Experimental Infrastructure for the Study of Interoperability of Map Databases

Project executed under contract to
California Department of Transportation
Testbed Center for Interoperability

Vehicle Intelligence & Transportation Analysis Laboratory
University of California at Santa Barbara
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Experimental Infrastructure for the Study of Interoperability of Map Databases

Final Report

This report identifies commercial data vendors by name, and should be treated as confidential

VITAL

Vehicle Intelligence Testing & Analysis Laboratory
National Center for Geographic Information and Analysis
University of California, Santa Barbara

December 1997

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Introduction

In January 1997 the National Center for Geographic Information and Analysis (NCGIA) established the Vehicle Intelligence Testing & Analysis Laboratory (*VITAL*) with startup funding from the Testbed Center for Interoperability (TCFI), California Department of Transportation (Caltrans).

TCFI and NCGIA had earlier sought two-year funding from the Federal Highway Administration (FHWA) through Oak Ridge National Laboratory (ORNL), to test two spatial data interoperability standards proposed by ORNL for Intelligent Transportation Systems (ITS) — the Location Referencing Message Specification (LRMS) and the ITS Datum (ITSD). Accordingly, the immediate agenda for the lab was to establish the technical infrastructure for the two-year program.

This document reports on the progress made over the initial funding period. We first explain the context of our work as it relates to ITS (“Interoperability and ITS”), then briefly discuss our technical approach to the study of geographic error (“Geographic Error and Remediation”), and document the infrastructure — data and systems — developed to date to support the experimental agenda for 1997–99.

Background — Interoperability and ITS

The promises of ITS are numerous, from mayday messaging to real-time congestion broadcasting and fleet management, collision avoidance, and ultimately autonomous vehicle control. Partial implementations have been prototyped or realized to varying degrees, but to date, the full suite of ITS capability has not been implemented anywhere, (a) because the definition of this capability is still emerging, and (b) due to lack of interoperability and standards.

Standards are now being developed by bodies such as the International Organization of Standards (ISO) and the U.S. Society of Automotive Engineers (SAE), to address message content and structure. For example, a “Position Report from Road Side Beacon” is composed as follows (ISO Draft Recommended Practice, Version 1.3):

- Message code (16 bits)
- Beacon ID (14 bits)
- Beacon Location:
  - Standard location reference (64 bits)
  - Offset from reference point (16 bits for 1 metre resolution)

This high-level standard does not (to date) define bit-level data formats. Notice how location is not broken down into specific fields such as x- and y-coordinates, but is specified vaguely as “standard location reference.” The lower level components of a location referencing standard have proved difficult to develop.

Spatial Data Interoperability

A process for communicating a location from one map system to another must be accurate, unambiguous and efficient. The following are some of the hurdles to interoperability in location referencing:

1. There are several ways to describe a location, for example:
   - Coordinates (e.g. latitude, longitude)
   - Route and distance (e.g. Interstate 95, mile 253)
   - Intersections (State Street and Hope Avenue)
   - Landmarks (Cottage Hospital)
   - Map references (page 35, E-6)

   Each method has its own advantages, which make it appropriate to a given set of applications. Interoperability demands ready translation between these referencing methods. The LRMS specification from Oak Ridge proposes standardization of this aspect of messaging.

2. Some data needs are more stringent than are others. For some purposes, measurement at the metre level is required; for other purposes 100 metres is sufficient. Clearly 100-metre data should not be used in 1-metre applications. For mission critical applications, standards must provide for metadata.

3. No two vendors' digital maps of the same area are identical in all respects. Vendors derive their base data over a period of time, from a variety of sources (e.g. aerial photography, printed maps, GPS surveys and field observation). There is usually a variation in quality in each of these dimensions. A location could be specified very precisely with respect to one map base, but when transferred to another vendor's map it could be off by several hundred metres. Similar problems apply to attribute data such as street names and aliases, and their spellings.

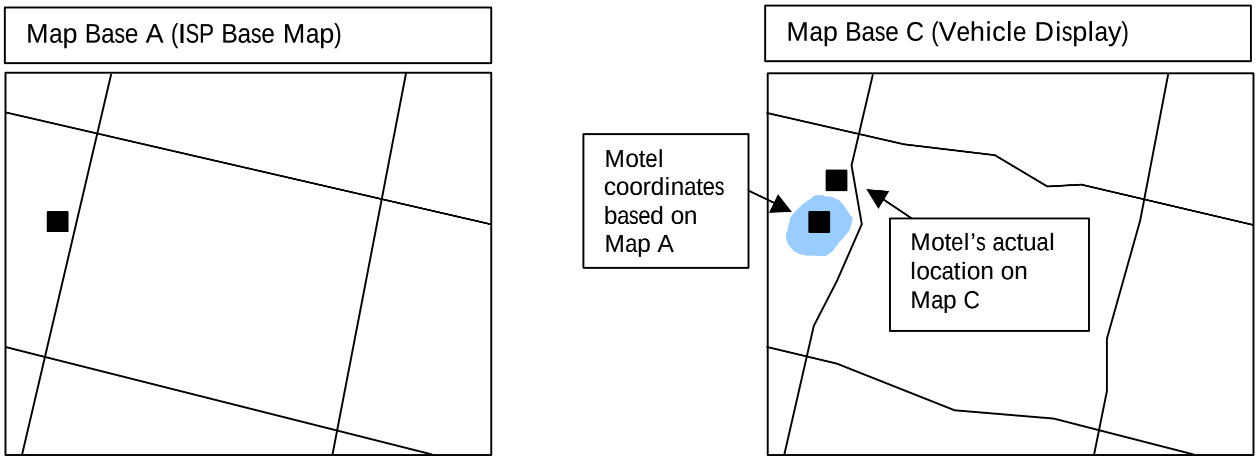
No two vendors' maps of the same area are identical

Consider the example of a driver traveling through an unfamiliar city and requesting motel and congestion information from all Information Service Providers (ISPs) in the area. One ISP responding to the request transmits motel locations based on map database A. ISP #2 supplies congestion data, based on database B, that the vehicle uses to compute the quickest route. The display and routing functions are executed in the vehicle, based on database C.

Two potential problems are immediately obvious. First, due to coordinate variations between A and C, locations transmitted from one to the other have different relative locations with respect to objects on the map. The motel may appear on the vehicle display to be located in the middle of a lake (Figure 1).

Second, there may be ambiguity in referencing. Suppose a freeway, Interstate 5, runs parallel to a country highway, Route 5. If, due to confusion of standards, the distinction between Interstate and Route is inadequately specified, the country highway could pick up the traffic flow attributes of the freeway; consequently the navigation system recommends an improbable route.

This example illustrates just two of several possible sources of potential messaging error: coordinates and impedance attributes. The other elements of map data bases — addresses and topology — are also subject to problems. In some cases the geographic error is slight, and can be easily reconciled by an intelligent observer. In other cases, referencing errors may be much larger (e.g. Marquette Street misinterpreted as Market Street). Errors such as these discredit ITS technology and negate many of its benefits.



Finally, communications efficiency can mean the difference between viability and failure of an ITS application. Consider a fleet of 200 police and emergency vehicles communicating with a central station. If each vehicle requires 10 seconds to sign on to the communications channel, relay information and sign off, the average update frequency for a given vehicle is about 40 minutes. This is clearly unacceptable.

The scenarios above illustrate potential problems that will inevitably result if ITS applications are developed haphazardly, without adequate controls and standards. Players in the ITS industry are impatient to implement applications for mayday and emergency services, among others. To ensure that such implementation is orderly and effective, it is critical that communications requirements for location referencing be defined and incorporated into emerging standards.

The role of *VITAL* is to address the standardization challenge by

(a) studying the characteristics of geographic error as it relates to street networks;
(b) developing measures of experimental error in communication of location references;
(c) investigating methods for reducing or correcting error;
(d) applying the above knowledge in evaluating and contributing to proposed communications standards.

The mandate is therefore simultaneously academic and industrial.

Geographic Error Remediation

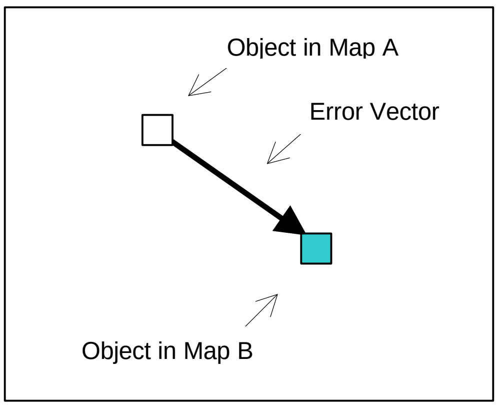
Characteristics of Geographic Error

It is fair to state that when two map data bases differ, one or both contain error. However, to take the position that any data are erroneous, demands that the "truth" be available for comparison. For positional error in GIS, this truth is relative, and usually amounts to data measured at a larger scale. To assess the accuracy of a street network data base, typically captured from 1:10,000 to 1:50,000 data, it may be compared against an engineering scale (e.g. 1:2,500) data base, assuming appropriate quality controls in the production of the engineering data base.

Alternately, one could select a sample of "tie-points" in the 1:50,000 data base, and capture the coordinates of those points independently using high precision surveys. Selection of tie-points is laborious; due to semantic problems it cannot be entirely automated (Nystuen et al 1997).

Conflation creates agreement, not truth

In a study of Ann Arbor, Michigan, Nystuen et al (1997) divided the city into a set of 36 grid squares (squares with side lengths of 2.24 km, area 5 km^2). For each grid square, they computed a number of cartometric statistics to quantify the degree of correspondence between two data bases. One useful calculation was the arc length in one data base that fell outside a specified buffer around the corresponding arc in the other data base. While this was a useful first step in the direction of map comparison, there are a few problems with the approach. Most obviously, at a numerical level the results are clearly dependent on the resolution and orientation of the grid. More seriously, the approach does not address the origins of error, and therefore does not propose useful means to remedy it.



Deviation from "truth" for a given point may be measured by a simple error vector, that characterizes the magnitude and direction of error. When deviation is known for a large number of points, an error vector field can be developed to describe the spatial distribution of error. Inaccuracies in map data base development occur (a) systematically, due to errors in dealing with the entire source map or large sections of it (e.g. errors in capture of reference points, or deformation of the source media) and (b) locally, due to cartographic generalization of the source map, compounded by inaccurate digitizing. If systematic error can be adequately characterized, it can be rectified. By studying the error vector field, it may be possible to isolate the systematic and local components of error, and to speculate on the origin and appropriate remediation of systematic error.

Remediation of Error

Positional error in street network data bases has not been considered a serious issue until recently. Users typically employ one data base at a given time, therefore consumer-level criticism of positional inaccuracy has not arisen. A more likely complaint is with the esthetics of digital maps compared with printed products. Accordingly, map vendors have focused on cosmetic processing, e.g. using fillets and splines to smooth sharply angular polylines.

A second area of remediation is now emerging. As multiple data bases become available for a given area, gathered by different agencies, e.g. delivery, transit and utilities, there is a need to blend the strengths of one data base with those of another, to create a high quality, information-rich composite. This process is known as conflation. GIS vendors offer tools to facilitate conflation; however the process still requires substantial operator intervention and is therefore laborious, expensive and subjective. Presumably this will improve as better algorithms are developed.

More fundamentally, the principal difficulty with conflation is that it simply creates agreement, not truth. Absolute positioning technologies such as differential GPS enforce truth with a relatively small envelope of uncertainty — about 2 to 10 metres. Vendor data may differ by more than 100 metres. If conflation simply secures agreement between data bases, without respect for at least the degree of truth afforded by D-GPS, interoperability problems will persist.

One would reasonably expect that over the next decade or so, vendor data will gravitate toward the positional accuracy made possible by D-GPS. However, future datum changes and tectonic movement may continue to require periodic coordinate updates on a large scale.

A promising solution to the interoperability problem, at least with regard to positional error, is the ITS Datum (ITSD) proposed by ORNL. When fully developed, the ITS Datum will in effect be a set of tie points with accurately measured position coordinates and universal identifiers. Vendors' line definitions may still be unique and proprietary, but the framework of reference points will ensure that interoperability is achieved. A *VITAL* task is to help determine the density of tie-points required to achieve a satisfactory degree of interoperability.

VITAL Infrastructure Development

VITAL's agenda as currently mandated by funding agencies in 1997–99 is to conduct a series of experiments in technical collaboration with ORNL to test LRMS and ITSD designs. Spatial interoperability will be studied:

a) at a theoretical level, e.g. comparing tie-points in commercially available map data bases, using error vector fields as described above, and other representations;
b) with simulated message transmissions from servers to clients, and
c) in field implementation, using wireless communications between distributed servers and a fleet of mobile clients.

Over the period January–July 1997, the task was to develop the experimental infrastructure of map databases, computing/communications hardware and experimental software to enable the spatial interoperability studies above. The following sections report on the outcome of the first six months of operations.

Infrastructure — Data

A selection of popular commercial street network data bases was compiled for the County of Santa Barbara. We sought the participation of all major vendors, especially those operating in California. The vendors listed below elected to be involved, in full knowledge of our agenda and the nature of our experiments. We are grateful for their cooperation.

- Etak (Menlo Park CA)
- Geographic Data Technology (Lebanon NH)
- Knopf Engineering (Visalia CA)
- Navigation Technologies (Sunnyvale CA)
- Thomas Brothers (Irvine CA)
- TIGER (U.S. Bureau of the Census)

The above data bases were generally priced in the $1000–2000 range, with the exception of TIGER, which is public domain. The Knopf database has exceptionally good positional quality, and might serve as a reference base the judge the accuracy of other databases. It is normally priced at about $45,000; we are attempting to secure the data at a substantially lower price for our purposes.

All data bases were ordered in ArcInfo export format. Some included auxiliary information such as hydrology and landmarks; others layered the contents, placing freeways and residential crescents in separate layers. Definition problems were evident as some vendors described a particular street as an arterial road, while others considered it residential. The first step was to build a common structure for all data bases, creating a composite layer containing all levels of roadway, and verifying coordinate datum, standardizing on NAD83.

Other relevant data have been acquired:

- US Post Office Carrier Route Information System (CRIS) — list of standard street names
- National Geodetic Survey data sheets — descriptions of high precision NGS benchmarks, including some control points from California's High Precision Geodetic Network (HPGN)
- National Highway Planning Network (NHPN) reference coordinates
- Various standards documents from ISO and SAE.
- Information on current ITS activities and projects in the United States, with recent literature on a handful of projects. A compendium of ITS acronyms and terminology has been compiled and published on *VITAL*'s web page (*http://www.ncgia.ucsb.edu/vital*).

Infrastructure — Systems

TCFI made available the following equipment:

- Notebook computer: 100 MHz Pentium, 40 Mb RAM
- Trimble Placer 400 GPS receiver
- ACCQPOINT differential GPS receiver
- Sierra Wireless AirCard CDPD modem, version 2.02

Using this equipment, mobile client system software was created ("StreetSmarts", fully described in Appendix A). The following sections highlight the principal features of the software.

Mobile Map Display

The display program runs on a Pentium-powered laptop computer carried in the vehicle. Any of the above map data bases may be selected at any time. The laptop currently in use is an Accura 100 MHz Pentium with 40 Mb RAM, supplied by TCFI.

- A differential GPS receiver continuously feeds in vehicle location coordinates. The vehicle is represented as a dot, its position snapped to the nearest navigable road (currently we have no need or plans to implement intelligent map matching). The map moves with the vehicle, so that the vehicle is always positioned around the center of the screen. At the user's option, the map may rotate in real time so that the direction of travel is always "up" on the display.

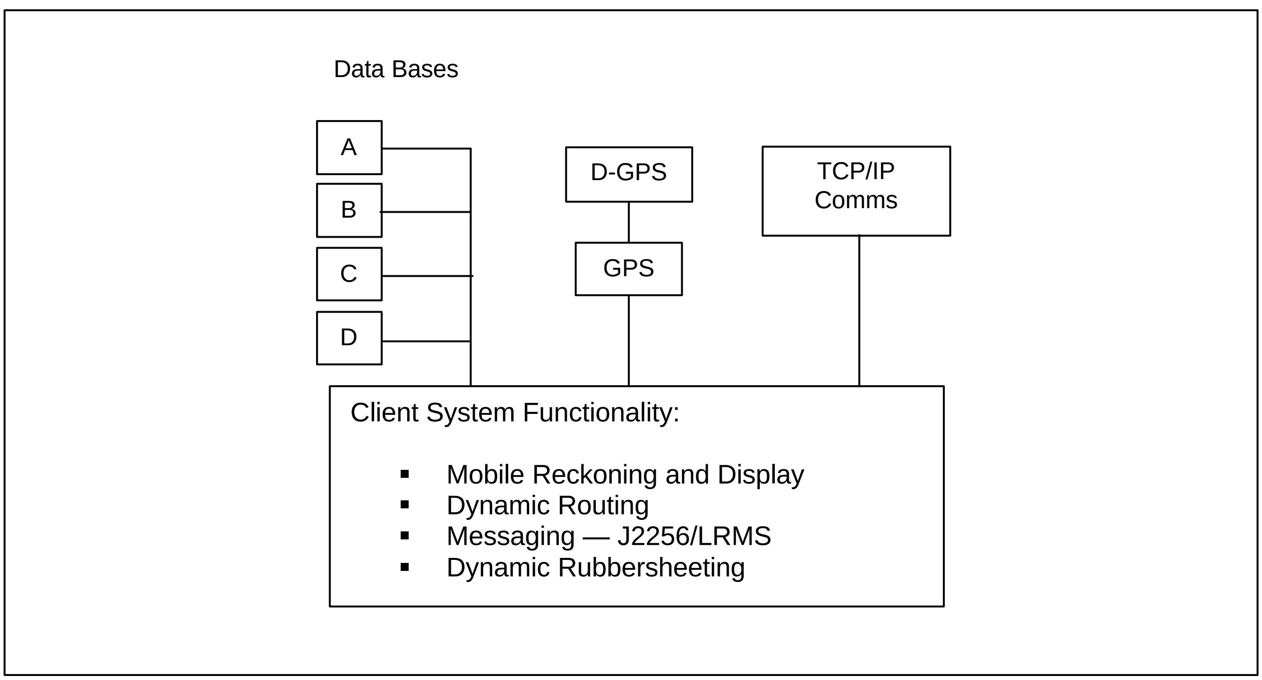
- Any map base may be turned on or off on the display, and the driving route is continuously traced. A Tag button enables the operator to save the coordinates of selected points to a file.
- Given a destination, the system computes the optimal route. If the vehicle strays from the prescribed path, the route is updated with respect to the current vehicle position.

Mobile Communications

The vehicle-based laptop may be considered a client, in communication with a remote server. Messages are passed between the client and server using 2-way wireless communications. For the present we have deployed the Sierra CDPD modem which runs at about 19,200 bits per second. Other less advanced wireless communications technologies — spread spectrum modems (2-way) and FM subcarrier broadcast (1-way) — may be implemented in the future for specific experimental needs or performance comparisons.

Server Display

The server also has access to the street network data bases listed above. At any given time it may make reference to the map base in use in the client, or any other map base. The server tracks a fleet of several vehicles, updating their positions on a map display. Vehicles may report their positions at regular intervals, or the server may petition a particular vehicle for a position report at any time (using SAE J2256 message formats 10L and 11L). A location may therefore be communicated from the server, running map data base A, to the client display, generated from map data base B. Each message is logged on transmission and receipt, for post-analysis of error.



Testing

The system has been road tested to determine its capabilities and limitations for future experimental work.

- GPS readings are reliable, and received throughout the county; temporary signal loss is experienced in downtown Santa Barbara, and in areas of dense forest cover.
- Differential GPS signals are received from a Los Angeles FM station. They are adequate in the immediate vicitinity of the city of Santa Barbara, but signals are lost at El Capital State Park, a few kilometres west of Santa Barbara, and are intermittent beyond that point. The range north of Santa Barbara is similar.
- With D-GPS active, location is steady, varying by about 1–2 metres. We have gathered GPS data at a single position over a 24-hour period to observe the reliability of the system.
- GPS coordinates are in latitude and longitude. They are transformed to Universal Transverse Mercator (UTM) by the display software. Results from the transformation routines have been compared against corresponding results from a leading GIS (ArcInfo); variations in results are of the order of 0.04 metres.
- CDPD signals depend on distance from Storke Tower, the antenna location at UCSB. Using the basic configuration of the Sierra AirCard (i.e. with built in antenna), signal strength is -60 db on UCSB campus, and rapidly deteriorates to –100 db about 5 km from campus. Using an external antenna mounted on the roof of the vehicle, signal strength of –60 db is available over a 20 km radius.
- The system has been tested by gathering coordinates while driving, and overlaying the coordinate trace on map databases. Coordinates compare favorably against most databases; significant errors of comission/omission, and topological/attribute errors, are observed in some databases. Observations on positional error are continually posted to our web site, *http://www.ncgia.ucsb.edu/vital/poserror.html*.

Next Steps

Over the next two years, a series of analyses and experiments will examine a number of issues with regard to interoperability, for example:

- to investigate the nature of discordance between map bases — how is error typically distributed; is it greater in residential neighbourhoods and less severe along freeways;
- to model positional discordance, so that it can be corrected by rubbersheeting and other techniques;
- to examine the LRMS and ITSD as potential solutions to interoperability challenges.

At the time of writing this report, preliminary results have already been generated (Appendix B).

Appendix A — StreetSmarts System Description

Design Parameters

The StreetSmarts system is a mobile environment for testing interoperability for ITS. It incorporates visual display of multiple transportation databases, GPS location referencing, interactive data collection, and wireless communication with remote servers.

Mobility

To allow interactive data collection in the field, the StreetSmarts system is designed to operate in a mobile environment. This requires operation on an easily transportable computer, using an internal power source or drawing power from the test vehicle. The system must also be able to monitor the physical location of the vehicle, information about which can be provided with a vehicle-mounted GPS.

Communication

A major part of testing interoperability for ITS involves communication between mobile vehicles and remote servers. This allows comparison of client-side versus server-side database operations, along with the communication of information to support this between the two, and allows real-time observation of the effectiveness of location information transfer schemes between systems and databases. To permit the greatest flexibility for testing, StreetSmarts is designed to be as independent as possible from the communication hardware, allowing various technologies to be tested without major revisions to the system.

User interface

As an interactive testing environment, StreetSmarts supports the simultaneous visual display of multiple network databases, along with pertinent location information, including current and recent mobile GPS information.

System Requirements

Memory

To support real-time display of the street networks, StreetSmarts maintains the complete spatial information for each database in memory. The system also maintains a complete topological network in memory, in order to support real-time routing. For large databases, such as the entire county of Santa Barbara (30,000 – 35,000 arcs), this can require 25 Megabytes or more of memory per database. The system does not require this much real RAM, however. Much of the data can be stored in virtual memory until it is needed. The actual memory requirements will depend not only on the number and size of the databases to be used, but on how many are to be displayed at once. As a general guideline, for databases on the order of Santa Barbara county, allow 25 Megabytes of total memory (combined real/virtual) per database, and 12 Megabytes of real memory per database to be displayed simultaneously. The system will function with less real memory, but performance will be degraded.

Disk storage

StreetSmarts requires enough disk storage to hold the network databases, support the necessary virtual memory requirements outlined above, and store any collected data. StreetSmarts stores both streamed GPS locations (GPS readings saved to disk as they are read) and tagged locations (interactively selected locations). Each streamed location requires 50 bytes of disk space, and each tagged location requires 80 bytes of storage. For example, when streaming is turned on and new GPS readings are available at a rate of 1 per second (a typical rate), the system will store approximately 175 kilobytes of data per hour.

Processor

StreetSmarts currently operates on a laptop computer with a 100 MHz Pentium processor. However, the system has been successfully tested for use with a 486 processor as well.

Operating system

StreetSmarts makes use of utilities provided by the Win32 System Services available in both Windows 95 and Windows NT. These utilities include TCP/IP communication services and serial port communications, and must be available from the operating system.

Software

Map display

StreetSmarts is capable of displaying multiple simultaneous street networks, along with various types of vehicle location information. Each individual network database can be displayed in a specific color, or hidden from view. The map display is centered on the current location of the vehicle as reported by the GPS receiver, with the display oriented so the current travel direction is toward the top of the screen (heading up) or so that north is at the top (north up). The scale of the display can be adjusted interactively at any time, with a key press or menu selection.

In addition to the network databases and current vehicle location, StreetSmarts displays other location information, including the nearest point on any street network to the current GPS location, and a location reported from the remote server. The server is currently implemented to bounce back the current GPS location as a visual indication of communication lag. The system will also show a trace of recent GPS locations on the screen. The number of positions displayed in this trace, as well as the sampling frequency, is user selectable.

Data collection

StreetSmarts collects data both automatically, storing each new GPS location in a file, and interactively, storing a uniquely labeled location. The captured information is as follows:

Streamed Data

- Current date (YYYYMMDD format)
- GPS time of reading (in seconds since midnight GMT)
- Number of satellites used to calculate position
- Northing and Easting of location in UTM coordinates, zone 11, NAD83

Tagged Data

- Tag ID
- Current date (YYYYMMDD format)
- GPS time of reading (in seconds since midnight GMT)
- Number of satellites used to calculate position
- Northing and Easting of location in UTM coordinates, zone 11, NAD83
- Number of seconds since last GPS reading
- Nearest street link to GPS location in active snapping layer
- Offset along nearest link of point closest to GPS location (in meters, measured from origin of link)
- Length of nearest link (in meters)

Hardware

GPS

StreetSmarts currently operates with a Trimble Placer™ 400 GPS sensor, communicating at 4800 baud, with 8 data bits, 1 stop bit and no parity. In addition, GPS differential information is received with an ACCQPOINT differential receiver.

Communication

Server/rover communication operates with TCP/IP packets, using Microsoft Windows Sockets Version 1.1, sent over a Sierra Wireless AirCard CDPD modem, with a maximum transfer rate of 57600 bps.

Programming Issues

Internal Data Structures

The internal representation of the network databases is designed to be generically useful and reusable, and is implemented in an object-oriented structure. Each database is represented by a single spatial layer class containing information about the entire database, such as the spatial extent of the database and how many objects it contains, as well as function calls which apply to the entire database, such as shortest path calculation. Each spatial layer class contains a set of spatial objects, each one representing a single arc shape in the database. The shape classes contain information specific to each arc, such as its bounding rectangle, the set of points making up its shape, street name and address information.

Shortest Path

Shortest paths are calculated across the street networks using Dijkstra's algorithm. This requires that a topologically connected graph representation of the street network be stored in memory. The system stores a set of nodes in memory, representing the intersections of the street network. Each arc object in memory stores pointers to its from-node and to-node, and each node object stores pointers to all the arcs connected to it. Dijkstra's algorithm operates by traversing the network in least-cost fashion, so that nodes are visited in such a way that the total cost to reach the node is minimized. Since each arc stores pointers to its nodes, and each node stores pointers to all intersecting arcs, the network can be traversed quickly, allowing very quick shortest path calculation.

Display

Real world coordinates are mapped to screen coordinates with matrix transformations. Three transformations are used: scaling, translation, and rotation. Rotation is applied first, to orient the map so that the direction of travel is towards the top of the screen, or so north is towards the top of the screen. Then a translation is applied to fix the location of the vehicle to the center of the screen. Finally, a scaling transformation is applied, to fit the map extent to the size of the display screen.

Each time the map display is updated, these three transformations are applied to all of the spatial objects that are to be drawn. To save time, however, only those objects which will appear on the screen are transformed. This is accomplished by reversing the transformation, calculating the bounding rectangle of the display screen in real world coordinates. Any spatial objects which fall inside this rectangle are transformed to screen coordinates, then drawn on the screen.

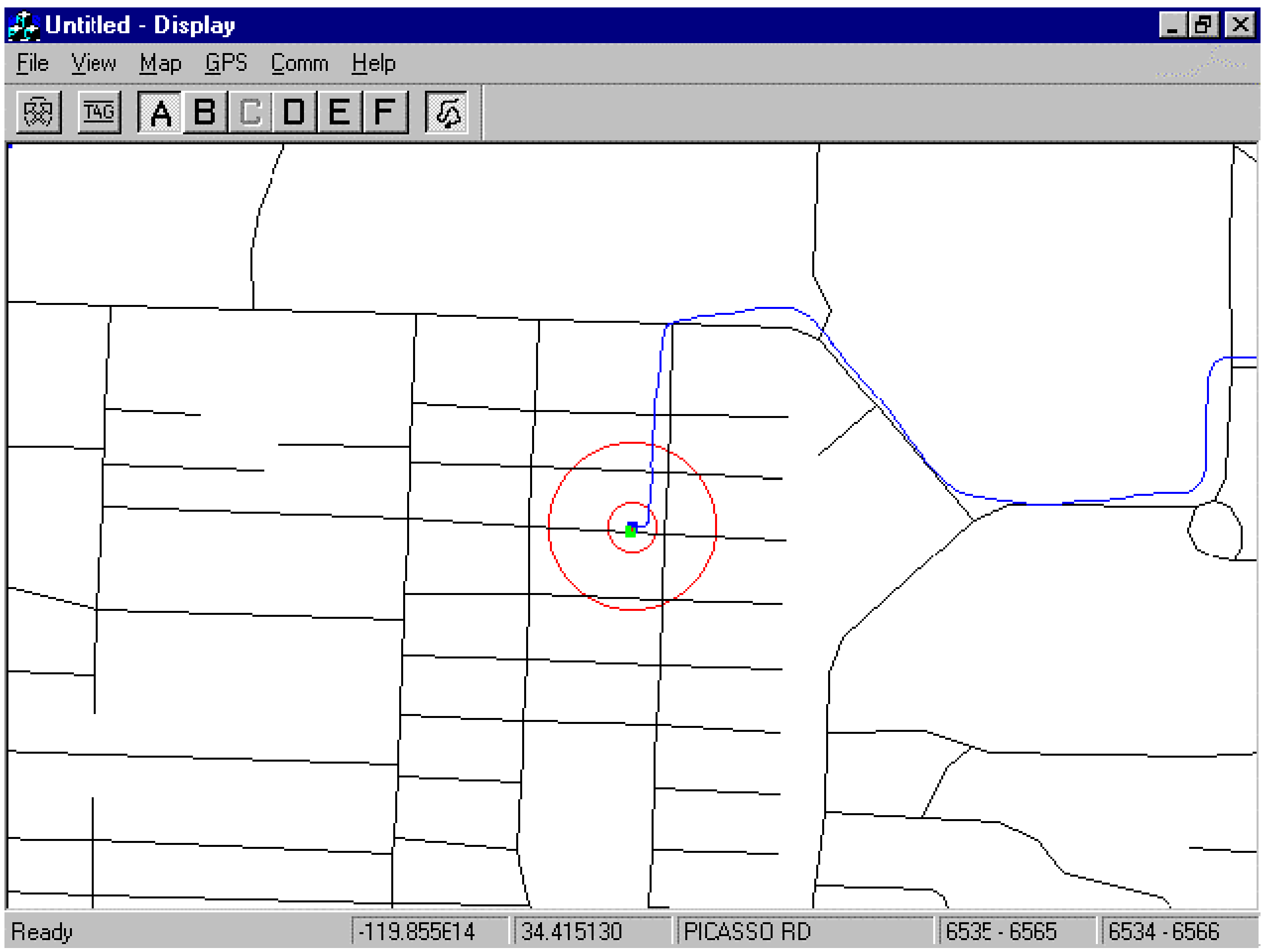


Figure 1: StreetSmarts sample display screen, showing Etak background map base and trace of vehicle route. Circles around GPS point are possible uncertainty zones of radius 30m and 100m respectively. Position is usually accurate to 2m.

Utility Functions

The network databases used in StreetSmarts are projected into Universal Transverse Mercator coordinates, zone 11 and the North American Datum of 1983. Location information obtained by the

Global Positioning System receiver is in spherical coordinates, requiring a projection from one to the other. To accomplish this, StreetSmarts contains a projection function to translate latitude and longitude values from the global coordinate system into eastings and northings of the UTM projection. Each time the map is redrawn, the current GPS location is projected into UTM coordinates to fix the center of the display to the location of the vehicle.

System Event Flow

StreetSmarts is a multi-threaded application, running with four main threads. Of these, central control of the system is contained in the application thread, which controls all graphical display functions, and responds to user input. Operating independently from this thread is the GPS query thread. The sole function of this thread is to send query messages to the GPS receiver through the serial port. The thread sends a query string to the serial port, requesting that the GPS unit respond with the current location. One query string is sent per second, which is fastest rate the GPS receiver can calculate a new position.

Screen updates are controlled mainly from the GPS listener thread. This thread continually polls the serial port, waiting for GPS location messages. Each time a new location message is received, the listener thread updates the current location of the vehicle, then sends a screen update request to the main application thread. The listener thread also writes the location information to the stream file, if it is active, and sends it to the server, if connected.

The final thread is only activated if a successful TCP/IP socket is connected to the server. Once a connection is in place, this thread listens for TCP/IP packets and updates the server location information. When the main application thread updates the screen, the server location information is drawn if a socket connection is in place.

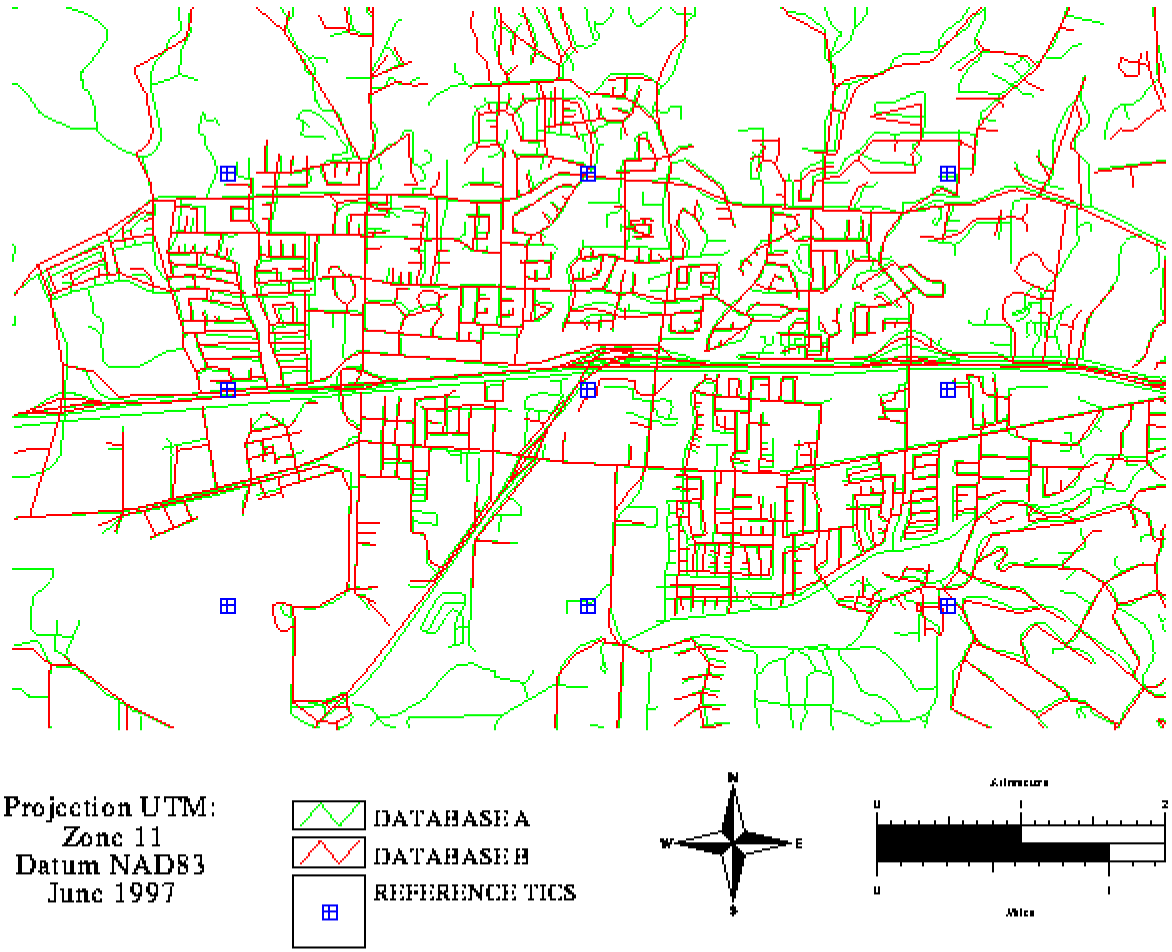
Appendix B — Map Comparison

Concordance is currently being studied by pairwise comparisons of data bases as follows:

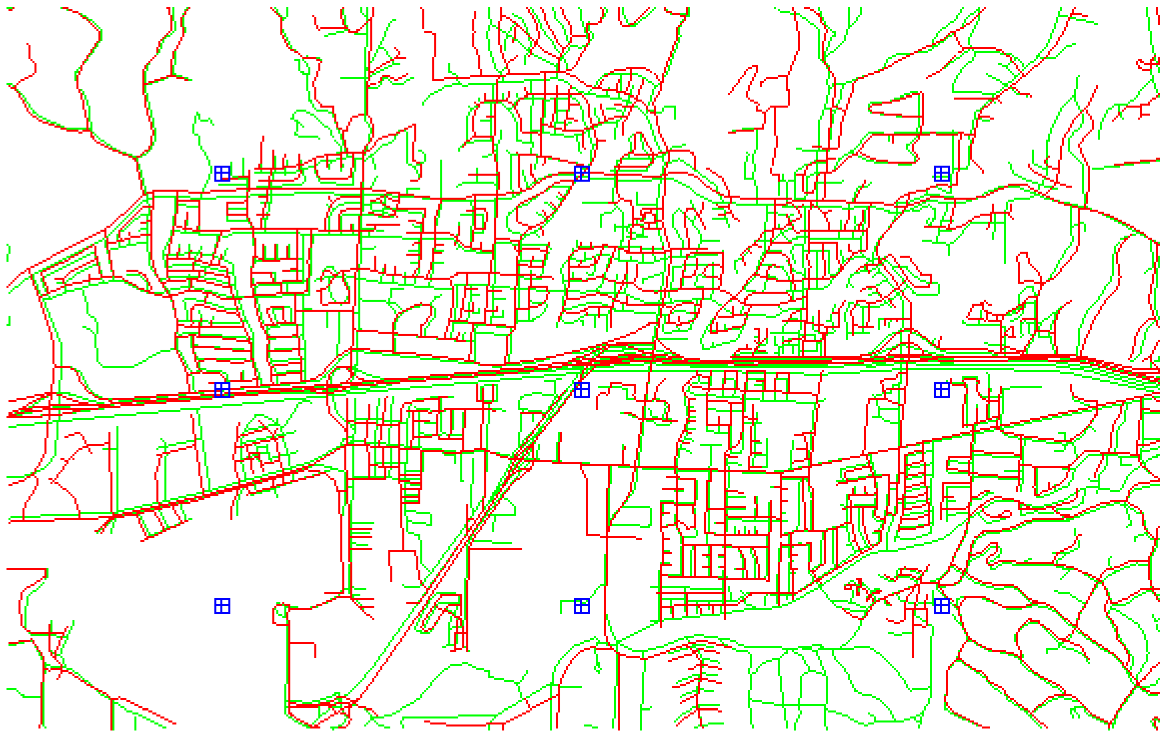
- Graphical overlay
- Development of vector field maps between corresponding points ("tie-points")
- Examination of street name tables

The maps on the following pages are pairwise overlays of the four data bases under study. Positional disagreements of more than 100 metres are observed in some places.

PAIRWISE COMPARISON OF:
DATABASE A AND DATABASE B

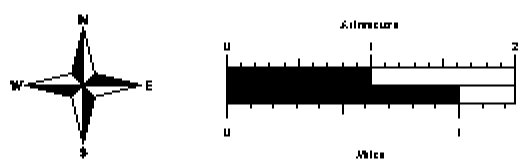


PAIRWISE COMPARISON OF:
DATABASE A AND DATABASE E

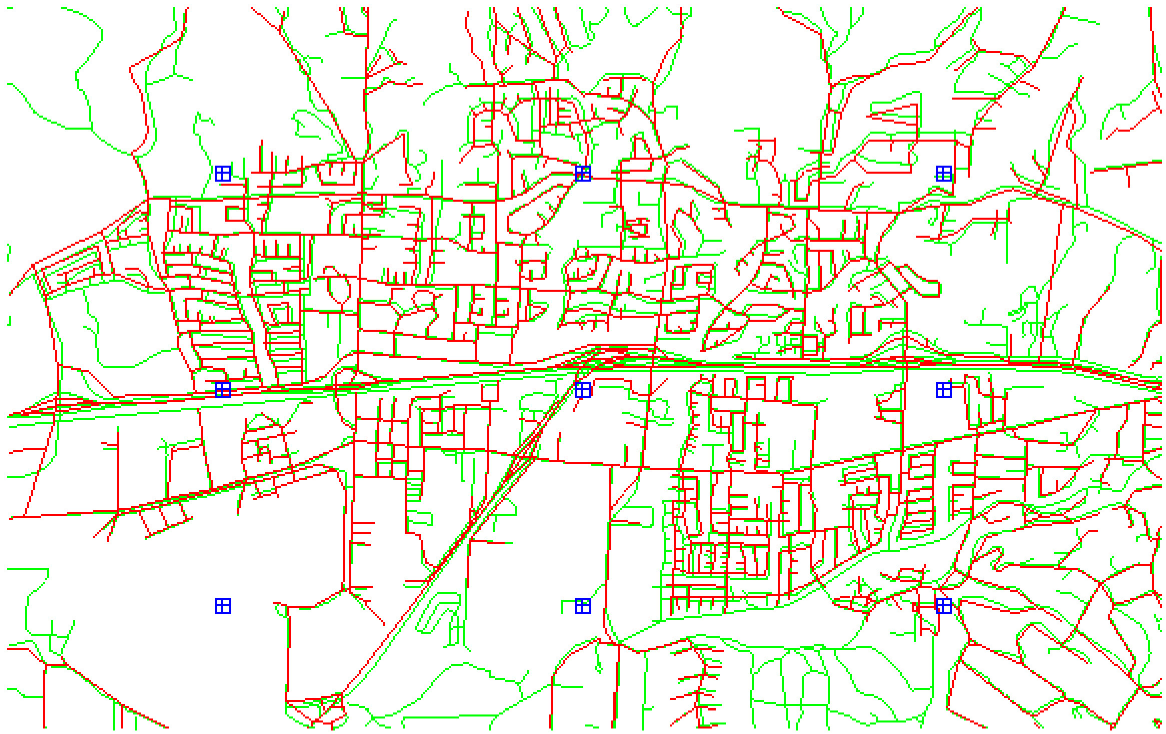


Projection UTM:
Zone 11
Datum NAD83
June 1997

DATABASE A
DATABASE E
REFERENCE TICS



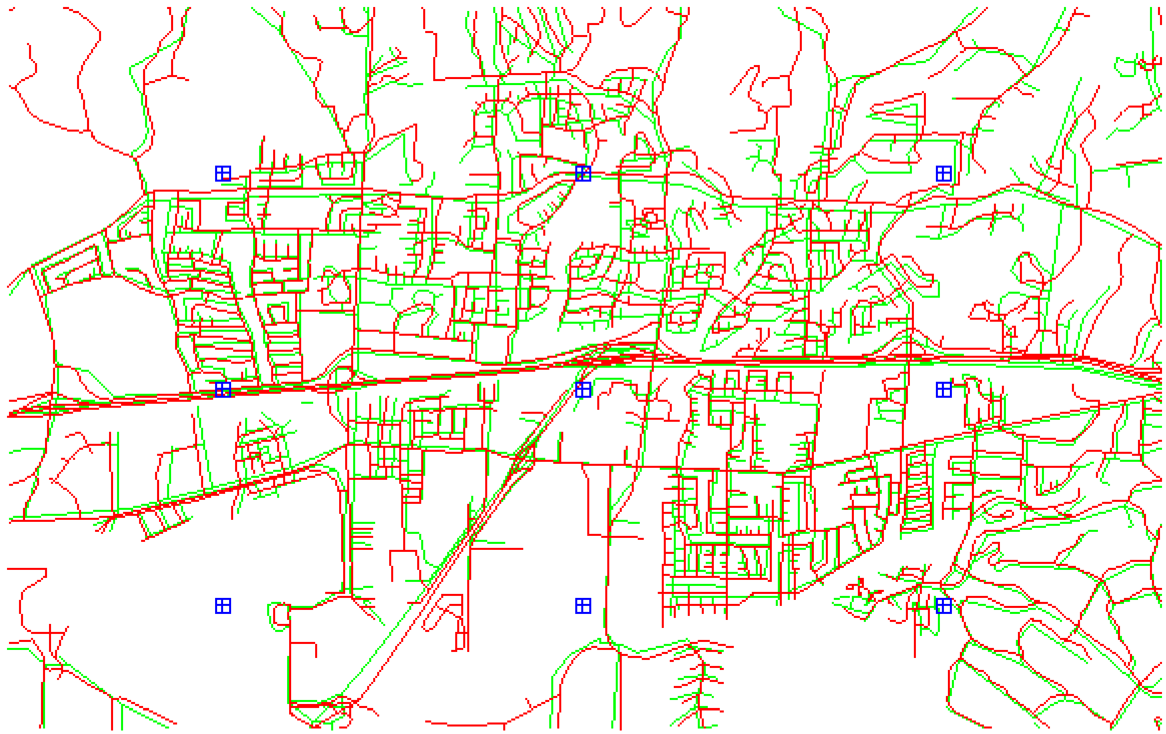
PAIRWISE COMPARISON OF:
DATABASE A AND DATABASE F



Projection UTM:
Zone 11
Datum NAD83
June 1997

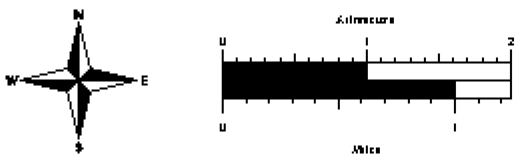
DATABASE A
DATABASE F
REFERENCE TICS

PAIRWISE COMPARISON OF:
DATABASE B AND DATABASE E

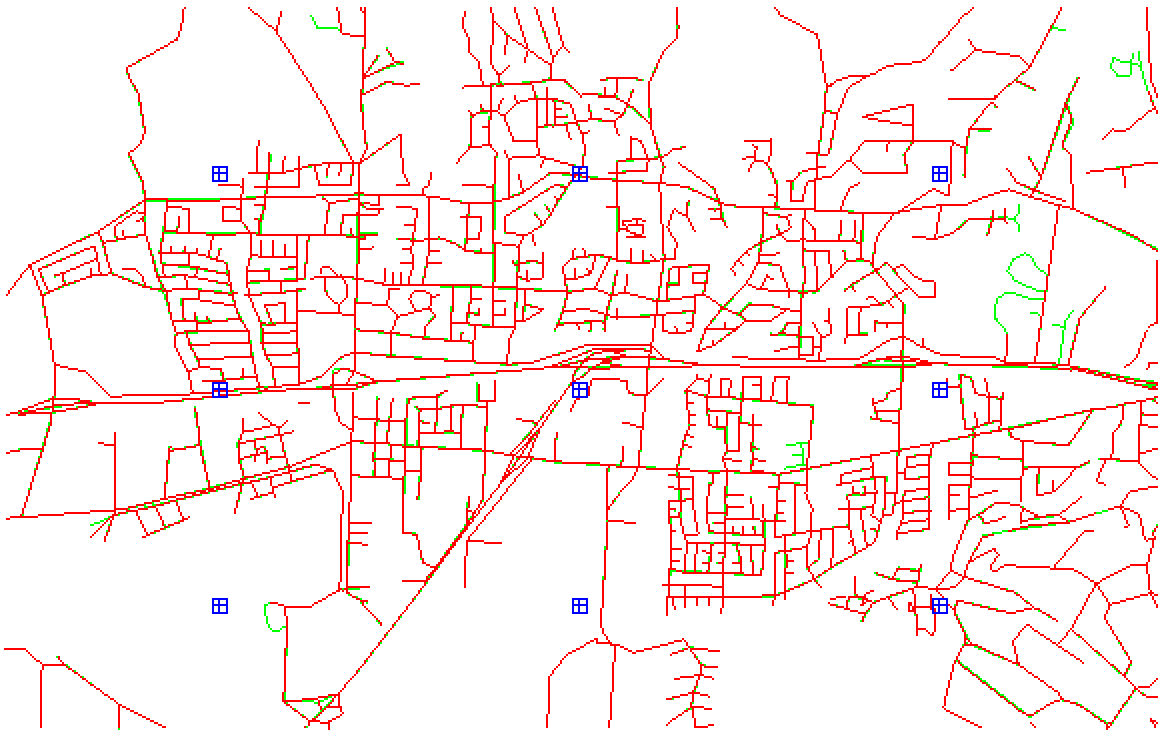


Projection UTM:
Zone 11
Datum NAD83
June 1997

DATABASE B
DATABASE E
REFERENCE TICS

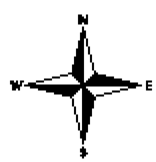


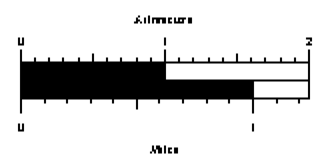
PAIRWISE COMPARISON OF:
DATABASE B AND DATABASE F



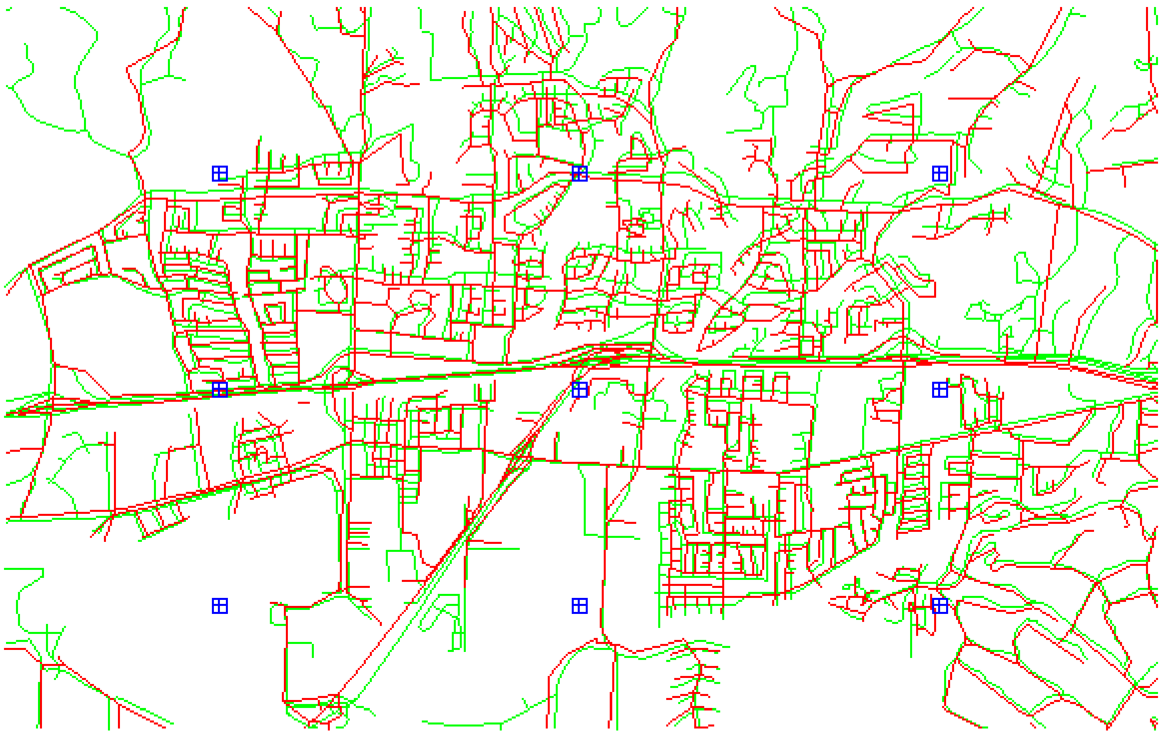
Projection UTM:
Zone 11
Datum NAD83
June 1997

DATABASE B
DATABASE F
REFERENCE TICS





PAIRWISE COMPARISON OF:
DATABASE E AND DATABASE F



Projection UTM:
Zone 11
Datum NAD83
June 1997

DATABASE E
DATABASE F
REFERENCE TICS