BIOGRAPHICAL INFORMATION

Muniru Ayotunde Owoola
GIS Manager
Maltais Geomatics Inc.

Specific Responsibilities

‘Tunde Owoola joined Maltais Geomatics in 2002. Tunde is responsible for GIS project planning, project management, quality control, and GIS staff performance at Maltais, and provides technical leadership on all Spatial Technology Group projects. He also evaluates new spatial technologies for the company, and liaises directly with GIS clients. Tunde is particularly skilled at developing GIS applications that result in productivity improvements and new cost efficiencies for government and private sector clients.

Past Experience

Tunde was previously employed as a Senior GIS Analyst by the Town of Oakville, Ontario. He was responsible for evaluating new GIS technologies with respect to existing information technology applications, creating design requirements for new projects, implementing project plans, developing GIS applications, and providing staff leadership and training.

Prior to migrating to Canada in 2001, Tunde worked as the Head of the GIS Unit of an environmental company based in Lagos, Nigeria. He also taught undergraduate and postgraduate GIS classes at the University of Ibadan, Nigeria between 1995 and 1998.

Education Information

B.Sc. Geography – University of Ilorin, Nigeria
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Professional Membership

Canadian Remote Sensing Association
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Alberta Geomatics Group (AAG)

A GENERIC SPATIAL DATABASE SCHEMA FOR A TYPICAL ELECTRIC TRANSMISSION UTILITY

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ABSTRACT

The disparate data sets collected by utilities such as electric, water and gas, present major challenges especially in terms of developing generic spatial and attribute database architecture that effectively model data; capturing the interrelationships between network structures; and developing front-end user applications that utilize the database in a GIS environment.

This paper presents an architecture that (i) captures the complexity of a typical electric transmission network data, and (ii) optimizes applications development and integration in an enterprise-wide framework using ArcGIS, ArcSDE, Microsoft SQL Server 2000 and .NET.

1 INTRODUCTION

The need to maintain accurate, reliable and timely data for operational and asset management purposes is one of the major challenges confronting utility companies in today’s deregulated economy. For instance, operational and maintenance requirements of a typical electricity transmission company depend on a multitude of data elements, both spatial (locational) and dynamic (attribute) in nature. Utilities often maintain data on (i) circuit characteristics that describe the physical characteristics of the line, its current condition, and that which is being transported through it; (ii) characteristics of structures and towers that provide physical support for the lines and other associated components – conductors, shield wires, guys, anchors etc. These characteristics form dynamic data elements necessary for day-to-day planning, analysis and decision making purposes for efficient delivery of power to consumers.

The location component is equally critical to the overall planning, operational and maintenance processes in most utilities. An electric network is a noticeable landscape feature, and its configuration in space impacts other land use activities. It is of no surprise that land-based data such as property ownership, parcels, legal fabrics, right of way etc is of interest to utilities.

Geographic Information Systems (GIS) are becoming increasingly popular as effective platforms for maintaining the disparate datasets used by utilities, and for developing operational tools that assist users in day-to-day business processes towards improving overall efficiency.

A few software vendors have responded to the data maintenance challenges facing utilities by developing solutions that provide tools for electric network data management purposes. However, these proprietary systems are often not truly GIS, not generic, expensive to implement, and most do not support further customizations beyond the basic built-in functionalities. This paper shows how utilities can tackle their data management requirements by utilizing a framework that permits enterprise-wide data storage, data access and generic applications development/ deployment using commercial, off-the-shelf GIS and application development software. The key advantage of the framework is its openness and the endless possibilities of developing customized applications utilizing the underlying, highly structured enterprise-database.

2 DATA MANAGEMENT REQUIREMENTS OF A TYPICAL ELECTRIC UTILITY

Data collection, update, retrieval and analysis are critical operational components in most electric utilities. However, it is only in fairly recent times that attention is focused on GIS as a technology that can provide an integrative platform for workflow processes related to:

- data gathering, integration and processing
- data storage and update requirements
- enterprise-wide/distributed data mining
- production of topographic products and their customized presentation, analysis and interpretation for decision making purposes

Data collected by a typical electric transmission company will normally include among others, information on Substations, Circuit, Overhead Structures, Transmission Towers, Airbreaks etc. Each of the data types has associated characteristics that need to be continuously accessed, updated, and maintained in a production environment to support ongoing operations. Typical characteristics of Circuits and Structures are summarized in Table 1.

Table 1: Data Typology of a Typical Electric Transmission Utility

	Characteristics	Subtypes
Circuit	Name	Primary/Secondary
	Load Name	Primary/Secondary
	Source name	Primary/Secondary
	Circuit Status	Single/Double
	Installation Date	Primary/Secondary
	Circuit Voltage	138,240,500,750 kv
	Circuit Owner	
	Circuit Rating	
	Circuit Thermal Rating	
	Conductor Size	
	Limiting Condition	
Overhead Structures & Transmission Towers	Circuit Name	Primary/Secondary
	Structure Number	Primary/Secondary
	Structure Type	
	Underbuild Type	
	Span Rating	Primary/Secondary
	Structure Span	Primary/Secondary
	Span Rating	Primary/Secondary
	Circuit Voltage	138,240,500,750 kv
	Circuit Phasing	
	Structure Install Date	Primary/Secondary
	Insulator Type	Primary/Secondary
	Conductor Type/Bundle	Primary/Secondary
	Shield Wire Type/Bundle	Primary/Secondary
	Structure Function	
	Structure Location	

For most utilities, maintaining a central repository for data storage and access to support ongoing operations is still unattainable. Data storage and maintenance is at best compartmentalized, with each line department often maintaining duplicated data sets. In the most extreme cases, data sets are not synchronized between departments thereby limiting data reliability. It is easy to guess that generic data-driven applications development and deployment would be stymied in such environments.

More and more utilities are realizing the need for a framework to manage the spatial and non-spatial data sets that support critical business processes. The key element of such a framework is that it should support enterprise-wide spatial and attribute data storage, data sharing, data mining and front-end application development.

3 AN ENTERPRISE-WIDE DATA MANAGEMENT SOLUTION FOR ELECTRIC UTILITIES

Existing facility management applications in some utilities often form the precursor of integrating GIS within the corporate data management protocols. Nevertheless, making the transition to enterprise GIS frameworks has not been without some hesitation, considering the infrastructural requirements and associated costs of investing in GIS technology. Where cost is not a factor, utilities still face a choice between selecting completely customized software products depending on the needs of each line departments, or embracing an enterprise solution for managing the vast array of data, and developing the necessary tool sets applicable to the work flow processes. Many problems are associated with the former approach. These include:

- Custom software products are often data specific, and this requirement strengthens data compartmentalization, and tends to steer utilities away from consolidated data sets necessary for developing enterprise-wide solutions
- Data sources for such products are often file based, which do not permit multiple editing of data, versioning or transactional views of data all of which tend to simplify data management procedures
- Performance degradation is usually associated with applications utilizing distributed large spatial datasets because of high network traffic. This results in slow display of spatial data and processing operations.
- Maintaining applications utilizing distributed data presents serious challenges, especially if data locations on disks are changed or servers are renamed. This results in broken data sources, application failures and operational down-time.

On the other hand, an enterprise-wide solution offers more advantages for data structuring, access, maintenance and application development, and at the same time, avoids the pitfalls associated with the former approach. This is the approach being proposed in this paper, and should help utilities to maximize returns on investments in GIS technology for data management and application development purposes by providing an integrative framework that removes many of the frustrations being experienced with spatial data management and usability of custom software solutions. These include:

- Elimination of redundant/duplicate data some of which are not necessary for an electricity transmission utility
- Better representation and structuring of data necessary for improving the workflow processes
- Developing database models based on the needs of the end-users
- Developing adequate metadata on enterprise-wide database, making data currency and accuracy assessments possible
- Providing multiple-editing, versioning, transactional, capabilities, and a highly secured environment for data and application sharing
- Integrating existing data and solutions within the overall enterprise-wide data architecture

The major components of this approach are discussed in the remaining sections of this paper. The software components are based on ArcGIS 8x/ArcSDE 8x (ESRI 2003) technology and Microsoft SQL RDBMS and Microsoft .NET (Microsoft Corporation, 2003) suite of development environments. Besides, the paper summarizes the empirical application of this approach in a real-life implementation within a major electric transmission utility in Canada.

4 MODELING ELECTRIC NETWORK DATA IN AN ENTERPRISE FRAMEWORK

Developing a database architecture that effectively captures the complexity of a transmission utility is a challenging task considering the requirement that such a database should remove any existing bottlenecks associated with distributed data architecture. In general, modeling requirements of the network-like data collected and maintain by utilities should take cognizance of the following steps:

- group all data elements into logical sets, subtypes and classes
- identify and model all possible relationships within datasets and associated attributes on one hand and between datasets/attributes on the other
- identify/incorporate future data requirements
- identify updates requirements
- capture all data objects and relationships with automation tools (UML and CASE tools) that streamline database design and development and also provide an automated means of populating databases

4.1 Logical Grouping and Feature Storage of Electric Transmission Data

Network representation of data in an enterprise GIS environment requires careful assessments of the internal business processes within the corporation of interest. A starting point of model development is to first disaggregate the entire network data into logical sets, subtypes and classes. Table 1 shows the logical sets that capture some of the most important data components managed by electric transmission corporations. Further dis-aggregation of major groups into subtypes and characteristics is another important feature of the network modeling process. Subtypes and characteristics in this sense refer to the peculiar attributes of each logical group. First level attributes are the subtypes or classes, while the characteristics are the attributes of both the logical groups and the subtypes. Conceptually, consider the following example of a Circuit (Transmission Line).

Logical Group	**Subtype**	**Attributes**
Circuit	Single	attributes a, b, c, d, ….
	Double	attributes a, b, c, d, …..

Operationalizing this simple conceptual model within a spatial database architecture as a logical network is subsequently easy to implement. In the empirical implementation, all circuits are associated with structures (tower or overhead structure), and these relationships will always hold true for circuits and structures:

1. Single circuit lines run off single circuit structures
2. Double circuit lines run off double circuit structures
3. Circuits and structures are associated by both location and shared name attribute

4. Subtypes of circuits are determine by the subtypes of structures associated with the circuits and each subtype can only occur at specified segments along a circuit's entire length
5. Subtypes of structures are determined by the number of circuits on each structure

The types of associative relationships specified above are prevalent throughout the empirical implementation and are useful for topological structuring of the database to reduce redundancy in the storage of the network features. Thus, for linear storage of double circuits in the database, it is not necessary to store each circuit separately. Instead, a single line segment will represent a double circuit segment and is also used to represent a single circuit segment whenever this occurs along the circuit (Figure 1)

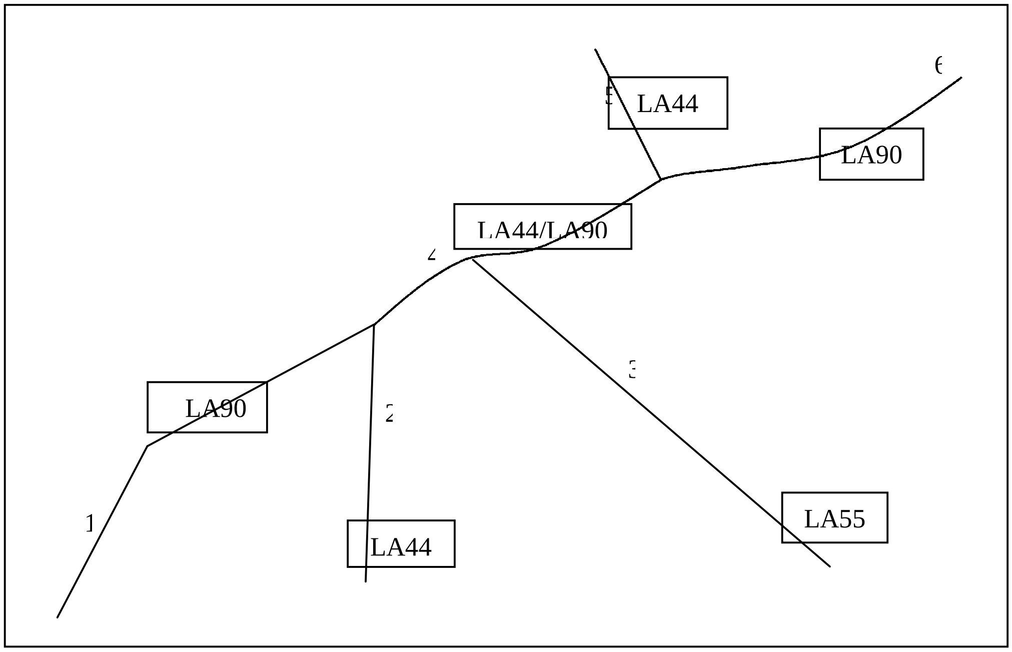


Figure 1: Topological Structuring of Circuits in a Spatial Database

In this example, circuit names are enclosed in text-boxes and the actual stored segments in the database are numerically numbered. Circuits LA90 & LA44 start off as single circuits (Subtype = Single) at segments 1 and 2 respectively. However, at segment 4, both circuits are running off the same set of transmission towers (Subtype = Double), before continuing independently as single circuits (Subtype = Single) at segments 5 and 6. Circuit LA55 at segment 3 is single circuit along its entire length.

4.2 Attribute Storage and Relationship Modeling

Attributing the network data in the empirical implementation is dependent on two rules:

1. Where the voltage of two circuits running on the same set of towers is the same, the primary circuit is the circuit with the lower alphanumeric number
2. Where the voltage of the two circuits on the same set of towers is different, the primary circuit is the circuit having the higher voltage

The rules were developed to aid data mining and database navigation and to structure the relationships between network elements. Also, these rules determine how attributes are structured and stored in the database. Following these rules, all attributes of the primary circuits and structures are stored at the feature class (spatial or graphical) level, while attributes of the secondary circuits and structures are stored in tables and managed using relationships.

The relationships defined between network objects (features and tables) determine how quickly and easily attributes of these objects can be accessed. Relationships also maintain the association between objects and aid in keeping the database in a synchronized state for editing purposes. Figure 2 depicts the relationship mapping for Overhead Structures in the empirical implementation.

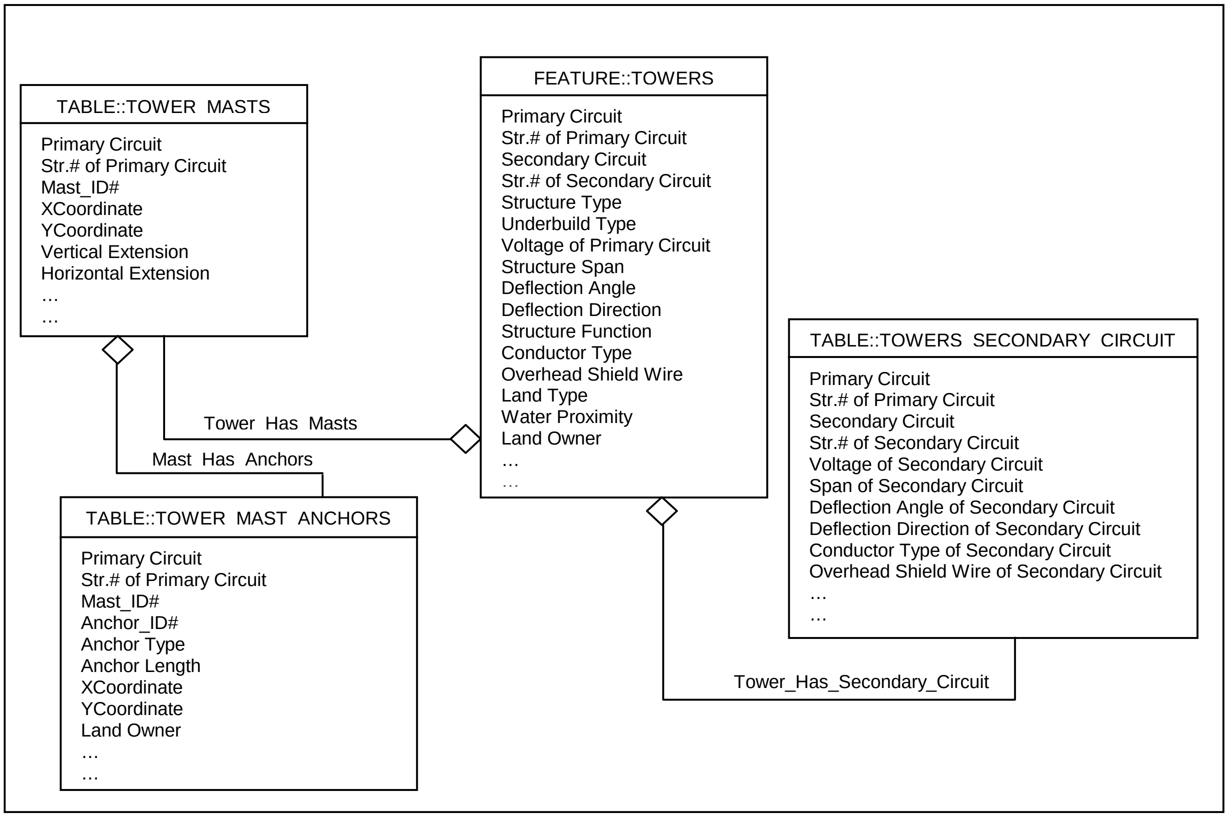


Figure 2: Relationships Schema for Overhead Structures

4.3 Modeling Future Data Integration Requirements

It is desirable to identify future data integration requirements at the conceptual database modeling stage, in order to reduce integration efforts associated with new data capture initiatives. This eliminates the need to extend the database design to incorporate new data collection efforts during future updates.

The framework being proposed will integrate all types of data including documents in different digital formats, orthophoto products, engineering and CAD drawings etc. One design consideration is that physical storage of these data sets within the enterprise-wide spatial database is not required, since data layers in this category remain static for a long period of time. Besides, reconfiguring existing applications that use these data sources is likely to make this approach less appealing. Given these factors, an efficient alternative was to use the solution’s APIs (Application Programming Interface) to access the data sets as they are.

4.4 Modeling Data Update Requirements

Another important modeling requirement is to identify and detail the procedures to maintain the database in a production environment when data is being updated, and also establish data integrity rules to reduce error propagation in the database. Data update in this sense relates to actions executed to input new data, delete existing data or change database schema. On the other hand, rules are mostly system-based, and are designed to impose constraints on certain actions when the database is being modified by the users.

User interaction is probably the most likely source of introducing errors in a spatial database. Although it is unlikely that a database will be 100% error free, however, internal workflow processes can be developed to QA/QC the database during and after any update to minimize database corruption. Besides, checklists can be developed to make sure that editors perform sequence of actions that ensure that errors will be minimized in the database. For example, some actions in this implementation involve:

- Depending on the feature class or tables being edited, a few data fields have to be always maintained to trigger the built in database relationships. A typical list of fields to be maintained and rules by feature class and tables is presented for circuits in Table 2.
- Some feature classes have associated tables that are related (using defined relationships) to the Feature class. Editing these feature classes would require editing the associated tables as well (Table 2).
- Some tables are standalone, and are related to each other in the database

Table 2: Maintenance Rules for Feature Classes, Tables and Fields

ARCSDE OBJECT	FIELDS	MAINTENANCE RULE
FEATURE CLASS		
CIRCUIT	PRIMARY_CIRCUIT#	Null or empty value not permitted if a line is added to the GIS
	SECONDARY_CIRCUIT#	Null or empty values permitted for single circuit lines, otherwise not permitted
	DBL_CIRCUIT	Should not have a null entry, valid values are Y or N
	CIRCUIT_1_2_OID	This is the primary field for the ***Secondary_Circuit_Info*** relationship. Auto Concatenate PRIMARY_CIRCUIT# and SECONDARY_CIRCUIT# fields to populate this field. If DC segments are > 1, add A, B, C etc after the line number to differentiate each segments
TABLE		
Secondary_Circuit_Info	PRIMARY_CIRCUIT#	Null or empty value not permitted if a DC line is added to the Database
	SECONDARY_CIRCUIT#	Null or empty values not permitted if a DC line is added to the Database
	CIRCUIT_1_2_OID	This is the foreign field for the ***Secondary_Circuit_Info*** relationship. Auto Concatenate PRIMARY_CIRCUIT# and SECONDARY_CIRCUIT# fields to populate this field. If DC segments are > 1, add A, B, C etc after the line number to differentiate each segments

Beyond stipulating rules that minimize error propagation, it is also necessary to establish data integrity rules that ensure that positioning of facility data and spatial associations between them are not compromised when features are being edited. This is done through geometric network development.

In this framework, a geometric network is designed to store connectivity information between spatial features in the geodatabase. The geometric network preserves the database and eliminates data corruption associated with data editing operations. In developing the geometric network for the database, careful consideration should be given to the following factors:

- The network rules adopted should support the existing database without any major change(s) to existing schema
- The rules should be simple enough to understand, and should reflect accepted standards for modeling typical electric networks
- The geometric network should be capable of supporting in-built functionalities and other existing ESRI network extensions

4.5 UML and CASE TOOLS

Unified Modeling Language (UML) and Computer-Aided Software Engineering (CASE) tools are being increasingly used to model database life-cycle, from conceptual development, to database re-design and database population activities. These tools are incorporated in ESRI's ArcGIS 8x and Microsoft product development environments to facilitate the following:

- modeling objects and their behavior
- creating schemas for database objects
- establishing relationships between objects in different object classes
- defining connectivity rules for objects participating in geometric networks

UML and CASE tools are used in this implementation in every stage of the database development process. One major advantage of using this platform is the flexibility for loading datasets into geodatabases based on previously defined schemas and relationships.

5 THE EMPIRICAL IMPLEMENTATION

This section of the paper provides a summary of the empirical implementation of the main ideas highlighted in this paper. This implementation is for a major electric transmission utility in Canada. It shows how a properly structured enterprise-wide database is used to develop and support an asset management information system application. This application aids facility managers in accessing information of interest, provides tools for the continuous update of the database and forms an integrative environment for field and office operations in managing electric transmission facilities. The implementation also shows how an open source development environment is used to develop standalone applications that utilize the spatial database in generating useful reports that aid the facility management process.

5.1 Asset Management Information System

The Asset Management Information System (AMIS) is the front-end graphic user interface (GUI) developed to provide users with the set of generic tools for searching the database, carrying out spatial analysis and utilizing other GIS functionality. This application was developed with ESRI's ArcObjects and Microsoft Visual Basic development environments and runs on ArcMap. AMIS is composed of two GUIs – Locator (Figure 3) and Circuit Summary and HyperLinks (Figure 4). These two GUI's integrate four AMIS tools:

- Facility Search Engine
- Legal Description (LandBase) Search Engine
- Circuit Information
- HyperLinks

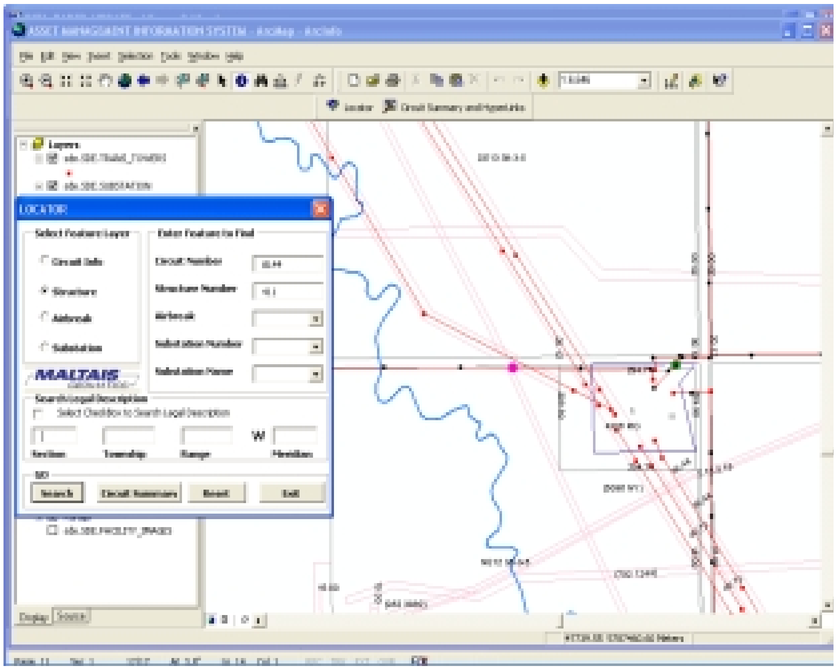


Figure 3: Executing a Structure Search using Locator

5.1.1 **The Locator GUI**

Locator enables users to search the database for any facility of interest – Substations, Circuits, Towers, Overhead Structures etc. Once found, the interface zooms to the facility and users are able to derive additional information (attributes) on the selected feature using additional tools. For ease of feature interpretation, different symbols and colors are used to represent each facility type (Figure 3). The display of background layers (landbase and facility images) is scale dependent and defaulted to 1:10,000. Since these layers are mainly used for spatial reference purposes, it is not necessary to have them displayed all the time. Consequently, feature display and refresh functionality is much faster using this approach.

The Locator GUI also allows users to search for any land location using legal description parameters. This is a very useful functionality, especially for the land division of utilities. Once a land location is found, managers can quickly find out what facility is in that particular location. In addition, that information is very useful in determining facility right of way and verifying land owners compensation claims.

5.1.2 Circuit Summary and HyperLinks

The Circuit Summary and HyperLinks tool integrates three functionalities (i) it provides access to pre-defined information on the currently selected feature(s); (ii) it calculates line length and circuit length if the selected feature is a circuit and (iii) it provides access to images and/or documents that are linked to the currently selected feature.

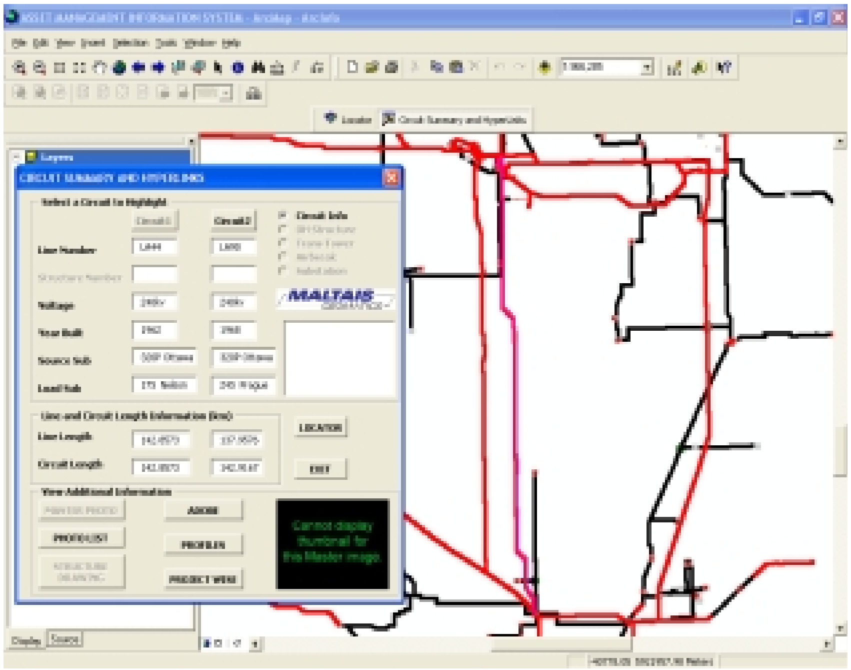


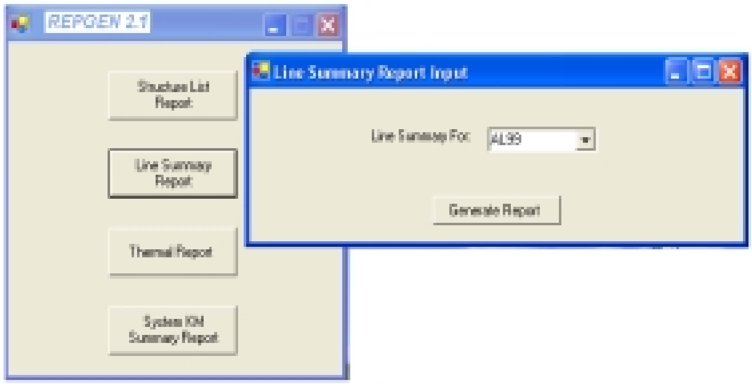
Figure 4: Using the Circuit Summary and HyperLink Functionality

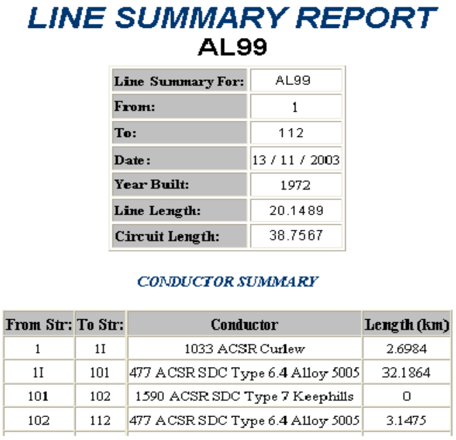
The Circuit Summary and HyperLinks GUI updates dynamically, depending on the feature class of the currently selected feature. Therefore, the interface looks different for Circuit than it does for Substation, Airbreaks, or Structures, and vice versa. For example, if the Circuit Summary & HyperLinks tool is used to select a line, the display updates to show the entire length of the line in the default selection color and the GUI updates to depict the relevant information of interest to users (Figure 4).

Access to documents, photos, images, profile drawings and existing applications relating to the facility of interest is provided through the View Additional Information section of the Circuit Summary and HyperLinks GUI. Again, available functionality is determined by the selected facility type. Besides, since most of the information accessed through this interface resides elsewhere on the network, the database size is kept at minimum, and GIS data display is optimized.

5.2 Report Generation

Quick and timely report on facilities is an essential component of the asset management process and helps the facility manager to schedule field inspections, determine replacement cycles and similar facility management tasks. In our approach, we consider that report generation should be flexible, user-driven and it’s development not constrained by the limitations of the GIS software. Indeed, this approach supports the development of any types of reports in the immediate implementation and in the long term, as long as the application development environment supports ODBC standards.





LINE SUMMARY REPORT

AL99

Line Summary For:	AL99
From:	1
To:	112
Date:	13 / 11 / 2003
Year Built:	1972
Line Length:	20.1489
Circuit Length:	38.7567

CONDUCTOR SUMMARY

From Str:	To Str:	Conductor	Length (km)
1	11	1033 ACSR Curlew	2.6984
11	101	477 ACSR SDC Type 6.4 Alloy 5005	32.1864
101	102	1590 ACSR SDC Type 7 Keephills	0
102	112	477 ACSR SDC Type 6.4 Alloy 5005	3.1475

Figure 5: Report Generator User Interface

Microsoft's C# is the chosen environment for developing the reporting application. Since the database itself resides in Microsoft SQL Server 2000 software, the development environment tightly integrates with the database environment and provides the needed application programming interface (API) for interacting with the database.

Reports on structure list, structure age, conductor types, conductor bundles, overhead shield wires, pole/mast length, structure and pole counts, line and circuit length etc are easily generated using the reporting tools (Figure 5 shows one of the reporting interface and a typical output is depicted at right.

6. Conclusion

Accurate, up-to-date data is essential for facility management purposes within utilities. Since electric utility data are both spatial and non-spatial in nature, developing effective database schemas to represent the data sets is a major challenge. In this paper, it is recognized that database schema development should focus on (i) optimizing data storage and access, (ii) allowing the development of front-end applications that are flexible to use and that provide users with the set of tools to display spatial data and view associated attributes and (iii) simplifying report generation by removing any limitation to using other APIs apart from those integrated with the spatial data storage and analysis software.

The paper summarizes the schema development process, and how electric data is modeled as a network. Besides, examples of an empirical implementation of the main ideas presented in this paper are discussed.