MAINTENANCE MONITORING FOR REMOTE PUBLIC FACILITIES

- A FEASIBILITY STUDY -

FINAL REPORT

by

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INTRODUCTION

In the sense used in this report, a "facility" is a structure with heating, electrical, water, or sanitary systems. A "remote" facility is one not regularly attended by skilled technicians with ready access to tools and supplies. A "monitoring system" includes transducers to signal operating conditions in the facility, logic to interpret the signals, and a means of communicating the output to human operators.

The Alaska Department of Transportation and Public Facilities (DOTPF) operates airports and highway maintenance camps. It is also responsible for other remote facilities under joint use or maintenance contract. It has been suggested that incipient failures might be detected by monitoring systems in time for preventive action to be taken. Savings in fuel for heating and electic energy might also result from prompt identification of inefficient operating conditions or faulty equipment.

This report attempts to identify the dominant maintenance problems in remote facilities, means by which they might be detected, the level of monitoring appropriate to various facilities, and a strategy for implementing it. Much of the information has been gathered from designers, managers, and operators of bush facilities, and their contribution is gratefully acknowledged. Especially helpful were maintenance personnel at village schools, who daily face the challenge of operating high technology equipment in a difficult environment. While DOTPF plays a diminishing role in the design and operation of schools, some of the findings may have application there.

Nothing will be gained from the finest monitoring system if its warnings go unheeded, and it is pointless to install one unless maintenance personnel have the skills, supplies, and motivation to take timely action. Providing these within existing legal, administrative, and economic contraints is a formidable task beyond the purview of this report.

CONCLUSIONS AND RECOMMENDATIONS

Two classes of monitoring systems are needed in remote facilities operated by DOTPF and other state agencies; power deviation monitors and freeze-up alarms. A third class, energy performance monitoring, will have widespread utility in the future and can conveniently be developed and tested at DOTPF facilities.

1. First priority should be assigned to developing and deploying monitors to record voltage and frequency excursions in village power grids. Such excursions are suspected of contributing to equipment malfunctions. Knowledge of their cause, severity, and rate of occurrence is needed to plan improvements in the power system or to isolate vital equipment from their effects.

2. A reliable freeze-up alarm of standardized design should be developed, with attention given to protecting it from power line disturbances if the data from the first task proves this necessary.

3. Development of an energy efficiency monitoring system should be initiated, and a prototype tested to ensure that the correct variables have been chosen for monitoring and that the system and its data transmission link are reliable.

TYPES OF FACILITIES

Remote facilities for which DOTPF is responsible include highway maintenance camps, airports, some joint use facilities and facilities under maintenance contract. Highway camps generally provide utilities for the crew, and shelter and repair areas for equipment. The highways they serve afford access to replacement parts and supplies, and their independent power, water, and sanitary systems are generally well maintained by experienced personnel.

Village airports include the terminal building, runway, and runway lighting system. Power is supplied by the village utility, and the airport is connected to a power grid shared with other users. DOTPF responsibility does not extend to radio navigation and communication systems operated by the Federal Aviation Administration.

Village schools are the largest network of facilities maintained by state funds in remote areas, and while DOTPF is only occasionally involved in their design or reconstruction, transfer of cost-saving technology to the school system would have magnified effects in savings to the State. In larger villages power is supplied by private or public utilities, often the Alaska Village Electric Cooperative, while in smaller ones the school system operates its own diesel plant. Maintenance of these facilities ranges from poor to excellent, depending on the level of training and dedication of the operator. Special problems are presented by the cost of air transportation, delays during bad weather, and by the difficulty of obtaining spare parts for the variety of equipment in use.

Other remote facilities not operated by the State include Public Health service installations, FAA radio sites, and pump stations on the Alyeska pipeline. Designers and operators of these facilities have valuable experience in remote site maintenance, and many have installed monitoring systems to assist the process.

FACILITY MALFUNCTIONS

A list of occurrences that interfere with normal functioning of a facility reveals some that are hazardous to life or disabling to the facility, others that are mere nuisances but costly in time, money, or morale, and a few that are wasteful but may go unnoticed for prolonged periods.

Catastrophic events include:

1. Fire
2. Vandalism
3. Power plant breakdown or premature runout
4. Foundation movement
5. Freezeup
6. Water damage
7. Untimely runway lighting failure

Nuisance events are:

1. Clogged drains
2. Vehicle starting problems
3. Control and electronic component failures
4. Power interruptions
5. Small motor burnout

Unnoticed events:

1. Excessive cold air infiltration
2. Leaks in water and fuel lines
3. Inefficient operation of heating equipment
4. Inefficient energy management

Among the catastrophic events, fire and vandalism can be detected by available equipment, and there is no need to transmit alarms beyond the immediate locale. Power plant breakdown or premature runout are recurring problems, usually caused by neglected maintenance or inexperienced operators. Managers are well aware of the situation and are actively seeking means to improve the level of maintenance, but power generation plants are of such varied age and manufacture as to require tailor-made monitoring likely to cause more problems than it solves.

Foundation movement results from thawing of underlying permafrost, often accelerated by blocked air circulation or by enclosing and heating spaces beneath the structure. Temperature sensors installed with the footings can detect impending trouble, but the process is slow enough so that continuous monitoring is not needed. Freezeup and the water damage that ensues when pipes rupture can be sensed by thermostatic alarms, and many sites have been so equipped. Almost invariably though, freezeup is triggered by failure of a pump, motor, or control, and early detection or avoidance of these failures would reduce the number of occasions on which prompt and sometimes drastic action must be taken to prevent freezeup. Repair of heating systems in the bush is often hampered by lack of replacement parts, and emergency use of wood stoves and space heaters increases the risk of fire in a facility already under stress.

CAUSES OF MALFUNCTIONS

Early in the investigation it became clear that most malfunctions are thought to be triggered by electric power disturbances. Prolonged outages at occupied sites attract prompt remedial action, but voltage spikes, low voltage, or frequency deviations destroy electrical equipment without drawing attention. Low voltage events may be local in nature if heavy loads are placed on part of the distribution grid, and may not be detectable at the power plant.

Low voltage causes overheating of electric motors, and control relays chatter or fail to close firmly with consequent arcing damage to the contacts. Voltage spikes, caused by switching inductive loads on and off the grid, damage transformers and are lethal to the solid-state electronics in modern control systems. Frequency deviations of more than 5 Hz are harmful to electric motors, and shifts of only 1 Hz will cause automatic shutdown of radio navigation aids. While frequency shifts affect the entire power grid and can be detected at the power plant, they have no conspicuous effect on electric lights or small appliances.

MALFUNCTION MONITORING

Freeze-up of buildings with water or sanitary systems is the most frequent and costly malfunction at remote facilities that are unattended at night or over weekends. While they would appear to be easily preventable by a simple thermostatic alarm, attempts to implement the scheme have met with little success.

If the alarm is electrically actuated, freezeup following power failure will find the alarm unpowered, while fail-safe alarms activated by loss of a "happy" signal are also triggered by momentary power interruptions when freezeup is not iminent. Only a few false alarms are cause for local operators to disable the device. Location of the alarm presents a difficult choice. A bell atop the affected building draws wide attention from residents who are prone to silence it with a well-placed bullet if maintenance personnel fail to do so promptly by less permanent means. Alarms hard-wired to the residences of maintenance personnel go unheeded if no one is home, and redundant alarms in several residences invite the assumption that someone else will answer. Alarm thermostats mistaken for control units are vainly adjusted to control temperature by occupants unfamiliar with their function. Any but the simplest switch-and-bell electrical alarms are heir to the same damage from voltage spikes that frequently disable the heating system, and their maintenance adds another unwelcome burden.

Power disturbances are particularly troublesome at facilities served by smaller utility systems. Distribution grids extending throughout the village are susceptible to damage, tampering, and local overload over which the utility may have little control. In many cases the plant is old or poorly maintained, and the economic climate of the village cannot support the revenue required to modernize the system or attract skilled operators.

Highway camps do not have extended power distribution grids, and are less susceptible to disturbance than village systems. Maintenance is generally performed by well-trained personnel, and replacement parts are available without prolonged delay. Normal activity may, however, leave the camp nearly deserted during much of the working day, and power failure at such times may have drastic consequences if the maintenance crew cannot be summoned promptly.

The ultimate malfunction at an airport is loss of runway lighting or radio communication with an airplane on final approach at night in bad weather. Runway lighting systems are reasonably tolerant of voltage and frequency variations, but radio systems are not.

Power disturbances in village installations may be minimized by a dedicated transmission line connecting critical parts of the facility directly to the power plant if voltage disturbances are caused primarily by events on the grid. Devices capable of recording the number, severity, and duration of deviations in voltage and frequency, installed at the central plant and at various points in the grid, will disclose whether the dedicated line would be an effective solution or whether the plant itself is at fault. Disputes between utility operators and their customers have polarized both parties, and impartial evidence is needed.

If improvement of the power supply proves impractical or too costly, critical items can be protected by other means. Motors and controls can be isolated from power surges by regulating transformers or line conditioners at a cost ranging from $250 for units of .25 KVA capacity to $5000 for 15 KVA. Components too large to be economically isolated can be protected by voltage sensors that trip the unit off-line during a prolonged low-voltage event, either placing it back on line when normal conditions return or sounding an alarm if the event continues. Unfortunately, reliable data on the occurrence of these events is not now available, and estimates of the damage they are suspected of causing vary widely. Data is needed before the benefit/cost ratios of various levels of protection can be assessed.

Quite elaborate voltage protection schemes may be justified if human life is at risk. Some 50 FAA radio facilities in Alaska are buffered against local power by storage batteries charged from the grid, with an inverter built to high standards providing the closely controlled power required by the electronic equipment. Battery capacity is adequate to carry the load for several hours after a local power failure. Cost of this uninterruptible power system is roughly $3000/KVA-hour. Monitoring equipment detects failure of any of the radio transmitters, and also senses temperature of the enclosure at remote sites. Since VHF radio signals cannot be received by distant ground stations, a leased Alascom satellite telephone is used to transmit monitored information to control sites. Even though equipment of the highest quality is used, false alarms and other problems in the monitoring system occur frequently and account for the majority of maintenance events. A thorough study of airport lighting requirements (2) suggests several classes of protection, including a continuously running organic vapor turbine ready to pick up the runway lighting load if power is lost at a village airport.

PERFORMANCE MONITORING

The "unnoticed" losses caused by fuel or water leaks, excessive infiltration of cold air, poorly adjusted furnaces, or careless energy management are amenable to detection by more elaborate monitoring. A typical system would meter use of fuel, water, electric energy, and degree days of heating load, for daily transmission to a central site. Any change in the use of electric power and water not matched by a change in use of the facility, or a rise in fuel consumed per degree day would indicate abnormal operation that should be checked if it persists. As a further refinement, weighting the data against the size and level of use of the facility would provide a comparison between various installations of similar character to see if any have significantly better or poorer than average efficiencies. Data could be taken by visual observation of simple meters and reported by telephone, but these seemingly unimportant tasks tend to be done casually or not at all in the bush environment. Monitoring equipment of this class must be designed to require no action on the part of remote site personnel.

Alyeska Pipeline Company employs quite elaborate monitoring systems to check the performance of equipment at pump stations, and computer programs calculate operating efficiencies of pumps, gas turbines, and other items are under development. In an operation of such scale it is economical to replace units when their efficiency drops below an acceptable level even though only a fraction of their life to failure has been used. Continuing increases in the cost of fuel may one day make this practice justifiable at remote facilities administered by the state.

Three maintenance philosophies, called Scheduled Maintenance, On-Condition Maintenance, and Condition Monitoring, are lucidly described in Reference 2. Scheduled maintenance is the familiar process of changing oil in engines after a specified number of operating hours, whether the oil looks dirty or not. It is well suited to equipment whose breakdown would be life-threatening or costly to repair. On-condition maintenance is typified by replacing light bulbs only when they burn out, and obtains maximum service life from items whose failure has no serious consequences. Condition monitoring involves instrumentation to test the performance of a component, replacing it when symptoms of approaching failure are detected or its efficiency falls below an acceptable level. Most remote facilities in Alaska employ scheduled maintenance for power plant equipment and on-condition maintenance for nearly everything else, with even power equipment occasionally defaulting to the on-condition mode.

In theory, monitoring would not be needed if scheduled maintenance were carefully planned and religiously performed, for all components subject to failure would be replaced before their expected lives had been used. Alarm signal monitoring is a valuable backup for imperfect scheduled maintenance and for on-condition maintenance where component failures, not in themselves dangerous, can lead to catastrophic consequences if long undetected. Condition monitoring maintenance requires monitors that transmit numerical data as well as simple on-off signals.

In the bush environment simple on-off alarms with local readout are useful, and are indeed designed into many existing installations.

Widespread use of condition monitoring may be feasible in the future, but for the present should be tested at accessible sites where "ground truth" is available to check its performance.

A PLAN OF ATTACK

1. A clear-cut need exists for special monitoring systems to determine the causes and severity of power fluctuations widely cited as a major cause of costly repairs and facility down time. Since continuous recording of voltage and frequency will require excessive data storage, the devices should be triggered only when an abnormal condition is sensed, recording the nature of the event, its duration, and severity. The recording devices should require no attention from local operators, be independent of the power grid for their operating energy, and be capable of storing a month's data in a form suitable for computer processing without change of the recording medium. Three of these units would be required for a typical village; one at the power plant, another at the DOTPF or other state facility concerned, and a third at some intermediate point in the power grid. Two units would suffice for a highway camp, one at the power plant and another at the most remote point in the power grid.

Commercially available devices can perform these functions, but they must be selected with care and packaged to survive transportation and operation at the remote sites. No maintenance whatever can be expected, for local operators have little patience with instruments that serve no obviously useful function.

From the data it will be possible to establish whether power line voltage and frequency variations are indeed the common cause of malfunctions that they are reputed to be, and whether they are caused by improper regulation at the power plant or generated on the grid by consumers. With this knowledge a choice may be made between improved power plants, dedicated transmission lines, voltage surge protection or voltage or frequency insensitive equipment as the most cost-effective means of dealing with the problem.

2. A simple, standardized low-temperature detection and alarm device may be all that it is practical to develop for on-site malfunction detection. Individual facilities vary so widely in the type of water, heating, and sanitary systems employed that local alarm

monitoring beyond that provided by the original designers or improvised by operators would have to be tailor-made for each application. One-off designs are difficult to ensure trouble-free and costly to develop, but enough application exists for freezeup alarms to justify a standard design suited to the bush environment. Ideally, it should be a tamper-proof box that will transmit a signal to recievers small enough to be carried about easily or moved from house to house as duty personnel are rotated. If many spaces are to be monitored a coded output will identify the space in distress.

Since transmission ranges need be only a few miles, a radio link between sensor and alarm unit would be ideal, but the external antenna required for monitoring a metal building may be an unacceptable addition to the maintenance burden. A carrier signal transmitted through the power grid could also serve if means can be found to protect the system from voltage surges.

Development of the freeze-up alarm should begin with a review of commercially available systems simple and durable enough to survive in the bush environment, and testing of the most promising candidates to ensure that they will not be damaged by power disturbances. It is imperative that they never give false alarms, for remote site operators will quickly discard them if they do. Failure to detect one freeze-up in ten is an acceptable price for this attribute if the system is left intact to try for the other nine.

3. Foreseeing the day when efficient energy use may justify its cost, it is time to begin development of an energy use monitoring system. Measurements of fuel, water, electric energy, and degree days, with daily transmission to a central site, would constitute the minimum useful system. Many of the components may be purchased off the shelf (flowmeters, wattmeters, etc.) and the hardware to be developed concerns means for encoding, storing, and transmitting their data as well as selection of a non-interruptible power supply that will prevent outages from being interpreted as periods of zero fuel consumption. At the first level of development the system might

be tested on a city residence or other small structure close to the laboratory. With the basic instrumentation operational, a field test at a nearby highway camp, perhaps using an autodial telephone line for data transmission, will test its practicality in field use and doubtless suggest additional quantities to be measured to enhance its utility (i.e. wind velocity, insolation, etc.). When the system is thoroughly tested and developed to a level that needs no local operator attention, installation at a truly remote facility using a radio data link (1) might be tried. At this level the cost of establishing a widespread energy monitoring network can be estimated, and compared with the benefit in reduced fuel costs that might ensue.

REFERENCES

1. T. Roberts, R. Merritt, K. Kokjer. Low Data Rate Digital Transmission Techniques for Alaskan Applications. DOTPF Report AK-RD-81-6.

2. CH2M Hill. Remote Airport Lighting Systems Feasibility Report and Design Guide. Alaska Department of Transportation and Public Facilities, Research Section.