GEOGRAPHIC INFORMATION SYSTEM APPLICATIONS FOR TRI-MET

NEEDS ANALYSIS AND PRELIMINARY IMPLEMENTATION PLAN

by

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ABSTRACT

Transit providers such as Tri-Met, are recognizing the potential benefits of using GIS concepts and technology to develop an integrated geographic database that supports a variety of transportation applications. The quality of information available affects the decision-making capacity of managers, and GIS is a tool by which various data can be integrated. Location is the key by which separate data can be integrated to paint a better picture of operations of infrastructure systems, such as transit, that function in a geographic region. This research identifies opportunities for increasing the consistency among databases supporting diverse application and a reduction in duplication of separate updates of independent application databases.

GIS can facilitate the many mapping and spatial analysis activities upon which successful transit operations are dependent. However, the successful implementation of GIS in the transit setting will depend upon the geographic base on which the system is built. The TIGER file is recommended as the appropriate geographic base on which to build Tri-Met's GIS applications.
1.0 INTRODUCTION

This report on Geographic Information Systems (GIS) Applications in Urban Public Transportation has two clients. One is Tri-Met, the transit provider in the Portland metropolitan area, who is seeking to better integrate agency data to increase its efficiency and effectiveness. The other is the U.S. Department of Transportation on behalf of other agencies that provide urban public transportation services. They are also clients for these research findings. Tri-Met’s experience with applying GIS concepts and technology can serve as a guide to other organizations seeking to use GIS concepts and technology to achieve greater systems integration in support of improved planning, management and operations.

Organizations providing urban public transportation services are operating in a rapidly changing environment. Continuation of traditional transit operations is insufficient. Better information is needed to provide a greater diversity of urban public transportation services, with greater efficiency and effectiveness. To achieve this, it is important to manage information well and to integrate the efforts of a number of initiatives in the organization because information is a corporate asset. The value of the corporate asset is a function of its accuracy and consistency. Out of date, redundant and conflicting data detract from its value.

1.1 Research Objectives

This research is jointly sponsored by the U.S. Department of Transportation via TransNow, a transportation research center consisting of a consortium of Pacific northwest universities with the lead university being the University of Washington. The objective of this research project is to examine the suitability and flexibility of a common geographic database to serve a variety of applications within a transit organization.
Meanwhile, other transit organizations can benefit from the approaches and findings of the process used to develop the preliminary implementation plan for Tri-Met.

1.2 Integration of Agency Geographic Data

A variety of transit organization functions are dependent upon geographic information. For GIS to be used effectively in managing this information, a systematic approach to implementation is recommended. Not only can GIS serve a variety of mapping, facilities management, and planning needs, but this research has identified a number of applications where better visualization of operations can be achieved with the aid of an integrated spatial database managed by a GIS.

An example of the variety of spatial data applications for which integrated spatial data management would be beneficial, involves the the scheduling and service planning functions at Tri-Met. While the scheduling unit has acquired a computer-aided drafting (CAD) package to draw maps for bus drivers, the service planning unit is looking for a means to digitize bus routes to relate to traffic analysis zones. Fortunately, Tri-Met has embarked on a systematic analysis of geographic information systems applications to avoid unnecessary duplication and proliferation of systems and databases. Not only do shared systems and data resources reduce costly duplication, but integrated spatial data management assures consistency among data used by various Tri-Met units. For example, changes made to transit routes are made once and transmitted to all applications needing route updates. If these functions remain uncoordinated there is no guarantee that the changes made to the route by one unit will be made in other databases.

A common database does not require that all applications and analysis be conducted at the same scale and detail. GIS technology allows for a great degree of application flexibility and digital maps can be rescaled and viewed from different geographical view points to fit the needs of
different users. For instance, a large-scale analysis may require that streets be shown as double lines indicating rights-of-way, while other analyses of transit routes are served by single width lines for streets, with bold lines or colored lines highlighting the streets serving as bus routes.

The investigation of potential applications of GIS at Tri-Met has identified the U.S. Bureau of the Census TIGER (Topologically Integrated Geographic Encoding and Referencing) line file as the underlying geographic framework for Tri-Met applications. Street segment and city blocks constitute the most elemental graphic and data units for a transit organization. TIGER is available in the public domain and it will be maintained by a variety of organizations with interests in urban and regional spatial data. Consequently, it will also serve as a vehicle for spatial integration and coordination with the GIS of other organizations and agencies in the metropolitan area.

Paratransit dispatching applications are a high priority at Tri-Met. Paratransit, or Special Needs Transportation, consists of a variety of flexibly scheduled van routes, Dial-a-Ride services, and taxi subsidy programs serving senior citizens and individuals who are mobility-impaired. The scheduling and dispatching of these services is planned to be consolidated into a central location and special attention is being paid to the spatial data requirements of this application. Therefore, Paratransit Service is identified as the lead unit for the development of applications using TIGER. In assuming this lead role, applications developed for paratransit will address the requirements of other units. In this way, a comprehensive systems development can be achieved in the context of a needed project while setting the stage for large benefits for subsequent applications.

Among these diverse application areas, a digital base map of the transportation system of the service area can be used most effectively if it includes the database functionality, attribute data, and topological information that enable it to be a shared corporate resource capable of providing the framework for data integration throughout the organization.
1.3 Literature Review

The lack of systematic literature on GIS applications in urban public transportation has been noted (Dueker and Vrana, 1990). Yet, there have been a number of partial applications, such as the use of GIS to support paratransit dispatch applications (COMSIS, 1989). The use of geographic base files in trip planning systems (Rousseau and Roy, 1989), and unheralded and inadequately reported GIS applications (Solga, forthcoming).

A set of more ambitious and integrated efforts are taking place under the label of AVL (Automatic Vehicle Location) systems. To the extent to which they have a map base for visualization, there is a need for a geographic database and GIS software to manage it (Hemily, 1988). In turn, this is part of a larger set of literature referred to as IVHS (Intelligent Vehicle and Highway Systems). The geographic dimension of IVHS is receiving modest attention and a proposed geographic data file standard has been proposed (Claussen, 1989). In addition, much can be learned from the growing literature on GIS—Transportation, even though most of the emphasis has been on highway applications (Nyerges and Dueker, 1988; Shaw, 1989).
2.0 TECHNICAL ANALYSIS

The technique used in this research consisted of an analysis of Tri-Met functions to assess opportunities for GIS applications and the development of a taxonomy of application areas. In discussion with Tri-Met’s GIS Task Force, priorities were established and a preliminary implementation plan was developed.

2.1 GIS Applications at Tri-Met

There are applications of GIS technology and concepts in nearly all areas of the Tri-Met organization. Implementing GIS solutions to these data processing needs may be done for the most part with common hardware and software components. Although the databases to support analytical functions throughout the agency may vary considerably, diverse applications may have similar needs to input map data, analyze spatial information and display query results. Thus, an investigation into the utility of how a common spatial base will support the data modeling tasks and requirements for specialized applications is warranted. For this report five principal functional areas are described. Particular applications are described in terms of the Tri-Met organization, but as functional areas, the five are intended to be representative of transit organizations at large. These are: Facilities Management (FM), Facilities Engineering (FE), Service Planning (SP), Operations and Control (OC), and Customer Service (CS).

Cutting across these application areas are several needs: 1) the posting of routine changes in services for multiple users in various parts of the organization, 2) data to manage emergency situations, 3) provision of a range of mobility services to individuals, and 4) strategies to manage transportation demand at a regional scale. These needs require the orchestration of all the functional areas of transit organizations.
The posting of routine changes is more than updating files. It is insuring that updates are transmitted throughout the organization. In other words, the organization should strive to reduce independent updates of separate files that lead to varying accuracy, currency and much duplication.

Emergencies require marshalling resources from the five functional areas described above, to plan for emergency response, to manage the response effort and to operate the emergency response plan. Since emergencies are most often locationally specific, GIS is a valuable tool, because it enables the collation of separate data by location. Mobility management and demand management cut across the organization as well. At both individual and regional scales, more than one of the functional areas of transit organizations are required.

Table 1 provides a framework for relating potential GIS applications at Tri-Met to GIS vendor capabilities that have been solicited. The application types are arrayed in relation to their position as one-, two-, or three-dimensional problem spaces. One dimensional problems are handled by calculating time and distance, such as for dispatching and routing. Two dimensional problems require analysis and map display in x, y coordinate space, while three dimensional problems require analysis and visualization in perspective, using three dimensional coordinate space, x, y, and z. The figure also identifies the location of types of vendor products in this dimensional space. Phase 2 of this research will develop this analysis of vendor capabilities to serve transit organization applications beyond this initial approximation. Vendors provide a number of useful products. The challenge to transit operators is to select modules and to integrate them. It is probably not possible or desirable to rely on a single vendor for an entire solution. GIS concepts can be viewed as a technology by which to integrate Computer-Aided Drafting and Design (CADD), Automatic Vehicle Location (AVL), scheduling and dispatching, and transportation planning modeling systems.
Table 1
Framework for Evaluating Vendor Capabilities for Urban Public Transportation

<table>
<thead>
<tr>
<th>Problem Spaces</th>
<th>One Dimensional</th>
<th>Two Dimensional</th>
<th>Three Dimensional</th>
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<tr>
<td>Type of Problems</td>
<td>Scheduling, Dispatching</td>
<td>Service Planning, Mapping</td>
<td>Design Evaluation in 3-D, Viewshed Analysis</td>
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<td>Functional Categories of Applications</td>
<td>Facilities Management</td>
<td></td>
<td>Facilities Engineering</td>
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<td></td>
<td>Service Planning</td>
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<td>Operations &amp; Control Dispatch</td>
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<td></td>
<td>Customer Service</td>
<td></td>
<td></td>
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<tr>
<td>Types of Data</td>
<td>( v, t ) speed, time</td>
<td>( x, y ) points, lines, areas network models (travel time and distance)</td>
<td>( x, y, z ) points, lines, areas, surfaces, and volumes network models (metric distances)</td>
</tr>
<tr>
<td>Types of Systems Available from Vendors</td>
<td>Scheduling and dispatch</td>
<td>2-D CADD, GIS</td>
<td>3-D CADD, terrain modeling</td>
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<td></td>
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<td>Transportation Planning Models</td>
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2.1.1 Facilities Management (FM)

A number of spatial databases are possible for the maintenance of what public utilities call “outside plant facilities.” For Tri-Met, these are facilities distributed throughout the region and for which a computerized GIS inventory would be useful. Existing tabular data management techniques keep a record of agency investment and maintenance requirements for individual bus shelters, information kiosks, and light rail transit (LRT) stations. GIS adds a geographic index to that inventory plus the ability to analyze spatial patterns in the data and to display the results in the form of a map.

An analysis of potential FM applications identified several types of facilities amenable to a GIS-based inventory system. These are:

- Bus routes, consisting of TIGER street segments, which will allow linkage to local government street data,
- Shelters, linked to routes, bus stop and TIGER street segment,
- Park and Ride locations, containing attributes such as type of ownership, number of spaces, and utilization, related to bus stop and route,
- Bus Stops/Signage, related to stop number and routes, and
- LRT route facilities and stations, spatially referenced by milestone.

For facilities such as bus stop shelters, which require a regularly scheduled maintenance procedure, a GIS can be used to determine routes that minimize travel by maintenance crews who must service all facilities in a given sector without regard to the individual bus routes they serve. Similarly, it is envisioned that a comprehensive inventory of the location of route signage can facilitate this maintenance task as well as improve route change notifications to the ridership. Another routing problem is the delivery of tickets, passes, and schedules to sales outlets. There is
some interest in combining this delivery route with routes for maintenance, bus stop signage, and shelters to minimize the number of single-purpose routings.

Although it not necessary to include the fleet inventory (rolling stock) in a GIS database, the bus and LRT identifier numbers will provide a link between the dispatch system and the fleet inventory. The ID provides links with other non-spatial databases (parts, repairs, operators). FM systems are not intended to contain engineering level detail and accuracy, but inventory data for maintenance. Similarly, the ID links the location and key attributes of an "outside facility" to large scale engineering design drawings or construction specifications.

Tri-Met may also wish to create special spatial databases for important rights-of-ways, such as the Transit Mall or MAX LRT if management wishes to access property information spatially or to display results of attribute searches of the database as a map. Such a spatial database is recommended for the MAX LRT right-of-way and for the downtown transit malls. An attribute database containing data for all important spatial objects should be created for inventory and maintenance of facilities contained in these rights of way. The location of the spatial objects should be referenced by milepoint, stationing, and x and y coordinate. This will allow both spatial search by pointing to a display of spatial objects, and attribute searches, with the map display of the objects meeting attribute search criteria.

2.1.2 Facilities Engineering (FE)

Plans of plant facilities (As-builts) are candidates for inclusion in a spatial database, although it is not a high priority. Maintenance facilities, such as bus barns and LRT maintenance buildings are too few in number to warrant inclusion in a separate spatial database. CAD drawings and scanned images of manually produced plans are needed, but not as part of the GIS. Similarly, as-builts of
transit transfer centers and the headquarters building are important for a maintenance program. What needs to be investigated is whether facilities within buildings must be inventoried spatially. Is location of items within a building important? Probably not, but a spatial index to digital images or analog plan drawings may be useful. As described above, the index would be to plant site plans, architectural drawings, LRT plans and as-builts.

The engineering design of LRT lines will benefit from the merging of CADD, photogrammetry, image processing, and GIS technologies to achieve 3-D visualizations or renderings of the proposed design in its environs. This requires the integration of rasterized image data and vector design data on a surface representing the landscape.

2.1.3 Service Planning (SP)

GIS can be very valuable for service planning. Service planners need to integrate data from various sources by location, and GIS serves that need. In addition to integrating data from disparate sources, service planners need to spatially aggregate and disaggregate data on regional economic and demographic characteristics which can also be facilitated with a GIS. Two applications that share this requirement are route planning and schedule planning.

Route planning is a function that has specific geographic considerations. Route data consisting of attributes and/or restrictions on segments and/or nodes are important for service planning databases. Service planners generate alternative routes that need to be related in the GIS to TIGER street and intersection data to provide map displays that illustrate the impact of proposed routes.

An important aspect of route planning is to relate the route description to demand or utilization data. Consequently, it is necessary to be able to aggregate automatic passenger count (APC) data from
bus stops to traffic analysis zones (TAZ) and to disaggregate TAZ data to bus stops. Linkage of route, TAZ, and bus stop data to the TIGER file street segments will foster flexibility in developing these relations as needed. The GIS and TIGER may also serve to link automatic vehicle location (AVL) and APC data to estimate bus stop boardings and alightings.

Schedule planning is a function that has more temporal than spatial considerations. However, it is still important to incorporate maps in the analysis. Maps are also useful in the analysis of schedule exception reports. GIS can be used to archive and analyze exception reports by location, route, and time. These displays can be of considerable use in service planning. Similarly, it may be useful to map changes resulting from schedule planning, such as comparison of schedules and levels of service. Use of GIS would enable linking transit service data to related information about other modes, traffic volumes, traffic signals, construction zones, and traffic accident data.

2.1.4 Operations and Control (OC)

The use of GIS in operations and control would serve to describe the geometry and topology of the route and street structures in the service area. In addition, and in conjunction with AVL, GIS serves to display the location of the fleet in real time. Bus dispatchers currently monitor the status of the system with computerized applications that log radio communications, exception reports, and various incidents and events for summary description in daily and weekly reports. Both operations dispatchers as well as dispatch supervisors have expressed interest in a computer console map display to assist these dispatching tasks. For operating dispatchers, this would be a benefit because, 1) they are already at the console, and would use the monitor for other functions as well as map display, and 2) they currently reference a map display in the dispatch center, but it is a system-wide wall map that extends from the floor to the ceiling. Dispatchers report situations that in some cases require leaving the radio console and physically getting on hands and knees to
examine the southern extent of the service area. Dispatch supervisors have a similar need to reference the geography of the system during operations, as well as the ability to get an overview of dispatching problems and incidents throughout the system.

GIS is less important to a LRT dispatch system. The route can be represented in schematic terms as a straight line with an AVL system to keep track of the location of vehicles and so needs no explicit representation of system geometry. However, the subsequent integration of fixed-route bus and LRT dispatch will require greater GIS functionality to be able to identify key system transfer points between bus and rail services. Similarly, integration of paratransit and fixed route dispatch systems will place demands on GIS technology.

Paratransit dispatching require GIS support of the geography of the service area at a detailed level. Door-to-door service requires address, intersection, and landmark geocoding, with grouping and routing procedures for scheduling. Of particular interest is the use of a continually maintained TIGER line file to update the current database used for paratransit scheduling.

Of broader concern is the use of the paratransit dispatch project as a prototype for an integrated and comprehensive system for scheduling paratransit, customer information and route planning, and other uses of the underlying system of geography that the TIGER line file provides. It is therefore important to specify the requirements of the paratransit GIS that will enable a growth path to an integrated system for Tri-Met. An example of this is the requirements of intermodal connections, in real time, which are to be addressed initially by integrating fixed route and paratransit trip planning. It is proposed that TIGER be used to support this integrated application.
2.1.5 Customer Service (CS)

Customer service has a number of uses for GIS. They include telephone customer information services, trip planning assistance, and map products for customers. Typically, customer information service consists of providing schedule information for routes. This customer information function could be made more productive if the service representative could reference a map display for alternative routes and trip strategies. A still greater degree of customer service could be achieved with an integration of customer service and dispatching functionality, utilizing AVL to provide actual, in addition to scheduled arrival times. In addition, the ability to compare scheduled and actual time is a needed feature of a complaint response system.

Integrating fixed-route, paratransit, carpool, and taxi trip planning is another area that would benefit from GIS. A common geographic database is needed to integrate the various modal data.

Computerized trip planning assistance, whether by phone or at customer operated kiosks, require the capability of handling point to point (address, intersection, or landmark specified) requests. The application must search for the nearest and most direct route within walking distance of both points that provides service during the time period requested. In addition, the database must identify connecting routes to provide transfer information. An additional complication in an integrated system is to provide special needs/paratransit clientele additional information about connecting to the fixed route system. This requires an algorithm that searches for accessible stops on routes that can take customers directly to their final destination. Accessible stops may be defined as those which contain curb cuts, wheelchair lifts, and other installed and maintained facilities that would be a part of the FM database. Finally, the system must be capable of analyzing whether that transfer to the fixed route system adequately provides for the needs of this clientele. Service standards may dictate that transfers on the fixed route systems are not acceptable for an
intermodal trip due to time limitations or other considerations. In this case the customer may be referred to non-fixed route alternatives.

Whether by phone or at a kiosk, map outputs of trip planning system queries are important. By phone, the telephone assistant needs a map display to provide instructions, followed up with a copy mailed to the customer. Interactive kiosk systems will need a map display to convey the results of the trip planning request.

Providing maps for customers is an important function at Tri-Met. Customer maps take several forms, a system map, sector maps, individual route maps for inclusion in schedules, and vicinity maps at transfer centers and shelters. These maps can be extracted from TIGER and tailored for specific uses. Some considerations for implementing mapping applications are taken up below.

2.2 Conclusions from Functional Analysis

The technical analysis of the functional areas of urban public transportation have identified a large number of potential GIS applications. GIS cannot be considered as an appendage, however. As an integrating technology, it must be carefully incorporated into the organization for maximum benefit. The demand for transportation and the transportation services are distributed in geographic space, and all the relevant data concerning supply of and demand for transportation must be matched up in geographic space. GIS is the tool by which data can be integrated by location.

For most GIS applications, the urban street system represented in terms of a street center line file will serve as the underlying geographic database. All objects relevant to urban public transportation should be expressed or linked to that geographic database. Fortunately, TIGER is an available resource that nearly fills the need.
The diverse needs and character of urban public transportation pose considerable challenge. Among these challenges is the real-time nature of transportation operations and control. GIS is not the whole answer; it must be used in conjunction with other technologies, principally AVL and communications. GIS will provide the important function of visualizing in map space the operations and control functions of transit operations.

3.0 IMPLEMENTATION PLAN FOR TRI-MET

The preliminary implementation plan for Tri-Met serves as a guide for phase 2 of the project, while at the same time serves as a general introduction to GIS applications in urban public transportation for other organizations. Consequently, it is intended to be conceptual in nature and focuses on the issues to be addressed in a more detailed implementation plan.

3.1 Implementation Issues

The broad range of GIS applications at Tri-Met requires considerable coordination, while at the same time allowing for simultaneous implementation paths. Opportunities for shared data and systems resources are sought. For a successful agency-wide GIS strategy, six considerations for implementation should be addressed. These major implementation issues are, 1) systems integration and data transferability, 2) visualization and mapping requirements, 3) real-time dispatch, communications, and control, 4) TIGER data enhancement, 5) initiating GIS applications, and 6) organizational alternatives.
3.1.1 Systems Integration and Data Transferability

A tradition of systems integration and data transferability already exists at Tri-Met. However, a GIS implementation creates a more explicit environment for the sharing of systems and resources concerning data referenced by spatial location. It places the emphasis on an integrated data model and away from file transfers involving the reformatting of data exported from one application into another. This common data model approach constitutes a framework for GIS implementation that leads to the sharing of geographic data which can reduce the high cost of database generation. This framework is necessary for rapid and accurate responses to analyses of transit service between origins and destinations, for example. However, this sharing requires tools for assessing the consistency and completeness of the data.

Although applications may have different requirements for data content, data structures, and file formats, a logical model based on vector topology, such as TIGER, provides a consistent spatial reference, eliminating the need to repeat coordinates in separate files. An important issue is the relationship between data structure and the specific implementation of application. This tradeoff will affect performance. The common geographic framework will prove useful in database development, but the data structures may need to be made more efficient for applications where performance is crucial. This is particularly true where TIGER will provide the geographic interface to existing systems, such as Tri-Met’s in-house scheduling software, ‘RUCUS’ and paratransit dispatching packages recently purchased from an outside vendor. In these situation, system applications are independent modules with attention to data and systems standards at interfaces.

The standardization of data and applications is taking place in the face of broader organizational issues of compatibility of computing platforms and systems architectures. These deal with such things as computing platforms, networking, operating systems standards, and interfacing.
3.1.2 Visualization and Mapping Requirements

Mapping of transit services can be enhanced using GIS concepts and technology. An integrated GIS approach applied to the diverse needs for transit map products can make current mapping activities more efficient. It can also enhance the spatial perspective of planning and management processes by providing new map products and spatial information not previously available.

Pilot project research conducted at Portland State University (Orrell, 1990), demonstrated how GIS, combined with the TIGER file street network, can be adapted to several current mapping activities at Tri-Met. These activities include the production of schedule-pamphlet maps and bus route maps for drivers. Emphasis is placed on the role of the TIGER file as a common geographic base from which all of the maps can be developed.

The importance of the TIGER file for cartographic production is emphasized because of the flexibility it offers for producing a range of map products for use in all five of the functional application areas noted in this report. The TIGER file street network is based on an elemental graphic level of street representation. Every street segment is defined by its intersection with other segments. This representation provides a convenient base for extracting subsets of street geography for use in a variety of transit maps.

For schedule pamphlet mapping, three methods for identifying bus route street segments from the TIGER file were examined with ARC/INFO software. In the first method, street segments were manually selected by the operator, while in the second, routes were generated by describing all the individual intersections along them. Finally, it was found that route selection was facilitated by the application of intersection data from existing ‘RUCUS’ route scheduling output. This instance involved the use of basic network analysis functions available in some GIS environments. By
combining the TIGER geocoding and a path-finding algorithm, the route geography was replicated with network analysis, given only the street intersection turning points. (Figure 1)

For producing route maps for bus drivers, it was found that the extraction of street segments from TIGER with a GIS was not alone sufficient, since “cartographic license” is required to exaggerate scale and geometry to illustrate driver facilities and special conditions of individual routes and transit centers. Still, the base geometry from the TIGER file, converted to a format that could be imported into a CAD application, is a considerable improvement over existing screen digitizing methods for reproducing the route structure before alteration and annotation.

Additional benefits in using basic GIS network functions include the capability of generating route directions and generalized route travel distances not easily available with other software. The network approach also provides tools for easily evaluating alternative route structures in case of route obstructions and for planning purposes.

The automation of existing cartographic production tasks is not the only benefit of GIS graphics capabilities. The use of maps and graphic displays as a means to visualize spatial relationships in agency data provides an opportunity for increased operations efficiency as well as management oversight. Different application areas have different requirements for “views” of the database. The dispatch function can be improved by providing dispatchers and supervisors with visualization of the route and street system and the locations of transit vehicles. Dispatchers need to be able to select route(s), vicinity, and perhaps related data about traffic flows, accidents, or other incidents. Supervisors may need similar information, but according to their own selection criteria. Schedulers and service planners may find graphic displays of the route structure useful but this time with data added from the archives, looking at monthly averages, or comparing one time period to another.
Figure 1a: The dense network of street segments through which runs the Fessenden 4 line.
1b: Route selection of the number 4 with ARC/INFO using 'RUCUS' intersection data and augmented with additional street detail and annotation.
Customers or customer service representatives have significant visualization requirements. Trip planning is a function that can be better understood with visual cues. Interactive trip planning systems, particularly those incorporating updated schedule adherence data, present significant demands on spatial query and visualization functions. These systems must be able to handle origins and destinations identified in several ways: by street address, by street intersection, or by landmark name. These locations are related to nearby stops from which bus schedule information can be called forth. At some point the operator or client may ask for the best route from an origin to an destination. In addition to providing the route and schedule information, the system should also provide a map display containing the suggested path.

3.1.3 Real-Time Dispatch, Communications, and Control

Narrowly conceived, transit operations can be characterized as a fleet management problem. Broadly conceived, transit operations is the real-time dispatch, communication, and control of fixed-route and demand-responsive transportation services. This function requires three temporal scales of geographic information.

Day-to-day operations function in a tight time loop and involve real-time dispatch, communications, and control. The system must determine the location of buses in relation to their schedules and direct information to drivers running ahead or behind to improve schedule adherence. Monitoring bus location and comparison to schedules, reporting exceptions, and corrective actions, generates a large volume of data.

The management aspect of dispatch, communication, and control functions within a second and longer time cycle. As part of the oversight function, exception reports are archived for weekly, monthly, or quarterly analysis. Analysis of exception reports can yield information on which to
base tactical adjustments for rescheduling if buses are consistently behind at certain locations or at certain times.

In a third and longer time frame, usually on an annual basis, routes and schedules can be examined to evaluate usage and system performance. It is this temporal scale that is characteristic of system planning and rescheduling, where monitoring is performed at intervals of the kind currently employed in the Tri-Met cordon count methodology and analysis of performance and load factors lead to a strategic analysis of the transit system. System mapping and transportation modeling in support of planning can be considered to employ data generalized to this temporal level. Figure 2 illustrates these cycles of operational control, management and strategic planning. The size of the loop indicates the time frame, and is inversely related to the data volume.

Similarly, paratransit dispatch, communications, and control functions in three time loops, one for real-time control, another for tactical adjustments, and the third for strategic changes. Emergency management must also function in these three levels. In real-time, the system must be able to respond to sudden events such as snow storms. In the intermediate scale, the system must be able to accommodate a planned event, such as a special event or large festival. In a longer timeframe, growth management or energy conservation strategies may require changes to transit service.

This broad view of fleet management increases the complexity of data management and can be characterized as “a real time geographic database problem.” This problem has received little attention in GIS research and development. Most GIS software is relatively static in comparison to this fleet management problem. The generation of location information for all transit vehicles every 20 or 30 seconds results in a considerable volume of operations data. For the most part a GIS is not geared to handle this large stream of data. Thus, there is a need to break the problem into these separate time frames and to aggregate data temporally. For some applications this can involve
Temporal Scales for Real-Time Dispatch, Communications, and Control

Mapping → Planning → Strategic Evaluation
Modeling → Management → Monitoring
Tactical Adjustments → Exceptions
Operations → Dispatch
Control

Figure 2: Operations, Management, and Planning functions applied to the temporal scales of real-time dispatch, communications, and control.
computing a moving average of incoming polling data, for others, such as exception reports, only data not matching expected values are reported, for still other applications, temporally local data (vehicle locations) are used for updating displays but not for longer term questions.

A major bottleneck in current transit systems is that the view of operations is dependent on the dispatcher. Similarly, exception reports cannot be visualized well by supervisors. Managers and supervisors need better visualization to gain understanding of the systems for which they are responsible. Real-time dispatch, communications, and control systems ought not be designed solely for the dispatcher, but to serve a broader set of users. Better graphics with a variety of views will serve that end.

3.1.4 Tiger Data Enhancements to Support Tri-Met Applications

The utility of the Census TIGER line files has been emphasized for its integrating capacity in a variety of Tri-Met functions. Unfortunately, TIGER has significant deficiencies in terms of map accuracy and the functional description of the street system. Enhancements are needed to make it useful for many local applications, including those at Tri-Met.

The U.S. Bureau of the Census was mainly interested in street address geocoding to develop the spatial framework by which to conduct, tabulate, and report the 1990 Census data. Therefore, the street network was included mainly to enable them to edit the completeness and consistency of the areal units of census geography. Consequently, cartographic accuracy of the street network was sacrificed, particularly in the metropolitan areas, where TIGER incorporates the older, 1980 DIME files, which contain inaccurate coordinates of intersections and few points to represent the shape of features. This deficiency can be observed in sections of the metropolitan area where TIGER represents straight streets as being crooked because each intersection was independently digitized.
Careful examination of Figure 1 illustrates the effect of this less than adequate cartographic representation. Other digitized versions of street systems exist, however. In the case of Portland, the metropolitan planning organization, METRO, is proposing to merge the attributes and topology from TIGER with the cartography from local sources or a street map digitized by the Oregon Department of Transportation. The resulting data would be in the same format as the TIGER line file, but supporting graphic representation that bears greater fidelity to street alignments.

In addition, TIGER street segments must be classified into a useable hierarchy. Tri-Met will wish to distinguish streets by type, one way or two way, arterial or local, for cartographic symbolization as well as network analysis. Similarly, nodes representing street intersections must be enhanced to include intersection data, signalization, and turn prohibitions.

Finally, there are segments and nodes in the TIGER file that do not represent portions of the existing street network. Railroad lines may be useful to represent for some purposes, but they should be on separate, non-intersecting layers to avoid automatically generating intersections with valid route segments. Similarly, multiple lines through railroad yards probably represent redundant data for Tri-Met applications. In some cases street segments have been digitized from plat maps or other sources of questionable veracity to ground conditions. New construction and/or street closures and realignments also should be included in an enhanced TIGER product.

Still, the basic format of the TIGER data can serve a wide variety of agency GIS requirements. For Tri-Met applications the key is to identify route, bus stops, and related entities in terms of the enhanced TIGER street segments and nodes. This will provide the link by which transit data can be utilized with any other data that are also related to TIGER throughout the metropolitan area.
3.1.5 Initiating GIS Applications

To undertake GIS at Tri-Met, several steps must be taken. First, priority applications should be identified and responsibilities assigned. Of particular importance is the responsibility for the underlying geographic framework, TIGER and enhancements needed for transit applications. In making these decisions, Tri-Met must decide whether to procure a system, develop one in house, or some mix of the two. If the strategy is to develop in house, wholly or in part, Tri-Met will have to acquire some general purpose GIS software.

Assuming a partial in-house development, Tri-Met is urged to participate in METRO’s effort to enhance the TIGER file for Portland and assume responsibility for relating transit routes and stops to TIGER. With this resource in hand Tri-Met might select a consultant from which to procure an integrated trip planning system to serve both the fixed route and paratransit systems. If this is viewed as a pilot GIS project, the experience gained will be useful for the subsequent incorporation of GIS functionality into a centralized dispatch system.

3.1.6 Organizational Alternatives

In addition to a strategy, outlined above, to introduce GIS into Tri-Met, consideration of a long-term strategy for GIS management is required. Generally, GIS is brought into an organization to support a particular project or application, and then the issue becomes how to institutionalize GIS. As has been shown, a common geographic framework serves many applications, and some degree of central support and control of GIS is necessary to successfully manage the integration of diverse applications and database needs. Yet, data processing units of most organizations are often not well suited or interested in geographic applications. For GIS implementation, Tri-Met faces a choice among four organizational strategies.
3.1.6.1 **GIS Service Center.** Often the original unit that brought GIS into the organization becomes a service center for other units. This unit begins to share its expertise and incidentally spreads the cost of the initial investment. Soon GIS permeates the organization as geography is part of many applications. Eventually there is pressure to centralize many of the support functions as they begin to duplicate services provided by the data processing unit.

3.1.6.2 **Coordinating Committee.** In lieu of establishing a GIS service center, some organizations establish separate GIS systems/nodes in various units, with a coordinating committee to deal with data transfer, duplication and incompatibility issues. This approach works well in organizations that are highly decentralized and whose units operate somewhat independently.

3.1.6.3 **Separation of Administration and Applications Development.** Another approach would be to provide systems support and database administration in the information systems unit and leave applications development to user units. This approach is a compromise, it provides some support, but leaves applications to those who know them best.

3.1.6.4 **Central GIS Administration.** The final alternative is to administer GIS centrally. This approach would call for the creation of a GeoServices unit in Information Systems. The GeoServices unit would provide database administration, systems support, applications development consulting, and education and training for users throughout the agency. The unit would also provide user units with GIS workstations, and support for input and output peripherals.
3.2 Implementation Plan Conclusions

Tri-Met's implementation of GIS must address the major issues identified above. To achieve systems integration, Tri-Met should strive for independent application and develop data and systems standards to insure workable interfaces. Perhaps the greatest power of GIS is achieved by consistent locational referencing of data for analysis, and visualizing the results. Maps will become more used and useful products.

This report, along with ongoing GIS task force meetings and pilot projects will serve to establish priorities among applications and to set the stage for organization development associated with bringing GIS into Tri-Met.

4.0 REPORT CONCLUSIONS

Application areas can be broadly grouped into five functional categories, facilities management, facilities engineering, service planning, operations and control, and customer service. For each of these functional categories, specific implementation issues must be addressed that relate to questions of integration and data transferability, visualization and mapping requirements, and temporal data processing and analysis needs.

The adoption of TIGER for all geographically related data supports the integration of systems and databases throughout the agency because it models the geography of relevance to a transit organization in a robust fashion, within a topological structure, at the elemental level of individual street segments and intersections. Integration across applications within the agency is therefore facilitated since all spatial data are tied to a common framework, provided GIS software is obtained which can process both the spatial as well as the attribute data. TIGER represents a means by
which to tie these applications to the system-wide base map, even in cases where a considerable investment in existing software systems is to be supported with more specialized data structures.

A GIS can assist the automation of existing cartography within the agency, with graphics derived from TIGER serving as base maps for a variety of applications. Additional special purpose maps can be developed that are consistent with existing products, and integrated into exception reporting, operations monitoring, and planning documents. Data visualization requirements for operations and supervisory staff can be assisted with graphic displays based on the TIGER file for improved dispatching, customer assistance and trip planning. However, to fully realize these visualization benefits, some enhancement to the graphic quality of the TIGER data will be necessary.

In the transit industry, real-time operations and control is viewed as a dispatching problem that can be solved with improved communications and automatic vehicle location technology. It is not generally considered a GIS application. This assessment is correct, given the current state-of-the-art of GIS. Nevertheless, real-time dispatch, communications, and control requires the integration of data by location, which is a function of GIS. Comprehensive dispatch requires the integration of functions now performed independently, such as dispatching, scheduling, customer information, and performance monitoring. Changes in one system need to be transmitted to the others for integrated management, which requires a variety of views on a common integrated spatial database that describes the operation of the whole system in geographic space and time.

At some point in the process of introducing GIS into transit organizations, organizational alternatives will need to be addressed. When appropriate, a strategic planning process should be undertaken to decide on the re-organization options and to anticipate and deal with the organizational development issues involved in the phased implementation of a GIS.
REFERENCES


