AUTOMATED INSPECTION OF EARTHWORKS FOR HAZARDOUS WASTE STORAGE

Gregory B. Baecher
Philip G. Greenspun
Walter E. Gillett
ConSolve Incorporated

119 Binney Street
Cambridge, Massachusetts 02142

ABSTRACT

Construction inspection for quality control and quality assurance is central to ensuring compliance to contract standards and to assuring owners that work has been done right. This is especially true on critical facilities where inadequate performance can have severe consequences, for example, in the construction of earthworks to contain hazardous waste. On these jobs, intensive quality assurance (QA) data are demanded both by regulatory authorities and by owners.

Traditionally, QA inspection has been done manually, with sometimes large crews of surveyors and inspectors. On some jobs the inspection crew has numbered as many as 1/3 the total staff on site. The process is labor intensive, time-consuming, expensive, and prone to error. Inspection can also delay other construction activities and thus have indirect costs.

A new, automated system has been developed for streamlining QA inspection. The system directly links real-time location measurement and electronic data entry to terrain analysis software running on an on-site engineering workstation. The system substantially decreases inspection cost, while reducing errors and providing continually updated information to management. On modest size projects the system has a payback of four to six months. To date, the system has been used primarily in construction control of engineered waste disposal facilities and in characterization of uncontrolled waste sites, but applications to broader construction problems are being pursued.

BACKGROUND

Surveying, site characterization and QA inspection are important parts of hazardous waste site remediation, but also increasingly expensive parts. High quality, precisely located data are the foundation for good design and effective remediation. Getting those data with surveyors and inspectors in full protective clothing or on difficult terrain, however, is difficult, costly, and time consuming.

One approach to the problem of obtaining high quality site characterization data while controlling cost is to automate surveying and site characterization functions. Considerable work is now underway to develop and install automation systems for surveying and environmental sampling. These systems are used to gather data of many types from dispersed locations at a construction site. The systems work in real-time, and are linked by data radio to terrain analysis software. This terrain analysis software is in essence a site model combined with a spatial database. The benefits of the systems are (1) reduced man power to perform site characterization, construction inspection, and other aspects of project control, (2) improved data quality and completeness, (3) real-time information, and (4) lessened worker exposure to hazardous conditions. In special cases, the system monitor survey vehicles as they move about a waste site, tracking precise location as data are gathered. This feeds time streams of arbitrary x,y,z located information to the terrain data base, where the data are used to continuously update site models. The result is timely, high quality data at a fraction of the cost of manual surveys.

Recent experience with defence and industrial end-users suggests that automated data collection and inspection systems may have broad applications to improving facility management, and streamlining the operations of field inventory control and marshalling yards.

AUTOMATED DATA COLLECTION

Automated data collection has fostered a revolution in the factory. In large measure, automated data collection has been the enabling technology behind factory automation. The availability of data has allowed improved schedule and materials control, tied the factory floor to management, and laid the ground work for computer controlled machine tools and robotics.

In the past few years, automated data collection has similarly fostered a revolution in logistics. Significant efficiencies in transportation, inventory control, just-in-time scheduling, and related operations have been effected through the relatively straight forward concepts of bar coding, real-time radio-linked data entry, and transaction processing. In 1988, over a half-million real-time data loggers were sold in the US for factory and logistics applications, and automation systems built around such data logging are advertised to have payback periods as short as a few months.

Automated Data Collection in Construction

Construction and related "outdoor" industries have benefitted little from this technology. The principal reason is not "industrial conservatism," but that available technology only works effectively in well-structured environments, while most construction users operate in "less-than-well-structured" environments.

Surveying is the one exception to the rule, and the reason, arguably, is that surveyors themselves provide the well-structuredness to field environments that automation requires. Surveying experienced a rush of new technology in the 1960's and 70's. Most surveyors now collect data in electronic notebooks, which are downloaded in batch to CADD systems. This has greatly improved productivity for survey functions, but misses the main opportunity of,

(1) collecting data of importance to <u>operations management</u>, and

(2) providing data in <u>real-time</u> that can be linked to materials, schedule, and quality control.

It is probably not far fetched to predict that surveying itself is on the threshold of another technological revolution that will both profoundly affect surveying practice, and bring it closer to the automated data collection systems needed for construction management. This next revolution will be driven by the availability of <u>mass market,</u> real-time positioning (e.g., kinematic GPS, and potentially certain terrestrial technologies) and the appearance of intelligent terrain analysis computer systems.

Data Collection Systems for Construction

If one accepts the hypothesis that automated data collection in "outdoor" industries has been inhibited by unstructured environments, then the first thing a data system must do is impose structure on a site. An obvious way of imposing structure is to define spatial location against a Cartesian reference, and then associate objects and activities to that reference. This requires two technologies, first, some system by which real-time Cartesian locations can be monitored, and second, a spatial data base incorporating that reference. Integrating these two technologies with standard, programmable data logger hardware provides the rudiments of a system which can function in the real world of construction (Figure 1).

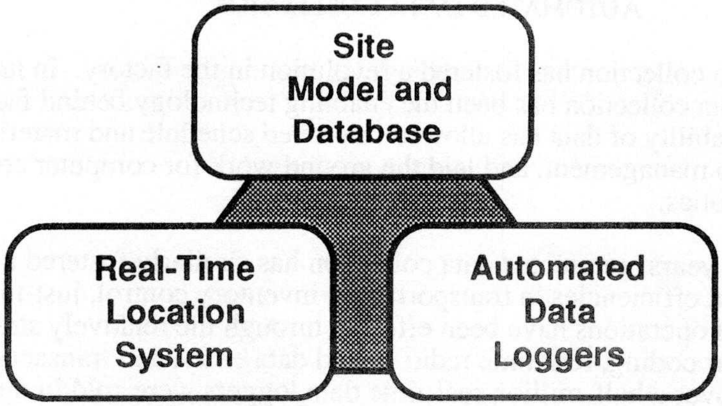

Figure 1--Components of Automated Data System for Construction.

Real-Time Location Systems

At present, neither real-time location nor flexible spatial databases are available in data systems developed for factory or warehouse use. These need to be specially developed and tailored to construction requirements. Location systems of various sorts are at present available and, with customization, can used on construction projects. A suggestion of available technology and its cost is shown schematically in Figure 2. For construction inspection and control uses, precision better than ±5cm is usually needed. For surveying, better than ±3mm is usually needed.

Today, the most cost effective location systems are based on various forms of radio triangulation. Such systems can be installed for $10,000 to $20,000, and provide x-y precisions of better than ±3-6cm. With sufficient topographic relief, similar precision in z is possible, but on most sites vertical control has to be provided separately. The fixed cost of installing receivers at a site is the bulk of the expense; the marginal cost per mobile unit monitored is quite small.

An important development to watch for the future is experience curve cost reductions affecting Global Positioning System (GPS) hardware. Given the mass market opportunities for GPS, cumulative production volumes in the hundreds of thousands or millions of units are not inconceivable by the middle of the 1990's. This could mean unit prices for GPS receivers in the $1000 range, producing relative x-y-z precisions better than ±5mm.

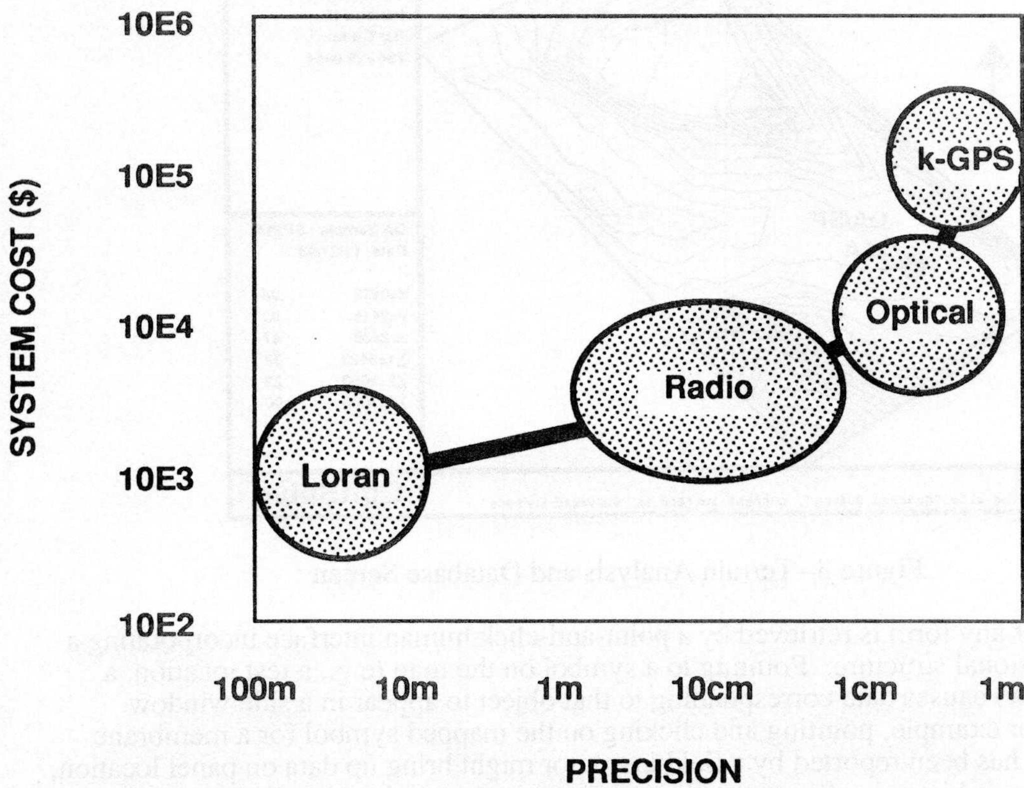

Figure 2--Schematic overview of existing location technology.

Terrain Model and Database

Data from data loggers can be downloaded to a terrain model and database either real-time or batch. This software typically runs on an engineering workstation in the project trailer, or at a remote site such as a home office. Query capability from the field can also be provided. The terrain model maintains all QA and related site data on a project, and may also interface to CAE systems to provide data for design, and design information for construction.

The terrain model and data base developed in our work uses an "intelligent map" of the project site, with an customized, project specific application layer running on top. The data base is object-oriented, which means graphic and non-graphic data can be linked to objects on the site map. The system is not a CAD tool, but a workbench more akin to an electronic spreadsheet. As needed, the system displays information graphically, and can be interfaced to commercial drafting, database, and analysis packages (e.g., AutoCAD, Oracle, or Lotus).

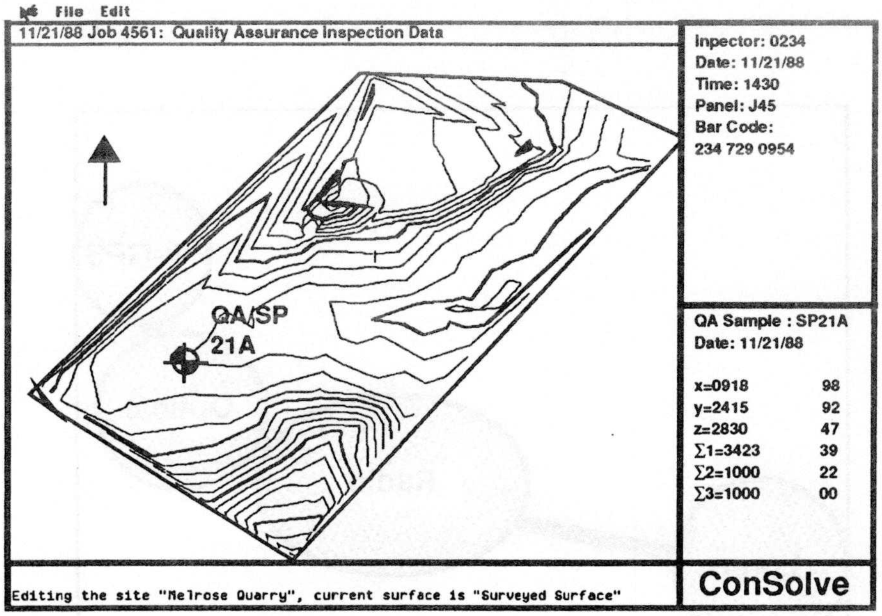

Figure 3--Terrain Analysis and Database Screen

Data of any form is retrieved by a point-and-click human interface incorporating a hypertext relational structure. Pointing to a symbol on the map (e.g., a test location, a membrane flaw) causes data corresponding to that object to appear in a side window (Figure 3). For example, pointing and clicking on the mapped symbol for a membrane liner flaw that has been reported by a field inspector might bring up data on panel location, size, cause, repair history, who reported it, who repaired it, and so on. Pointing and clicking on the panel location in this data window will retrieve data pertinent to the panel itself, for example, manufacturer's lot number, when it was laid down, who did the welding, and so on.

The architecture of the system is shown schematically in Figure 4. The user interacts with a object-oriented map showing a plan or sectional view of the site. The map interface interacts, in turn, with a generic electronic map substrate and with a project specific applications layer. Each of these has access to the set of objects entered by users, and to data of any form associated with the objects. Three support modules can be called from the map substrate, a rule-based inference module, a set of analytical tools, and a simulation engine. While a certain number of generic capabilities are built into these modules, some customization is usually required to meet the needs of a specific project.

USER ECONOMICS

The payback period for automated data collection systems on a typical site remediation project can be as short as a few months, depending project size and hazards posed to field personnel. Depending on the complexity of the installation and required customization, data system costs start at $50,000.

On the other side of the equation, both tangible and intangible benefits are gained from data systems. The more obvious are,

- Reduced man-power needed to measure data locations.
- Reduced wait time while data locations are being measured.
- Streamlined data entry.
- Reduced errors and omissions in field data.
- Reduced call backs to collect overlooked data.
- Elimination of time and error due transcribing data into the computer database, and rechecking entered data.
- Reduced time preparing daily or weekly reports and maps.

Often, unanticipated benefits are identified once a system is installed. Many of these derive from the integration of data collection with CAE.

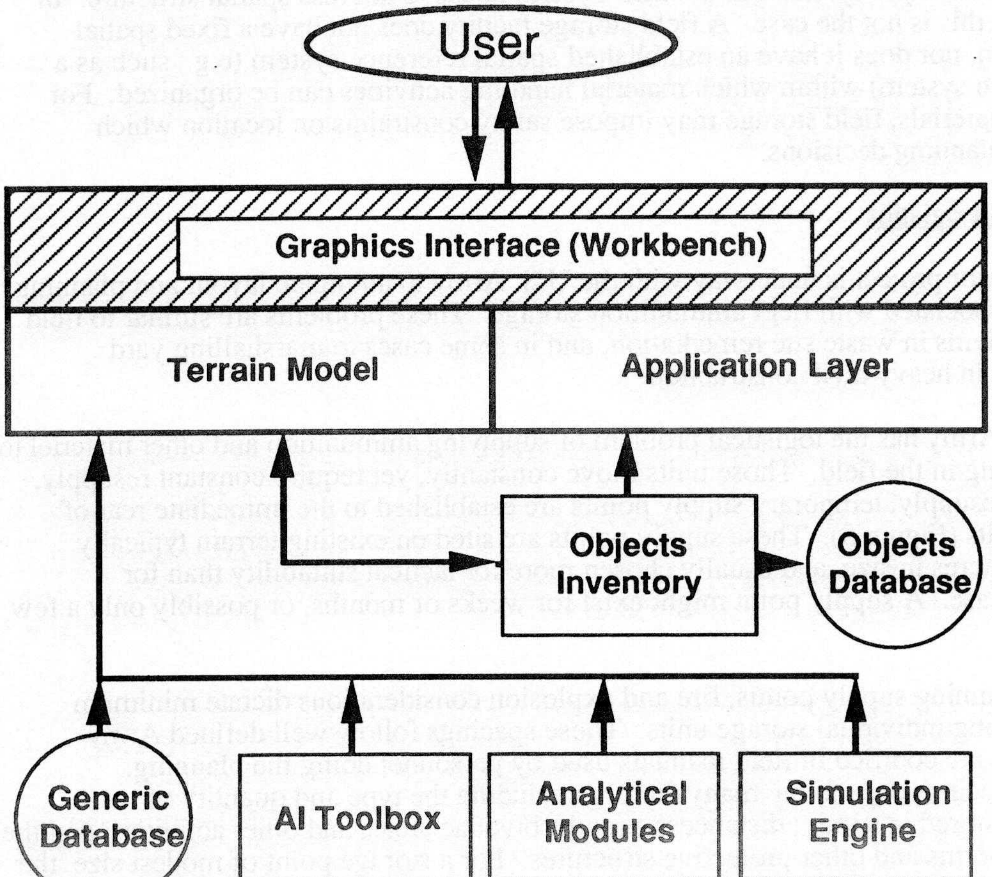

Figure 4--Site Model and Database Schematic

Quantitatively, the cost savings on a particular project depend on project specifics. Typically, a person making measurements has to be supported by someone shooting or taping his location. Thus, at least one person and sometimes many people can be eliminated from field crews. Similarly, office personnel who transcribe data, draw maps, and compile reports can be partially eliminated. Automated data systems also increase the efficiency of inspectors themselves. Summed over all activities, a data collection system usually eliminates at least two people from even a small size job. On a larger job, greater reductions are typical. The savings due to replacing one technician is about $50,000 per annum. Thus, a data system pays for itself in 6 months on small jobs, and in as little as two months on larger jobs.

FIELD STORAGE AND MARSHALLING YARDS

In addition to straight forward inspection and QA, automated data systems have proved useful in a a variety of ways that were not apparent at first. One of these is in the area of field logistics planning. Field storage and marshalling yards are usually established on natural terrain. As with other construction operations, such sites lack spatial structure. In traditional warehousing, structure is taken for granted. When inventory is received at a loading dock or moved into bin storage, corresponding locations are fixed before the fact. Neither the data input system nor the MIS system needs to address spatial structure. In field storage this is not the case. A field storage facility does not have a fixed spatial configuration, nor does it have an established spatial reference system (e.g., such as a numbered bin system) within which material handling activities can be organized. For hazardous materials, field storage may impose safety constraints on location which complicate planning decisions.

Field Logistics

A major project is underway with the U.S. Army to automate layout and planning operations associated with field ammunition storage. These problems are similar to field storage problems in waste site remediation, and in some cases to marshalling yard management in heavy civil construction.

The Army has the logistical problem of supplying ammunition and other materiel to units operating in the field. Those units move constantly, yet require constant resupply. To provide resupply, temporary supply points are established to the immediate rear of operating units (Figure 5). These supply points are sited on existing terrain typically hundreds of acres in size, and usually chosen more for tactical suitability than for operational ease. A supply point might exist for weeks or months, or possibly only a few days.

In planning supply points, fire and explosion considerations dictate minimum spacings among individual storage units. These spacings follow well defined Army doctrine, and are codified in field manuals used by personnel doing the planning. Minimum spacings depend on many factors, including the type and quantity of ammunition stored in a unit ; distances to roads, bivouac areas, and other activities; and the presence of berms and other protective structures. For a storage point of modest size, the level of complexity in simultaneously balancing such requirements across an entire site is considerable. For example, a site of reasonable size has thousands or tens of thousands of distance set backs that must be satisfied (the number increases as the combinations of the number of storage units). In addition, terrain features, such as drainage and ponding areas, slope angle, and soil and vegetation distributions all affect how a site can be laid out. In most cases not all the constraints can be satisfied simultaneously.

When a trained person lays out a supply point on a paper map, human perception can be used to simplify the design problem. Many terrain analysis aspects of the problem, such as the identification of stream channels or steep areas, can be achieved by visual inspection. Storage units that are widely removed from one another can be ignored in calculating quantitative set backs against requirements. Yet, even with such short cuts, a detail layout can take man-weeks of time.

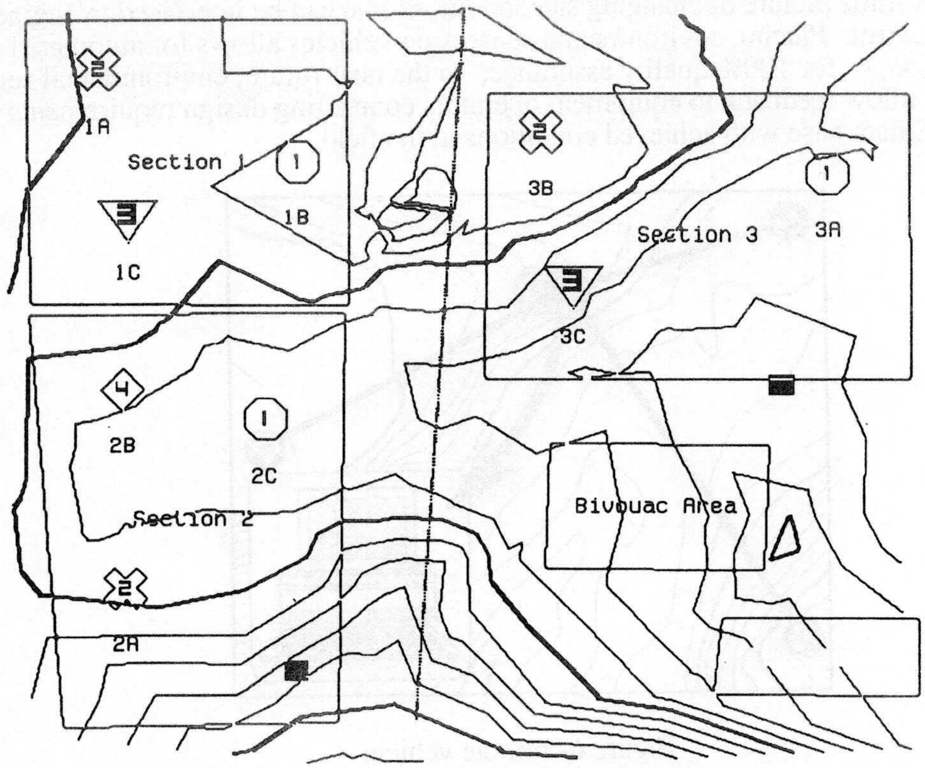

Figure 5--Ammunition Supply Point layout

Using automated data collection systems integrated to a special purpose CAE applications layer running on top the terrain model and data base, great efficiencies can be achieved in, first, gathering the field information needed for planning decisions, and second, in laying out a facility that best conforms to codified requirements. The layout can be interactively designed on the electronic map interface that addresses site information, while analysis and advisor modules run in background to check tentative designs against requirements. In essence, the automated data collection systems becomes an highly interactive, intelligent terrain analysis system, with real-time link to field data. Direct experience demonstrates that, with the system, a supply point can be laid out in a few hours, and in greater conformance to Army doctrine than usually achieved manually in several man-weeks.

Interface to Vehicles and Equipment

It seems apparent today that the next generation of automated data collection technology will involve vehicle monitoring. This allows large numbers of data to be continuously collected, not only on site conditions, but also on vehicle operations and maintenance.

Vehicle Monitoring Surveys

Every vehicle on a construction site potentially provides a time-stream of valuable data for site control. As a vehicle moves over the ground surface its time-stream of x-y-z data provides a locus of topographic points (Figure 6). As a motor grader, dozer, or excavator undertakes some function, its time-stream of x-y-z data provides geometric information on as-built conditions. Monitoring the location and configuration of vehicles provides a real-time picture of changing site conditions that can be interfaced to engineering and project control. Placing environmental sensors on vehicles allows for automated site characterization, or for 100% quality assurance. In the near future, environmental sensors will probably allow feedback to equipment operators contrasting design requirements read from the CAE data base with achieved conditions in the field.

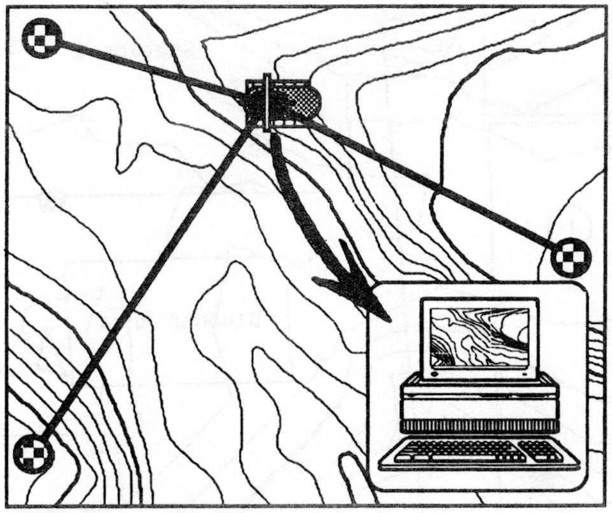

Figure 6--remote vehicle

Detailed Archival Record Keeping

There is a continuing trend in site remediation work toward ever more detailed quality assurance record keeping. Regulatory agencies at all levels require detailed data, and will certainly demand more rather than less detailed data in the future. Increasingly, legal departments in engineering and construction firms are also demanding detailed data, not to assure compliance, but as protection in future litigation. Automated data collection tied into well-organized computerized site models provide a platform for archiving detailed operations data. Location and operations data collected off vehicles or personnel can be retained on mass storage media (e.g., optical disks or digital tapes) to provide a chronicle of all activities, all environmental information, and all engineering data collected during even an extended project. Fedback as input to an operations simulator, detailed historical information can be quickly retrieved for any stage of project life.

CONCLUSION

Automated data collection and management for field operations places new demands on technology, compared to related activities in the factory. Yet, the potential benefits of automated systems have been clearly demonstrated. The keys to automated data systems for the field are real-time, precise location technology, and a new generation of terrain analysis and database software. Both are available today, and their technology is quickly advancing.