Abridgment

Summary of Research on Data Collection Systems for Maintenance Management

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Data acquisition technologies and telecommunications offer maintenance field managers convenient procedures for entering data into the maintenance management system. Many of these technologies offer the potential for daily if not real-time retrieval of information (emergency work orders, equipment availability, and effectiveness of different maintenance methods) and help improve field operations and inventory management and control. Among the technologies are lap-top and hand-held computers, electronic tablets (clipboards), bar coding, voice recognition, and navigational and locational devices such as distance-measuring instruments and satellite global positioning system receivers. This equipment, when combined with telecommunications such as cellular and satellite, can be molded into discrete data acquisition systems for (*a*) daily cost reports (accomplishments, location, labor, equipment, and materials), (*b*) inventory management and control, (*c*) roadway feature inventory updating, (*d*) inputs to short-run scheduling, (*e*) bridge inspection and maintenance reporting, and (*f*) monitoring of snow- and ice-control operations in remote locations and heavy snowstorm conditions.

The objective of NCHRP Project 14-10, *Improvements in Data Acquisition Technology for Maintenance Management Systems*, was to identify the latest technological means to acquire, record, verify, transmit, and receive field-related data for maintenance management systems. The project sought to identify requirements for field data collection and develop system designs for a variety of maintenance data collection activities (*1*). That research is summarized here.

DATA COLLECTION SYSTEMS

A variety of practical, fairly rugged, commercially available data collection technologies can be combined into field systems to enhance the effectiveness of crew leaders and their supervisors. Field systems can be composed of data entry and retrieval equipment [lap-tops, hand-held computers, electronic tablets (clipboards), bar code scanners, and voice recognition] in combination with navigational and locational devices [satellite global positioning system (GPS) receivers and distance-measuring instruments]. Telecommunications, such as regular phone, cellular phone, and low data rate satellite transmissions, can enhance data transfer to and from distant or remote locations.

The following systems are summarized: crew-card data collection, inventory management and control, roadway feature inventory updating, inputs to short-run scheduling, bridge inspection and maintenance, and monitoring snow-removal equipment.

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Crew-Card Data

Two field data collection systems for daily work reporting were developed, one for outdoor field use and the other for inside a vehicle. Figure 1 shows a portable field data collection system for outdoor use. A hand-held portable data entry terminal, perhaps with integrated bar code reader, might serve as the data entry device. The feasibility of a bar-coded crew card was tested in equipment demonstrations conducted for field managers. The crew card required no writing or keying of data or performance of calculations, but only the scanning of bar codes. Field managers were receptive. Many also responded favorably to using an electronic clipboard to enter crew-card data. Thus an electronic tablet, lap-top, or some other suitable device might work just as well or better depending on the application.

Location information could be obtained from a GPS receiver. The in-vehicle system that was designed indicates that either a distance-measuring instrument or a GPS receiver could be used to enter the location of the work site. Data could be transferred daily to the host computer by an appropriate method such as removable memory, an RS232 cable, or a docking device for the data collection terminal.

Maintenance field workers could retrieve useful information daily from a terminal located at the staging area where they report to and leave work. Most data collection devices allow data retrieval from the field by using cellular phone.

The types of data a field manager could retrieve from the maintenance management system include comparative efficiency of different maintenance methods, urgent and emergency work orders and related information, availability and location of equipment and materials, budget balances for maintenance activity by management unit, and planned versus actual work.

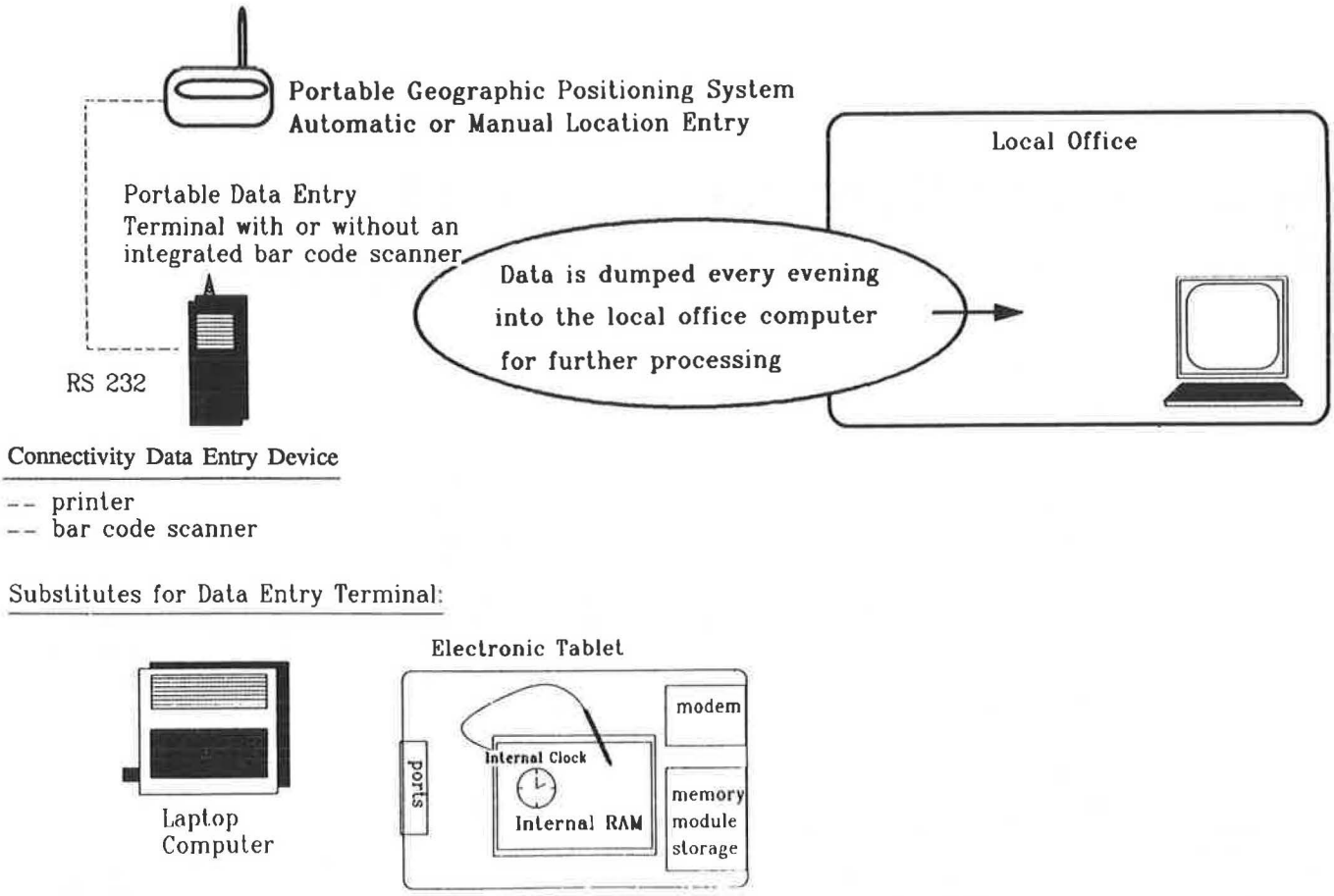

FIGURE 1 Portable field system for crew-card data.

Inventory Management and Control

Given the receptivity of maintenance managers to bar coding, it was concluded that a state or local agency could easily justify implementing a physical asset inventory management system based on bar codes. Among the assets that might be included in this system are vehicles, equipment, office furniture, and selected tools. Maintenance organizations typically use a checkoff list to take inventory and later enter the results into a computer. Use of a hand-held computer with a bar code scanner would greatly speed the process of taking inventory and improve its accuracy. The cost and convenience of applying bar code labels to physical assets would determine the scope of items that could be covered in the inventory system.

Bar codes, and perhaps complementary forms of data acquisition, could be used for a material inventory management system. Material inventory management is much more complex and costly, and may be warranted only in selected circumstances. The rule of thumb in private industry, however, is a payback period of 1 year or less.

In a material inventory management and control system for a large warehouse and maintenance yard, stockkeepers might use a variety of hand-held or fixed terminals with bar code scanners to record inventory transactions. Demand-responsive or serial bar code label printers, or both, could be placed strategically in warehouses to provide labels. Electronic scales could be used to measure odd lots and small parts, which could be labeled with bar codes and scanned once placed in plastic bags. In special situations radio frequency links between portable data entry devices and the host computer may be warranted. Bar-coded personal identification cards might provide access to gasoline and record who withdrew each quantity of fuel. Radio frequency identification tags placed on trucks could help provide access to bulk materials and furnish estimates of usage. In special instances a truck scale might be justifiable for determining the amount of bulk materials removed.

A significantly improved inventory management system would not only serve accounting, financial, and upper management functions, but could also provide rapid, accurate information for maintenance field managers. Information that field managers might desire, besides equipment and material availability and location, includes unit costs, status of materials on order, and repair history of a vehicle.

Roadway Feature Inventory Updating

Maintenance field managers, partly because they know the road so well, frequently have responsibility for updating roadway feature inventories, especially maintainable features. Agencies that rely on measuring elapsed distance from known

reference points will continue to use distance-measuring instruments in building roadway feature inventories. An in-vehicle system for updating the inventories would involve some type of data entry device used with a distance-measuring instrument.

If an agency implements a geographic information system (GIS), location information should be expressed in latitude and longitude. This research project identified a prototype system, similar to that being developed under the 38-state GPS/GIS project, for establishing a base inventory including maintainable features. Updating could be accomplished with the same type of data collection system proposed for collecting crew-card data, including the use of a GPS receiver to establish latitude and longitude. More accurate and costly systems would involve differential processing with a second receiver located at a known reference point and a specially designed van for routine feature updating throughout an entire highway district.

Inputs to Short-Run Scheduling

Maintenance field supervisors need to consider a variety of information for short-run scheduling of maintenance operations. Maintenance deficiencies and problems identified while traveling to and from work sites or while patrolling must be combined with citizen complaints, pavement condition and distress surveys, and planned maintenance work based on the annual work program.

A lap-top, hand-held computer, or electronic tablet can potentially be used to combine these data for viewing and consideration by the maintenance field supervisor. The source of location data can be a GPS receiver or a distance-measuring instrument. Software that can assist the field supervisor in setting priorities and determining if needs are being met would be part of the system.

Bridge Inspection and Maintenance

Bridge maintenance work orders are often a direct result of bridge inspection. Also, bridge inspection reports frequently include written reports, sketches, and photographs. To date, pen and paper and a portable camera have proved to be the most suitable tools for recording bridge inspection information.

The recent appearance of electronic tablets capable of handwritten data entry and receiving and transmitting images suggests that there now may be a more efficient approach to bridge data collection. By using an electronic tablet, bridge inspectors could record standard inventory and appraisal information, make sketches, and furnish written comments, including maintenance and repair recommendations. A digital still camera could take photographs, and, potentially, digital images of the bridges could be transmitted and received by means of a cellular telephone. Locational information could be obtained from a map displayed directly on the screen or acquired using a GPS receiver. The internal clock in the clipboard could "date and time stamp" data.

In a data collection system with two-way communication between the field and the headquarters computer, an inspector could retrieve bridge inventory and appraisal data, predicted future condition, repair histories, progress on current work orders, and other useful information.

Monitoring Snow-Removal Operations

Snowplows and blowers operating in heavy snow conditions in remote and many rural locations occasionally collide with cars buried under drifts or slip into a ditch or ravine, sometimes disabling or killing the operator. There is a need to be able to quickly locate snow-removal equipment and injured operators when an accident occurs.

The technology and telecommunications examined in this study suggest a solution to this problem. Inexpensive sensors, a low data rate satellite transmitter, and an omnidirectional antenna can be placed on each snowplow or blower to transmit information on the snow-removal equipment's status to a central monitoring facility. The information that might be transmitted includes location and whether the equipment is moving, the engine is operating, and the snowplow or blower is upright or tipped over.

FURTHER EVALUATION, TESTING, AND IMPLEMENTATION

The technology assessment and the system designs developed in this research represent a first step toward automatic data acquisition and retrieval by maintenance field managers. Although vendor product specifications indicate that equipment is available to withstand rugged, outdoor conditions, practicality and user acceptance must be demonstrated in day-to-day maintenance data collection activities.

Maintenance field workers will welcome improved data collection and work-reporting procedures provided the procedures are simple; result in significantly less paperwork; and provide timely, easily accessible, and valuable information not previously available. To be accepted by maintenance field workers, the new procedures must be perceived as clear benefits to them and not as instruments of increased control and monitoring.

It is not enough that the data collection devices work in the field. They must work as part of a system that provides two-way communication, meets the needs of the field manager, and serves the objectives of maintenance management. Thus the data collection systems as a whole require field testing and evaluation. This research, therefore, calls for further evaluation and testing, including an assessment of the circumstances under which the value of each system and its practical variants exceeds the costs. Further evaluation should lead to the implementation of cost-saving data acquisition systems.

REFERENCE

1. W. A. Hyman, A. D. Horn, O. Jennings, F. Hejl, and T. Alexander. *Improvements in Data Acquisition Technology for Maintenance Management Systems*. NCHRP Report 334. TRB, National Research Council, Washington, D.C., 1990.