EXCHANGING TRANSPORTATION NETWORKS BETWEEN TWO GISs VIA THE SDTS

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ABSTRACT

Performing meaningful network analyses is greatly dependent upon accurate and complete transportation network models, which are digitized into a GIS or, more often, imported from another GIS. Transportation networks can be converted thoroughly between different GISs if they model semantically similar features. Such is the case with Arc/Info Network (by ESRI) and MGE Network (by Intergraph). The graphic features modeled, associated attributes, topology, and metadata can be translated between the two GISs via the Spatial Data Transfer Standard (SDTS). In particular, the draft Transportation Network Profile (TNP) of the SDTS has been used to experiment with this type of conversion. This paper compares the two GISs' transportation network modeling capabilities, briefly discusses the functionality of a software utility (written for a Geography Master's thesis) to convert transportation networks between the two GISs, and assesses the usefulness of the Transportation Network Profile of the SDTS.

INTRODUCTION

Modeling transportation networks is necessary for all but trivial networks before several kinds of spatial analyses can be performed. If highways and city streets are modeled accurately and completely, shortest path analyses can be performed producing ideal paths for shortest, fastest, safest, or least expensive travel. Location / allocation problems can be solved which determine locations for various kinds of centers, e.g., retail outlets, and calculate which geographic groups should be serviced by which centers. Tracing can answer questions of effects from breaks in network connectivity, e.g., how many homes will not receive their mail-ordered merchandise if a certain bridge is out? There are other analyses that can be performed on networks, but the three cited serve to justify the need for modeling networks and to model them accurately and completely. Many times a transportation model is prepared from data acquired from an organization outside the one planning to conduct the analysis. When a model is prepared from external data, it is equally important to be accurate and complete as when creating original data. Therefore there exists the need for dependable spatial data exchange programs.

This paper discusses an experience with translating transportation networks between two GISs, Arc/Info and Modular GIS Environment (MGE) via the Spatial Data Transfer Standard (SDTS). The experience began with a comparison of the two GISs' modeling capabilities and assessments of existing exchange programs (Schmidt, 1997). After a study of the Transportation Network Profile (TNP) of the SDTS, translation programs were written and conclusions were made about the TNP.

COMPARISON OF TRANSPORTATION NETWORK FEATURE TYPES

Arc/Info models transportation networks using arcs for the links of the network (ESRI, ArcDoc, 1995) such that arcs and links become nearly synonymous terms. The original attributes of the arcs apply to the links which include from-node number (fnode#) and to-node number (tnode#). The from-node and to-node numbers are calculated by Arc/Info and form the topology of connectivity in the network. It is this connectivity information that allows Arc/Info to determine shortest paths, make network user allocations, perform tracing functions, and more. To and from impedance values and demand values are added with the attributes associated with arcs to support these analyses. Arc/Info creates the nodes of a network by finding end points and intersections of arcs. An additional database table, called a "node attributes table," is used to hold the attributes for nodes. Points and point attributes are not used in transportation networks.

When arcs are used as links, additional attributes are added to the standard arcs attribute table to serve as the links attribute table. These additional attributes include from/to impedance, to/from impedance, and demand (ESRI, ArcDoc, 1995). Impedance is the generalized term for distance, time, or cost of traversing a link. Demand values represent economic resource requirements of an entire link. Demand values are also stored in node attribute tables to indicate resource requirements of nodes.

Arc/Info networks can include three other pseudo feature types called "centers", "stops", and "turns" (ESRI, ArcDoc, 1995). They are qualified with the pseudo adjective because they are not truely separate feature types with separate coordinates from the ones discussed previously. In each case they are closely associated with existing nodes as additional information. In the case of turns, they are spatial relationships (topology) between pairs of links at nodes. Centers are the identification of nodes that are locations of resource supplies and demands, e.g., product distribution centers and entire cities of product consumers. A separate database table (sometimes called a "centers file") holds attributes of centers and relates to the nodes attribute table using the node identifier. Center attributes include supply, which is the total quantity of a resource, and maximum impedance, which is maximum allowed cumulative impedance along links allocated to that center. Stops are also the identification of nodes, but are the locations to stop during the traverse of the network, e.g., to board passengers or to deliver goods. Attributes pertaining to stops are in a separate stops table (sometimes called a "stops file") that relates to the node attribute table via node identifier. Stop attributes include stop impedance, which is the cost of stopping, and stop transfer, which is the amount of people or goods loaded or unloaded during a stop. Turns are pairs of links that meet at nodes. A turns table (sometimes called a "turntable") is used to hold information about allowed/disallowed turns and costs of turns, where cost is often measured in time. Permissions and costs of turns are recorded in an impedance attribute of the turns table. Again the turns table is related to the nodes table because turns occur at intersections.

Example Arc/Info and MGE transportation network features are illustrated in Figure 1.

MGE can model a transportation network with the addition of the MGE Network software module. Basic point features in MGE are identified to MGE Network as "node" features. Alternatively, node features can be created in MGE Network without an associated, displayable, graphical point in the map. One or more contiguous line strings are identified to MGE Network as "edge" features. Individual line strings within an edge are called "sections" in the MGE Network context (Intergraph, Network, 1995).

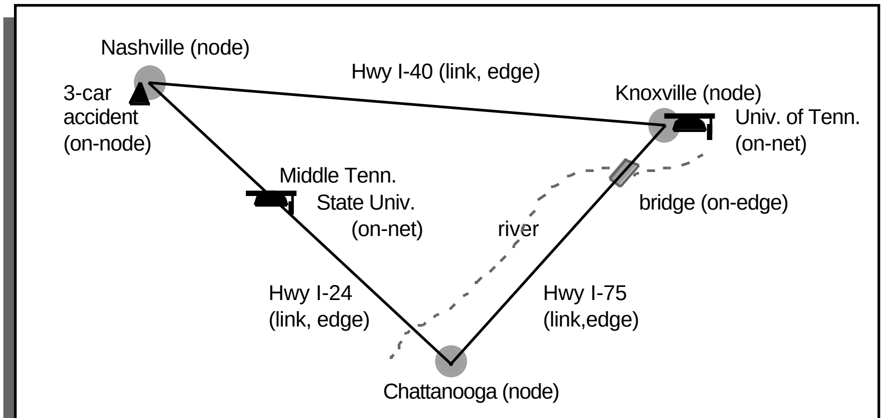

Figure 1 - Example Transportation Network Features

MGE Network supports three other network feature types, on-node, on-edge, and on-net. They are all fundamental point-type features as are node features. Examples of these type features include accident locations, bridges, and service locations, respectively (Intergraph, 1995). The difference among these feature types can be read in their names. On-node features are coincident with a node feature within the transportation network. On-edge features lie somewhere along an edge within the network. On-net features lie anywhere on the network, i.e., coincident with nodes or lie on edges. These features are illustrated in Figure 1. These three feature types collectively are called “components” in the MGE Network environment.

Another constituent of an MGE Network transportation network is the “from/to edge pair.” They are, as their name connotes, pairs of edges. From/to edge pairs are connected at nodes such that movement along the “from” edge may continue on the “to” edge.

Associated with the network features are additional attribute tables distinct from the attribute tables associated with the basic point or line string type features. There are node, edge, on-node, on-edge, and on-net attribute tables. If a map contains no instances of features of a particular feature type, that feature type attribute table does not exist. The attribute table for edges contains from-node and to-node identifiers which form the topology of connectivity in the network. It is this information on connectivity that allows MGE to calculate shortest paths, make network user allocations, and perform tracing functions. Indirectly related to network features are center set, stop set, and intersection (edge pair) database tables. Center set tables identify nodes and links as network centers and hold values of centers’ capacities and maximum service distances, times, and costs. Stop set tables also identify nodes and links as stops on the network. Intersection (edge pair) tables hold information on turn costs and permissions, e.g., time delay to turn left and presence of no-left-turn signs. Other tables are created within MGE Network to add cohesion among all of the attribute tables and will not be discussed here because these other tables are artifacts of database and program design rather than reflecting the actual transportation network characteristics.

Separate from graphic features and their associated attribute tables, other characteristics of a transportation network can be included in an MGE Network network model. Constituents of a network may have “impactors” toward their traversal. Impactors include “one-way indicators” applied to edges, “no-turn indicators” applied to from/to edge pairs, and general purpose “blockages” applied to edges and nodes. Impactors are also costs applied to the traversal of an edge, node, or from/to edge pair; factors used to modify node and edge costs; minimum/maximum restrictions on flow along edges; and demands of an edge.

Arc/Info’s and MGE’s transportation modeling capabilities have some similarities and some differences. Table 1 aligns analogous transportation network feature types of the two GISs.

The Arc/Info section feature type is the closest feature type to the MGE edge feature type. The Arc/Info section differs from the MGE edge by being able to be comprised of a fractional number of arcs. The MGE edge is constructed from a whole number of MGE sections. MGE on-node, on-edge, and on-net feature types have no counterparts in Arc/Info. The three Arc/Info pseudo-feature types are included because they compare to feature types in MGE when combined with center set, stop set, and intersection (edge pair) tables.

Table 1 - Transportation Network Feature Types in Arc/Info and MGE

Arc/Info Feature Type	MGE Feature Type
node	node
link	section
(section)	edge
	on-node
	on-edge
	on-net
centers	on-node & center set table
stops	on-node & stop set table
turns	from/to edge pairs & intersection table

THE SDTS DATA MODEL

The Spatial Data Transfer Standard (SDTS) is a Federal Information Processing Standard (FIPS) created to advance the opportunities for exchange of spatial data (geographic and cartographic data) by encouraging the use of a single transfer format by all agencies, institutions, and companies who use many different GISs (Wortman, 1992). Exchanges of data occur both when data providers distribute data sets and when agencies share data among themselves. In an attempt to be thorough in the development of the SDTS, it became more than just a data transfer format (ESRI, SDTS, 1995). It includes structures, definitions, and a methodology to allow the preservation of all aspects of a single spatial data set as well as being capable of handling a variety of spatial data types while providing machine and media independence. This means SDTS can handle both vector and raster data types, primary attributes and other indirectly related database tables (secondary attributes), topology, quality reports, and other metadata, but not all concurrently. While the standard is written to define all aspects of each of these spatial and aspatial data types, profiles guide the use of the SDTS for a single class of spatial data (USDOT, 1996). Currently a Topological Vector Profile (TVP) is the only approved profile. It serves as a FIPS for the sharing of vector data with topology and attributes. A Raster Profile (RP) and a Transportation Network Profile (TNP) are awaiting approval. The TNP is the profile used in the exploration of spatial data exchange in this study.

Before trying to understand the TNP, one must look at the whole SDTS. It defines numerous spatial objects from zero dimensioned points to three dimensioned voxel spaces (USGS, Part 1, 1995). Many of these spatial object types are listed in Table 2. In addition, the SDTS defines how coordinate and attribute data are to be stored in SDTS files and allocates particular data types to particular modules. SDTS uses the term “module” in place of “file” because the media independence goal allows for the possibility of a file being transferred in pieces, which on any computer would also be called files. Most often modules are equivalent to files. A list of most of the modules (files) is provided in Table 3 along with brief descriptions of each and grouped into categories. A complete list of all 37 SDTS module types and full descriptions of them are given in the SDTS Part 1, Logical Specifications (USGS, Part 1, 1995).

Table 2 - Aggregate Feature Types in Arc/Info, MGE, and SDTS

Arc/Info Coverage Type	MGE Map Type	SDTS Composite Object Type
point	point	entity point
arc	line	line segment
arc, link	section "	string "
(section [1])	edge [2]	chain
(arc)	(edge)	link
polygon "	area boundary "	G-polygon, GT-polygon
polygon label point	area centroid	area point
(polygon) "	(area boundary) "	G-ring, GT-ring
		interior area
annotation	label	label point
link/node	node [2]	node
	undefined	
		arc

[1] Arc/Info sections are topological features created using dynamic segmentation while all other features in this table are static, graphical features.
[2] Node and Edge features can be modeled fully with the addition of the MGE Network module.

Each module is defined to contain certain records, fields, and subfields. This is the major portion of Part 1 of the SDTS and, due to its size, will not be repeated here. A look at Part 1 of the SDTS will reveal great detail in defining each subfield in words and tables including qualifiers of optionality and when mandatory.

The next to last column, TNP, in Table 3 indicates with a “Y”, for yes, which modules are to be included in a TNP transfer (USDOT, 1996). These indicators should not imply that omitting a module will cause the transfer to fail but rather indicates a full set that completely preserves all content and characteristics of the original spatial data set. For example, an exchange of data can occur although the STAT module is not present.

Table 3 - SDTS Modules

GLOBAL MODULES

Module*	Module Name	Description	TNP	New
-- Identification Module --				
IDEN	Identification	Identifies this as an SDTS file set	Y	Y
-- Catalog Modules --				
CATD	Catalog / Directory	File names of all modules	Y	Y
CATX	Catalog / Cross Reference	Associates modules, e.g., which attribute module relates to which vector graphic module	Y	Y
CATS	Catalog / Spatial Domain	Relates modules to spatial domain, map, theme, or aggregate object	Y	
-- Spatial Reference Modules --				
IREf	Internal Reference	Internal coordinate scale and offset	Y	Y
XREF	External Reference	External coordinate system	Y	Y
RGIS	Registration	Registration points		
SPDm	Spatial Domain	Extent of coordinate data	Y	
-- Data Dictionary Modules --				
DDDf	Data Dictionary / Def'n	Definitions of entities and entity attributes	Y	
DDOm	Data Dictionary / Domain	Attribute value domains and definitions	Y	
DDSh	Data Dictionary / Schema	Defines attribute data types	Y	Y
-- Security Module --				
SCUr	Security	Security classifications at various levels of aggregation	Y	
-- Statistics Module --				
STAT	Transfer Statistics	Total module record counts and total spatial address counts	Y	

DATA QUALITY MODULES

Module	Module Name	Description	TNP	New
DQHl	Lineage	Lineage of data set	Y	
DQPa	Positional Accuracy	Testing procedures & related details	Y	
DQAa	Attribute Accuracy	Statements of attribute accuracy	Y	
DQLc	Logical Consistency	Statements of logical consistency	Y	
DQCg	Completeness	Statements of completeness	Y	

ATTRIBUTE MODULES

Module	Module Name	Description	TNP	New
Axxx e.g., AP00	Attribute, Primary	Feature Attributes	Y	Y
Bxxx e.g., BP00	Attribute, Secondary	Other Attributes	Y	

(continued)

Table 3 - SDTS Modules (Continued)

SPATIAL OBJECT MODULES

Module	Module Name	Description	TNP	New
-- Composite Module --				
FFxx	Vector, Composite	Aggregation of other spatial objects	Y	
-- Vector Modules --				
NAxx	Vector, Point-Node	Area Point features	Y	Y
NExx	Vector, Point-Node	Entity Point features	Y	Y
NOxx	Vector, Point-Node	Node (planar) features	Y	
NNxx	Vector, Point-Node	Node (non-planar) features	Y	Y
LSxx	Vector, Line	Line String features		Y
LQxx	Vector, Line	Link features	Y	
LExx	Vector, Line	Complete chain features	Y	
LWxx	Vector, Line	Network chain (planar) features	Y	
LYxx e.g., LY00	Vector, Line	Network chain (non-planar) features	Y	Y
PGxx	Vector, Polygon	G-polygon features		
PCxx or PRxx	Vector, Polygon	GT-polygon features	Y	
RSxx, RAxx, or RMxx	Vector, Ring	G-ring features		
RUxx	Vector, Ring	GT-ring features		
ACxx, AExx, AUxx, or ABxx	Vector, Arc	Arc features		
-- Raster Modules --				
G2xx	Raster, Cell	Raster 2D image		
G2Lx	Raster, Cell	Raster 2D image, labeled		
-- Voxel Modules --				
G3xx	Voxel, Cell	Voxel 3D image		
G3Lx	Voxel, Cell	Voxel 3D image, labeled		

GRAPHIC REPRESENTATION MODULES

Module	Module Name	Description	TNP	New
TEXt	Text Representation	Parameters for text placement		
LNRp	Line Representation	Line styles and widths		
SYRp	Symbol Representation	Symbol types and sizes		
AFIl	Area Fill Representation	Fill styles		
CLRx	Color Index	Definitions of colors in RGB		
FONt	Font Index	Font names and indices		

* lowercase letters are replaced by either uppercase letters or digits

Another use of the profile is to identify which spatial object types are to be exchanged in an SDTS file set. Table 4 shows which are required, which are optional, and which are not allowed by the TNP (USDOT, 1996). The rightmost column, New, identifies which spatial object types are transferable by the new data exchange program. These spatial objects are network nodes and links plus two more point-type features and one more linear feature.

Referring to Table 3 again, the last column, New, indicates with a "Y" which modules are used by the new data exchange programs written for this study. Some non-TNP modules are created for pedagogic purposes and other TNP modules are not created. Therefore the new data exchange program does not create a transfer that complies fully with the definition of the TNP. To do so would be an effort in preparing production-worthy software. To experiment with a core sample of the module types was the intent here and furthermore to carry the subset of data through a full cycle from Arc/Info to MGE and back.

The SDTS data model is implemented as a set of computer files created in the FIPS PUB 123 (ISO 8211) data descriptive format (ANSI, 1994). Each file contains one type of information. For example, one file contains the locational data while a separate file contains the definition of the coordinate system for the locational data. All file names begin with the same four characters thus effecting a distinct group of files. The module type adds an additional four characters to the file name and an extension is added resulting in a set of files named in the format of PPPPMMMM.DDF, where "PPPP" is the prefix, "MMMM" is the module identification, and "DDF" stands for data descriptive file. Groups of modules provide catalog and statistical information, identification and coordinate system information, data quality information, and data dictionary information (ESRI, SDTS, 1995).

THE NEW TRANSLATION PROGRAMS

Four translation programs were written, collectively called ARCXMGE, two to convert to and from Arc/Info formatted GIS databases and two to convert to and from MGE formatted GIS databases, all of which convert to or from the SDTS format. Figure 2 shows the four programs in relation to the Arc/Info, MGE, and SDTS formatted files.

The ARC2SDTS and SDTS2ARC programs are written in the AML (Arc Macro Language). AML is the required language for creating programs that run in the Arc/Info Unix environment. In addition, C and C++ programs are called from the AML programs. SDTS2MGE and MGE2SDTS are written in the MDL (Microstation Development Language). MDL is the "C-like" language for creating programs that run in the MicroStation environment, the CAD upon which MGE is built. All four programs prompt the operator to specify a GIS data set, a feature type, and an SDTS file set and then proceed to translate the data without further operator interaction.

A GIS data conversion program must address numerous and varied details. Converting GIS data involves much more than reading one file of a given format and writing another file of a different format. It involves accessing multiple files to read/write the graphic data, the coordinate system and related projection, the attribute data definitions and the attribute data values. Each of the four new conversion programs read or write eight SDTS modules (files).

Table 4 - SDTS Object Types Transferable Via TNP

Code	Object Type Name	TNP Required	TNP Optional	TNP Not Allowed	New
FF	Composite		X		
NA	Area Point		X		Y
NE	Entity Point		X		Y
NO	Node, planar	X or			
NN	Node, non-planar	X			Y
LS	Line String			X	Y
LE	Complete Chain		X		
LQ	Link	X or			
LW	Network Chain, planar	X or			
LY	Network " non-planar	X			Y
PG	G-polygon			X	
PC	GT-polygon (chains)		X		
PR	GT-polygon (rings)			X	
RS	G-ring (strings)			X	
RA	G-ring (arcs)			X	
RM	G-ring (mixed)			X	
RU	GT-ring			X	
AC	Arc (circular)			X	
AE	Arc (elliptical)			X	
AU	Arc (uniform)			X	
AB	Arc (bezier)			X	
G2	Raster			X	
G2L	Raster, labeled			X	
G3	Voxel			X	
G3L	Voxel, labeled			X	

Source: United States Department of Transportation (DOT), Bureau of Transportation Statistics, Spatial Data Transfer Standard Transportation Network Profile, John A. Volpe National Transportation Systems Center, Cambridge, Massachusetts 1996.

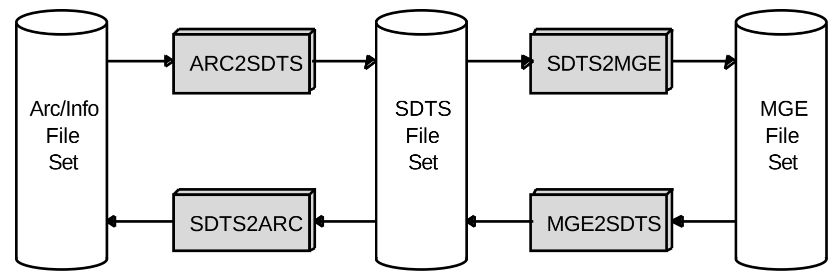

Figure 2 - The Four New Conversion Programs

THE INTERIM DATA EXCHANGE FILES

A subset of the SDTS module types are used to experiment with the transfer of locational, attribute, and metadata between Arc/Info and MGE. The names of the 12 modules employed along with the names of the fields/subfields read and written within the modules are listed in Table 5. The LS00, LY00, NA00, NE00, and NN00 modules are modules whose use depends on whether links, lines, area points, entity points, or nodes are being transferred. The other seven modules are always transferred by the new data exchange system totaling eight modules used in each transfer.

To illustrate these modules, fields, and subfields, Figure 3 shows the contents of eight SDTS modules if two hypothetical roads were written by ARCXMGE to an SDTS file set with a file prefix of "FG34" (Schmidt, 1997).

FEATURES EXCHANGED

The new data exchange system translates a proper subset of all feature types, only point (entity point, area point, node) and linear (string, chain) features. These feature types are listed again in Table 6, omitting most of the feature types not translated. Arrows indicate translations. Arc/Info nodes are translated indirectly to/from SDTS nodes via an interim conversion to the Arc/Info point-type feature. This is because nodes are not available for "ungenerating" using the Arc/Info UnGenerate function. SDTS nodes are translated to MGE points and MGE nodes are translated to SDTS points because points serve as nodes in MGE. (Point features in MGE can be made into node features using setup functions of the MGE Network program.) Otherwise, features are translated directly to the corresponding feature type in the other GIS. The exchange of area points is handled by ARCXMGE although this point-type is only meaningful within the context of polygons. The exchange of polygon features is not performed by the new data exchange system. MGE edge type features are not exchanged since Arc/Info has no corresponding feature type that exactly matches.

Table 5 - Fields/Subfields Per Module Used by ARCXMGE

	Field Mnemonic	Subfield Mnemonic	Description
CATD Module:	CATD	NAME	Module Name
	CATD	FILE	Name of File containing Module
CATX Module:	CATX	NAM1	Module Name
	CATX	NAM2	Related Module Name
DDSH Module:	DDSH	NAME	Name of Attribute Module
	DDSH	TYPE	Module Type
	DDSH	ATLB	Attribute Label or Name
	DDSH	FMT	Format of attribute data
	DDSH	PREC	Precision of numeric data
	DDSH	MXLN	Max. Length of character data
IDEN Module:	IDEN	PRID	SDTS Profile Identification
IREF Module:	IREF	SFAX	Scaling Factor along X axis
	IREF	SFAY	Scaling Factor along Y axis
	IREF	XORG	X coordinate of Origin
	IREF	YORG	Y coordinate of Origin
XREF Module:	XREF	RSNM	Reference System Name
	XREF	HDAT	Horizontal Datum
	XREF	ZONE	UTM, UPS, or SPCS Zone
	XREF	PROJ	Projection
	ATID	MODN	Projection parameter Module Name
	ATID	RCID	Projection parameter Identification
AP00 Module:	ATPR	RCID	Record Identifier
	ATTP	*	Attribute value (“*” is the attribute label)
LS00 and LY00 Modules:	LINE	OBRP	Object Representation
	ATID	RCID	Record Identifier of associated attributes
	SADR	X	X coordinate of vertex (repeats)
	SADR	Y	Y coordinate of vertex (repeats)
NA00, NE00, NN00 Modules:	PNTS	OBRP	Object Representation
	ATID	RCID	Record Identifier of associated attributes
	SADR	X	X coordinate of point
	SADR	Y	Y coordinate of point

CATD Module (FG34CATD.DDF):

NAME	FILE
LS00	FG34LS00.DDF
AP00	FG34AP00.DDF

CATX Module (FG34CATX.DDF):

NAM1	NAM2
LS00	AP00

DDSH Module (FG34DDSH.DDF):

NAME	TYPE	ATLB	FMT	PREC	MXLN
AP00	ATPR	composition	A		8

IDEN Module (FG34IDEN.DDF):

PRID
SDTS Transportation Network Profile

IREF Module (FG34IREF.DDF):

SFAX	SFAY	XORG	YORG
0.000001	0.000001	0.0	0.0

XREF Module (FG34XREF.DDF):

RSNM	HDAT	ZONE	PROJ	MODN	RCID
SPCS	NAX	4100			

AP00 Module (FG34AP00.DDF):

RCID	COMPOSITION
1	concrete
2	asphalt

LS00 Module (FG34LS00.DDF):

OBRP	RCID	X	Y	X	Y	X	Y	X	Y	X	Y
LS	1	1	5	6	7						
LS	2	1	2	3	1	5	1	7	3	9	4

Figure 3 - An Example Set of SDTS Modules

Table 6 - Features Translated by ARCXMGE

Arc/Info Feature Type	SDTS Object Type	MGE Feature Type
node	node	node
point	entity point	point
polygon label point	area point	area centroid
arc	string	line
link	chain	section
(section)		edge
polygon	G-polygon	area boundary

CAPABILITIES OF THE NEW DATA EXCHANGE SYSTEM

The new data exchange system transforms locational data, attribute data, attribute definitions, and coordinate system data. Point-type features (nodes, entity points, area points) are translated to points and line-type features (strings, chains) are translated to lines. Attributes are translated between GISs. The coordinate system information is taken from one GIS and used to define the coordinate system of the other. Topology is not transferred by the new system, but is built inside the target GIS instead. All of these classes of data are transferred via a single SDTS file set.

Importation of points and line strings into Arc/Info creates Arc/Info points and arcs, Arc/Info's name for line strings. Importation of points into MGE does not create points but instead creates degenerate lines, lines whose start and end vertices are identical. Degenerate lines are used because MGE is built upon a CAD which has no point graphic element type. Also note that, while importation of line strings into MGE yields line strings, they are limited to 101 vertices each (Bentley, 1995). Line strings longer than 101 vertices are broken into separate line strings of 101 vertices or less by SDTS2MGE with each separate line string linked to the same set of attributes. Arc/Info has a similar limit on the size of arcs. Arcs may contain no greater than 500 vertices (ESRI, Concepts, 1992). SDTS2ARC does not check for the 500 vertex limitation.

The splitting of line strings into 100-line segments creates a new issue during the maintenance of the MGE map. Calling the collection of 100-line segments fraternal twins (or triplets, etc.), if one of the fraternal twins is deemed unnecessary for whatever reason and then deleted, are the associated attributes to be deleted also? As long as fraternal twins remain, so should the attributes. Only when all fraternal twins associated with the attributes are deleted should the attributes be deleted too. If attributes are allowed to remain after all fraternal twins are deleted, computer disk space is wasted and the integrity of the database could easily be questioned. An alternative to the creation of separate 100-line segments would be to create a MicroStation complex chain and make a single link to the attributes. A complex chain is the encapsulation of the series of 100-segment linestrings into a single graphic element (Bentley, 1995). Complex chains are not created by SDTS2MGE. The 100-line segments are created instead.

The new data exchange system translates only point and line-type features fully enumerated in Table 6. (Other feature types could be added to ARCXMGE with additional programming.) Of these various feature types, only one feature type is transferred in a single exchange while an SDTS formatted set of files is capable of hosting multiple feature types. The eight SDTS files created by ARCXMGE contain coordinates, attributes, and metadata for a single feature type. Again since this study is an exploration or experiment with SDTS, full SDTS capability is not a goal.

Feature attributes are imported and exported by ARCXMGE. Attributes in tables not directly associated with features are not transformed, although the SDTS provides a module for these secondary attributes. SDTS2ARC and SDTS2MGE add attributes directly to the attribute tables associated with features and not to a separate table that would require the operator to associate them afterwards with features. This works well when only primary attributes are involved, which is the case with ARCXMGE. If secondary attributes exist and are to be imported by an import program, use of separate tables would abide by the normal forms of relational databases better (Healey, 1991).

KNOWLEDGE GAINED AND CONCLUSIONS MADE

Developing working knowledge of the SDTS was definitely the most difficult part of this endeavor. With only the printed standard itself and a few additional articles and without technical support, it was not a subject to learn quickly. It was only after developing my first small segment of code to read an SDTS file that I became confident enough to proceed with SDTS as the interim file. The FIPS PUB 123 Function Library provided the file access functions and examples to begin working with SDTS files.

The translation of the attribute data types emerged as the most tedious task in the development of ARCXMGE. There are often multiple names for the same data type, for example Arc/Info's B, SDTS's I, RIS's Integer, and MDL's DB_INTEGER (Schmidt, 1997). Since ARCXMGE is composed of four translators, translation of various sized integers, real numbers, and characters were addressed in length.

Arc/Info and MGE appear to model transportation networks adequately but not identically. Both GISs model nodes and links, but MGE has the three additional feature types called on-node, on-edge, and on-net. Both GISs can hold and use information about centers, stops, and turns. Arc/Info has the ability to model routes which are built from sections, both of which are a super-feature type. Through the use of a linear referencing system in addition to a Cartesian coordinate system, routes and sections of routes may start and end more dynamically than the statically stored link features. This is part of a capability called "dynamic segmentation" that was not examined in this thesis, except for the Arc/Info section feature type. The MGE installation used in this study did not have the additional dynamic segmentation module sold by Intergraph, but I assume it has similar capabilities.

Both Arc/Info and MGE perform shortest path, allocation, and tracing analyses, but Arc/Info performs location in addition to allocation analyses, i.e., the location / allocation problem. Arc/Info is able also to perform touring (the traveling salesman problem), covering, and spatial interaction analyses. My conclusions are that Arc/Info is better equipped for quickly preparing flexible network models and analyzing these models (from a count of analysis types), while MGE is better equipped at accurate and consistent representation of transportation networks since it uses a CAD program for graphic feature digitization.

The use of the SDTS for the interim format in exchanging data between Arc/Info and MGE is more difficult than using simple ASCII files such as those created by Arc/Info's UnGenerate and UnLoad commands, but the SDTS is much more capable than elementary ASCII files. The SDTS Transportation Network Profile is defined to contain topology, data quality statements, and secondary attributes and is intended for the exchange of GIS data among all GISs. Also much was learned by using a non-vendor defined transfer standard, for example generalized feature type definitions and various tabular data type definitions as well as the SDTS itself. The use of the SDTS in this thesis provided a solid introduction to the standard.

Only two weaknesses were seen in the SDTS. First, the SDTS has no date and/or time attribute type. To transfer dates and/or times, complete definitions of these attribute types must be placed in the Data Dictionary modules. This did not create difficulty in the new data exchange system because the new system does not attempt to transfer date/time attribute types unless they are stored as character type attributes, in which case they are treated unknowingly like character attributes. Second, a deficiency in the Transportation Network Profile (TNP) application of the SDTS is the lack of explicitly stated requirements for the inclusion of centers, stops, and turns information. While these tables can and should be transferred as secondary tables in an SDTS file set, the TNP does not require them to be.

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VITA

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