stray too far from acceptable gate openings and hence desired gage levels.

There are two separate upper pool gage sensors and corresponding gage readings transmitted by each of the two separate systems, for a total of four upper gage values. The four readings for the upper pool may vary by as much as 0.25 ft in random fashion, and lock personnel do not know which is reliable. The lockmaster believes the problem originates in the adapters that input signals to the system as a result of their connection to shaft encoders, which in turn are driven by manometer ("bubbler") gages. He believes his main upper pool gage at the dam (which is not a part of the automatic system) is very reliable; it is a gage driven by a float in a stilling well. This gage does not produce a reading at the lockhouse. The lockmaster wants to see a sel-syn motor and telemark installed on this gage so he can read it at the lockhouse. When this is accomplished, he would rely on that reading as accurate. At the time of the visit, there was a proposal being considered by the District from a vendor to do this, to tie this reading into the au-

tomated system, and to discontinue the use of the manometer gages. The cost was estimated to be \$40,000.

There is not an entirely satisfactory procedure for servicing or solving problems with the system. Although there is a technical contact in the District office, the lockmaster does not think the technical familiarity with the automated equipment at the District level is any better than his own. The lockmaster at Lockport Lock upstream has been able to provide some technical assistance to the Marseilles crew, since there is some similar equipment on the upper lift-type gate at Lockport. In general, however, the Marseilles lockmaster has been on his own to troubleshoot or repair the system, and he is able to replace minor components. A new electrician had joined the crew shortly before the visit, and this man had experience with automated industrial control equipment, so the lockmaster was familiarizing him with the system as much as possible.

The lock crew has no users' manual or troubleshooting guide, because none were provided as part of the contract. When problems cannot be solved, the manufacturer of the components is called, and while there is no service or maintenance contract, a technical representative is available within 72 hours—usually much sooner. The manufacturer's technical representative has been out a few times, but the undependable upper gage problem remains. If the system were to become totally inoperable, the lockmaster could station someone in an overtime status at the dam to operate the facility manually.

Some problems have been encountered with weather effects on components: high temperatures in input/output (I/O) boxes on each dam gate pier, water leakage into cable connections, etc. The lockmaster is also concerned that excessive temperatures occur in large control boxes at the dam and at the lockhouse; he has wondered if there should be artificial cooling for these components.

There are three remote TV cameras at the dam that allow remote observation of the dam on monitors at the lockhouse. However, these cannot be used to verify gate operation. A short time earlier the lock crew had installed a staff gage that can be seen by one of the cameras, and is readable to a tenth of a foot. So far the cameras have given satisfactory performance, except when their video tubes have been destroyed by excessive light (such as sunlight reflected from the water).

The Marseilles lockmaster's opinion is that the remote dam operation is a valuable asset, but that the automation part of the system is excessive and unnecessary technology. With the unreliability of upper gage readings, he believes that the automation system could actually prove to be dangerous.

Melvin Price L&D, Alton, Illinois

This Mississippi River project is quite new, built in recent years to replace the failing Lock and Dam No. 26 located about two miles upstream, and it was designed to have modern automated control technology. The site visit on 23 July 1991 was hosted by an electrical engineer from the St. Louis District, who conducted a thorough tour of the project and demonstrated the automated systems. This engineer came to the Corps after the system at Melvin Price was designed and specified, but he had been closely involved with inspecting the system during construction and installation, working out the relatively few problems with the system since completion, and modifying the system as actual operating experience dictates.

The extensively automated project offers lockhouse control of all tainter gates, filling and emptying gates, miter and lift gates, etc. The automated control system at Melvin Price is made up of sensors of various types (e.g., limit switches, inclinometers on tainters, etc.), "cards" in input/output (I/O) boxes (or panels) at each controlled device, cables (two four-strand cables linking each I/O box with the central computer), programmable logic controllers (PLCs), and the central computer.

Any changes to operational procedures that are to be controlled by the system are made by modifying the programs in the PLCs. The lead electrician on the lock crew can program PLCs on site, or the electrical engineer can program the PLCs from his office at District headquarters via modem. In fact, one could program/reprogram or operate any part of the automated system from anywhere in the District or even the country via modem.

The system of PLCs has never given any problems, but individual sensors have given a few problems. If a new operation or function is needed, all that is required is to install a sensor, limit switch, or whatever device is needed, and then run wires to the nearest I/O box. There is never any need to string new cables back to the lock operations building. The operation or function

then is programmed into the system so that it can be operated from the lock control room. Many new tasks were added to the system since the original design and since the project went into operation in the late 1980s.

The central computer system has a master program known as a "ladder-and-rung" type, with about 1100 rungs. In this program, any desired sequence of processes or operations can be arranged. Also, "interlocks," or steps that can proceed only after some particular condition is met (e.g., other devices open, closed, on, off), can be chosen as desired and incorporated into any part of the program. Any conceivable variety of operational procedures thus can be achieved with a few minutes of software revision, either at the lock or at the District office, and either by qualified local lock personnel or by an appropriate engineer at the District.

The automated control system for Melvin Price L&D was designed and specified by St. Louis District personnel. No outside consultant was used. In a few instances the contractor substituted inferior equipment (encoders, cards, switches, etc.), most of which have failed and been replaced with better equipment.

There is no users' manual. The lock operators need to learn very little. The main burden of the system falls on the programmers—they have to be sure all operations are sequenced and interlocked appropriately.

St. Louis District personnel strongly believe that developing a system such as that at Melvin Price with the use of an outside consultant is not likely to give satisfactory results. This would be especially true if the consultant is primarily an expert in the electronics of process control. What is essential, they believe, is that the designer, and especially the programmer, be intimately familiar with the details of lock and dam operations, the hazards, and the rationales that govern operations under all river and seasonal conditions.

Ice Harbor Project, Pasco, Washington

On 7 January 1992, the Ice Harbor Project was visited. This is Walla Walla District's most downstream hydroelectric and navigation dam on the Snake River. It is also the oldest project on the Snake, having been opened to navigation in 1962. As with all of the Walla Walla District and Portland District projects visited during January 1992, hydroelectric generation is the dominant activity at this installation. In addition, fish-

handling facilities are an important adjunct to this project and the others visited in the Northwest. Navigation is very important also, but in terms of man-hours to operate and maintain the facility, navigation is a secondary activity.

The tour of the project was conducted by the chief of maintenance and the chief of tech services/contract services. From the standpoint of navigation, very little automation exists at this project. The tainter gates of the dam are automated as part of the overall hydroelectric control system, a highly automated system (networked with other projects in the Columbia Basin) that was at the time undergoing complete upgrading. Readout of tainter gate position is available in the hydroelectric control room, and remote operation from the control room is customary. Preprogrammed sequencing and coordination of gate operation is theoretically possible, as is remote operation from the McNary Project at Umatilla, Oregon, or the Bonneville Power Administration's control center in Vancouver, Washington, but none of this is done, mainly as a matter of policy.

Lock operation is done from the lock stands, and is largely manual/visual. For the most part the lock components are operated by means of electromechanical, relay-based systems. Along with a lift of 103 feet, a noteworthy feature of the Ice Harbor lock is the lower gate, a "guillotine" or vertical lift gate of very substantial size and weight. (This type of lower lock gate is also present at the Lower Monumental Project, just upstream on the Snake River, and at the John Day Project on the Columbia River.) The gate poses several operational problems, one of which is controlling skew. This kind of problem is quite amenable to a fairly simple automated monitoring and control system, but at present the operators must watch a readout giving skew indication, and make manual corrections in operating the separate left and right lifting machinery. Operator inattention is covered by limit settings for skew values, which if exceeded will result in shutdown of gate movement.

The upper lock gate is a tainter gate. This gate also is subject to skew during movement, but it is generally not a serious difficulty.

On the same day that Ice Harbor was visited, a brief stop was made at the Lower Monumental Project, which is also under the supervision of the Project Manager located at Ice Harbor. Lower Monumental is 32 miles upstream from Ice Harbor. This project is nearly as old as Ice Harbor,

and the level of automation is substantially the same.

Lower Granite Project, Pomeroy, Washington

This project, visited on 8 January 1992, is Walla Walla District's most upstream dam on the Snake River, being about 97 miles above Ice Harbor and 30 miles downstream from Lewiston, Idaho. It is also the newest project on the Snake River, having opened to navigation in 1975. The inspection of this project was hosted by the chief of operations/maintenance and the chief of maintenance engineering/contract services.

As with the Ice Harbor Project, the major presence of automation at Lower Granite is in the hydroelectric area. Although over a decade newer than Ice Harbor, the lock machinery operations are accomplished with traditional non-solid-state equipment, calling for conventional manual/visual operations.

The lower lock gates at Lower Granite are miter gates. In spite of their large size (there is a 105-foot lift here), they function well. The upper lock gate is a tainter, similar to that at Ice Harbor.

McNary Project, Umatilla, Oregon

The McNary Project is on the Columbia River at Umatilla, Oregon, the most downstream project in the Walla Walla District. It was visited on 9 January 1992, with the chief of technical staff/contract administration conducting a tour and handling inquiries.

Navigation at McNary has been conducted since 1953; it is an older project with very little automation involved in the lock operation. The lift at McNary is 83 feet and is accomplished using miter gates at both the upper and lower ends of the lock.

The principal automation item, which has been in place for just a short time, is a PLC-based system for operating the opening of the left and right filling valves. Prior to this installation, filling valve operation had to be watched closely by the operator to balance the inflows from each side, and thus minimize hazardous cross-currents in the lock chamber. Now the openings and opening rates of the filling valves are monitored and kept in balance automatically by the PLC. The operator simply has to initiate the filling operation, and the system manages the process according to a program that has been developed to maintain balanced flows.

As described previously for the other Walla Walla District projects, hydroelectric production

at McNary is heavily automated. McNary serves as the central control facility for all power generation in the District, although its capability to actually remotely operate the upstream Walla Walla District projects is not extensively employed.

John Day Project, Rufus, Oregon

This project is the most upstream facility under the jurisdiction of the Portland District. Navigation through the 113-foot-lift lock began in 1968. John Day was visited on 10 January 1992, under the guidance of two powerplant control room managers.

The lower lock gate is of the guillotine type, as is present at Ice Harbor and Lower Monumental Projects. The upper gate is a submergible vertical lift gate. The latter gate has been subject to accidents that occur as follows: When a tow in a filling pool is too close to the upper end of the chamber, the prow of the lead barge strikes the gate's superstructure from beneath. The most recent instance of this happening was in July 1990. The gate was damaged beyond use, and lockages had to be made using a floating bulkhead to effect an upper closure. This continued for several months until a convenient service outage could be scheduled for replacing the gate.

It is possible to visualize automation schemes where this kind of incident could be guarded against. Such a scheme would include a means of monitoring the precise location of a vessel or a tow in the chamber. As a practical matter, the District placed large concrete buttresses in contact with the floor and the walls of the lock chamber at the upper end, preventing an upbound tow from stationing itself too far forward during lock filling.

The Dalles Project, The Dalles, Oregon

This project is about 25 miles downstream from John Day; it was opened for navigation in 1957 with a lift of 90 feet. The power plant superintendent coordinated this visit on 10 January 1992, as well as the visit to John Day on the same day. Both projects are under the same supervisory team, based at The Dalles. The tour of the project was conducted by an operator.

The lower lock gate at The Dalles is a conventional miter gate, while the upper gate is a submergible tainter gate. As at John Day, the lock machinery operations are accomplished with conventional non-solid-state equipment and manual/visual procedures. While all of the Columbia/Snake projects visited in January 1992 are large,

The Dalles Project is particularly extensive. It is a drive of 1¹/₂ miles from the administration building to the lock along the top of the structure. If such a trip also included a stop at certain fishway weirs to change control settings, for example, the

one-way travel would exceed three miles. It is easily seen that, for reasons as simple as reducing travel and travel time, it would make sense to equip various items of equipment with remote readout and remote and/or programmed control.

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