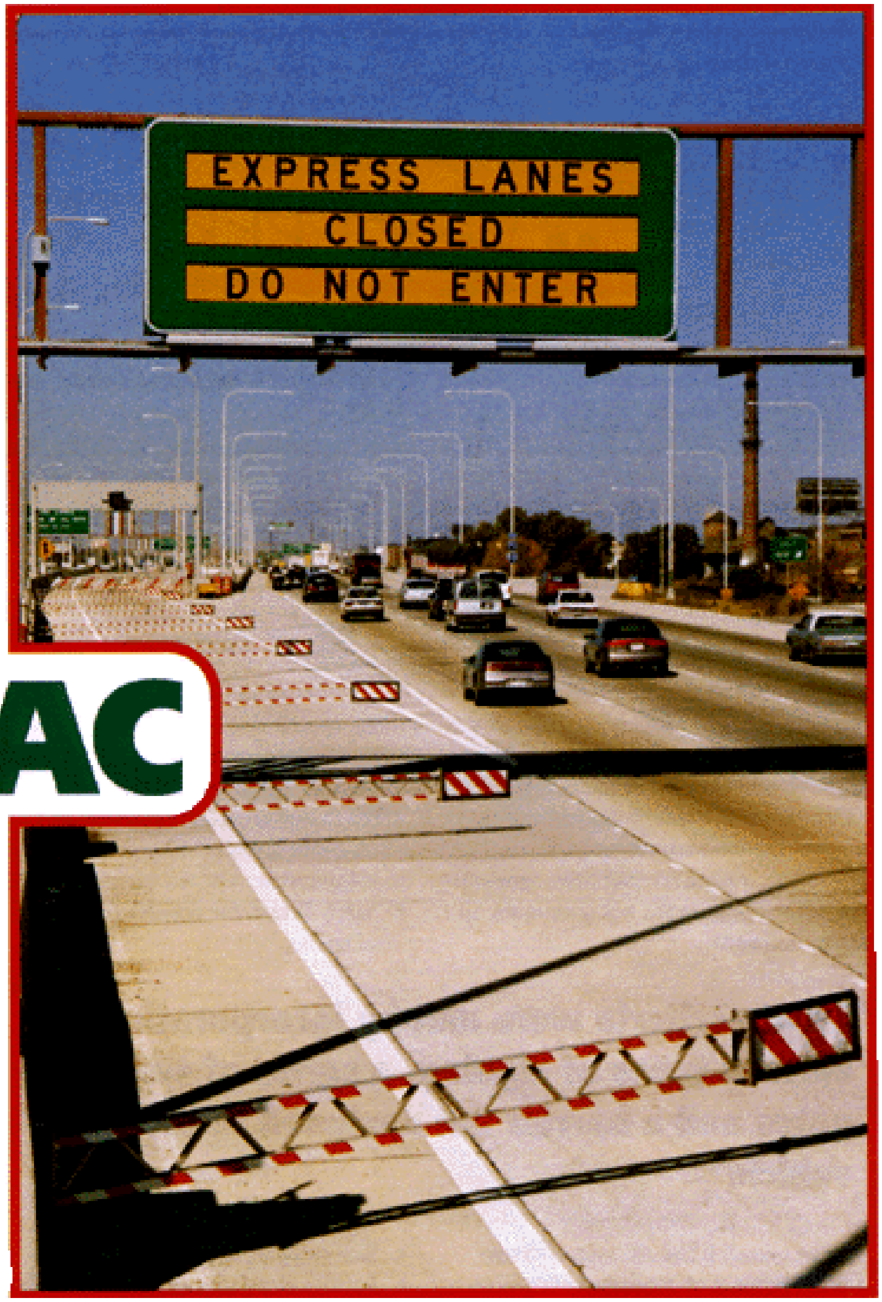

REVLAC

Turning the flow in Chicago

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A comprehensive control and alarm system lies behind the latest reversible lane procedure on one of America's busiest roads

The recently reconstructed Kennedy Expressway (Interstate Route 90/94) in Chicago, Illinois, operated by the Illinois Department of Transportation (IDOT), is one of the busiest stretches of highway in the USA. It incorporates two isolated reversible median express lanes along a seven mile portion of the roadway extending northwest from the city, with typical operation utilizing the reversible lanes inbound in the morning and outbound in the afternoon. Reconstruction doubled the entry ramps to the reversible lanes, from two outbound and one inbound, to three in each direction.

The REVersible Lane And Control (REVLAC) System controls the traffic flow reversal of the center lanes. The new system was created to replace the original REVLAC of the 1960s. The previous system incorporated a motorized barrier for ramp closure but each entry ramp change required manual placement of barricades by IDOT's Emergency Traffic Patrol (ETP) 'Minutemen', a time-consuming, manpower-intensive operation that exposed personnel to danger from traffic. Increased entry ramps, if changed in the same way, would reduce the utility of the

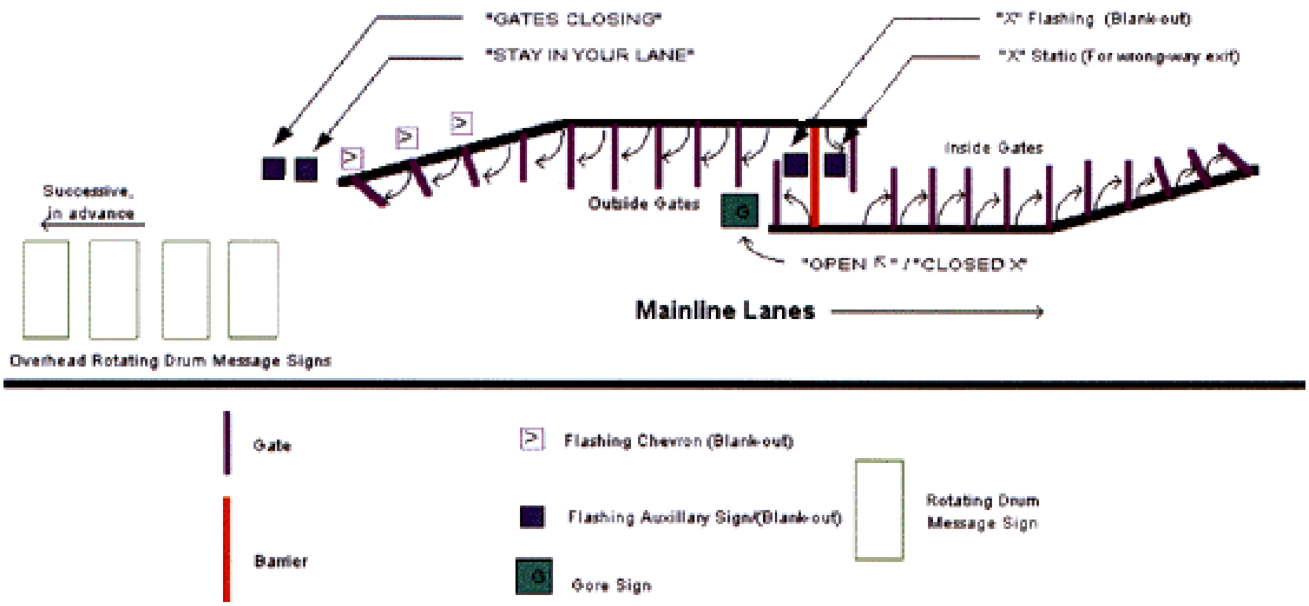


Figure 1: Typical ramp arrangement

reversible lanes and increase personnel exposure. Therefore, to optimize utility of the reversible lane, the goal of the REVLAC project was to automate lane reversal for minimal crew requirements without increasing reversal time. Safety and reliability were the key criteria for all design decisions.

"Safety criteria were met by incorporating various types of signing, a series of swing gates and a barrier net designed to stop a vehicle"

The overall REVLAC system design was the product of cooperative engineering by IDOT's Bureau of Electrical Operations and consulting engineer Lester B. Knight and Associates of Chicago. Certain control system integration and programming, which were dependent upon specific equipment selected during construction, were the responsibility of the construction contractor. The key mechanical components were procured in advance by IDOT, and in 1993 the main contract was bid and awarded to Illinois-based Divane Brothers Electric Company. Engineered Software Products (ESP) Inc. of Georgia, was selected by Divane Brothers to develop the control logic and system programming according to general operational rules specified in the contract and the specific requirements of control equipment developed between IDOT and the contractor.

The design criteria for the system included four levels of safety:

- Information;
- Safely-defeatable positive redirection of traffic;
- Safe stopping of an errant vehicle;
- Positive entry closure against wrong-way entry.

The safety criteria were met by ramp systems incorporating various types of signing, a series of swing gates, and a barrier net designed to stop a vehicle and close a ramp. Human factors analysis featured heavily in establishing the basic system design.

System power distribution and control had separate performance criteria, including redundancy of systems and components, failsafe operation, self-diagnostics and fault reporting and self-healing fault tolerance. Operating power was to be de-energized except during change operations. Minor faults were not to halt system operation or create traffic congestion while being resolved.

Alarms and diagnostics were to be extensive. Faults that signaled violation of basic safety criteria must obviously halt the system against unsafe operation, but system reliability was not to be compromised by spurious reactions, false alarms from detector failures and non-critical failures.

Ramp Configuration

A typical entry ramp is an add-lane to the mainline roadway, requiring a positive entry maneuver for entry. Before each ramp location are multiple rotating drum message signs, indicating ramp status, and fiber optic auxiliary signs that warn motorists of impending change operations. Within each entry ramp is a series of breakaway swing gates, each with a flexible tip, which, on closing, rotate away from storage slots within a vertical concrete barrier wall to direct approaching vehicles away from the entry ramp. Swing gates also are deployed inside the reversible lanes to close the ramp to wrong-way exit. Between the inside and outside wing gates, a vehicle absorbing net is raised and lowered to capture errant vehicles and provide traffic protection against wrong-way entry. Fiber optic red 'X' closure signing above the barrier and similar 'Open/Closed' gore signing supplement other ramp information. Ramp configuration is depicted in Figure 1.

The rotating drum signs are placed well before the ramp entry areas to give advance notice to approaching motorists and are the first system element to change during ramp closure. When all critical signs are acceptable, subsequent transition steps can proceed.

The auxiliary signs and chevrons are added to indicate to traffic that devices are transitioning to the closed position. The messages 'Gates Closing' and 'Stay In Your Lane' are direct and concise, and the chevrons suggest the swing gate movement; all to increase awareness that the ramp is closing. These signs have no function when the ramp is being opened. The gore sign is a device to substitute for a static sign and it flashes its 'Closed' indication along with a red X sign above the barrier during closing operation. Upon completion of transition, these signs have constant messages.

The outside gates are the first swing gates that traffic encounters when approaching the ramp. They are the most critical and many safety mechanisms are built into the devices and control program to ensure safe operation. When closing the ramp, the last three gates are delayed to provide a momentary 'out' for motorists failing to heed all system cues and warnings, thereby minimizing system damage and closure incidents.

The barrier is the final defense on the ramp. Since the swing gates function as breakaway devices, the barrier is placed in the middle of the ramp to stop vehicles from entering into opposing traffic in either direction. It consists of a net that is lowered when the ramp is closed and raised when the ramp is opened and must function properly for normal opening and closing processes to continue.

The inside gates are designed to keep opposing traffic in the express lanes from entering the local lanes. They operate the same way as the outside gates.

Automation System

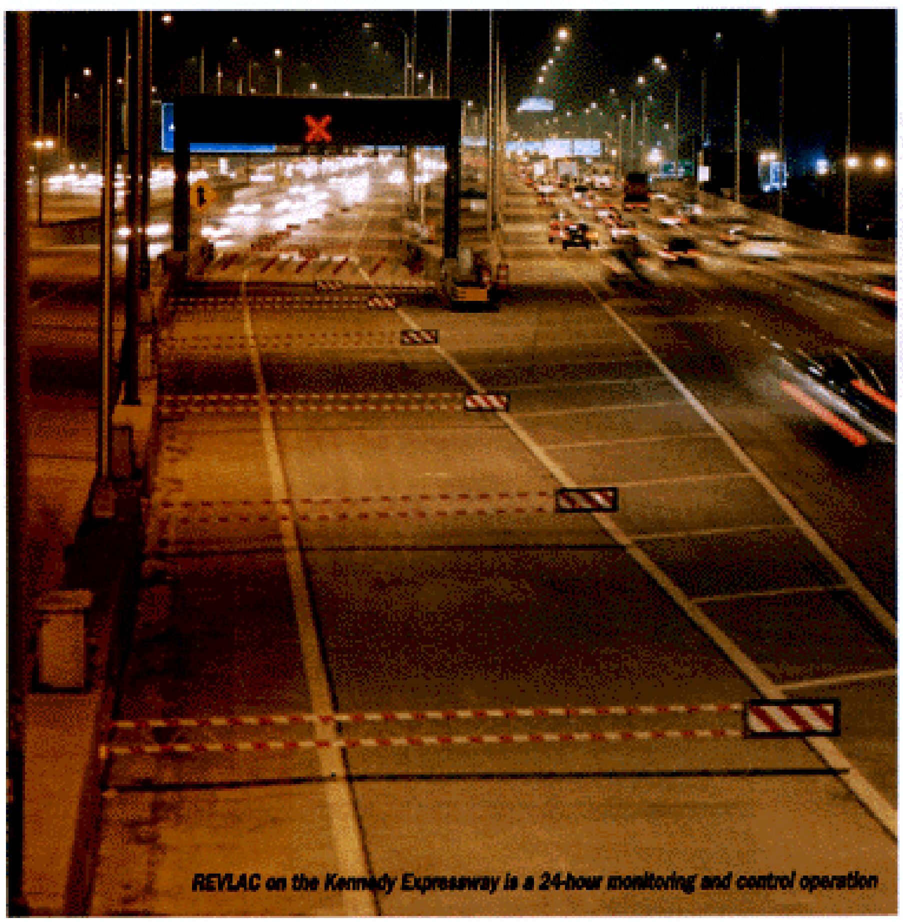
To maximize reliability, provide ease of maintenance, facilitate upgrade, and minimize cost, the basic control design is centered around the application of standard products as opposed to proprietary systems. A programmable logic controller (PLC)-based system was specified to provide system control.

Five independent, hot-standby, redundant processors control the system. The processors and associated I/O are located at the IDOT District 1 Headquarters ComCenter in Schaumburg, Illinois, and four remote buildings situated in close proximity to the ramps. These processors communicate via a triple redundant communication network to determine the state of all devices on the system, issue commands and generate alarms. Interlocks on the system prevent the operator from achieving an unsafe traffic condition unless snow removal operations, maintenance or emergency procedures require interlock bypass.

Four system control panels (SCPs) are located at the ComCenter and additional panels are located at each remote building. An operator may control the devices from any of these. The panels have equal capability in controlling the system, but only one can be in active control at any time. Near the SCPs are two CCTV monitors that allow the operator to view the devices. A video system records all ramp transitions automatically and can record camera views.

In normal operations, an operator at an SCP works with an ETP foreman who is physically located at the entry ramp. Programmed sequences allow the operator to arm the ramp after viewing and approving CCTV surveillance of the ramp area. Simultaneously, a portable radio controller with the foreman is activated and the foreman then initiates multiple device group steps through push button sequences. Fixed ramp control panels (RCPs) located in the ramp areas can substitute for the portable controller, but no action can take place unless all permissives are satisfied and the system is properly armed. This multistep two-person operation is an intentional level of safety redundancy, even at operator level.

In 'abnormal' operation, the operator may open or close a single device, a group of devices, or the entire ramp. When command is generated, the processors initiate movement of the devices. This movement is automatic and initiated in a set sequence with communication between all processors ensuring that the ramps are transitioned in a safe sequence. The SCP shows the status of the field devices including: open, close, halting alarm, and non-halting alarm.



REVLAC on the Kennedy Expressway is a 24-hour monitoring and control operation

Hardwired operator control panels (OCPs) located in each remote ramp building allow manual operation of the respective building's ramps in the event of a PLC failure. These OCPs contain a series of key-operated switches and LEDs to provide control and indication of device status independent of the control system.

Alarms are generated by the processors and displayed on video display terminals (VDTs) located at each controlling station. Additional VDTs are located in the remote buildings for maintenance and troubleshooting. The maintenance contractor has direct access to the alarm information that identifies the fault, down to the sensor level, from a remote VDT. A voice alarm annunciation system (VAAS) is also used to provide the operator and maintenance personnel with alarm information. This system calls the intended recipient via standard telephone lines and announces the alarm using digitized voice messages. It can page individuals if no answer is received at the normal telephone number. The VAAS also calls select individuals for different types of alarms. If the alarm is considered a maintenance alarm and requires no action from the ComCenter, the VAAS only calls the programmed maintenance number. It can also be programmed to call certain numbers at different times which can be useful to assign home or pager numbers after hours. The VAAS may also warn the operator of certain conditions on the ramp that may cause problems under normal operations, such as circuit breaker trips. These 'preflight' alarms are generally called out two hours before a normally scheduled lane reversal.

As the five processors control the system in a distributed manner, a method was needed to track and record system operations. Engineered Software Products developed a network manager system which is a data-logging system designed to record alarms and log input and output transitions over the entire REVLAC control system. Detailed information is captured for every device operation or fault. The information is then stored in a standard database format. The PLC at each building captures its own alarms and input/output and records the time of the transition. This data is transmitted to the headquarters and logged by the network manager. Date, time, device description and state are recorded. The PC clock in the network manager supplies the date of the transition. On-line review of system changes of state is available through preconfigured database queries.

"Due to the high cost of continuous telephone service, the telephone communication is used only in the event of a long-duration outage of the microwave system"

Approximately 1,200 database entries are recorded during each reversal of the expressway. Combined with the videotape recording of the transitions, this provides a complete historical record of each operation and has become a valuable troubleshooting tool.

Communications

As each processor functions independently, communication between the nodes is extremely important. A triple redundant communication scheme was developed to connect the five nodes. The primary communication medium is microwave radio. The main function of the microwave system is to broadcast the CCTV signals between nodes. The data communication uses only a small bandwidth and shares the same microwave links as the video. The microwave communication has an uptime rate greater than 99 per cent, however it can be affected by severe rain and snow. A UHF radio network runs in parallel with the microwave. Though the slowest communications medium, the UHF is cost efficient and available as a 'hot-backup'. The third means of communication utilizes secure dial-up voice-grade telephone lines. Each node can establish a dedicated telephone link to all other nodes with modems attached to allow for 9,600 baud communications. Due to the high cost of continuous telephone service, the telephone communication is used only in the event of a long-duration outage (over one minute) of the microwave system. Once the microwave communication is lost, the UHF system immediately takes over as the primary communication medium and the telephones initiate a dial-up routine. When the telephone system has established communications (usually about 30 seconds) the UHF drops to hot-backup status once again. When the microwave system is restored and stable, the telephone system automatically drops off the line. All backup media are automatically tested daily.

Fault Tolerance

A key design criterion was to maintain operation in the event of device failures. Fault tolerance allows failure of certain parts of the system without affecting the operation of the system. According to Tim Rusk of Engineered Software Products: "The most challenging aspect of the REVLAC project was implementing the fault tolerant criteria in the PLC programs."

The goal was to limit device failure interruptions without compromising safety. Indication of a single device is not trusted without proper indication of another associated device. For example, each gate supplies four limit switch inputs, two indicating the retracted position and two indicating the extended position. A gate is only considered retracted or extended if all four limit switches indicate the proper position, or if a limit switch transition occurs within a preset time window to indicate proper operation of the device. This allows for multiple limit switch failures within a single gate without affecting operation. Rusk points out that, "Examples of this type of fault tolerance using backup methods for determination of states can be found on every device in the system." Even the communications system incorporates three separate systems so that failure of one or two systems will not cause complete failure of the system.

Failure of a non-critical device is also an example of fault tolerance. Gate density was designed at twice that required by the human factors studies so that, if a non-critical gate fails to extend, this will not stop the current operation. The ramp can be determined fully closed by the system even though a non-critical device has failed to extend. Failure to open the variable message signs when opening the ramp is another example, as a sign would

not prevent opening a ramp to traffic. The system is made up of many circuit breakers and manual control switches. Although the VDT may report that a circuit breaker has tripped or a manual control switch is in the wrong position, this will not prevent the operator from attempting to perform a desired procedure. If, indeed, the circuit breaker has tripped or the switch is placed in the wrong position, then the device(s) controlled by that element will fail and a halting condition may occur. However, if only the sensor indications are false, no loss of control of the system is observed.

System Performance

The majority of equipment for the REVLAC system was installed during mid-1996. Testing was a challenge for IDOT and the contractor. Such a complex system required exhaustive testing under varied conditions, including introduced failures. High traffic volume limited testing to nights and weekends. Divane Brothers designed a quick-connect system that allowed the ramps to be converted from manual to automatic operation.

"Our crew was able to change over the control in about an hour so that we could test system-wide for several hours each evening without inconveniencing commuters with extended lane closures," said Ken Bieber, project manager at Divane Brothers. Completion of the project increased the useful time of the reversible lanes as reversal is accomplished in less than half an hour by a ComCenter operator and a single ETP foreman. This is about half the time needed for manual changes of the old system, which had fewer ramps. The detailed diagnostics available on the system mean reduced repair times and faster maintenance response.

Larry Bradley, IDOT's District 1 communications section chief, says, "The entire team approached this project with a high standard of care and concern for safety. This comprehensive system is the result of a truly partnered effort, and the technology has been up to the task."

System automation has allowed Minuteman crews that would otherwise be engaged in manual reversal operations to perform their real mission which is to assist motorists on the IDOT expressways and keep traffic flow free of incident delays. The REVLAC system's capabilities have also fostered improved reversible lane availability in response to inbound and outbound traffic demands, increasing the usefulness of fixed lane capacity. ■

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