7 percent basis, this $297 would represent an initial investment of $3143/mile. Thus, it may be very cost effective to install the system. At a higher interest rate, the plan would be even more attractive.

CONCLUSIONS

1. Nighttime roadway visibility can be greatly improved over present conditions, and energy can be simultaneously reduced.
2. The changes required in city street lighting systems to achieve improved visual conditions with substantial energy savings are cost effective.
3. Study areas show energy savings of 50-60 percent and that adequate visibility is maintained at night on city streets.
4. The overall owning and operating cost for a relighted city street will probably show a substantial reduction in cost over a present system that approximately meets existing lighting recommendations.
5. Whereas energy savings are easy to develop on a factual basis, total owning and operating costs are very difficult to develop. Each specific job must be analyzed separately by using local costs for labor, materials, interest, energy, inflation, taxes, etc., to arrive at a specific answer.

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Radio Control of Highway Lighting

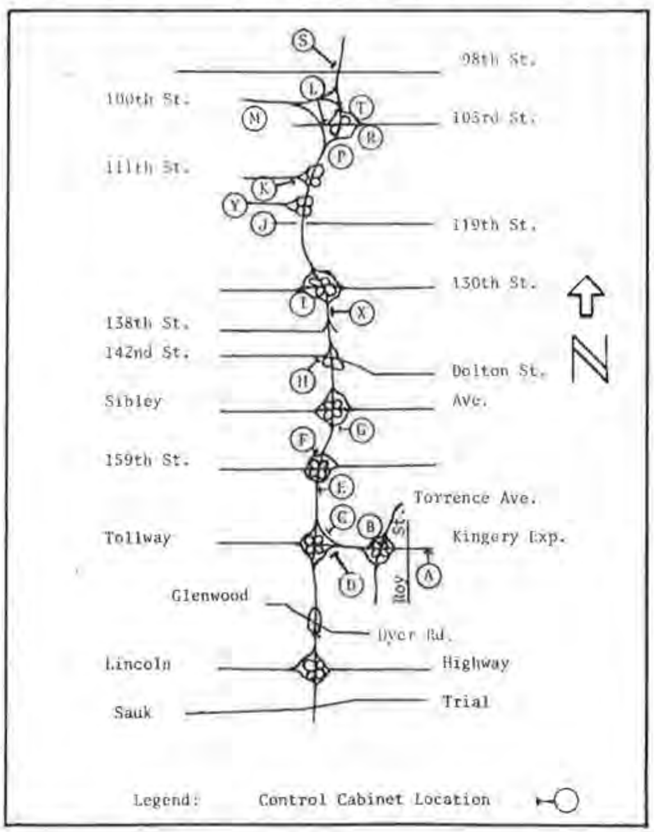
RICHARD E. STARK

Reduction in energy consumption and in public criticism of sporadic control of lighting and the need for flexibility in providing lighting under adverse weather conditions were the bases for installing radio control of freeway lighting in the Chicago metropolitan area. The problems leading to the recommendation of this type of installation are described, and the various systems available for lighting control, as well as the advantages and disadvantages of each, are discussed. The decision to use the existing Illinois Department of Transportation voice radio system as a signaling medium for control of some 166 lighting power centers was made after several trial installations of different methods of control, including radio and power-line carrier systems, were tested. The installed system is automatic in operation and has manual override. It provides instantaneous control over the entire system of some 20 000 luminaires, over individual control cabinets, or over whole freeways. Encompassed in the system are seven two-way transmitter-receiver units that feed

back information about light levels and electrical conditions at these locations. Advantages of such a precise control system are the reduction of energy use; the uniform, on-time illumination of the freeways; and the ability to turn on lighting during bad weather. Ease of maintenance and reduction of driving time for maintenance workers, who can simply call for lights on, are additional benefits. A number of problems encountered in the system installation are discussed along with the potential benefits of using the basic idea as an information network for monitoring electrical parameters, traffic information, or other measurable field conditions.

In the early 1970s, a tornado warning was issued for the Chicago area in the middle of the day. The skies were unusually dark, and a call was received from the District Highway Engineer asking that all freeway lighting be turned on. Since the 166 lighting power center distribution cabinets (referred to here as control cabinets) and some 20 000 overhead highway lights were controlled by astronomical time clocks, this request meant sending out a large force of men to turn on the lighting system. By the time all systems were energized, the sky had brightened up and it was evident that the lighting was no longer needed. The procedure then had to be reversed, a costly and ineffective solution to this visibility problem.

Figure 1. Lighting control cabinets on I-94, Calumet Expressway.



Since that time, a number of calls have been received from the police and other local authorities indicating a need on various freeways for illumination or optical guidance during other than normal nighttime hours. These requests were difficult to satisfy and emphasized the need to develop a more efficient method of turning on highway lighting with a minimum investment of labor.

In addition, the energy crisis provided the impetus to follow more precisely the patterns of light appreciation and depreciation (1). Originally, each control cabinet was equipped with a mechanical, astronomical time switch (astro-timer) to turn lights on or off. The astro-time switches had to be set about 15 min early for turn-on and about 15 min late for turn-off to allow for occasional dark periods due to heavy cloud cover. Photoelectric cells had been previously tried, but since the cells controlled blocks of lights, differentials between cells created an off-on pattern along the freeway. This is particularly annoying to motorists traveling at the rate of 40-55 mph, in and out of lighted areas, during the dusk and dawn periods. Much criticism was received from the motoring public and the news media concerning the lack of synchronization of lighting along the Chicago-Area Freeway System. A typical freeway with control cabinets indicated alphabetically is shown in Figure 1.

INVESTIGATION

A number of methods of lighting control were explored, ranging from power-line carrier to solid-state astro-timer. Table 1 gives the various types of systems considered and the advantages and disadvantages of each system. The group A types of controls are local, provide no coordination, and must be constantly cleaned and adjusted to perform within expected limits. Even with the most exacting maintenance, including weekly cleaning and adjusting, the limits of operation are too variable and exclude coordination.

Group B is the cascading method (2). This is simply using one control cabinet to turn on the next by laying cable between the two and using the voltage from the first to operate a relay in the second control cabinet, closing a contactor energizing that cabinet. Each cabinet, in turn, is energized by the previous one until the whole system is energized. This requires an extensive interconnecting cable installation. As noted earlier in the system description, each control cabinet is now isolated from each other. Separate power control was the method used when the system was originally built; thus, the installation of cable to interconnect each control

Table 1. Comparison of various types of lighting system controls.

		Light Sensitive					Remote Control				
Group	Type of System	Entire System	By Area	Coordinated	Daytime Activation	Maintenance	Entire System	Individual Center	Group	Area Feedback	Installation Cost
A	Local photocell	Yes	No	No	No	Low	No	No	No	No	Low
	Local mechanical astro-time switch	No	No	No	No	Low	No	No	No	No	Lowest
	Local solid-state astro	No	No	No	No	Low	No	No	No	No	Still untested, not available at that time, now medium
B	Cascading	Yes	No	Yes	Yes	Medium	Yes	No	No	No	High cabling costs
C	Power-line carrier	Yes	No	Yes	Yes	Medium	Yes	Yes	Yes	No	Very high cabling costs and transmission
	Radio switch	Yes	Yes	Yes	Yes	Medium	Yes	Yes	Yes	Yes	Moderate to high

cabinet would be very expensive and disruptive to traffic and roadway components.

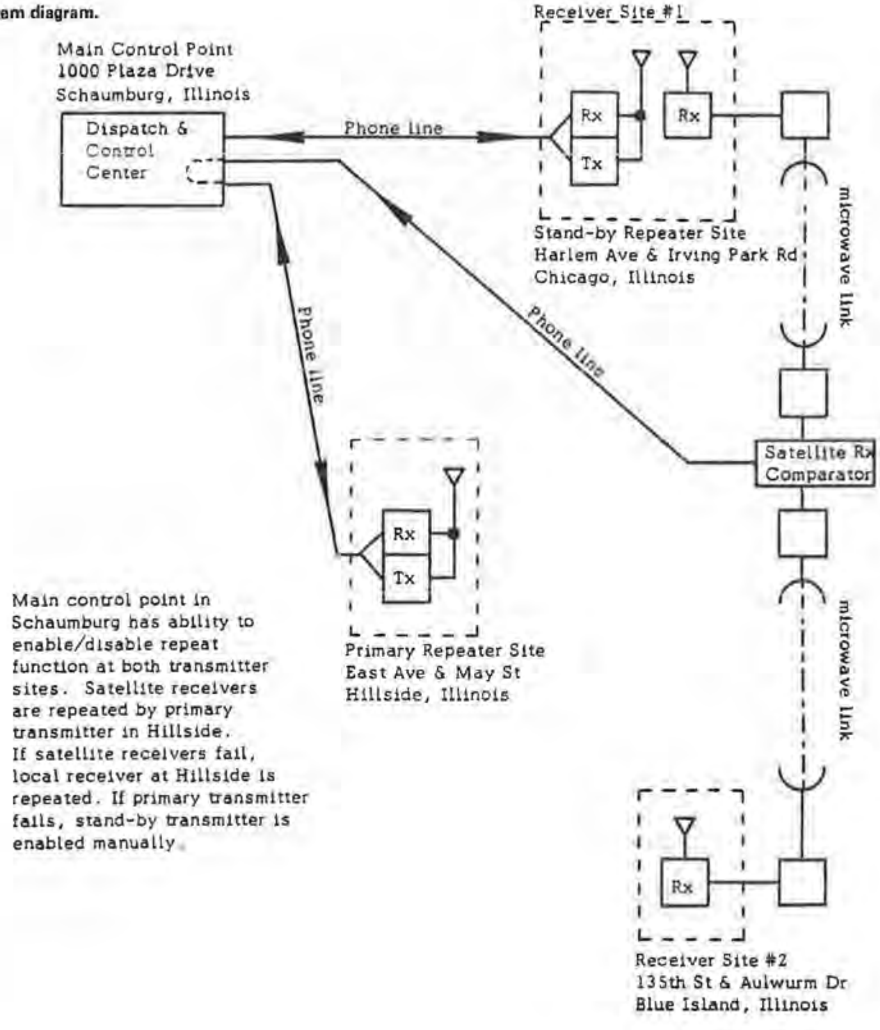
Group C systems not only are coordinated but also allow for individual control of the control cabinets by use of a coding system. The power-line carrier system is similar to the radio system in that a turn-on or turn-off signal is generated and sent to each control cabinet. The power-line carrier, however, uses the existing electrical cable system as a means of transmission rather than direct electromagnetic waves as in the radio system. This again requires the costly total interconnection of electric lines with additional isolation filters to allow signal penetration but prevent electrical power interconnection. Transmitter and receiver costs were comparable to the radio equipment, but the added interconnect cost results in a greater overall cost for this system.

SYSTEM SELECTION

The system selected, the radio switch, had the most reasonable cost and the greatest flexibility. It was also the system that had undergone a series of tests over a period of years before the project was implemented. Tests run on early models indicated that falsing (the misinterpretation of tones by decoders) was one of the major problems. Falsing, operating on an incorrectly interpreted received signal, causes turn-ons or turn-offs at incorrect times, thereby negating proper operation. A new digital sequential coding system was developed that ensured against the probability of falsing and thus made the radio switch a possible choice for this installation.

A major factor in the final selection of a radio switch was the existing radio communication system of the Illinois Department of Transportation (District One, Highway Division). The existing radio system is composed of some 850 mobile transceivers and 10 base stations operating on 10 Federal Communications Commission (FCC) allocated frequencies. FCC rules allow for the use of voice channels for signaling if the signaling is restricted to a small percentage of the air time. Thus, the probable use of existing transmitting and receiving equipment gave the radio switch system an advantage. Eventually, channels at 151.100 MHz transmit and at 156.045 MHz receive were selected (see Figure 2). The base-station transmitter selected has the widest coverage and was reinforced by a standby transmitter in case of failure. An auxiliary generator would operate automatically under remote control in case of power failure. The backup transmitter is located at a different site (to avoid related storm and vandalism damage) and also has emergency power. Thus, the basic components of the radio switch system were already in place and, with backup features, they represented a major advantage for this type of system.

Figure 2. System diagram.



SYSTEM COMPONENTS

The final system design was composed of 166 receiver switch units, 7 transmitter-receiver units, and a central control. Figure 3 is a system map that shows the various freeways involved and the location of the 7 transmitter-receiver units as well as the central control. The system serves 135 miles of freeway lighting. The individual receiver switches located at each control cabinet are designated alphabetically. One freeway (Calumet), with its 19 control cabinets, is shown in Figure 1. Each freeway has from 15 to 30 individual control cabinets. Radio switches are spread fairly uniformly over its length, and one transmitter-receiver unit installation is located in a control cabinet in the approximate middle of the freeway length. The system components and their location are shown in Figure 4.

SYSTEM OPERATION

The basic system operation is simple. At dusk, a photocell located atop the District headquarters building in Schaumburg, Illinois, indicates by a contact closure that the ambient light level has fallen below 2 horizontal footcandles (1). This closure generates a coded signal that is automatically transmitted by radio at the first break in verbal radio traffic. The signal is received by the 166 radio switches, and this causes a relay in each control cabinet to close a contactor, which energizes the lights (see Figure 5).

The seven transmitter-receiver units located in control cabinets verify that the lighting contactor has closed at their distribution point and send a return verification signal to the headquarters central control center (see Figure 6). Each control cabinet still retains the existing astro-timer switch as a backup to the radio switch (see Figure 7). Fifteen minutes after dusk, or as set, the lights will be turned on by the astro-time clock override should the radio switch fail or the radio signal not reach the particular location. This operation also overcomes the problem of vandalism of items such as antennas.

The existing astro-time clock also serves another function in that it disables the radio switch power until 45 min before dawn the following day. This function prevents the accidental turning off of lighting by radio during the crucial nighttime hours.

Once the radio switch in each power-center distribution cabinet has been energized, a signal emanating from the headquarters control center to indicate a light level in excess of three horizontal footcandles can be received. If for some reason the radio signal fails, the astro clock will turn the lights off at some previously determined time, such as 15 min after dawn.

Since the radio switches are now energized, the lighting system may be activated at any time during

Figure 3. System map.

the day. A coding system that allows the activation of the entire system, by groups of freeways or by individual control cabinets, can be used to facilitate maintenance on the system, or the system can be activated during extremely dark periods that occur in normal daylight hours.

Additional features incorporated into the system are related to the seven transmitter-receiver units and the central control unit. Each control cabinet

Figure 4. System components.

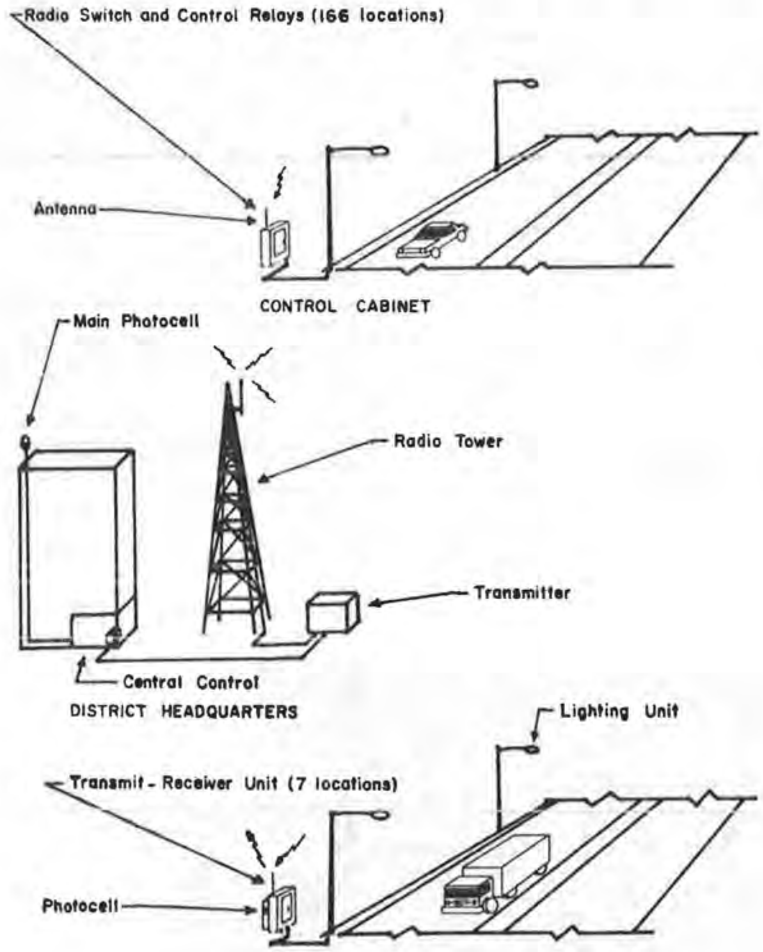


Figure 5. System block diagram.

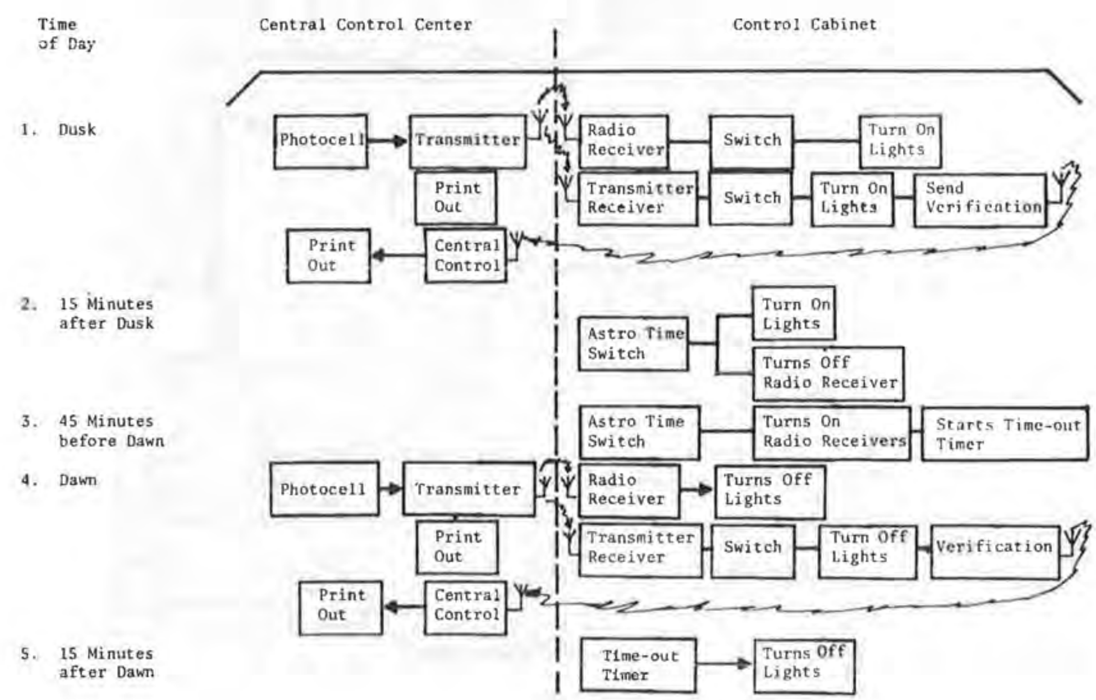


Figure 6. "Status change" verification and reporting.

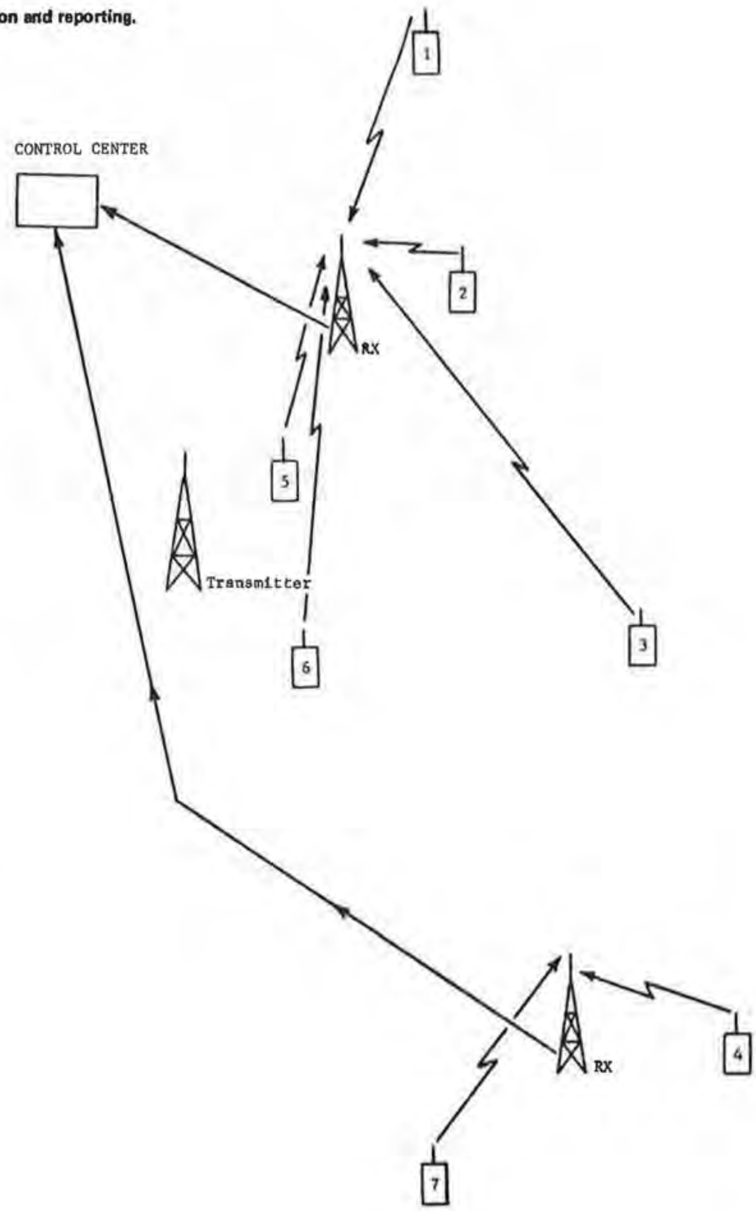
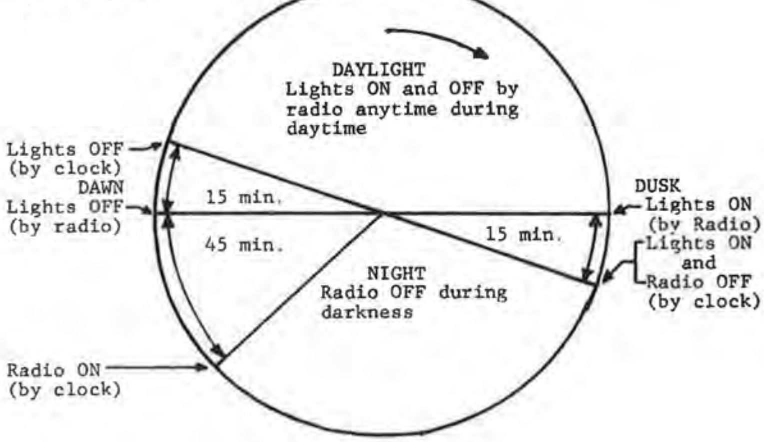


Figure 7. Twenty-four-hour operation cycle.



containing a transmitter-receiver also has a photocell that, by way of the transmitter, sends a signal to the central control in the communications room at Schaumburg when light levels fall below preset values. If these signals indicate a lower level of light on the particular freeway monitored that requires the activation of lighting, and are at sufficient variance with the central control photocell at Schaumburg (a half-hour difference between field and central control), then an alarm with digital readout will sound, alerting personnel in the Communication Center. They will then manually turn on lighting on that freeway. A special astronomical program is built into the central control unit to provide for a 1-h alarm lockout period (a half hour before and after dusk and dawn) to prevent nuisance alarms.

Each of the seven transmitter-receiver units, in addition to indicating light levels, also monitors individual circuit conditions within the control cabinet. Since the transmitter-receiver units are activated 24 hours a day, any circuit failure in these control cabinets will send an alarm to the central control located at Schaumburg headquarters. The communications dispatcher at the central control in Schaumburg then alerts the maintenance patrol person, who proceeds to the location to repair and restore the disabled circuit.

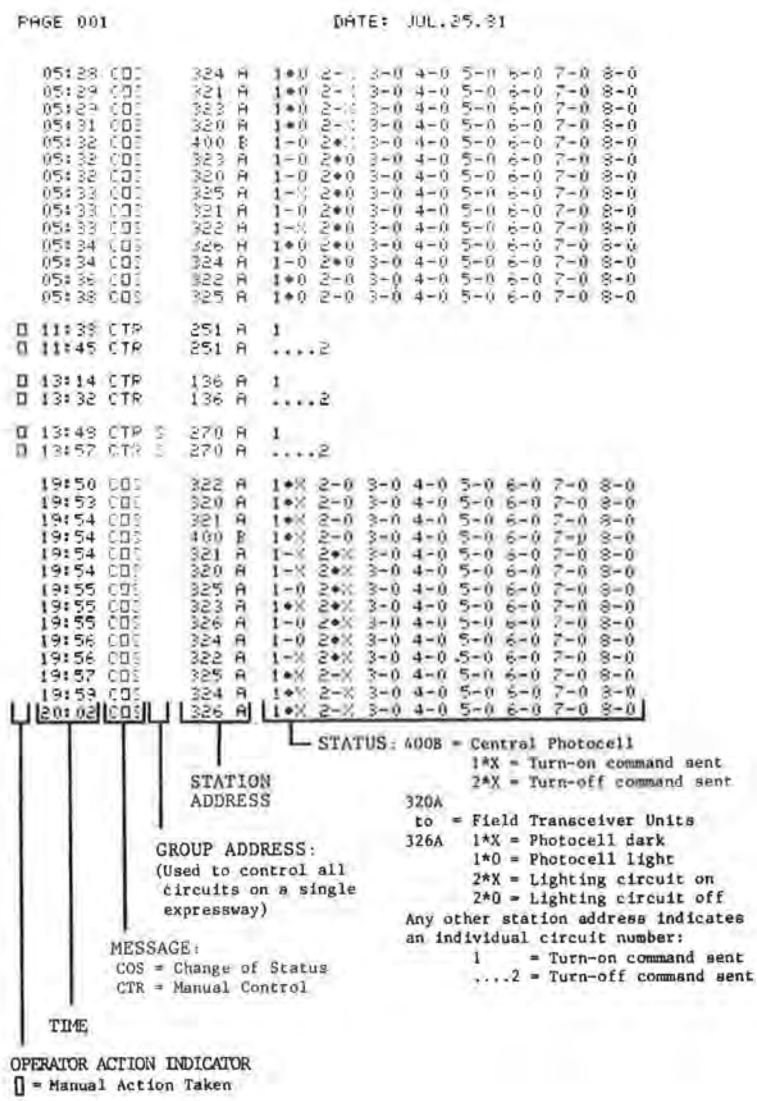
The entire system functions automatically on a daily basis unless some unusual situation occurs, such as extreme darkness during daytime hours, circuit failure at one of the transmitter-receiver units, or a request from maintenance people for turn-on at selected locations. These situations require the communication dispatcher's attention and subsequent manual operation of the system. Manual operation of the system is fairly simple and requires the dispatcher to select the proper code for individual or group turn-ons or to push one button to turn on the entire lighting system.

System operations are printed out by the central control unit on a daily basis (see Figure 8). This allows for a full check of the main photo control operation and any alarms or malfunctions of field electrical equipment at the seven transmitter-receiver locations, as well as the standard confirmations from each of the seven field units. An automatic record is also made whenever a maintenance person shuts off power to service the equipment.

SYSTEM PROBLEMS

A number of problems developed during the installation of the system. Although it was known that the existing astro-time switches were somewhat erratic in operation, it was found that, due to inherent

Figure 8. System printout.



looseness in dial-gear meshing and relation between dial settings and actual time, there were substantial differences in timing operations. Until all clocks were brought into the shop, tested, and properly adjusted, a number of difficulties occurred in getting the radio receiver switches on early enough to enable the radio signal to perform its intended function. The preciseness of the radio operation brought attention to the impreciseness of the mechanical clock mechanism.

Since the system uses an existing voice frequency, coded signals with their accompanying sounds can be a nuisance unless they are minimized. During initial installation, problems developed before the photocells of the seven field transmitter-receiver units were properly tuned to the surrounding ambient light conditions and numerous alarms were sent to the central control. This problem was overcome by ensuring a clear viewing area for each photo control.

Another problem of growing magnitude with any type of field equipment is vandalism. Field equipment that had not been bothered for many years is now being subjected to vandalism. In the case of radio control of lighting, the only new piece of exposed equipment is the antenna. All other equipment except the seven transmitter-receiver units has been mounted within the existing locked light control boxes. The antenna, however, is symbolic of control, and it presents a unique opportunity for persons who want to disable lighting or to just vandalize, since it is so easily destroyed. We have been fortunate, however, in that most lighting control cabinets have been in place for many years and are hardly noticed in their surroundings.

BENEFITS

Generally speaking, most of the aforementioned problems have been overcome and the system operation has provided numerous benefits. The prime reason for such an installation was the energy benefit. The system not only conserves energy but also provides savings that rapidly recover the original investment. As mentioned previously, it is no longer necessary to advance turn-on times or to retard turn-off times to compensate for overcast days. This results in a minimal 30-min saving in energy per day, and this amount is often exceeded. At the present annual kilowatt hours consumed, this amounts to more than $50 000/year. At this rate, the installation and equipment cost will be recovered in less than five years. Maintenance costs have so far been extremely low, but a figure of $6000/year was included in the estimated pay-back calculation.

A second benefit of the system is a feature termed "system equivisibility". With field sensors

Figure 9. Operations and Communications Center report.

Illinois Department of Transportation

TIME RECEIVED	INFORMANT
6:24PM Sun. 8/2/81	G. Guderley

SUBJECT:

Early turn on of Expressway lighting

LOCATION:

District 1 Expressway System

DETAILS AND NOTIFICATIONS:

Due to numerous reports from Emergency Traffic Patrol units of poor visibility resulting from heavy rains, and a request that the expressway lighting be turned on from 904-Mr. Daugherty, Emergency Traffic Patrol Foreman, the Expressway lights were turned on via the Manual "ON" switch on the Highway Lighting Controller.

VERIFIED(NAME):
POLICE & REPORT #:
E.P.V. Assist (IF ANY):

ELECTRICAL MAINTENANCE CONTRACTOR #:

COMMUNICATIONS:	COPIES SENT TO:	INCIDENT REPORT
G. Guderley	Mr. Stark, Mr. Bushman	

reporting area lighting conditions, should any unusual visibility condition develop, alarms will alert the dispatcher in the Communication Center and acceptable lighting levels can be achieved for the particular area. An example would be a heavy rainstorm in early evening that involved only one freeway. The transmitter-receiver unit for that roadway would signal low light conditions, and the dispatcher would energize that freeway lighting. Reports from field traffic personnel, executives, and others also result in turn-ons during normal daytime hours (see Figure 9).

The problem that is most noticed and causes the greatest public reaction, that of scattered turn-ons and turn-offs of highway lighting, is now replaced with instantaneous system operation. Since the system is designed to energize or de-energize whole groups of lights at one time, there are never any individual lighting units continually burning and going unnoticed for days or weeks at a time.

Finally, maintenance service time is reduced due to the ability to simply make a mobile radio call to the dispatcher for the turning on or off of any control cabinet. This saves considerable time, since these control cabinets are located off the freeway on frontage roads or cross streets. Specifically, it is necessary to energize high-mast lighting installations in order to service the luminaires. The time saved for the maintenance worker varies from as little as 10 min to 1 h round trip. As many as three other workers may be waiting during this period. Since this operation must be repeated after the repair is finished, an average of 1 h/worker is lost two to three times per week. It is estimated that an annual savings of $6000/year would be realized due to this feature.

The installation of a radio control system for highway lighting has resulted in the solution to the many aforementioned problems. The possibilities, however, for future applications of this technique are very impressive. The development of small-sized transmitters and other electronic equipment opens the way for many practical applications. One of the features of the present system, monitoring of the circuit condition, could be expanded to monitor individually each of the 20 000 luminaires. It is envisioned that a daily printout of lamp outages would be available, which would eliminate the necessity of patrolling for outages. This would result in a more efficient lamp replacement program and reduce energy and the person power required in patrolling. Installation of highway lighting systems requires substantial capital investment, which can only bring a return if the systems are properly operated and maintained. System monitoring can detect problems early and reduce the size of repairs as well as conserve energy (3).

OTHER USES

Information of various types that can be sent to the transmitter-receiver unit can then be forwarded to the central control of the Communication Center for analysis. This might include traffic information as well as electrical parameters. Traffic information, such as detector loop output or detector information of any kind, could be sent over special frequencies. Economic comparisons of the various systems need to be made to ensure future low-cost, reliable information retrieval.

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Abridgment

Programmable Roadway Lighting System as an Integral Traffic Management Component

A. KETVIRTIS

Analysis of vehicle traffic on public roads and streets in urban and rural areas indicates that traffic density and volume vary regularly within a 24-h cycle and that there is a close relation between traffic volume and accident rate. The gap between vehicle miles of travel (demand) and available road capacity (supply) is projected to increase steadily in the future. Traffic planners are faced with the need to improve the present use of the road system without investing major sums of money. Among the objectives of such improvements is maximizing the impact of roadway lighting on traffic flow. It is recommended that roadway lighting systems include a switching flexibility that will enable traffic system operators to relate lighting levels to traffic characteristics. The operation of such variable-level lighting systems is briefly described.

An orderly and effective traffic flow depends on a number of factors, each of which in its own way influences the totality of environmental characteristics in which the motorist is performing the driving task. In planning traffic management, therefore, it is important that these factors are clearly identified, weighed, and integrated into a unified scheme. It is obvious that, if one or more of the major contributors are ignored, success in such a system operation will be limited or, in some cases, inadequate.

The analysis of vehicle traffic on public roads and streets indicates that in urban and rural areas traffic density and volume vary regularly within a 24-h cycle. This variation establishes specific traffic-flow patterns, accentuating the morning and evening peaks as well as a slack period that normally falls between midnight and the early morning hours (Figures 1 and 2).

Based on accident distribution data within a 24-h cycle, it appears that the degree of difficulty in