GIS APPLICATIONS IN URBAN PUBLIC TRANSPORTATION: PILOT PROJECTS AND IMPLEMENTATION STRATEGIES FOR TRI-MET, PORTLAND, OREGON

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ABSTRACT

Applying geographic information system technology to urban public transportation involves identifying the requirements of several application areas, adopting an integration strategy based on a common representation of geography, evaluating the analytical and data modeling contributions of a number of GIS vendor products, assessing the results of several pilot projects, and identifying implementation strategies. This report summarizes the incremental experience of the Tri-County Metropolitan Transportation District of Oregon (Tri-Met), as it implements a strategy of database integration around a modified version of the TIGER line files. The research identifies opportunities to increase the consistency among databases supporting diverse applications and to reduce the duplication of separate application database updates.
1.0 INTRODUCTION

Tri-Met, of Portland, Oregon is a public transportation provider that has begun to coordinate and increase the effectiveness of information activities supporting mass transportation services. In the metropolitan area, these services consist of light-rail transit (LRT), fixed route bus operations, special needs transit (SNT) or "paratransit", and carpool matching. Many functions related to each of these services are dependent upon geographic information. Nyerges and Dueker (1988) point out the benefits of implementing GIS technology as a means to manage and integrate transportation data. For GIS to be used effectively in urban public transportation organizations, a systematic approach to implementation is necessary. Not only can GIS serve a variety of mapping, facilities management, and planning needs, but better visualization of transit operations and control functions can be achieved with the aid of an integrated spatial database managed by a GIS.

In the rapidly changing urban public transportation environment, better management of information is needed to provide efficient and effective transportation services. Prominent among information management priorities is the improved management of the geographic dimension of operations data. Improved management of geographic data has two aspects. One is to link maps and databases about routes, schedules, and other geographically distributed equipment, such as bus stop shelters and signs. This provides a map window to important databases. Second, is the need to better integrate data by the elimination of separate, redundant databases, especially where multiple units in the organization can share expensive and frequently updated data. Better integration can be achieved by identifying operational and analytical applications that depend on sharing data within the enterprise; examining the common requirements for those data with the
aim of centralizing database administration and updating; and developing strategies for the technical and organizational restructuring of the information management environment.

When considered as an agency asset, the value of geographic and other data is a function of their accuracy and consistency. Out-of-date, redundant, and conflicting data detract from this value. Not only do shared systems and data resources reduce costly duplication, but integrated spatial data management assures consistency among databases used by Tri-Met units. This integrated environment provides efficiency and effectiveness gains to individual programs, that, taken as a whole, can translate into an enterprise benefit for the agency. Therefore, Tri-Met has embarked on a systematic analysis of geographic information applications to avoid unnecessary duplication and proliferation of systems and databases.

1.1 Research Objectives

This research is jointly sponsored by Tri-Met and the U.S. Department of Transportation via TransNow, a transportation research center consisting of a consortium of Pacific Northwest universities led by the University of Washington. This report on Geographic Information Systems Applications in Urban Public Transportation therefore has two clients. Tri-Met seeks to use these findings to provide a pathway for acquiring GIS technology and integrating with existing resources to increase the effectiveness of transit management throughout metropolitan Portland. The U.S. Department of Transportation on behalf of other agencies that provide urban public transportation services is also a client for these findings. Tri-Met’s experience with applying GIS concepts in an integrated systems environment can serve as a guide to other organizations seeking to improve planning, management, and transit operations in other parts of the country.
This is the second report on this research initiative. The first report (Duerker, Vrana, and Orrell, 1990) provides a detailed examination of user needs that resulted in a typology of GIS application areas. The report identified the benefits of integrating agency geographic data, which in turn suggested several GIS implementation issues. The typology, as well as some of these implementation issues, are revisited in this report, prepared a year later, as a means of defining the setting for database and application integration.

The specific objective of this phase of the research is to examine the suitability and flexibility of a common geographic database to serve a variety of applications within a transit organization. This report presents findings from several pilot projects applied to the wider arena of Tri-Met operations. These pilot projects have been used as a proof of concept and as an opportunity to gain experience for structuring an implementation plan to institutionalize GIS at Tri-Met.

The focus is on specifying data and software issues to be faced in developing an integration strategy. This strategy builds on the U.S. Bureau of the Census TIGER line file as the underlying geographic base for Tri-Met applications. Street segment and city blocks constitute elemental geographical 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 geographic data management. Consequently, it will also serve as a vehicle for integration and coordination with the geographic information systems of other organizations and agencies in the metropolitan area.

A common database does not require that all analyses 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 perspectives to
fit the needs of different users. While an enhanced version of TIGER may serve as an integrated database, specialized databases derived from it will be required. A data flow diagram for sources linked to this enhanced TIGER and some of the applications it supports is presented as a preliminary view of the proposed implementation. In addition, since software from a single vendor is unlikely to address the full range of potential applications, a framework for evaluating from among many options is presented.

The four pilot projects are then presented. They are a reasonably representative subset of typical agency applications using Tri-Met and the TIGER data. Their assumptions and methodology are indicated and the results expressed.

Finally, an implementation plan identifies the broad strategy to institutionalize GIS at Tri-Met. In several cases, specific issues yet to be resolved are identified for further Tri-Met action.

1.2 Literature Review

The literature on GIS applications in transportation is growing rapidly. Much of the state-level DOT work emanates from Fletcher's (1987 and 1990) pioneering applications, the Nyerges and Dueker (1988) review for FHWA, the GIS-T short courses by Fletcher and Lewis (1989, 1990a, 1990b), and the AASHTO sponsored symposia on GIS-T (Bacon and Moyer, 1989; Bacon and Moyer, 1990; and Moyer and Larson, 1991). In addition, the NCHRP has sponsored a major research project on GIS-T (Travis, et al., 1990). There has also been an increase in the application of GIS in urban transportation planning (Kiel, 1989; Lewis, 1990).

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). Other researchers have reported the use of geographic base files in trip planning systems (Rousseau and Roy, 1989), and the development of home grown GIS applications such as TransGeo at Seattle Metro (Antonisse, 1991). Currently, research similar to this project is being conducted by Azar and Ferreira (1991).

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 file standard for geographic data has been proposed (Claussen, et al., 1989).

To date, transportation GIS efforts have focussed on specific applications. Comparatively little attention has been given to the integrative aspect of improving consistency and reducing database redundancy for separate transit applications. In highway applications, guidance in integration is provided by Fletcher's (1987) examples of overlaying linear pavement and other data such as traffic and accident counts. TenEyck, et al. (1989) shows how highway shoulder data can be used with run-off-road accidents to identify problem areas, which can be integrated with proposed expenditures to see whether the problems will be remedied. Basile, et al. (1991) summarize an approach to implementing a GIS in the Pennsylvania Department of Transportation that stresses the importance of an integrated data environment and its organizational implications.
2.0 TECHNICAL ANALYSIS

In this kind of a study, technical analysis consists of detailed examinations of GIS application areas and their data and computing requirements.

Virtually all Tri-Met GIS applications rely on some representation of the fixed route, or urban street system. For some spatial analysis tasks a topological street network alone suffices. For applications in mapping and dispatch, a geometrically accurate depiction of the base geography is also important.

Computationally intensive applications are mainly a function of the dual need to process large files and offer interactive visualization. Trip-planning is one such application. It requires a topologically structured street network to be geocoded with address ranges. Route descriptions and map displays are generated in near real time for quick response to telephone or interactive kiosk users.

2.1 Functional Application Areas in Urban Public Transportation

Although databases to support some specialized analytical functions may vary considerably, diverse applications have similar needs to input map data, analyze spatial information, and display query results. Five principal functional areas can be described, however, as serving public transit operational needs. Though individual applications are described in terms of Portland Tri-Met, the five application areas 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).
2.1.1 FM- Facilities Management

Geographic databases are used to maintain what public utilities call "outside plant facilities." At Tri-Met, tabular databases serve as an inventory of characteristics in bus stop shelters, information kiosks, and light rail transit stations. GIS adds a geographic index to that inventory plus the ability to analyze geographic patterns and display the results as a map.

For public transportation applications, facilities to be maintained can be geographically located and related to bus and rail routes encoded as TIGER street segments which are in turn linked to a digital map representation of the local street network. An analysis of potential FM applications of this kind identified several types of facilities amenable to a GIS-based inventory system.

- Shelters linked to routes, bus stop, and TIGER street segment,
- Park and Ride locations, with ownership, capacity, and utilization related to transit stops and routes,
- Bus Stops/Signage, related to stop number and routes, and
- LRT route facilities and stations, spatially referenced by milepoint.

For bus stop shelters, which require regularly scheduled maintenance, a GIS can be used to determine maintenance routes that minimize travel by crews servicing all facilities within a given sector. When crews service facilities by following along a single bus route, shelters on nearby or adjoining routes can be missed or require redundant travel. Similarly, an inventory of route signage can facilitate its maintenance as well as improve change notifications to the ridership.

Tri-Met may also wish to create spatial databases for managing facilities in important rights-of-ways, such as the downtown bus transit mall or LRT corridors.
With these, management can access property information spatially or display results of attribute searches of the database as a map. An attribute database can be created for inventory and maintenance of facilities such as information kiosks, shelters, and ticket dispensing machines contained in these rights-of-ways. These facilities would be represented as spatial objects, with location referenced by milepoint, stationing, and x, y coordinate. This will allow both spatial searches 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 FE- Facilities Engineering.

Plans of plant facilities (As-builts) are candidates for inclusion in spatial databases, although this is not a high priority at Tri-Met. Maintenance facilities such as bus barns and LRT maintenance buildings are too few to warrant inclusion in separate spatial databases with scale and level of resolution so different from the route geography. CAD drawings and scanned images of manually produced plans are occasionally needed and a computerized index to the location of these may be useful, but it is not considered a vital part of the agency GIS. What remains to be investigated, however, is whether facilities within buildings should be inventoried spatially. Is location of items within a building important? Probably not, but a spatial index to digital images or analog plans may be useful at a future date.

Engineering design of LRT lines eventually will benefit from the merging of photogrammetry, CAD, image processing, and GIS technologies to achieve 3-D visualizations or renderings of the proposed design in its environs. This requires integration of rasterized image data and vector design data on a surface representing the landscape. The visualization benefits can be useful in public presentations as well. To date this has only been done by consultants to Tri-Met to create
visualization products (image enhancement) to use in public hearings on LRT preliminary engineering.

2.1.3 SP- Service Planning.

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

Route planning has specific geographic considerations. Route data consist of attributes and/or restrictions on route segments and/or nodes. Service planners generate alternative routes that must be related in the GIS to TIGER streets and intersections to provide map displays that illustrate the impact of proposed routes. Routes must also be related to demand and utilization data which are represented in terms of traffic analysis zones (TAZ). Consequently, it is necessary to aggregate automatic passenger count (APC) data from bus stops to TAZs and to disaggregate TAZ data back to bus stops. Linking route, TAZ, and bus stop data to TIGER street segments will facilitate developing these relations as needed. TIGER may also serve to link AVL and APC data to estimate bus stop boardings and alightings.

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

2.1.4 **OC- Operations and Control.**

With AVL, GIS can display fleet location in real time. For Operations and Control applications, this can be tailored into a Schedule Adherence Dispatch System for a unified representation of dispatch and scheduling functions. Both dispatchers and supervisors have expressed interest in computer console maps. For operating dispatchers, this would be a benefit because they are already at the console and would be using the monitor for other functions as well as map display. Dispatch supervisors have a similar need to reference the location of the system assets in real time, as well as the ability to get an overview of dispatching problems and incidents.

GIS may be less important to LRT dispatch. Routes can be represented schematically as straight lines with an AVL system tracking vehicle location. As a stand-alone application, this requires no explicit representation of system geometry. However, the subsequent integration of fixed route bus and LRT dispatch will require greater GIS capability to identify key system transfer points between bus and rail services. This implies a topological representation of LRT and bus route geography.

Since paratransit vehicles may utilize streets not assigned to fixed routes, integration of paratransit with fixed route dispatch will require the full geometric and topologic representation of the metropolitan street system in TIGER. Paratransit dispatching requires a detailed level of service area representation. 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. This is currently implemented with a proprietary COMSIS Routing and Scheduling System (CRSS) and Paratransit Information System (PARIS).

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. For this reason it is important to specify the requirements of the paratransit GIS that will enable a growth path to an integrated mobility management system for Tri-Met.

2.1.5 CS- Customer Service.

Customer Service applications provide one of the widest ranges of functional requirements in the organization. Mapping of the fixed route and LRT systems, presently is done in a mixed environment with manual graphic production augmented by a CAD system. 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. Each of these maps can be extracted from TIGER and tailored for specific uses. Thus, while design requirements can be customized for map application, each schedule or system map would refer to the same basic depiction of the Tri-Met system. While CAD software currently used by Tri-Met may adequately perform mapping and graphic operations, a GIS which manages the underlying base map data can facilitate the transferability and maintenance required for several concurrent mapping applications. This observation has also been made by Antonisse (1991) concerning the Boston and Seattle transit providers.
A conventional spatial analysis application relating to the customer service function is the task of route finding for ticket outlet distribution. This is much like the route finding applications associated with FM applications detailed above, except that it generally consists of fewer facilities, spread out over the entire metropolitan area.

As has been noted, trip planning is quite an intensive customer service GIS application. Route schedule information could be relayed to customers more efficiently if service representatives could reference a map display for alternative routes and trip strategies. A still greater degree of service could be achieved by integrating customer service and dispatching, utilizing AVL to provide actual, in addition to scheduled, arrival times for each stop. The ability to compare scheduled vs. actual times is a needed feature for a future complaint-response system.

Computerized trip planning assistance, whether by phone or at customer operated kiosks, requires handling point to point requests (address, intersection, or landmark specified). The application must search for the most direct route within walking distance of both origin and destination that provides service at the time requested. In addition, a GIS must identify connecting routes to provide transfer information. An additional complication is to provide special needs clientele 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 destination. 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, paratransit alternatives.
This analysis resulted in the development of a Request for Information (RFI) for a Trip Planning system. The RFI included language to identify the state-of-the-art of real time GIS support for trip planning. The RFI was devised to determine: 1) whether vendors could supply a suitable trip planning system that had an imbedded GIS; 2) whether vendors had satisfactorily coupled a trip planning system with a GIS; or 3) whether an off-the-shelf GIS could be configured to perform trip planning. It was decided to pursue the second approach and a Request for Proposal has been prepared, but is being held back, pending budget approval.

2.1 Tiger As An Integrating Framework

The demand for transportation services is distributed in geographic space, and therefore data concerning transportation supply and demand is characterized by location. GIS is the tool to integrate data by location. Piecemeal or independent GIS do not yield as much benefit as integrated applications, and they are likely to produce situations of redundant and sometimes inconsistent data.

2.2.1 Integrating Tiger-Oriented Systems.

A GIS creates an explicit environment for the sharing of systems and resources concerning spatially referenced data. It places the emphasis on an integrated data model and away from file transfers which reformat data exported from one application into another. In particular, the common data model approach constitutes a framework for GIS implementation that promotes sharing geographic data, thereby reducing the high cost of database generation and data redundancy. 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 quality of the data. These tools are in the form of
software which can document the results of tests for positional and attribute accuracy, logical consistency, and the completeness of data as defined in the proposed Spatial Data Transfer Standard (SDTS) which has recently been reviewed by the ANSI process and is about to be adopted as a Federal Information Processing (FIPS) standard. (USGS 1991)

Although applications have different requirements for data content, structures, and file formats, a logical data 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 requirements. This tradeoff will affect performance. A common geographic framework will prove useful in database development, but data structures may be optimized for certain applications where performance is crucial. This is particularly true where TIGER will provide the geographic interface to existing systems, such as the Tri-Met Run Cutting and Scheduling System (RUCUS) and vendor-provided paratransit dispatching packages.

In these situations, applications are independent modules to be integrated with attention to data and systems standards at interfaces. Since TIGER represents a common store of topologically referenced street segments and census geography, these data, along with Tri-Met's facilities and route data, can be updated and maintained.

Figure 1 is a data flow schematic of a proposed implementation for a “TIGER-centric” constellation of transit applications. The schematic reflects current priorities for trip planning, paratransit dispatching, and service planning and mapping at Tri-Met. Facilities Management and Engineering functions may be
integrated at a later date. The diagram illustrates seven mapping and analysis tasks that have been discussed above as specific applications within the functional application areas. These applications all utilize TIGER street segments, augmented with additional data that describe current fixed routes. These applications are:

1) Trip planning,
2) Service planning,
3) Schedule adherence dispatch system,
4) CRSS/PARIS street and address updating,
5) Shelter siting and maintenance,
6) Region-wide system mapping, and
7) Route maps for customers and drivers.

Additional data sources that contribute to these applications are also noted in Figure 1 including the in-house developed RUCUS system, defining spatial and population attribute data for TAZs, schedule information, and AVL data when that system comes on-line.

2.2.2 Tiger Enhancement.

As supplied by the Census Bureau, TIGER has significant deficiencies in terms of map accuracy and the functional description of the street system. This is mainly an artifact of its construction and intended application. Enhancements are needed to make it useful for many local applications, including those at Tri-Met. Figure 1 indicates several sources of enhancements for the TIGER file.

The most noticeable deficiency with TIGER is the planimetric distortion introduced in areas where it has been constructed from the older, 1980 census DIME files. For many data inventory and analytical purposes this may be a minor inconvenience. But because TIGER will potentially support several mapping and
Figure 1: Geographical Data Flow for TIGER-Oriented Transit Applications
visualization functions at Tri-Met, attention must be paid to improving the cartography of the base. In Portland, as in many metropolitan areas, a number of regional agencies have an interest in collaborating on the updating and maintenance of a regional TIGER structured database. Portland Metro, the metropolitan planning organization, has taken the lead in developing a regional land information system, RLIS, with street center lines tied to survey control with known accuracy. In a joint effort with Tri-Met, this agency will be importing that geometric accuracy into the TIGER files by conflating the two databases that represent the regional street network system.

In addition, TIGER street segments must be classified into a useable and functional hierarchy. Tri-Met will wish to distinguish streets by type, one way or two way, arterial or local, for cartographic symbolization as well as using network analysis for path finding. For network analysis applications, a specialized database containing street intersections represented as nodes will also require attributes indicating turn prohibitions and signalization.

As a result of this analysis concerning the importance of a street centerline file, the second step has been taken. A digital representation of transit routes has been extracted from the enhanced TIGER product. Also, Tri-Met is one of several sponsors of Metro's joint venture with the Thomas Brothers Co. to maintain the enhanced TIGER file.

Finally, with paratransit dispatching and some service planning functions dependent on the address geocoding capabilities of TIGER, missing address ranges on street segments should be augmented from local sources and their update coordinated among local agencies, the Census Bureau, and possibly the Postal Service.
Despite these deficiencies, the format of TIGER data can serve a wide variety of transit agency 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.

2.3 Evaluating GIS For Transit Applications

Implementing GIS solutions to the data processing needs described above may be done for the most part with commercially available hardware and software components. But no one system is likely to provide optimum performance for all applications. Moreover, since key software for paratransit dispatch and other functions already has been acquired, unnecessary duplication would result from an “all-in-one” package. The key is to evaluate the modeling and analytical capabilities of a number of systems before formulating a specification for an eventual system design that may include integrating systems from several vendors as components accessing the common geographic database.

Tri-Met has not yet finalized its system specifications. System integration is taking place in the face of broader organizational issues of computing compatibility and systems architecture. Computing platforms for GIS may be evolving toward some variant of networked workstations, but communications and concurrency control, decisions on network hardware and software, operating systems standards, even staffing and space requirements all involve strategic planning. In this light, it is especially important to present a rational framework by which the claims of competing vendors may be evaluated.
Such a framework is presented in Figure 2, and is based on examining the underlying dimensions of functional application "problem spaces." The capabilities of certain vendor products are compared in a preliminary way with respect to these dimensions of transit applications. Two additional requirements for transit-geographic modelling and analysis are highlighted by this framework, 1) visualization and 2) real time abstraction. Both of these must be carefully examined for cost-effective solutions that add benefits without being unduly exotic.

2.3.1 Problem Dimensions and Vendor Capabilities.

The proposed framework characterizes the many kinds of applications within a transit agency according to the predominant dimensionality of the problems they address. For the purposes of this typology, each problem is cast in terms of one, two, or three spatial dimensions plus time.

In the one-dimensional plus time context (1D+T), is the scheduling and dispatch problem. These are applications characterized by analyzing time and one-dimensional linear distance.

A 2D +T problem example is service planning and mapping. As previously stated, planning must relate linear routes to areas with rider demand. System mapping, even the mapping of single routes in isolation, takes place with respect to the two linear dimensions. Each of these activities involves a temporal dimension as well. In the case of schedule planning, the temporal dimension accommodates peak-hour, weekday, and/or holiday service scheduling requirements.

Finally, the realm of Facilities Engineering encompasses at least two important 3D +T problems. Evaluation of engineering design for new facilities, particularly LRT extensions, requires managing versions of 3D CAD output. Dynamic viewshed
Framework for Evaluating Vendor Capabilities
for Urban Public Transportation Problem Spaces

<table>
<thead>
<tr>
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<th>Three Dimensional 2D + Time</th>
<th>Four Dimensional 3D + Time</th>
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<td>Scheduling and dispatch</td>
<td>2-D CADD, GIS</td>
<td>3-D CADD, terrain modeling</td>
</tr>
<tr>
<td>Transportation Planning Models</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Functional Application Areas and System Evaluation
analysis incorporating these engineering plans is also important for public presentation and review.

A broad range of vendor GIS, CAD, and transportation modeling software is available and must be evaluated with respect to the spatio-temporal formulation of these functional areas. Furthermore, key components are already in place and further integration will have to incorporate these systems. Portland Metro is an ARC/INFO shop and they will maintain TIGER and the TAZ. Tri-Met's paratransit service uses a system for geocoding client addresses that is based on MAPINFO, and Tri-Met's Project Development/Engineering group is using the McDonnell-Douglas GDS CAD system for engineering LRT extensions. Clearly there are some interfacing and file transfer issues to be addressed in implementing an integrated database approach. Complicating this task further are requirements for data visualization and real time data handling inherent in these "problem spaces."

2.3.2 Visualization and Mapping Requirements.

The marketplace of vendor products features a variety of graphic and mapping capabilities. How are these to be evaluated? An integrated TIGER environment 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.

A number of mapping activities at Tri-Met will apparently benefit from an integrated GIS environment. 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. Not only does TIGER provide the most elemental representation of
system geometry in the form of individual street segments, but route and schedule mapping can be extracted from the same database as the entire regional system map, eliminating the need for separate cartographic database updates and maintenance.

The first criteria therefore, for evaluating vendor products for mapping capabilities has to be the ability to process TIGER data. This includes topological processing as well as cartographic design, since the common database may require some boolean overlay and/or analysis to produce the desired map product.

While demonstrating mapping capabilities it was found that route mapping from TIGER can be facilitated by combining intersection data from RUCUS and basic network analysis functions available in ARC/INFO. By combining the TIGER geocoding and a path-finding algorithm, the route geography was replicated, given only the street intersection turning points. Therefore, a second requirement of mapping is the ability for software to interface with non-GIS databases in the organization, and to effectively link with various analytical and modelling packages. The use of the ARC/INFO network module to facilitate a mapping task was notable in this regard. Ordinarily, network algorithms are regarded as analytical tools that become useful subsequent to the major mapping activity. In this case, these tools were employed to perform the kind of map extraction and compilation that can otherwise be very time consuming.

For bus driver route maps, even more than for schedule pamphlet mapping, extracting street segments from TIGER is not alone sufficient, since “cartographic license” must exaggerate scale and geometry to portray driver facilities and special conditions of routes and transit centers. Therefore the traditional strengths of a CAD tool have an important role to play in the mapping and data visualization requirements. Still, exporting the base geometry from TIGER to a CAD application
is a considerable improvement over existing screen digitizing methods for reproducing the route structure before alteration and annotation.

Elsewhere in the agency, CAD continues to play an important role, but this role will increasingly be linked to a GIS as a database management tool for digital spatial data. This is especially true with respect to Facility Engineering applications. It is expected that the westside light rail extension project will continue to make use of the McDonnell Douglas GDS software or another standard CAD package. A current concern is with coordinating the computing requirements to fit within a common systems architecture. This involves designing networked computing platforms, file servers, and peripherals that will meet the CAD needs of LRT engineering, the boprader management needs of the agency, and the GIS-based applications. Implementation of expanded networks and hardware platforms is taking place in an integrated environment capable of both providing and acquiring spatial data from the TIGER-centric GIS at Tri-Met.

The automation of existing cartographic production is not the only benefit of GIS graphics. The use of maps and graphic displays to visualize spatial relationships provides opportunities for increased operations efficiency and management oversight. GIS provides the flexibility for mapping a variety of different “views” of the database. An example was illustrated with the dispatch function, which requires visualization of the route and street system and the real time location of transit vehicles. Dispatchers may need 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.
Customers and customer service representatives have significant visualization requirements. Trip planning can be understood better 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 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. 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.

Powerful and flexible mapping and analysis functions that are easy to use and well integrated with other mapping and drawing tools constitute the set of requirements for mapping and data visualization for vendor products.

2.3.3 **Real Time Data Abstraction.**

The framework for evaluation explicitly recognizes the temporal aspects of a variety of functional areas at Tri-Met. These can be summarized as pertaining to:

1) managing versions of maps and CAD documents,
2) posting routine service changes for users throughout the organization,
3) data to manage emergency situations, and
4) real time dispatch, communications, and control.

Managing time dependent data for transit operations will require a consideration of appropriate temporal scales, or update cycles. Each of the tasks outlined above is a problem characterized by the kind of data abstractions needed at
different temporal scales. Temporal data management within GIS and other database management systems is a subject of ongoing research in a number of fields. Revisions to traditional data models have been proposed, (Langran and Chrisman, 1988) while Vrana (1989) points out that there exist a number of de facto methods by which the current technology can account for and utilize time dependent data. A key requirement is to recognize the nature of temporal cycles for transportation planning, management, and operations. For this, it is necessary to develop an approach by which data are generalized according to these temporal cycles for review and archival purposes.

Principal among these challenges is the real time nature of transportation operations and control. Its prominence requires special attention here. 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 temporally variable data for operations and control. This interplay between temporal generalization and visualization for different units in the Agency is an essential requirement for a GIS environment at Tri-Met. It warrants a detailed description applying to the dispatch, supervision, and route planning functions.

Narrowly conceived, transit operations can be characterized as a fleet management problem. Broadly conceived, they are 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 of real time dispatch, communications, and control. (See Figure 3) The system must determine the location of buses in relation to schedules and direct information to drivers running
ahead or behind to improve adherence. Monitoring bus location, reporting exceptions, and logging corrective actions generates a large volume of data.

The management aspect of dispatch, communication, and control operates within a second and longer time cycle. Exception reports are archived for weekly, monthly, or quarterly analysis. Analysis of these reports yields tactical information for rescheduling if buses are consistently behind at certain locations or times.

In a third, longer time frame, usually annually, routes and schedules are examined to evaluate system performance. This temporal scale characterizes system planning and scheduling, where monitoring is performed at intervals using current cordon count methodology. This analysis of performance and load factors leads to a strategic assessment of the transit system. Mapping and transportation modeling in support of planning employs data generalized to this temporal level.

Similarly, paratransit dispatch, communications, and control operates in three time loops, one for real time control, another for management 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, like a snow or ice storm. 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 time frame, 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 relatively 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
Figure 3: Operations, Management, and Planning functions applied to the temporal scales of real time dispatch, communications, and control.
vehicles every 20 or 30 seconds results in a considerable volume of operations data. Thus, there is a need to break the problem into these separate time frames and to aggregate data temporally. For some applications this will involve computing a moving average of polling data. For 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 analysis.

3.0 PILOT PROJECTS

Four pilot projects demonstrate the utility of GIS for public transportation applications. The purpose is to provide proof of concept and to illustrate GIS applications to problems of concern to Tri-Met. All four of the pilot projects are of an independent nature and do not require systems integration. They are:

- Incorporating transit routes into a GIS, with relation to the enhanced TIGER,
- Analysis of aged and disabled paratransit clients and trips to determine the proportion served by fixed route transit service,
- Use of GIS for analysis of land use adjacent and near bus shelters, and
- Use of GIS to relate bus stop locations to traffic zones.

3.1 GIS Input of Transit Routes

One way to input transit routes into a GIS is to digitize them from a map. This is not recommended because it would not yield an integrated product. Routes would not be expressed in terms of the street centerline file to which infrastructure
and street names and addresses are related. TIGER provides this framework. Consequently, it is strongly recommended that transit routes be expressed as a sequence of TIGER segments, which will be periodically maintained and updated.

Orrell (1990) examined alternative ways of making the relation of TIGER segments and transit routes. 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. In the second, routes were generated by describing the individual intersections along them. In the third method, the existing RUCUS route scheduling file was used to automatically identify bus route street segments.

The current pilot projects refine this approach. Algorithms are implemented with the ARC/INFO AML macro language and the ADDRESSMATCH procedure to create point coverages of turns and bus stops and to create arc (line) coverages of bus routes from the TIGER line file street segments. From the point coverage, a route coverage is created by using the ARC/INFO procedure, ROUTE. (See Figure 4) Corrections then need to be made because there typically may be address matching or routing errors (e.g., more than one intersection may exist for a given pair of streets). ARCEDIT, an interactive module, is a way to visually check bus routes against the stop locations and to correct inconsistencies. However, there may be some problems with this strategy. There can be some difficulty with updating ARC/INFO coverages from altered Tri-Met “First Line” and bus stop file. This is due to the use of descriptors other than street addresses such as landmark names, utility pole numbers, and business or institutional names. A uniform descriptor system based on intersection or addresses for Tri-Met’s “First Line” and bus stop files is recommended.
Figure 4a: The dense network of street segments through which runs the Fessenden 4 line.

Figure 4b: Route selection of the number 4 with ARC/INFO using 'RUCUS' intersection data and augmented with additional street detail and annotation.
Figure 4c: Selection of Route 67 with Point Coverage of Bus Stops and Time Points
3.2 Analysis of Paratransit Client Trips in Relation To Fixed Route Transit

Analysis of aged and disabled paratransit client trips in relation to fixed route transit is an application well suited for GIS. This consists of geocoding client home addresses and trip origins and destinations with the ADDRESSMATCH procedure, and determining if these locations are within a given distance of a bus route. This was accomplished by generating a 1/4 mile buffer around each bus route. Points representing the home, origin, or destination are then spatially related to these buffer polygons. Tabular reports and maps can then be easily generated. (See Table 1 and Figures 5) This is an effective means of assessing the availability of fixed route transit for the travel needs of the aged and disabled.

3.3 Analysis of Advertising Potential at Bus Stop Shelters

Analyzing bus stop shelter advertising potential is timely issue for Tri-Met. The larger question deals with the use of GIS for facilities management.

From the RUCUS bus shelter files, a spatial database was generated using ARC/INFO commands and programs similar to those described in section 3.1. In addition to the street intersection information, a near side/far side code along with the routes’ direction was used to more accurately place the bus stops location at the intersection.

Polygons based on a certain distance from the bus stop were generated around each bus shelter to determine nearby land ownership information. (See Figure 6) This information was provided to an analyst to assess the compatibility of nearby parcels to bus shelter advertising.
Table 1

Summary of Paratransit Clients in the Eastern Washington County Study Area

Number of Elderly and Disabled Passengers in the study area:

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geocodeable</td>
<td>480</td>
</tr>
<tr>
<td>Non-Geocodeable</td>
<td>57</td>
</tr>
<tr>
<td>Within 1/4 mi. Buffer</td>
<td>268</td>
</tr>
</tbody>
</table>

Number of Elderly and Handicapped Passengers within 1/4 mi. of:

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Route</td>
<td>198</td>
</tr>
<tr>
<td>2 Routes</td>
<td>70</td>
</tr>
<tr>
<td>3 Routes</td>
<td>0</td>
</tr>
<tr>
<td>Route 52</td>
<td>99</td>
</tr>
<tr>
<td>Route 59</td>
<td>196</td>
</tr>
<tr>
<td>Route 67</td>
<td>43</td>
</tr>
</tbody>
</table>

Handicapped and Elderly Passengers by the Passenger type:

<table>
<thead>
<tr>
<th>Passenger Type</th>
<th>Within 1/4 mi.</th>
<th>Outside 1/4 mi.</th>
<th>Geocoded Totals</th>
<th>Unable to Geocode</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>200</td>
<td>144</td>
<td>344</td>
<td>33</td>
<td>377</td>
</tr>
<tr>
<td>Altered Mental State</td>
<td>5</td>
<td>9</td>
<td>14</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Confused Person</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Alzheimers</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Difficulty Communicating</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Needs Escort</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Multiple Disabilities</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Visually Impaired</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Blind</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Hearing Impaired</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Deaf</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wheelchair</td>
<td>17</td>
<td>23</td>
<td>40</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>Uses Scooter</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Walker</td>
<td>14</td>
<td>8</td>
<td>22</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>Crutches</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cane</td>
<td>24</td>
<td>18</td>
<td>42</td>
<td>2</td>
<td>44</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>268</strong></td>
<td><strong>212</strong></td>
<td><strong>480</strong></td>
<td><strong>57</strong></td>
<td><strong>537</strong></td>
</tr>
</tbody>
</table>

34
Figure 5: Map of Paratransit Clients in Eastern Washington County and a 1/4 mi. Buffer Around Route 52.
Geocoded Land Parcels Within 100 feet of Tri-Met Bus Shelters

Figure 6: Geocoded Land Parcels Within 100 feet of Tri-Met Bus Shelters
3.4 Relating Bus Stops to Traffic Zones

Service planning, particularly route level analysis, requires that travel demand data, maintained by TAZ be related to routes. At a minimum, a buffer created by a 1/4 miles on either side of a route can be intersected with the traffic zone polygons to create a new set of intersecting traffic zone polygons that are within 1/4 mile of the route. This type of analysis assumes each zone has a uniform density of population, employment, trips, etc. If 40% of the traffic zone is within the transit route buffer, then 40% of the population is served.

The purpose of the pilot study was to explore other options to relate transit service to traffic. One refinement is to buffer around the bus stop instead of around the route. This will provide a better approximation of service area in locations where stops are infrequent or vary. Another refinement is to use more detailed information, such as block or parcel data, to obviate the need for the uniform density assumption within traffic zones.

Three methods to avoid the uniform density assumption within traffic zones were explored. The first was to assume density is directly proportional to the number of street segments. The ALLOCATE command of the NETWORK module of ARC/INFO was used to select streets within 1/4 mile of bus stops. The proportion of the traffic zone served is determined by summing the street segments within the traffic zone for all bus stops serving the traffic zone and dividing by the sum of all street segments within the traffic zone.

The second method assumes density is proportional to population by block. This method uses the population count block data developed from the U.S. Bureau of the Census. Data values for each block are encoded to a block centroid coordinate. The population within a 1/4 mile search radius all bus stops serving the traffic zone
is divided by the sum of all population by block within the zone to determine the proportion of demand served. This method will handle residential areas, but not non-residential traffic zones.

The third method was designed to handle non-residential zones. It consists of determining the non-residential floor area represented as centroids of parcels within a 1/4 mile search radius of bus stops. The proportion of a non-residential traffic zone served by transit is the sum of non-residential floor area in the traffic zone within 1/4 mile of bus stops serving the traffic zone divided by the sum of non-residential floor area in the traffic zone.

4.0 IMPLEMENTATION PLAN

A detailed implementation plan for Tri-Met awaits the outcome of some strategic decision making about computing platforms, vendors, networking strategies, and even the locations of the engineering, operations, planning, and service units that will benefit from GIS technology. The discussion presented in this section serves as a guide for the institutionalizing of GIS, while at the same time identifies implementation issues and organizational options for other transit organizations.

4.1 Integration Issues

Implementation of GIS in an organization such as Tri-Met, that already has a number of highly computerized applications will find systems integration to be an essential task. The alternative to an integrated environment is tightly bundled,
isolated GIS installations replacing many of those existing applications, but data sharing between offices would be adversely affected. Consequently, systems integration is the key challenge in adopting a GIS implementation plan at Tri-Met.

As in any systems integration problem, a range of alternative scenarios exist. A top-down approach to integration might be to propose a single GIS application, running on one very powerful platform, providing services to all users of geographically referenced information within the organization. At the other end of the continuum, a highly decentralized scenario could be proposed that envisions GIS as one of a large number of desk-top data processing tools which only interface with each other when files are reformatted onto disks and forced to work with other applications in other departments.

A realistic middle ground is to consider that a range of software tools, including packages supplied by CAD and GIS vendors will be adapted for a variety of functions within the organization and the approach to integration is to identify data flows and information products necessary to the organization, standardizing data models and file transfer formats where necessary (Dueker and Vrana 1991). At Tri-Met, this integration is guided by the TIGER-centric nature of metropolitan transit applications. That is, one underlying representation of base map geography will accommodate the overwhelming majority of spatial data applications. This represents an advantage for Tri-Met relative to other organizations which lack such obvious data-driven logic to guide integration decisions.

The development of the TIGER-centric approach will yield enterprise benefits that are likely to exceed the efficiency and effectiveness benefits that are usually associated with using computers to automate a manual process. Efficiency benefits accrue when automation increases productivity associated with producing the same
products by reducing or avoiding cost. Effectiveness benefits result from producing new products and services that are possible by introducing and using the GIS. The enterprise benefits result from systems and data integration. Adopting a common underlying geographic database upon which various applications can be built will produce enterprise benefits.

4.2 Organizational Options

A strategy to introduce GIS into Tri-Met will take advantage of incremental work being done on the TIGER database regionally by Metro. At Tri-Met, several functional application areas can be aided immediately with specific additions to existing databases derived from the TIGER enhancements. A starting point must be identified by Tri-Met management, a position funded, and a hardware/software configuration procured that can operate on a stand-alone basis now but integrated into the larger picture, later.

This is generally consistent with the way the technology is brought into organizations. A GIS is acquired to support a particular project or application, and when its benefits are recognized widely in the organization, the issue becomes how to institutionalize it. 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. Consideration of a long-term strategy for GIS management is required. For GIS implementation, Tri-Met faces a choice among four organizational strategies. In advance of key management decisions, it is not the intent of this report to specify which of these is the optimum strategy. Rather, it is the intention here, to present a range of possibilities and organizational scenarios.
4.2.1 GIS Service Center.

Often the original office that brought GIS into the organization becomes a service center for other units. Once a GIS project has been shown to be successful, other units engage these personnel for similarly managing spatial data. The original office complies because it is eager to share its expertise and incidentally to spread the cost of the initial investment. Soon GIS permeates the organization as geography is part of many applications. The original office is now performing many more functions than it once did, perhaps more than it can effectively handle. Eventually there is pressure to formally centralize many of these support functions as they begin to duplicate services provided by the data processing unit.

4.2.2 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. This process does depend upon active participation from informed representatives from units with roughly similar investments and experience with the technology.

4.2.3 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.
4.2.4 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.

4.3 Institutionalizing GIS in the Organization

Regardless of the choice of the organizational option, there are a number of requisite steps to follow in preparing for GIS implementation. The agency needs to commit to the following: 1) using and maintaining a common geographic base file to enable systems integration, 2) adhering to data standards to foster sharing of consistent data, 3) establishing a systems architecture environment/policy/framework within which a GIS client-server model can develop, 4) selecting an appropriate entry-point application for bringing GIS in-house, and 5) staffing the entry-point application adequately to allow the evolution to one of the organizational options.

To utilize GIS as a strategy to integrate systems in a transit organization is an ambitious undertaking that requires incremental implementation. It is too much to undertake at one time. It needs to be planned as a whole and implemented in parts. Partly, it is a process of learning by taking on the less complex applications first, in order to gain experience with GIS.
4.3.1 A Common Geographic Base File.

The importance of a common geographic base file for GIS applications to share has been a recurrent theme in this investigation. Street centerline files, such as TIGER can provide the basis, but procedures and cooperative agreements need to be established to enhance and maintain it. Some enhancements are common to a number of agencies needing an up-to-date street centerline file, while other enhancements are unique to transit organizations, such as on what street segments specific transit routes run, the addition of light rail transit segments that do not run on streets, and the addition of landmarks that are important to the transit organization, such as transit centers and their access roads.

4.3.2 Data Standards.

The establishment and adherence to data standards is crucial to the long term goal of integrating applications. Complex applications such as trip planning, mobility management, and real time operations and control requires that the transit organization be able to integrate here-to-for separate systems. The alternative is to buy vendor integrated systems and maintain each separately. This could mean maintaining three sets of geographic data files for each of the complex applications identified above. Each vendor may use a slightly different data model, or choice of definitions of objects that are maintained in their database. This adds to the burden of maintaining each system.

Eventually there may be more than one computerized application accessing the common geographic base file. Add-on applications that offer modeling and specialized functions may be worthwhile for some of the functional activities outlined elsewhere in this report. GIS industry trends are supporting open systems and modular designs in part to encourage this flexibility. In addition, data standards
at both the model and file transfer levels have been developed (USGS 1991). These standards will be augmented with software to implement them and methods of describing the quality and content of databases to further facilitate data exchange among agencies and between applications within an organization.

Another aspect of standards relates to non-GIS attribute data throughout the organization. Adopting an agency-wide relational database management system facilitates GIS access to agency data resources without time consuming file transfers. An industry standard SQL relational database format, and such databases are currently used at Tri-Met, will be compatible with any of the major GIS packages and in conformance with the Spatial Data Transfer Standards as they are implemented.

4.3.3 Systems Architecture Environment/Policy/Framework.

Systems integration and GIS applications are fostered in a multi-user, multi-tasking server-client model environment. The server-client model is built around the concept of specialized workstation nodes on a network. Nodes can be added and the network expanded without replacing equipment (Travis, et al., 1991). The key is a multi-user and multi-tasking operating system and networking that will allow the transfer of large amounts of information. This is particularly the case for graphics applications, such as GIS.

4.3.4 Entry-Point Application.

Finding the appropriate entry-point application for GIS introduction and institutionalizing is important to success. Unfortunately, the appropriate entry point may be idiosyncratic to each organization, as organizations vary considerably as to where logical entry points for GIS technology exist.
In preparing the 1991-92 budget Tri-Met’s GIS Task Force decided not to incorporate GIS into the organization in a formal way, but to encourage a unit to undertake a GIS application that would serve to introduce and move to institutionalize GIS.

Although mobility management for Special Needs Transportation and a trip planning system for Customer Services constituted the most immediate needs for GIS functionality, they were not deemed to be logical entry points for GIS introduction. Both are too complex for a first application as they require integration with a number of non-GIS components.

On the other hand, there exists a number of conventional GIS application areas within the purview of the Scheduling and Analysis unit of the Operations Division. In addition, the pilot project work demonstrated their feasibility. Unfortunately, the subunit felt to be most appropriate, Service Planning, chose to contract out the analysis most suited for GIS analysis, the determination of whether disabled persons are served by fixed route transit.

This action will best meet the immediate needs to comply with ADA (American Disabilities Act) requirements, but there is adequate experience in other organizations to show that contracting out is not a good long-term solution. GIS needs to be in-house to be effective. It is such an integrative technology that it cannot be a peripheral function. An entry point must be found.

4.3.5 GIS Staffing.

In addition to an organizational entry point, staffing for the function must be developed, initially to perform the entry-level applications and ultimately to serve as GIS manager, GIS database administrator, and GIS application developer.
Without budgetary authority, two options were considered, to train a current staff person or the hire an intern to maintain the GIS route database and to initialize a bus stop file application. As of the date of this report, no action has been taken.

5.0 STRATEGIC CHOICES

GIS is more than a tool for technicians, it has significant potential for creating understandable map displays and for providing useful information for management and policy levels. This flow of information up the organization provides the basis for informed decisions and actions to flow down for improved operations. Thus, it is important to involve and gain the support of top level management in GIS implementation and use.

To this end, the following goal, objective and supporting actions are proposed.

**Goal**: To provide the management and policy levels with accurate and timely locationally integrated information by which to evaluate public transportation system performance and upon which to base actions.

**Objective**: Utilize GIS technology and a common geographic database to integrate data about transportation users, providers, and infrastructure, in user friendly map displays.

**Supporting Actions**:

1) Use GIS technology to integrate data within Tri-Met and with related organizations, such as Metro, the three counties, and cities.
2) Share digital data with other organizations to reduce costs and to increase accuracy and ensure timely updates.

3) Organize and maintain geographic data as an agency asset to support other new applications of technology to improve public transportation, to provide information solve problems that may occur, to respond to mandates, and to provide information to seize opportunities

This goal and the objective provide the link by which the investment in GIS technology provides a payoff to top-level management. And top-level management support is necessary to realize the full advantage of an integrative technology.

6.0 CONCLUSIONS

Managing spatial and other computerized data for urban mass transportation is a critical requirement for efficiently responding to new demands for service. Tri-Met is planning to acquire GIS technology to link route planning, paratransit scheduling, facilities maintenance, and other customer service functions.

A crucial issue in the adoption of this technology involves the integration of data used by various Tri-Met divisions. It is often said that geographic information is the common thread of planning, engineering, and transportation functions. In this context, a GIS becomes an inherent integrating tool. This is facilitated by a common digital base map for the region, to which various divisions can tie data required for the mapping, modeling and operation of transportation related services. A common digital base map of address coded street segments is available
by modifying the TIGER line files available from the US Bureau of the Census. The resulting database can be used by a generic GIS as well as some transportation-specialized software to support applications across the organization.

An integrated solution moreover will insure currency, consistency, and integrity among applications. In turn, this emphasizes the importance of cooperative enhancement and maintenance of TIGER, not only for Tri-Met applications, but for the opportunity to obtain data from other organizations, such as traffic volume data from the local governments and the state highway division.

Implementation of an integrated solution with TIGER, however, requires addressing issues of systems integration, visualization requirements, real time dispatching, and some required TIGER data enhancements. Tri-Met GIS implementation is being developed in the absence of strong vendor support for GIS products designed specifically for integrated transit applications. An important part of Tri-Met's work is to examine several GIS products and evaluate their competing claims and functionality. A typology for comparing GIS solutions is presented in this report to aid in this process.

In addition, the challenge for integration grows when considering opportunities for external linkages to "mobility management" – a broadened concept of trip planning, and Intelligent Vehicle and Highway Systems (IVHS) for better coordination with the street and highway systems. This challenge for interorganizational integration calls for an open systems architecture that will enable configuring and reconfiguring systems as technology and applications evolve. These architectures are in fact being developed and further supported by the major GIS vendors. Installations are usually implemented according to the client-server model where GIS applications run on one or more workstation platforms.
under a UNIX multitasking operating system and linked on a high speed network which may include other workstations and/or PCs.

To further examine Tri-Met functional requirements, and to demonstrate GIS approaches to Tri-Met spatial data management and analysis problems, a series of pilot projects were undertaken as a part of this research. The first project involved automating the relation between an existing tabular database describing route segments and the TIGER files. This results in an efficient method for encoding the transit route structure into the street base map without digitizing. Later, this coverage can be updated with additional routes or better versions of the TIGER as they become available. In another pilot project, address matching was used to analyze the origins and destinations of aged and disabled transit clients for determining the mix of fixed route and paratransit service to be provided by Tri-Met. A third project involved the use of GIS for analysis of land use adjacent to and near-by bus shelters for advertisement revenue projection. The fourth project was aimed at service planning efforts. A method was developed to apportion total trip data aggregated by traffic analysis zones to individual bus stops located within and bordering those zones.

Findings from these pilot projects sustain and reinforce the technical analysis and the conclusions of the Tri-Met GIS Task Force, an ad-hoc committee which has regularly met throughout the period of this investigation. These findings lead to the conclusions that a common geographic base file, the ability to integrate data from one part of the organization to aid planning and operation of other units, and a disciplined approach to standards for data maintenance and exchange are cornerstones in building a geographic information management strategy.
Implementation strategies for Tri-Met involve some crucial in-house decisions about platforms, networking, staffing, and funding. Institutionalizing GIS in transit organization requires top-level management support and a prominent place in the organization. This generally evolves from an initial entry point of a project. Success on projects generates enthusiasm for more ambitious applications. Then is when the integrated GIS plan is unveiled. Hopefully, this report provides the framework for such a plan.

Finally, it is appropriate to note that the success of this project will likely be enhanced by the participation of key individuals from across the organization who contributed to the project by offering advice, data, information about transit applications and overall guidance to the researchers.
REFERENCES


