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GIS in the utilities

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This is a time of major change in the utility industry. Privatisation, deregulation, and the introduction of advanced technology are all having profound impacts on utilities. This chapter examines how GIS has been used by electrical, gas, and water utilities. It focuses on automated mapping, facilities management, and geographical information systems (AM/FM/GIS). Critical utility applications include map editing, creation of map products, facility query and display, design/work order processing, network modelling, and executive information systems.

The costs and benefits of implementing AM/FM/GIS in utilities are briefly examined. It is concluded that any assessment of the impact of GIS on utilities must look at the wider political and economic considerations of competition and change.

1 INTRODUCTION

Utilities throughout the world are facing unprecedented change. Privatisation of government-owned utilities, competition for wholesale and even retail customers, and mergers and acquisitions have added new elements of risk to the management of utilities today. No longer are energy and water providers able to rely on regulatory protection of territory and customers; those who are not affected by direct deregulation are facing increasing awareness by their key customers of price and service options. New tools and strategies are required for capital-intensive companies to stay competitive in the marketplace. Better use of spatial data is one of the key areas of focus for many electrical, gas, and water utilities.

Improved hardware, software, and networking technology have created opportunities for the utility industry to build and benefit from more comprehensive and sophisticated GIS. GIS applications have evolved from their foundation in map production to advanced analysis tools for planning and operations. GIS products are commonly used by utilities for marketing, facilities location, and engineering applications (Birkin et al, Chapter 51). There are two common objectives of these applications: driving down costs and improving customer service.

This chapter provides an overview of how GIS is being used in the utility industry to help meet today's needs. It begins with a brief discussion of how GIS has evolved in electrical, gas, and water utilities to its current technological state. The principal focus of the chapter is a discussion of the current state of AM/FM/GIS, including a description of GIS data sources, critical traditional and non-traditional applications, and costs and benefits. The chapter concludes with a brief section on how GIS implementation may impact upon competition and change in the utility industry.

2 EVOLUTION OF GIS IN THE UTILITIES

The primary goal of any utility is to plan and manage the use of facilities to deliver a commodity such as water, natural gas, or electricity to its customers. The utility industry has always relied on hardcopy maps to manage facilities, so it was natural that electric, gas, and water companies should be among the first users of digital mapping software.

The earliest efforts at automation during the 1970s and early 1980s were focused around producing digital maps. Since this was largely a graphics-driven task, most utilities chose Computer Aided Design/Drafting (CAD) software as the basis for systems which came to be called Automated Mapping/Facilities Management (AM/FM). A number of approaches geared to map reproduction were taken, based around the CAD technology of the era. The original use of this technology was expensive, with costs ranging from US$ 50 000 to 100 000 per user and more. Long range benefits were projected, but rarely realised owing to the limitations of the available technology, which centred on the problems of linking databases to sets of graphic primitives.

Among systems in use during this time frame, one mainframe-based system was developed which focused on a data modelling approach to the problem. Called Geo-Facilities Information System (GFIS), this technology built an elegant and comprehensive model of facilities networks, using IBM's IMS database technology to house the data model. Despite the expensive nature of the solution, it was popularised by several large utilities in North America and Europe. Many observers credit this IBM system with the first true network model usable for tracing electric circuits, gas, and water networks, and for allowing performance analysis of network models (Antenucci et al 1991).

As mid-range, minicomputer-based systems became popular replacements for mainframe-based technology, AM/FM systems which relied on hierarchical or network data models for representation and storage of facilities data began to exploit this new platform. Relational database technology came to the forefront in the mid 1980s. In a separate field of endeavour, GIS were popularised in the early 1980s, largely in the purview of land and natural resource management (Coppock and Rhind 1991). These systems were geared towards abstracting different layers of information about a geographical area and providing a topological model (i.e. a representation in which spatial relationships among geographical features could be analysed: see Martin, Chapter 6). By the late 1980s, many utility users of AM/FM began to embrace the ideas of GIS, using the georelational technology to model and map facilities and land. In this model, spatial definitions of land and facilities are stored in terms of their coordinates in binary flat file format, while attributes about those entities are stored in relational database management system (RDBMS) tables (see Oosterom, Chapter 27). The ability to relate customer and accounting systems to spatial representations of the facilities in a service area (area covered by a utility) transformed a mapping system into an information system.

Like many popular acronyms, both AM/FM and GIS have come to assume very broad definitions, perhaps even broader than their originators intended. Many use the term GIS to mean the entire system of hardware, software, and data (and even people), rather than just the particular technology for building a digital map (Maguire 1991). Others use the acronym AM/FM to mean any and all technology used in the field. These two are sometimes used together (as AM/FM/GIS) and are often used interchangeably. Most utility implementations of GIS, when they include the mapping and modelling of networks, are referred to as AM/FM or AM/FM/GIS.

The wide use of AM/FM/GIS among utilities has provided the motivation for some key technological improvements, driven by the different and in some aspects more difficult requirements of detailed facilities models. The key improvements since the mid 1980s include:

- open systems that have the ability to interconnect with and manage commercial RDBMS (Sondheim et al, Chapter 24);
- ability to manage edits on individual model entities (e.g. a single pipe, valve, or wire), known as 'feature locking' database management;
- ability to provide long transaction and version management functions, to permit multiple users to edit or modify the same geographical data at the same time (Newell 1994);
- a move to Windows-based/desktop systems with no decrease in functionality or performance (Elshaw Thrall and Thrall, Chapter 23);
- use of object-oriented programming languages and modelling techniques (Maguire, Chapter 25; Worboys, Chapter 26).

Today's typical AM/FM/GIS is built using some form of client/server model with both geographical and attribute data stored on a central server which is accessed by clients in several different environments. It may serve from one or two to hundreds of users, and almost certainly has the capacity to share data with applications which are external to the GIS (Gittings et al 1993). It will have a graphical user interface (GUI) which has been customised to suit the specific utility's business operations and a system for transaction management (that is, a procedure for managing how multiple users interact with the same data at the same time). The modern AM/FM/GIS will perform analyses based on topological relationships, such as tracing lines to find customers affected by a power cut, and data relationships, such as isolating pipelines constructed from a specific material or installed before a certain date.

New trends in AM/FM/GIS technology include more sophisticated geographical data types and advanced software tools. The overarching trend in the industry is the convergence of technologies which began as isolated tools for mapping and record keeping into integrated systems where it is difficult to distinguish geographical and other related attribute data. The second major trend is a move towards the availability of desktop applications through the use of GIS servers which supply distributed client applications, without the overhead of large databases and complex GIS models (Coleman, Chapter 22). There is increasing interest in object-oriented methodologies for defining complex object classes (Worboys, Chapter 26; Martin and Odell 1995) and standard development environments and analysis tools (see Maguire, Chapter 25).

3 GIS DATA: SOURCES, MODELS, AND AUTOMATION TECHNIQUES

Data are the foundation of a utility GIS. While it is difficult to generalise, it is common for the cost of data to be 60 to 80 per cent of the total first cost of an AM/FM/GIS solution (see Rhind, Chapter 56, for a general discussion of data costs and pricing). Utility data automation is complicated by the diverse quantity and quality of the source documents, the detailed facilities and base-map data that may be necessary to support application requirements, the existence of segregated departmental databases containing existing facilities records, and even the lack of standards for cartography among different departments and geographical regions of a company. Accordingly, any attempt to generalise about the cost of data capture is nearly certain to be misleading. That said, the graph presented in Figure 1 gives a range of expected data capture costs in terms of US$ per customer served from several utilities surveyed.

Data may be grouped into low, medium, and high average cost acquisitions, both for gas and electric companies. Not surprisingly, higher average costs are incurred by electric companies, since these tend to have more detailed models. Yet costs incurred in respect of low and medium cost sources tend to be

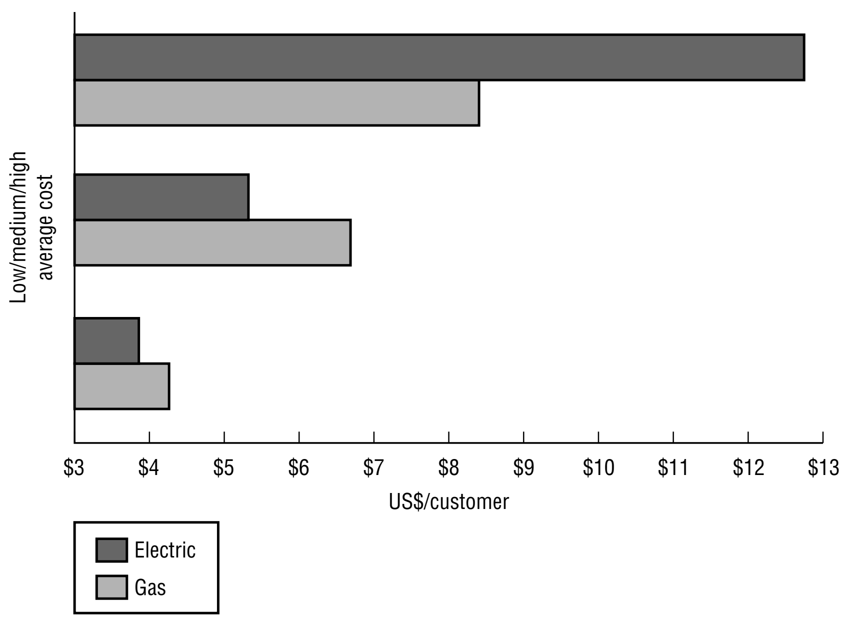

Fig 1. AM/FM/GIS data capture costs.

higher for gas companies, and in general the cost variance for gas companies is smaller than that of electric utilities.

The following section offers a brief review of the key sources of AM/FM/GIS data, describes the relationship between data model and applications, and overviews some critical automation techniques.

3.1 Key sources of AM/FM data

A data conversion project at a utility consists of at least three phases:

- identifying existing data sources and converting them to digital formats;
- defining a data model which fits both geographical and business process needs;
- designing screen displays, output maps, analysis functions, and reporting features that the GIS should produce.

By far the largest and most common source of data used in AM/FM/GIS is existing paper records (Rogers 1996). Most utilities use a variety of maps of varying scales, content, and detail. Among the common paper map types are:

- inventory, distribution, or physical maps showing accurate locations for facilities (typically large-scale, detail maps);
- electrical schematic/feeder (or network maps) or gas/water system pressure zone maps showing connectivity (often not-to-scale);
- special facilities maps, such as cathodic protection (a technique used to save metal pipes from corrosion by passing a positive charge though the pipe) or valve testing location maps;
- leak survey maps;
- rights-of-way or easements maps (containing detailed cadastral information);
- service record cards (usually with a sketch and text);
- corridor or strip maps (usually on odd-sized, long and narrow media) showing pipe runs, access points, etc.;
- municipal/regional government and private sources (base-map).

Dowman (Chapter 31) provides an overview of the problems inherent in capturing digital maps from paper sources. Existing paper maps are not just the source of facility location, but also a link to attribute data which are often already in digital form. Such digital databases offer a wealth of information about plant and customers for utilities. Among the more common digital sources for companies are Customer Information Systems (CIS), Continuing Property Records (CPR) or Asset Management Systems, and Plant Accounting and Equipment Databases. These corporate systems are often supplemented by departmental databases for storage of individual facilities data, like valve records, or transformer or protective equipment databases. These are often small, PC-based systems, built and maintained by a specific department or group within a company. The data in these databases are often supplemented by personal knowledge of the staff, which is not recorded in any digital database, paper map, or other document.

Existing paper and digital records may provide the best information available, but may still be inadequate to support AM/FM/GIS applications. Examples include paper maps which do not depict the location of facilities, are out of date, or do not show the relationships required. In these circumstances, field surveys are often undertaken and increasingly global positioning systems (GPS) technology is employed (Lange and Gilbert, Chapter 33).

3.2 AM/FM/GIS data and applications

There are three key aspects of the utility data model which contribute to the success of an AM/FM/GIS. The first is the accurate (at least in relative terms) depiction of the locations of all physical facilities, including lines, devices, and structures, which make up the network. Shown in conjunction with base-map and foreign facilities data (from other utility companies), this model provides the basis for automated map-making. When attribute information is added the data model can be used for many basic facilities management functions. These data support the basic spatial and attribute query operations which are familiar to GIS users. They additionally provide the foundation for many executive information system, customer service, and marketing functions, and also support some basic engineering and operations applications.

The second key characteristic is the ability to define a model of the utility which provides an accurate representation of the way the system operates. Integrity of topology is critical to the accuracy of the model. By storing attributes which define whether a pathway is open or closed (as might be indicated by a valve in a pipe system), or if the magnitude of flow has changed (as might be indicated by regulators, transformers, and other devices in an electric model), sophisticated applications are possible, especially in the realm of operations (switching, valving) and engineering analysis.

The third important aspect of the utility data model is the ability to integrate a spatial representation of facilities with other utility databases such as customer, accounting, or work management systems. A broad range of aspatial data is required to enable the integrated functions which make up the full range of traditional and non-traditional AM/FM/GIS (e.g. customer files, geodemographics, and billing information). Birkin et al (Chapter 51) provide an overview of GIS applications in business and service planning.

Figure 2 shows the relationships among the spatial representation of facilities data, related attributes, and external utility systems. The core of any AM/FM/GIS is the spatial model of facilities and land base features. Attributes of these entities are typically stored in a RDBMS and referenced by the many applications of an AM/FM system which perform analysis, respond to queries, and create maps. Many of the applications which are part of the system also reference data from external corporate systems.

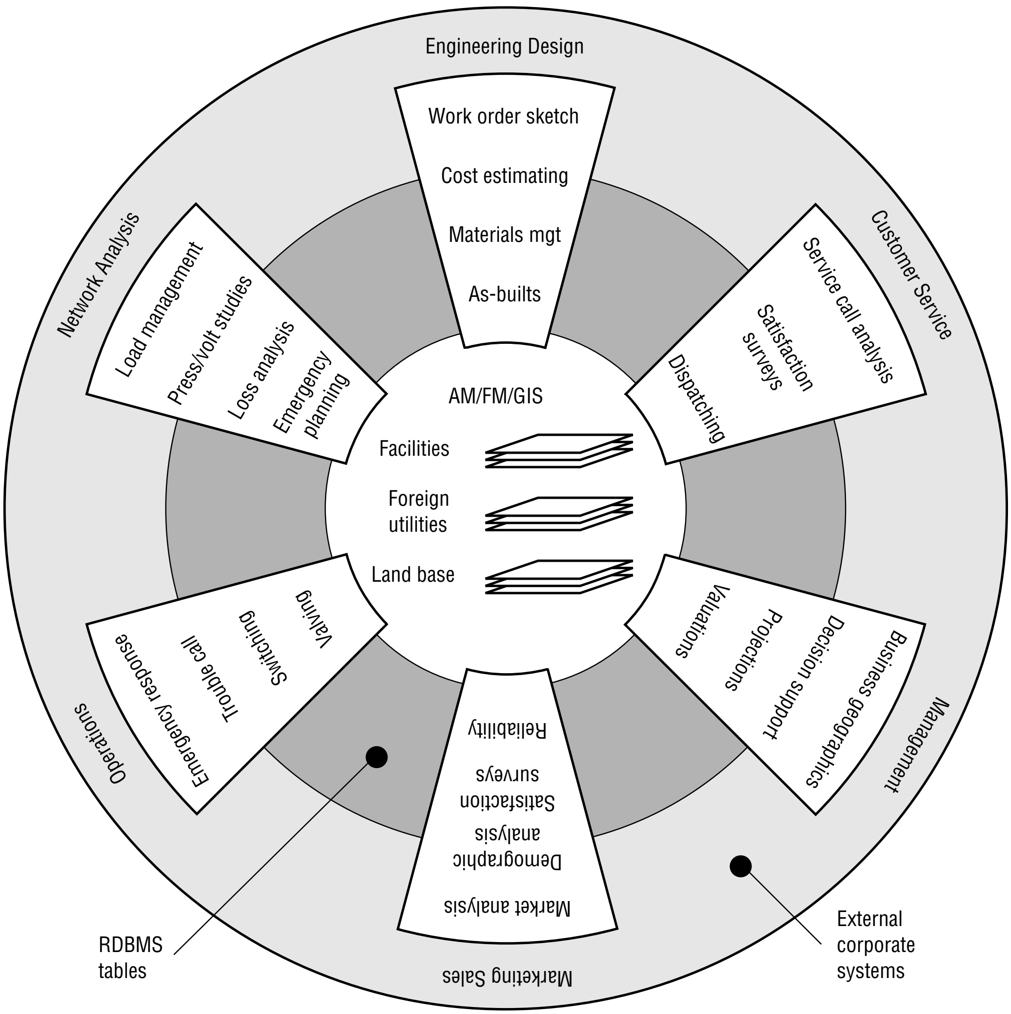

Fig 2. AM/FM/GIS data and integrated functions (Press = pressure; Mgt = management).

3.3 Techniques for AM/FM/GIS data automation

This brief treatment cannot adequately identify all of the possible aspects and implications of AM/FM/GIS data automation, and some further details are provided by Dowman (Chapter 31) and Jackson and Woodsford (1991). However, no discussion of the topic would be complete without a survey of the available technology and at least a summary discussion of the relative merits of each technique. This section will seek to identify the common data capture techniques and summarise the strengths and weaknesses of each.

3.3.1 Base mapping

Many utilities have the opportunity to use base map data produced by a local, regional, or national government agency, or in rare cases, by another utility serving the same area. In cases where simple streets and land forms match AM/FM/GIS requirements, commercially available street files with address information may be an economical choice. When digital base maps are not available, companies are forced to rely on other sources for base mapping. Many utilities simply digitise base map planimetric features in vector format from existing paper facilities maps. Others prefer to scan the existing utility or other paper base map source, and use the resulting raster image as the backdrop for the digital facilities map.

Digital orthophotography, a method in which very accurate aerial photographs are rectified (see Dowman, Chapter 31), has grown as a source for base map information, although some users may argue that photographs are prohibitively expensive to update. One possible answer to the high replacement cost of digital orthophotos is the use of very accurate (+/- 1m) satellite images, which are becoming technically and economically feasible alternatives as low-altitude commercial satellites' images begin production (see Barnsley, Chapter 32; Estes and Loveland, Chapter 48). The relative merits of methods for base mapping data capture are summarised in Table 1.

3.3.2 Facilities

By far the most common technique still in use in data capture today is board (table) digitising (Dowman, Chapter 31; Flanagan et al 1994) in which source documents are placed on a digitiser table and traced electronically. Preparation of source documents, including verification of data and updating (often called 'scrubbing'), enhances the reliability of the data, but adds to the time and cost involved. At the very least, digitising is expensive and requires intense labour for completion. In addition, because of the diversity of source data available, this method is often inadequate for producing the consistent format of spatial data required to support AM/FM/GIS requirements.

Another technique for acquiring digital vector data involves scanning the source maps and using semi-automatic line tracing to 'vectorise' the appropriate facilities. This method can result in significant savings, but difficulties can arise with the vectorisation accuracy, especially when source documents are cluttered or unclear. Commercial data vendors have recently developed expert systems to permit more accurate automatic vectorisation, with the potential to reduce costs greatly.

Some companies prefer to begin their utility application implementation with a raster only base-map for their facility database, and then convert selected features (usually pipes and fittings, or wires and devices) to vector format in each area as needs arise. Called 'incremental conversion', this technique allows the deferment of large-scale data capture effort, focusing only on those areas where current work is ongoing. In some cases, digital data from corporate systems can be used to populate attributes of existing facilities, or to validate data entered by other means.

When maps are out of date or non-existent, field surveys are often undertaken to verify the state and location of lines and equipment. Several advanced techniques combining the use of GPS and other locational devices like laser range-finders have automated the process (Lange and Gilbert, Chapter 33), but field survey is still regarded as expensive and labour-intensive.

Table 2 provides a summary of the strengths and weaknesses of the various techniques available for data automation in AM/FM. Variations on these techniques are often used in AM/FM data capture, with combinations of two or more methods employed.

4 CRITICAL APPLICATIONS

The benefits of AM/FM/GIS are realised through the implementation of applications. This section reviews the requirements and functions of the critical applications that determine the success of AM/FM/GIS applications through meeting business needs and improving processes. Traditional applications such as mapping, ad hoc query, work

Table 1 Base-map data capture methods: advantages and disadvantages.

Capture Technique/Source	*Advantages*	*Disadvantages*
Base-map – Shared data from agency/utility	– Low initial cost – Access to non-utility data owned by others (e.g. cadastre, foreign utilities) – May eliminate maintenance	– Accuracy/content may vary from utility requirements – Update responsibility must be clarified/negotiated – Facilities data from existing source maps may have to be adjusted to fit base
Base-map – Commercial street centreline files	– Very low/low initial cost[1] – Address, demographic information often already included – Good support for dispatching and routing applications – Can more easily be adjusted to fit existing facilities source maps	– Accuracy and planimetric content may be too limited for utility requirements. – Update process (for original address, demographic data) may be cumbersome
Base-map – Raster backdrop from existing facilities maps	– Low initial cost – Good fit to geometry of existing facilities	– Non-intelligent; no support for spatial operations, address matching, or tracing functions – Ongoing maintenance may be awkward; re-scanning of updated maps required
Base-map – Raster backdrop from digital orthophotos	– Very accurate base – Low labour requirements – More planimetric features available for use	– High initial cost – Non-intelligent; no support for spatial operations, address matching, or tracing functions – Moderately high replacement or update cost (high-resolution satellite photos may reduce)
Base-map – Vector digitised from facilities detail maps	– Best fit to geometry of existing facilities – Can be used for spatial analysis, depending on detail available – Familiar 'look-and-feel' for users	– High initial cost – Ongoing maintenance for all vector planimetric features – May be hard to share common data across agencies

[1] Based on current US data pricing practices: see Rhind (Chapter 56) for a discussion of international data pricing policies.

Table 2 Facilities data capture methods: advantages and disadvantages.

Capture Technique/Source	*Advantages*	*Disadvantages*
Facilities – Board digitising	– Most straightforward, direct method – Produces maps with familiar 'look-and-feel'	– High initial cost – Typically requires expensive 'scrubbing', which inflates in-house staff efforts
Facilities – Scanning/automatic vectorisation	– Low initial cost – Fast turn around	– May require manual intervention to produce quality data – May not be suitable for cluttered, old, or unclear source documents – Large volume storage requirements
Facilities – Scanning vectorisation using incremental conversion	– Very low initial cost – Vectorisation confined to focused or important areas – Fast turnaround (for raster base)	– All normal drawbacks of raster-based systems – Slow development of intelligent facilities models for analysis
Facilities – Field survey using GPS	– Produces accurate facility locations – Helps to validate facility locations and connectivity relationships	– Can add significantly to cost of capture – May result in locational data (from GPS or laser range-finder) which fits poorly with existing data

order design, and network analysis are reviewed (Meehan 1994), along with more non-traditional applications such as marketing, customer service, and executive information systems.

4.1 Mapping applications

Mapping applications perform three basic requirements:

- map editing tools provide the ability to create and maintain the facilities database;
- standard map products can be applied to utility operations;
- ad hoc mapping tools allow creation of maps in response to specialised requests.

Following this intensive period of activity, there is usually a much less intensive, but equally important and much longer term, spatial and tabular data maintenance requirement. As described previously, bulk data conversion is often used to create the initial database, using specific tools geared for efficient data loading. Once a database exists, editing tools are used to create new map features and make updates to existing components of the utility network.

4.1.1 Map editing

Although many applications use the data in an AM/FM/GIS, maintenance typically comes through four applications: a map sheet editor, a desktop design editor, a field design editor, or a tabular data entry system associated with legacy data. The map sheet editing application shown in Figure 3 is typical of many AM/FM editing applications used to create or maintain a utility distribution system.

The fundamental goal of any AM/FM editing system is to locate facilities (e.g. pipes or electrical conductors and the associated devices) so that they will function correctly, within the context of the public they serve. Figure 3 shows a screen display of gas mains (solid thick lines) through a neighbourhood and their relationship to the street network. It also identifies the customer service connections (dotted lines) and building locations (shaded polygons). Symbology shows the presence of fittings (white), indicating that there is a change in pipe material or size, and a regulator which signals a change in gas pressure. The topological integrity with which these features are placed, frequently using sophisticated coordinate geometry, establishes

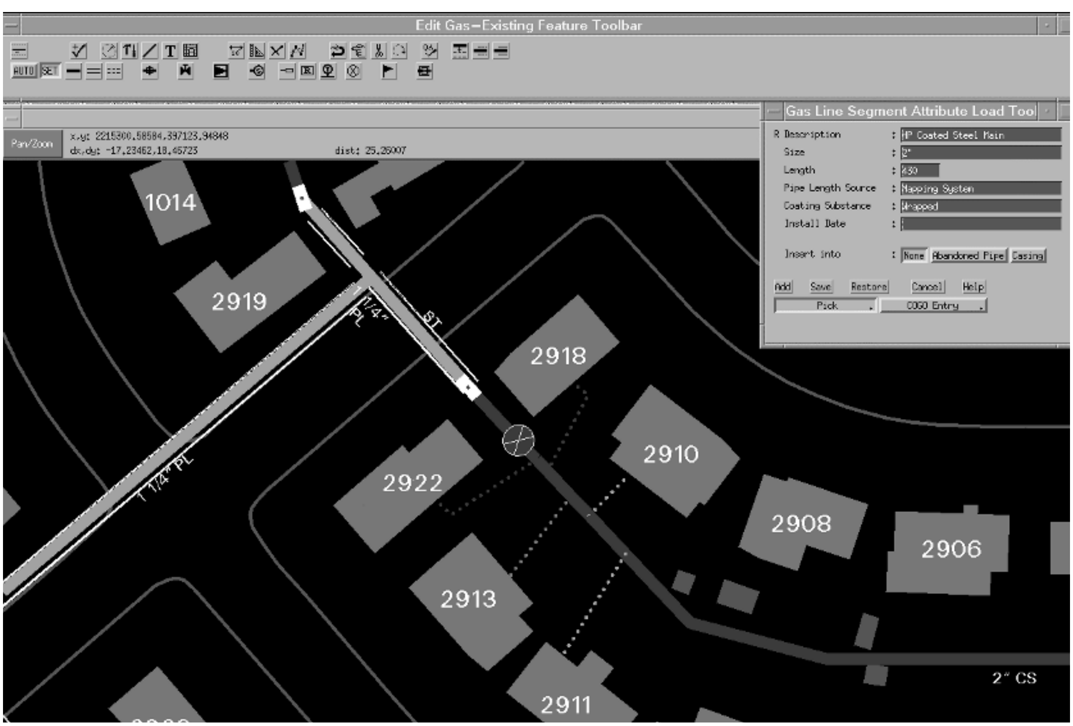

Fig 3. Typical gas distribution map sheet editor.

the gas distribution system model. Associating database attributes of pipe size, material, and pressure transforms a map of the gas system into a functional model of the network, providing the ability to perform many types of analysis.

Feature placement refers to the set of tools used to build and maintain a utility's database. The term includes both the cartographic representation of facilities and their incorporation into an underlying database. The process of feature placement is undertaken using tools selected from a user interface (see the toolbars across the top of the display and the menu in Figure 3). Through these tools, business rules are built into the application to ensure model integrity. The key rules or relationships in an AM/FM/GIS include:

- enforcement of topological connectivity – features which need to be linked in the AM/FM/GIS are actually connected in the database, rather than simply appearing to be connected graphically;
- maintenance of referential integrity between both the spatial (graphical) and attribute (tabular) data components – for example, if a transformer bank is deleted, all transformer units associated with the bank are also deleted;
- validation of feature combinations – for example, only a limited number of pipe diameters are valid for a section of plastic pipe.

4.1.2 Map products

Producing the standard, time-tested hard copy output from an AM/FM/GIS is typically the job of a *map products* application. Utilities rely on maps for many operational tasks; it is not uncommon for utilities to produce and update seven to ten or more different map products. These may vary from detailed distribution and transmission facilities maps, to property and rights-of-way maps, to schematised network views. Part of the benefit of AM/FM/GIS is the ability to drive these different views from a single integrated database.

The feeder map in Figure 4 is an example of a standard map product which is used by many electric utilities. A feeder is the path of electrical current from its source (typically a substation circuit breaker), to its many destinations at residences, schools, hospitals, and other commercial locations. Cartographic decisions, which specified that the feeder should appear as a bold linear feature against a background of street centrelines and that only significant building locations are identified, were pre-defined as

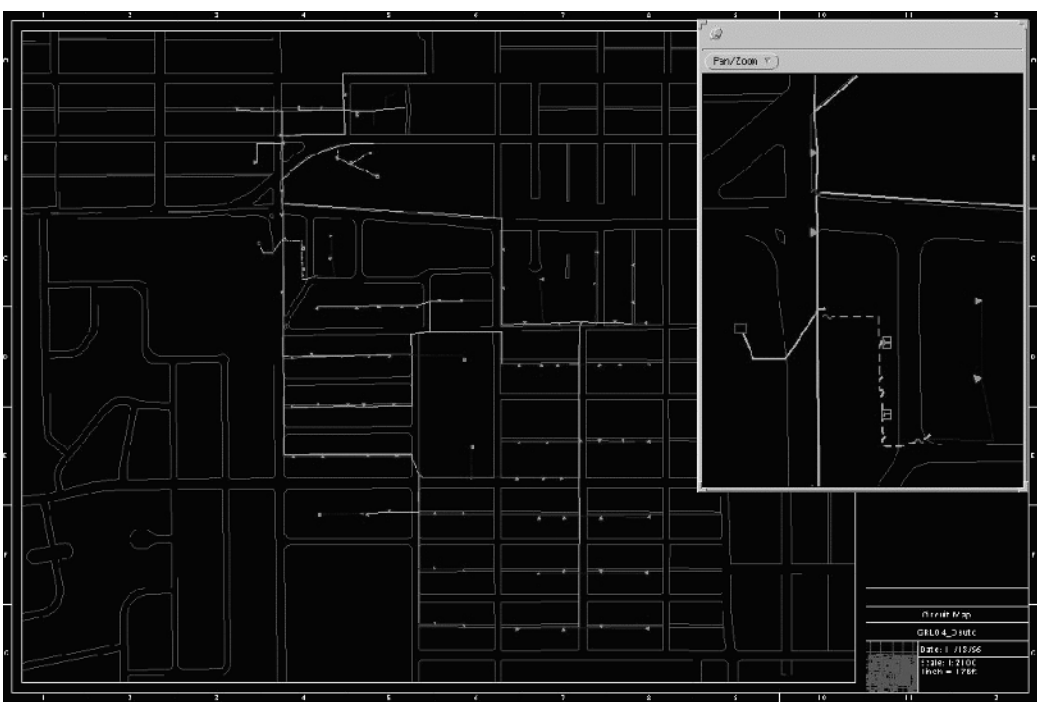

Fig 4. Electric distribution feeder map product.

part of this map product. Note that buildings, poles, or devices which affect the flow of electrical current are symbolised on the map display.

Many electric companies produce schematic views of electric networks. Other common map products, such as pole inventory or physical maps, rights-of-way or corridor maps are very different depictions of the data in common integrated databases. In the pipeline utilities (gas, water, waste water) there are analogous map products for different operating purposes.

Map scale is one of the key challenges to be faced in a map products application, and is reviewed by Weibel and Dutton (Chapter 10). A wide variation in scales (1:1200 to 1:24 000 or greater) makes the placement of entities and annotation very difficult. For example, a map symbol for a valve may be perfectly appropriate at a detailed map scale such as 1:1200. However, even with symbols scaling continuously, its location may obscure other features when it is displayed at scale 1:24 000. Modern GIS typically include tools to manage 'whitespace', and to mitigate over-posting of text and symbols.

4.1.3 Ad hoc mapping

As the above discussion suggests, map products are defined by a specific format which includes scale, map surround or marginalia, contents (facilities and map features), and symbolisation. Ad hoc maps are also widely used in utilities. Their content and appearance are defined entirely by users, including which facilities to display at which scale. Often such maps are the result of a particular query or analysis. Figure 5 shows a user-defined section of a waste water application, together with the results of a query for pipe material in pie-chart form.

Many desktop systems, with functionality reduced from full-blown professional GIS, have been perfected for use as ad hoc mapping tools, making the technology available to a wider audience on less expensive hardware.

4.2 Facilities management applications

Facilities management applications move AM/FM/GIS beyond the mapping to the analysis and management of the operation of a utility network.

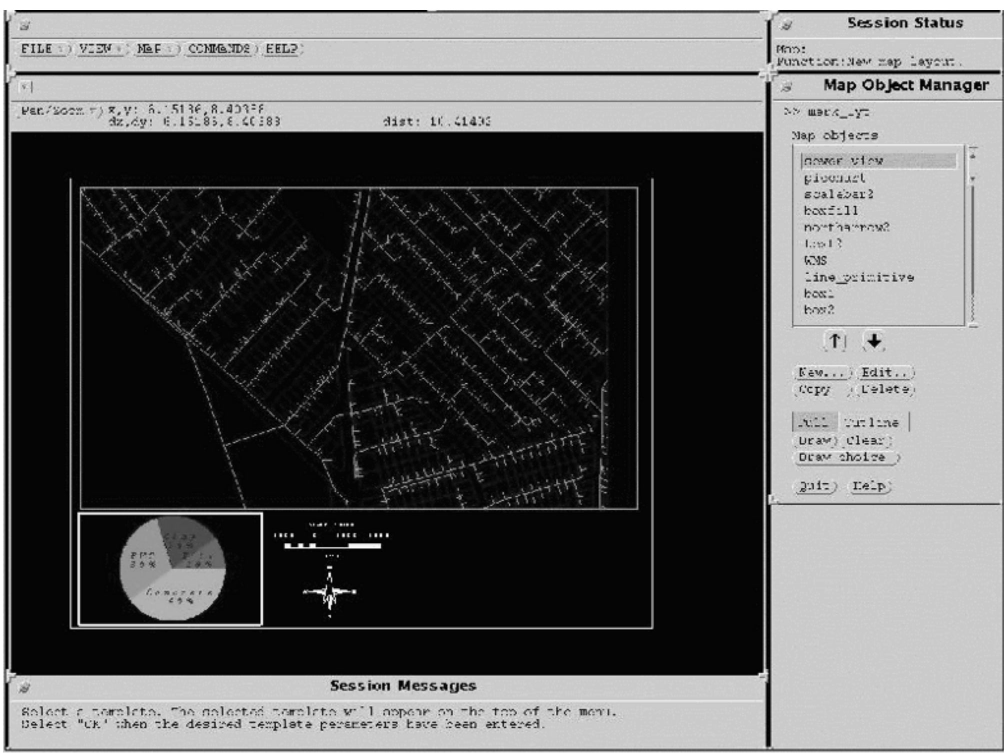

Fig 5. Ad hoc sewer system map.
Source: BaySys Technologies, Inc.

The goal of the FM application is to place spatial and attribute data in the hands of those that make decisions about how a utility can maximise its resources and minimise its costs. FM applications may be grouped into the following general categories:

- query and display;
- design/work order processing;
- equipment maintenance;
- network analysis;
- customer service/service call analysis.

Two examples, query and display, and design/work order processing, should serve to illustrate the range of FM systems.

4.2.1 Query and display applications

The simplest form of FM application is a query tool, used by a broad range of utility personnel from executives to customer service representatives. By providing a link between spatial and attribute facilities and even customer data, query applications have provided tremendous benefits for companies. The combination of spatial and logical queries is among the most powerful functionality in AM/FM/GIS. Simple questions like 'How many streetlights do we operate in the town of Jonesville?' may result in great labour savings over traditional manual methods.

Figure 6 is a view of a desktop query application. It shows the results of a simple spatial query which lists the attributes of a single electrical customer, including the criticality of the customer for operating purposes, the unique identifiers for the customer, and the type of metering used.

Geospatial relationships are the basis for a number of utility applications which may include ad hoc queries, such as the one represented above. More periodic or repeated queries may be used for applications such as *maintenance* or tracking of *work orders*.

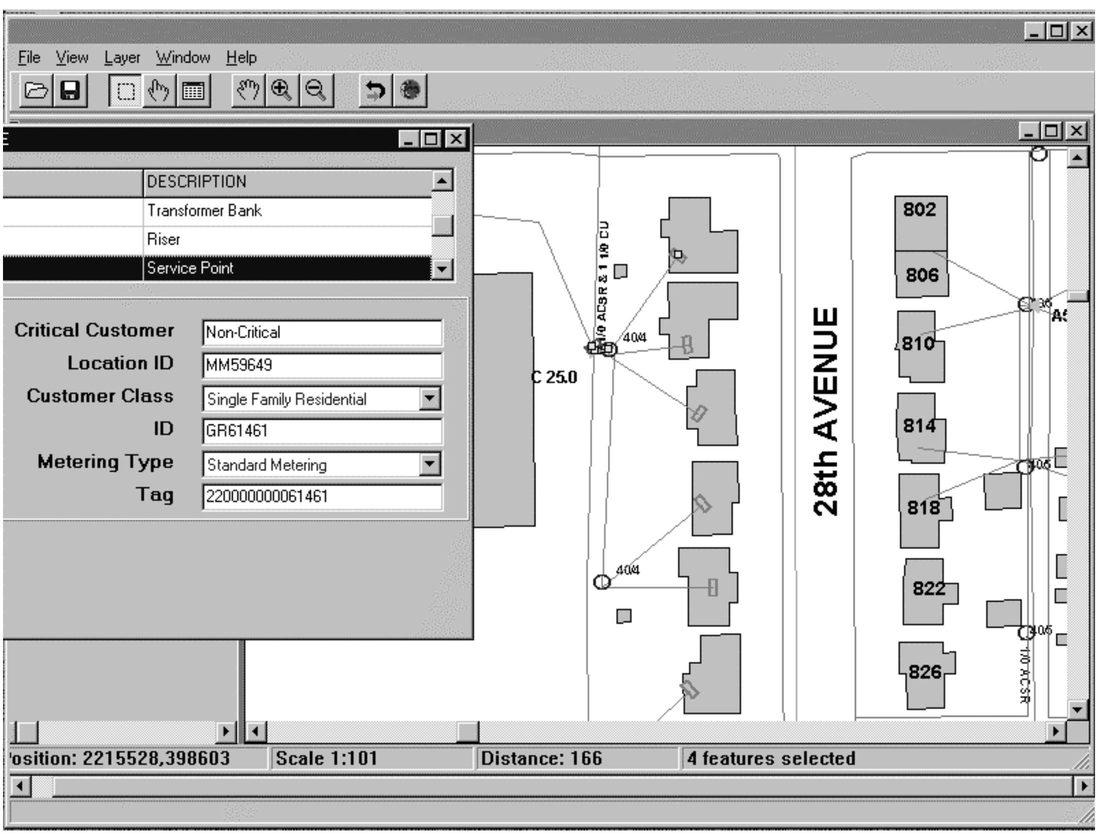

Fig 6. Desktop spatial and logical query tool.

4.2.2 Design/work order processing applications

Utility companies generally manage additions or modifications of outdoor plant with a *work order*, a document or set of documents which describes the work to be accomplished. A work order package often includes a sketch made from a map, or drawn from scratch, illustrating the work area, together with construction notes and instructions. Following completion of the work sketch, it may be issued to a crew for construction. After amending the sketch to include any field changes (the so-called 'as-built' representation) the sketch is used to update the permanent record of a database (Figure 7).

This design process is often labour intensive, and at many companies results in delays of record completion and duplication of effort. For these reasons, many utilities seek to automate this process through an AM/FM/GIS application. Figure 7 shows the sketch for a new electrical line extension. The screen represents the output product from the design, including construction notes and a vicinity map.

Of course, the graphic output is only a part of the benefit to be gained from automating the work order process. Several companies have integrated the GIS design environment with external digital work management systems, to provide integrated cost estimating for rapid customer response and a capability to update a corporate plant accounting system. In the most advanced systems, the 'as-built' representations of outside plant are fed back into the AM/FM/GIS database and thus feed into the maintenance process.

4.3 Network modelling applications

Network analysis tools can be categorised into two major groups on the basis of the time frame over which they operate. Engineering analyses are generally performed on an irregular basis usually in response to some known condition, while operations applications are driven by near real-time operating conditions.

An example of an engineering analysis application is shown in Figure 8. Using the base GIS database as its source, this electrical network analysis application employs a detailed energy usage model to assess system performance. Like most engineering analysis packages, it includes functions for evaluating load flows, voltages, and short-circuit

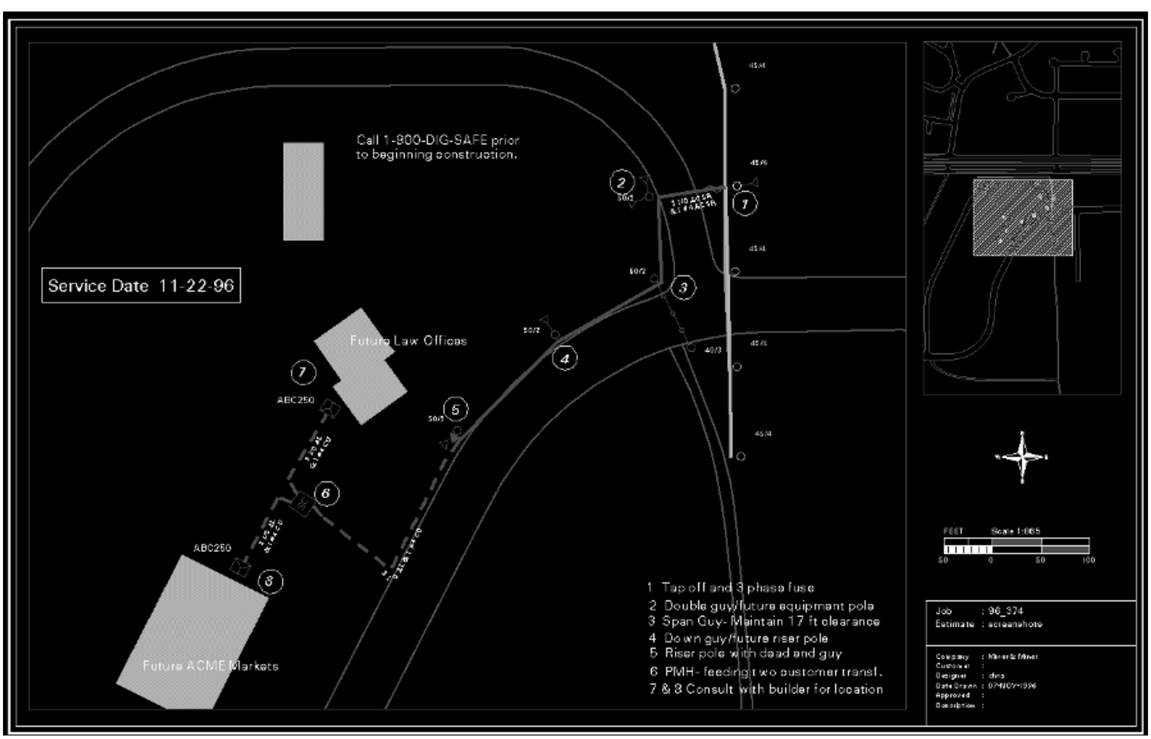

Fig 7. Work order design sketch.

currents, as well as some switching and other miscellaneous functions. Unlike other such tools, however, it operates directly on a GIS database, rather than a separate dataset prepared and maintained specifically to support network analysis. Figure 8 shows, in the top half of the screen, the results of an analysis of a single circuit or feeder, traced from a point of interest back to the source substation. Voltages for each node along the feed path are computed and displayed in a line graph in the bottom portion of the screen.

In the water and gas industries, analogous applications are available for providing hydraulic analysis, and determining pressure and flow based on pipe network characteristics and demands. Techniques like this permit engineers and technicians to undertake analyses with current data and make models in seconds or minutes that formerly took days or weeks. In addition to increased productivity, GIS-based applications like this can be based on more detailed models, and can produce results in ad hoc mapping or report form.

The second network modelling application discussed here is oriented towards operations. It uses an AM/FM/GIS database for real-time or near-real-time trouble call or outage management. In such applications, an operator uses a model of a network, along with data from customer calls or monitoring equipment, to determine the location of a problem, possible consequences and even the best method for restoring service to affected consumers.

A trouble call management application is shown in Figure 9. In this desktop viewer, trouble calls which were originally entered into the CIS on a mainframe are relayed to distributed district office databases, based on an identification tag. Once loaded, the address of the caller is used to associate the call through address geocoding to the nearest point in the network.

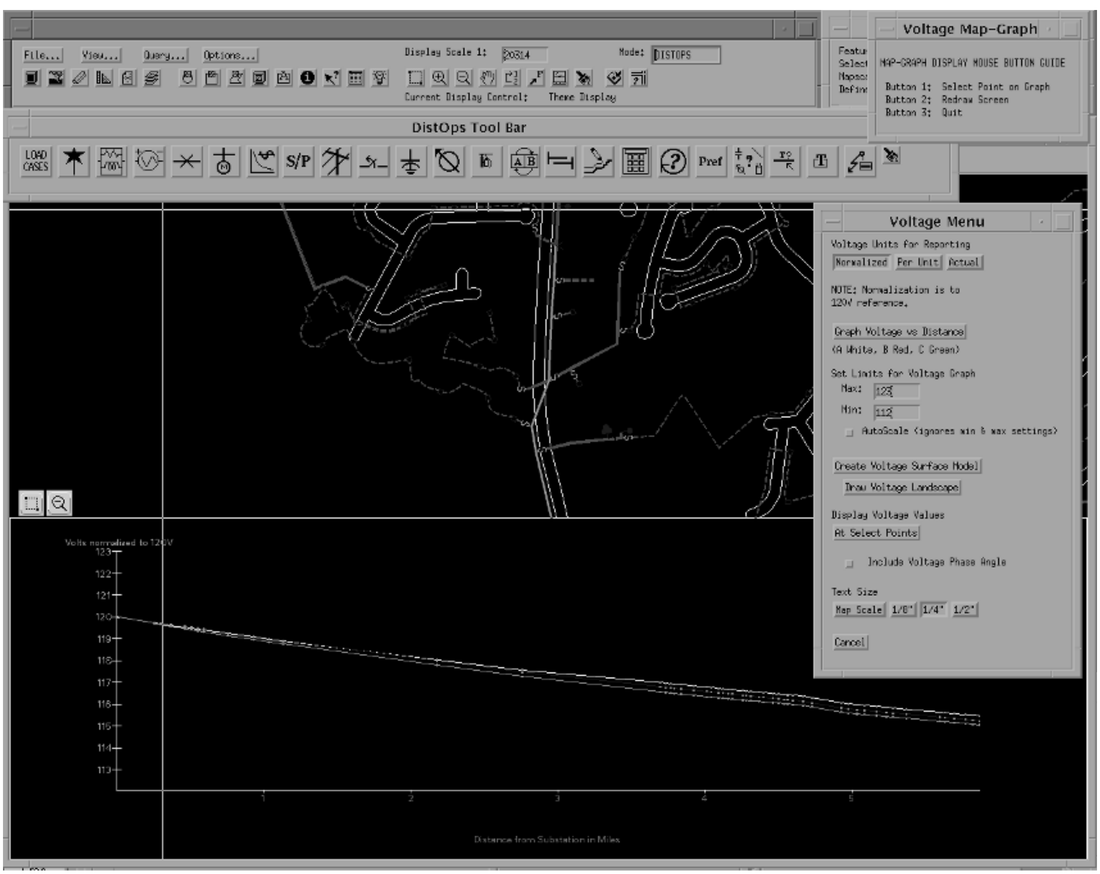

Fig 8. Electrical distribution network analysis.

In normal outage events, a number of customers call to register complaints. After locating the available calls, traditional network processing is used to determine the probable outage device, or the point at which the network has been isolated. Once the outage device has been found, a reverse network trace can be used to identify all points in the network downstream of the device. When this information is combined with address information, engineers can be dispatched to investigate the device and affected customers can be notified.

Integration with the customer system is one obvious requirement for efficient trouble call management. Modern systems are also beginning to be integrated with telemetry or supervisory control and data acquisition (SCADA) systems for outage and problem information. Traditionally constrained to the transmission or bulk delivery level, SCADA technology has moved into the distribution systems' domain in the past few years, providing data from key points in a network. This real-time data can be used to anticipate problems in gas, electric, and water delivery systems, and to provide network operators with data about the nature and location of a problem in all networks.

The trouble call system is a valuable tool for utilities, especially energy companies (electric, gas), for responding to customer complaints during an event. However, these applications also provide great benefit for compiling statistics about network performance, and reporting on the nature and duration of outages. These data have proved to be extremely valuable in identifying and correcting repetitive system failures based on faulty equipment or poor maintenance practices.

4.4 Executive information systems

The technical nature of GIS applications has traditionally restricted their use to technicians, drafters, and engineers responsible for mapping and analysing the operation of a given utility network.

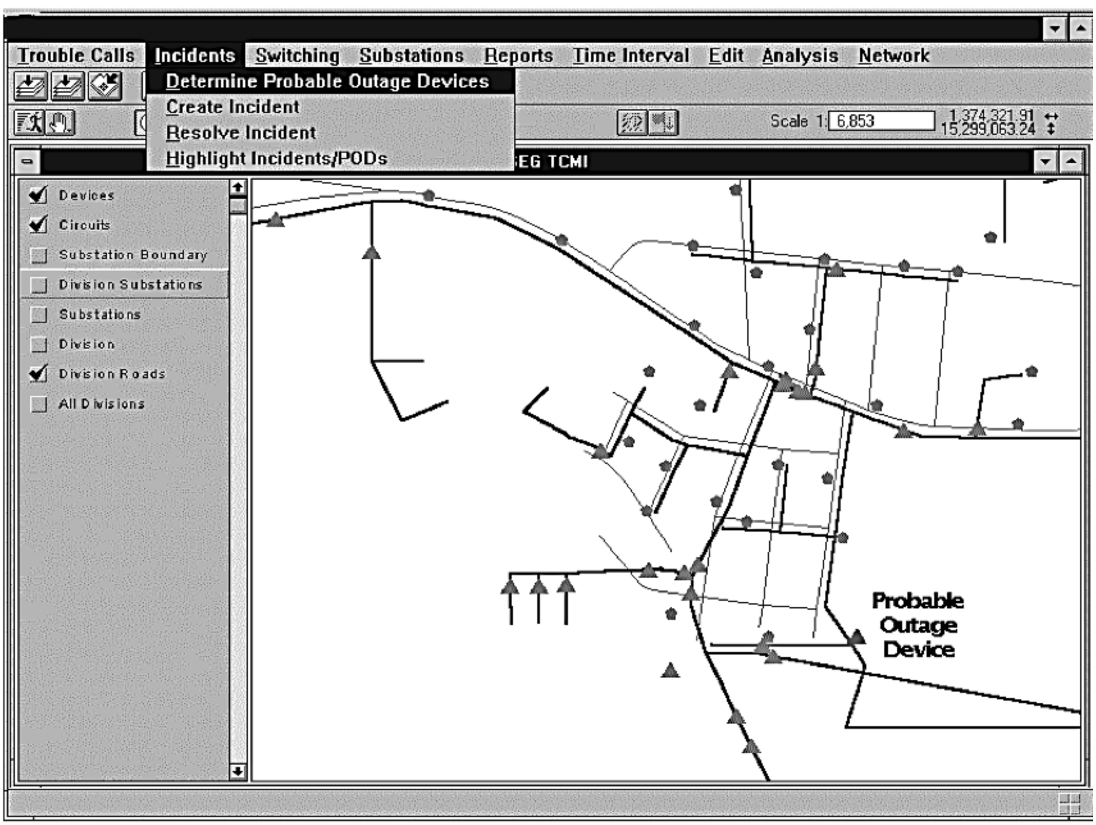

Fig 9. Desktop trouble call management interface.

With the advent of desktop GIS (see Elshaw Thrall and Thrall, Chapter 23), the capability to analyse and use spatial data can be put into the hands of those who make decisions about how a utility can maximise its resources and minimise its costs, so that they are able to survive in a competitive environment. These 'non-technical' GIS applications have simple IT industry standard interfaces and run on lower cost platforms (typically PCs). They can be considered spatial executive information systems (EIS) for use by the traditional executives of a utility.

Figure 10 is screen output from a desktop GIS/EIS showing a combined spatial and logical query. The user has asked the application to make a map of all 'critical' customers (such as police stations, fire stations, and life-support dependent households). Furthermore, the query has been graphed on the basis of the classification of the customers who are noted as critical, based on whether they fall into the residential, small commercial, or industrial rate tariffs. Note the Windows-style standard user interface, designed to provide a non-GIS user with familiar functions.

This simple query is only one of many possible examples which illustrate the power of GIS to add intelligence about location to management applications. Marketing questions such as 'Show me all the customer locations within 100 feet of our gas mains, now classified as Residential Electric Heating customers', or 'Make me a map of every customer who has called to report a problem in the Hamptonfordshire District within the past 13 months' are now at the direct disposal of managerial staff. Operating queries such as 'Show me the location of all current work orders' are just as easily performed. Birkin et al (Chapter 51) provide an assessment of how such functionality fits with the management and strategic functions of business and service organisations.

While not all AM/FM systems currently perform these functions, they are among the critical applications that will determine which companies will set the pace in

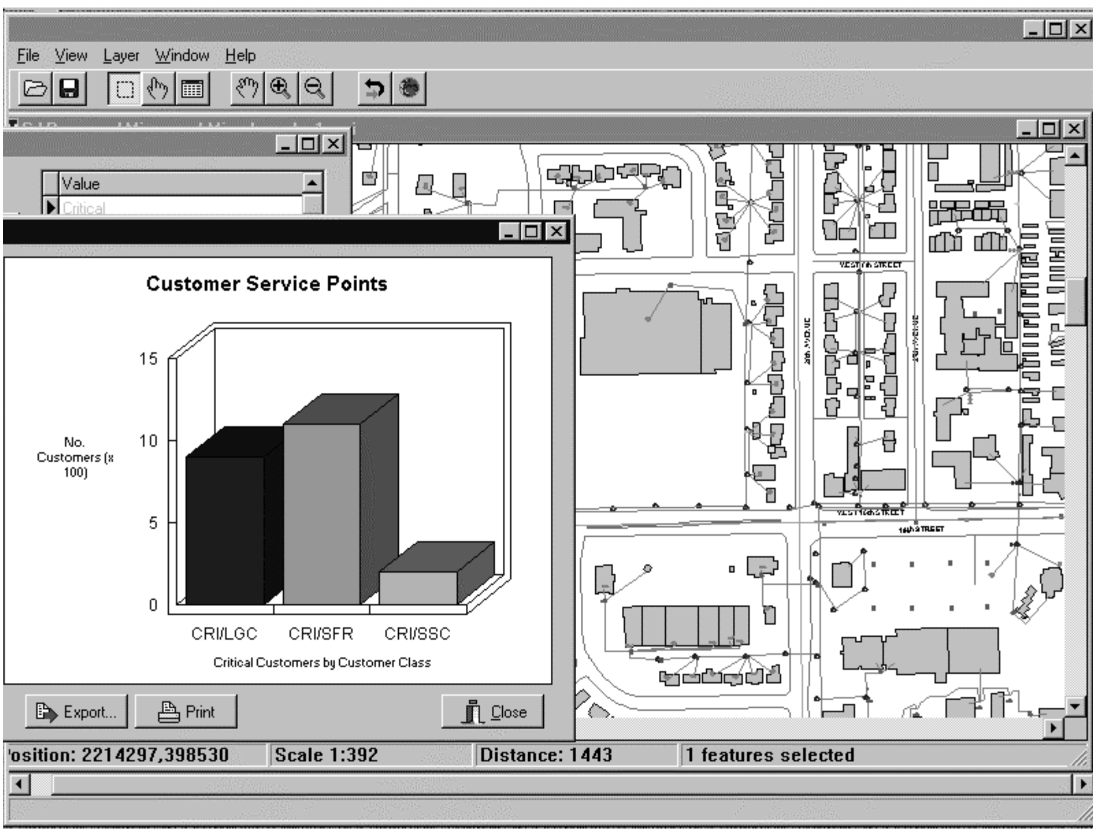

Fig 10. Desktop GIS executive information system.

an industry driven by the market economics of deregulation. These functions also emphasise the need to integrate GIS with other corporate functions that have historically operated independently.

5 COSTS AND BENEFITS

This section explores the nature of benefits and costs of AM/FM/GIS, beginning with an assessment of the factors in the costs of implementation. A high-level view of the principal benefits is also presented, with examples which identify key areas for reducing costs: as such, this section complements that of Obermeyer (Chapter 42) who conducts a more general review of the benefits and costs of GIS. Finally, the factors which will affect competitive advantage for utilities in the coming years are discussed, in the context of the impact of AM/FM/GIS.

5.1 Cost assessment and examples

There are a number of factors which affect the cost of building an AM/FM/GIS and integrating it within the information systems of a utility. The cost of implementation typically varies depending on the applications required, the size and scope of the data to be captured, and the number of users to be supported. The legacy of existing systems and available procedures for data automation also affect the cost. Any analysis of system development costs is also complicated by the fact that there are many political and historical factors to consider. Unfortunately, because of the current competitive environment, many utilities are reluctant to share specific information about the costs of their AM/FM/GIS development. However, it is hoped that the following summary of factors affecting each of the six critical cost components for utilities (Rector 1993), along with a few examples, will provide a useful background.

5.1.1 Data automation

Data capture costs are affected by the portability of existing data sources, the geographical size of the utility, and the scope or detail of the data to be automated. Commercially available sources of digital data for the coincident territory are also a factor.

5.1.2 Hardware and software acquisition

System acquisition costs vary widely depending on the hardware selected, the network requirements, the type of base GIS and commercial database software selected, and number of user seats implemented.

5.1.3 Project management

Project management costs consist of the direct costs of utility employees and consultants hired to help manage AM/FM/GIS system development. There may also be hidden project management costs associated with out-sourcing data conversion and third party GIS software development. It should be observed that project management costs occur throughout the project life-cycle, and may also arise from migrating existing AM/FM/GIS applications to new platforms (Rogers 1996).

5.1.4 Applications development

The scope and cost of applications development varies with the nature and complexity of the applications to be implemented. In particular, the use of commercial off-the-shelf software versus entirely customised solutions plays a major role (see Birkin et al, Chapter 51; Elshaw Thrall and Thrall, Chapter 23; Maguire, Chapter 25).

5.1.5 Support staff

Development of internal support for utility applications may include the cost of staffing for a system administrator and one or more application support specialists.

5.1.6 Training

Training is an often overlooked component of the cost of building an AM/FM/GIS. Costs vary mostly with the level of involvement in data conversion and quality assurance/quality control, and with the scope of applications and number of users to be trained.

5.2 Tangible benefit assessment

In assessing benefits, many of the same variables which affect costs come into play, along with other factors associated with the current state of facilities and business processes. The benefits to be realised from AM/FM/GIS must be carefully and conservatively analysed for each prospective utility. A number of sources have identified areas of benefit (Meehan 1995; Meyers et al 1996). The five most common high-level categories of tangible benefit normally cited are addressed below, along with brief examples.

5.2.1 Increased productivity in mapping

Virtually every utility investing in data automation can increase the efficiency and accuracy of map production and deliver maps which serve a broader range of business needs. Utilities with production systems have reported savings from one to three person-years of effort per year, based on eliminating the need for one or more drafters, or reducing outside contract labour for mapping.

5.2.2 Increased productivity through information access

Network models for engineering and operations analysis require data that is time consuming and costly to produce and maintain. Creation of intelligent network models is typically highly labour-intensive and normally requires a highly skilled technician or engineer. Driving the analysis model from the AM/FM/GIS database can actually result in reduced labour costs and improved analytical models. Utilities surveyed by Meyers et al (1996) report tangible savings that amount to reduced technician or engineering labour of one or more person-years, to the benefits of better, more consistent plans based on accurate analysis.

These benefits also extend to maintenance, especially where gas and water utilities invest large sums of money. An accurate data source with built-in query tools makes it possible to perform a number of maintenance analysis functions which either could not be accomplished using paper maps, or would be much less efficient (Cotting and Daniels 1994; Marshall 1996). The savings in maintenance may amount to hundreds of thousands of dollars per year, both in reduced engineering labour costs and more focused use of capital for improvements.

5.2.3 Improved engineering and operations efficiency

The opportunities for improving the efficiency of designing and operating a utility network range from better maintenance and corrosion protection to improved subdivision service design. Cost savings for this category are normally measured in terms of more efficient scheduling, or reduced costs in plant through better design and maintenance. Gas and electric utilities with production AM/FM/GIS have estimated annual savings in capital outlay of US$200 000 to US$1 500 000 through better design, reduced plant and inventory, and deferment of unneeded improvements.

5.2.4 Decreased use of mainframe computers

For some utilities, the cost of maintaining and expanding mainframe computing to support an existing AM/FM/GIS system can be avoided by moving functions to a distributed microcomputing environment. The costs avoided are usually calculated in terms of reduced computing cycles which are then considered to be available for other expanding requirements such as CIS or work management, or in one notable case, permitting the utility to eliminate one of two mainframe computers. In one example the reduction resulted in a net monthly operating reduction of US$120 000 for the five-year life of the new system.

5.2.5 Eliminating costs in map and records replacement/consolidation

At utilities where diverse and non-standard maps exist, because of historical practices which led to differing mapping standards, or through mergers and acquisition of other companies, the cost of redrawing and maintaining duplicate sets of records can be significant. This cost is also present when hardcopy map (e.g. paper, mylar, vellum, or linen) records need to be replaced because of degradation. For example, a gas company calculated that it would save US$485 000 over ten years by avoiding consolidation and replacement of existing strip maps.

5.3 Competition, change, and GIS

Utility restructuring, privatisation, and open energy marketing will soon have affected nearly every region of the world. Electric, gas, water, and waste water utilities from Australia to South America are being privatised (that is, government-run utilities are being sold to private companies for operation). Deregulation of utilities is a present or fast-approaching reality (Rector 1993). Throughout the globe utilities are under increasing pressure to reduce costs and improve the value of service.

Against this backdrop, the following four key issues will affect utility performance in the coming decade.

5.3.1 Coping with changing governmental and regulatory policies

Without question, utility restructuring and reregulation is the single most significant challenge facing the modern energy utility. Policy changes will affect aspects of rate making, expansion, and obligation to serve. AM/FM/GIS will play a key role in providing the integrated spatial view of plant and customers for changing policy environments.

5.3.2 Attracting and retaining customers

Utility restructuring means competition, especially in urban areas where facilities in place can be economically utilised. The ability to attract new or retain existing customers in a competitive market will depend on efficient operations that deliver high-quality service at reduced costs. The accurate and efficient methodologies for engineering analysis and creative design strategy offered by AM/FM/GIS technology will be key to fulfilling this objective. Further, encroaching utilities will be required to pay a transportation or 'wheeling' charge for using in-place facilities to deliver a commodity; accurate costs for plant in service, aided by AM/FM/GIS, will be critical in building a defensible cost base for wheeling charges.

5.3.3 The link between environmental responsibility and financial capability

Like many other businesses, the utilities industry has become increasingly aware of the capital markets' interest in environmental responsibility, and the possible risks associated with investment in entities with unsound or risky environmental practices. Beyond the realm of social responsibility to protect the environment, utilities are now faced with the economic reality of projecting a 'green' image of good stewardship in order to attract and retain investment capital. AM/FM/GIS can and will play a key role in helping utilities mitigate or eliminate environmental risks.

5.3.4 The ability to promote sustainable development

Many utilities have been actively involved in economic development at local, regional, and national levels. Investment in industries that use energy and water commodities is a rapidly growing facet of utility marketing and management. Partnerships with sound, resource-wise businesses will be one key to sustained growth in markets. AM/FM/GIS can provide the integration of commodity usage, network capacity, and reliability necessary to attract these sound partners to the service area of a utility.

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