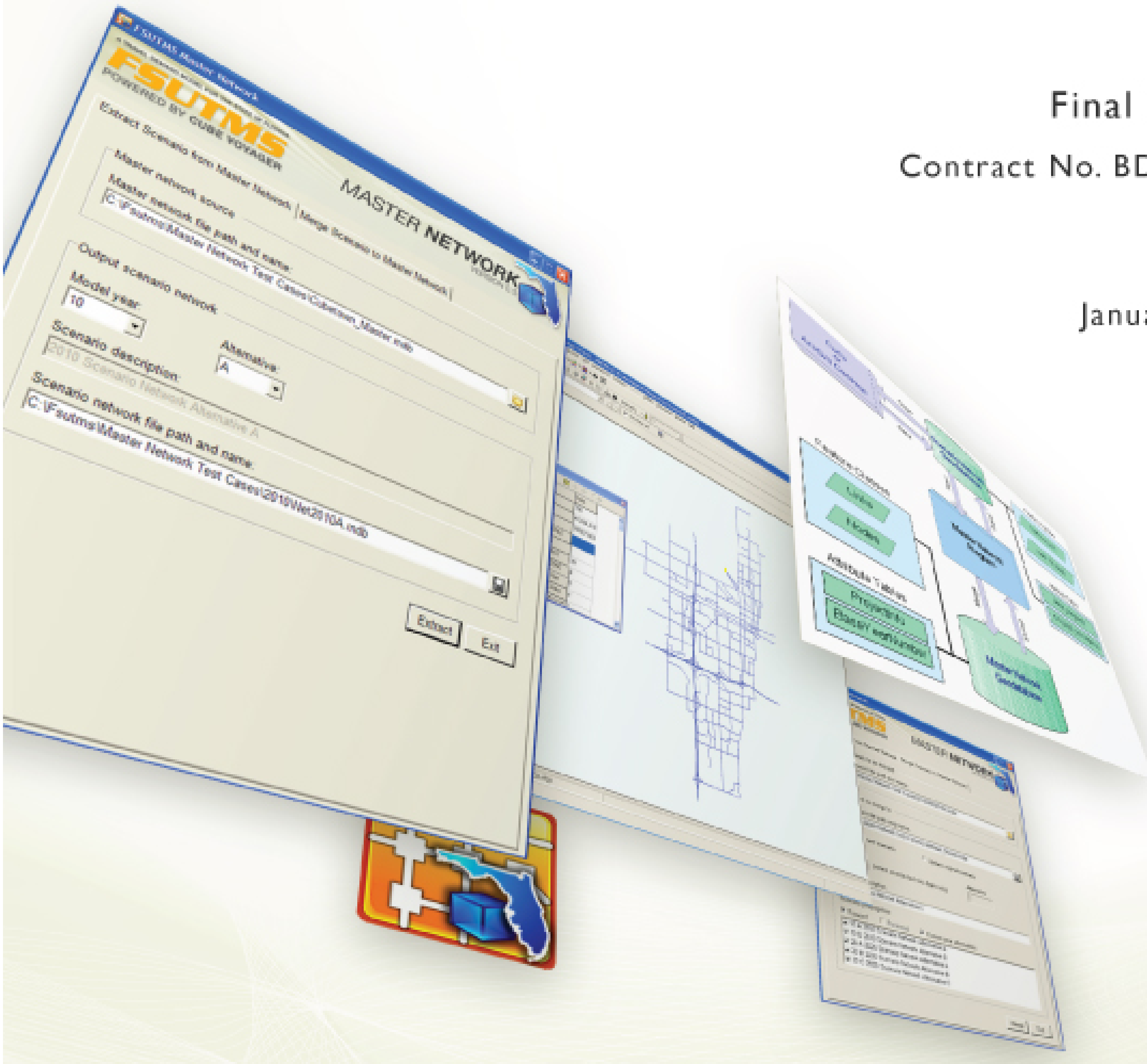
Development of a Prototype Master Network System for FSUTMS



Final Report

Contract No. BD-015-21

January 2009

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Systems Planning Office
Florida Department of Transportation

Prepared by:

Lehman Center for Transportation Research
Florida International University

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Development of a Prototype Master Network System for FSUTMS

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Mr. Vidya Mysore of FDOT Systems Planning Office serves as the project manager for this project.

16. Abstract

Maintaining modeling networks in travel demand modeling has been a time-consuming and problematic process. In a typical demand modeling application, multiple versions of a network are usually created to represent the different network conditions associated with different model years and alternatives. Traditionally, these networks are modified individually and stored in separate network files. The process is cumbersome and is prone to network coding errors that result in network inconsistencies. This has led to an increased interest in the modeling community to use the “master network” approach of building and maintaining modeling networks. Unlike a traditional network, a master network combines the base-year and all future-year networks in a single, integrated, and consistent spatiotemporal database. To work on a particular network, the user would simply indicate the timeline of a specific network to extract from a master network. After an extracted network is modified, it can be merged back into the master network. During the merging process, changes to the network can be automatically applied to other networks in the master network. This does not only save time from repetitive manual network editing, but also avoid potential inconsistencies among the different scenario networks. This research report describes a standalone master network system that was developed to work with Cube Voyager—the modeling engine of the Florida Standard Urban Transportation Model Structure (FSUTMS). Stored in ESRI’s Personal Geodatabase format, the master network database structure was designed to minimize data storage space, extract efficient networks with consolidated links, support open and unlimited data attributes, and implement both forward and backward network propagations. While the current structure was designed for only highway networks, it can be extended to transit and TAZ networks. The system has been successfully tested with both small and large networks and is ready for deployment to various FSUTMS models.

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CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Network maintenance is a time-consuming and often problematic task in travel demand modeling. The four-step demand model on which the Florida Standard Urban Transportation Model Structure (FSUTMS) is based requires the use of highway, traffic analysis zone (TAZ), and transit (if applicable) networks. In a typical demand analysis, multiple versions of a network are usually created to represent specific network conditions associated with individual model years and/or design alternatives. Traditionally, these networks are modified individually from their respective base-year networks and stored in separate network files. Maintenance of these networks is not only tedious, but is also prone to network coding errors, which result in network inconsistencies. For example, a simple link split in a network will require that the same action be performed individually for all the other networks that are affected by the split. This manual and repetitive process is both cumbersome and is prone to coding errors.

The difficulties of the traditional approach in maintaining modeling networks have led to increased interest in the modeling community to use the so-called “master network”. Unlike a traditional network, a master network combines the base-year and all future-year networks in a single, integrated, and most importantly, consistent spatiotemporal database. With such a network design, the user can extract a future network from its master network by simply indicating the timeline of the network. After an extracted network is modified, it can be merged back into the master network. During the merging process, changes to the network can be automatically applied and propagated to other networks in the master network.

In Florida, only the Northeast Regional Planning Model (NERPM) has used a master network. The NERPM master network stores all networks in a single file and allows the users to perform both spatial and attribute editing on all networks in one place within Cube. However, the benefit from using the NERPM master network has reportedly been offset by a significant increase in the model’s run time.

1.2. Project Objective

The objective of this project is to build on the NERPM experience to develop a prototype master network structure for highway networks that works with Cube Voyager and is able to support efficient data storage, data update, and network extraction. The transition of Cube Voyager from its VIPER-based network editing tool to ESRI’s GIS editing environment provides an excellent opportunity for various FSUTMS models to transition to a Geodatabase-based master network system.

1.3. Report Organization

The rest of this report is organized as follows. Chapter 2 provides a review of two existing master networks, one for the Northeast Regional Planning Model (NERPM) and a second for the Baltimore Metropolitan Council (BMC). Chapter 3 describes the FSUTMS master network system framework, the system installation, and system requirements. Chapter 4 describes the functionalities of the master network program developed in this project and introduces the user interface designed to implement these functionalities. Chapter 5 presents the design and inner workings of the master network database designed and developed in this project. The many advantages of the design are also described in this chapter. Finally, chapter 6 summarizes key findings of the project and provides several recommendations for further developments of the system.

CHAPTER 2
REVIEW OF EXISTING MASTER NETWORKS

A search was conducted at the beginning of this project to identify agencies that have developed, or were developing, a master network for their planning models. In addition to the known master network development for the Northeast Florida Regional Planning Model (NERPM), the search identified the following agencies where have developed a master network, or were in the process of developing one:

1. Metropolitan Washington Council of Governments (MWCOG)
2. Baltimore Metropolitan Council (BMC)
3. North Central Texas Council of Governments (NCTCOG)
4. San Francisco Bay Area Metropolitan Transportation Commission (MTC)
5. Southern California Association of Governments (SCAG)

Requests were made to these agencies for information on their master networks. Detailed information was only received from the Baltimore Metropolitan Council (BMC) for its Baltimore Region Travel Demand Model. This chapter reviews the NERPM and BMC master networks.

2.1. NERPM Master Network

2.1.1. Background

The Northeast Florida Regional Planning Model (NERPM) covers a four-county area consisting of Clay, Duval, Nassau, and St. Johns County, representing the First Coast metropolitan planning area. NERPM was originally developed for TRANPLAN by the Florida Department of Transportation (FDOT) District 2 Planning Office for a base year of 1998 and future year of 2025 (Cambridge Systematics, Inc., 2006). The NERPM 2000 Model Validation Study was subsequently initiated in the Fall of 2002 to evaluate the current NERPM structure, compile base year 2000 data, update the NERPM trip generation model, review data assumptions, validate a new base year 2000 model, conduct training on applications of the model, and implement unspecified model enhancements (Cambridge Systematics, Inc., 2006).

In 2004, the Florida Model Task Force (MTF) reached a decision to migrate from the TRANPLAN software platform to Cube Voyager. Upon adoption of the 2030 LRTP, the software developer, Citilabs, began converting the TRANPLAN version of NERPM to the Cube Voyager platform. The TRANPLAN version of NERPM made use of GIS-TP software for network editing and storage. GIS-TP used GIS databases for network development, maintaining alternative networks in a single database. In converting NERPM to Cube Voyager, a master network database was developed to maintain the storage capabilities of GIS-TP (Cambridge Systematics, Inc., 2006). Currently, the NERPM highway master network contains all of the links for each of the base year 2005, 2010, 2015, 2025, and 2030 networks and editing of the master network is done within Cube. Figure 2-1 shows the scenario manager screen for the NERPM master network. It allows the user to specify the master network file and the model year and alternative of a specific scenario to use. Figure 2-2 shows all of the master network links as displayed in Cube 5.0.

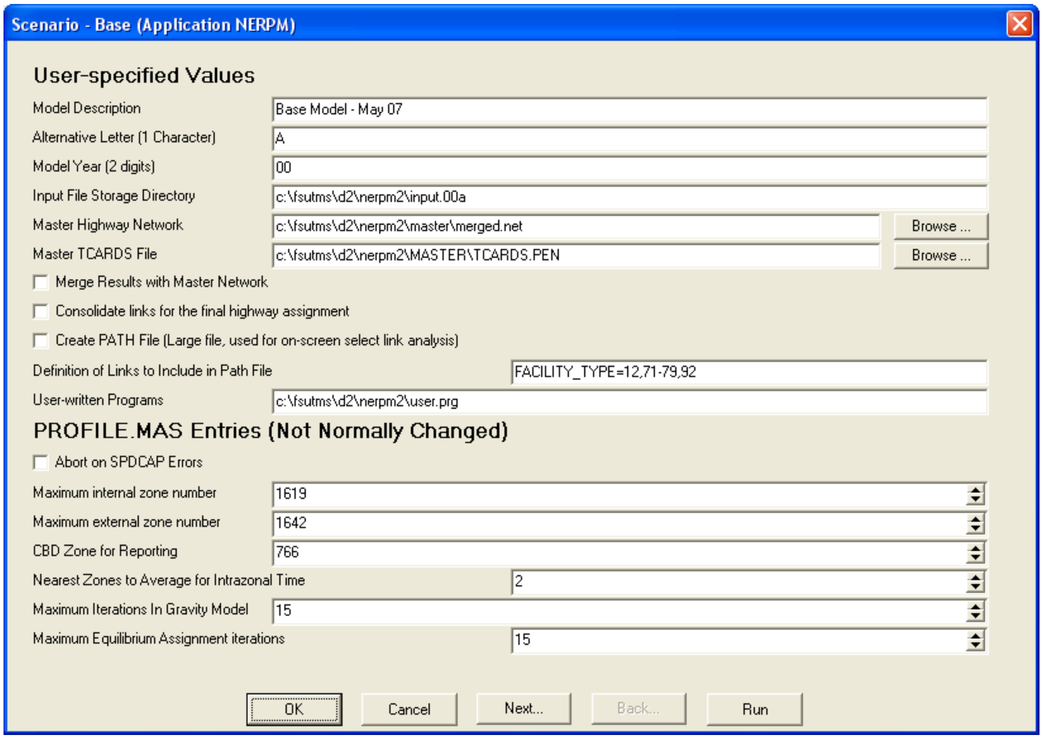

Figure 1-1. Scenario Manager Screen for NERPM Master Network.

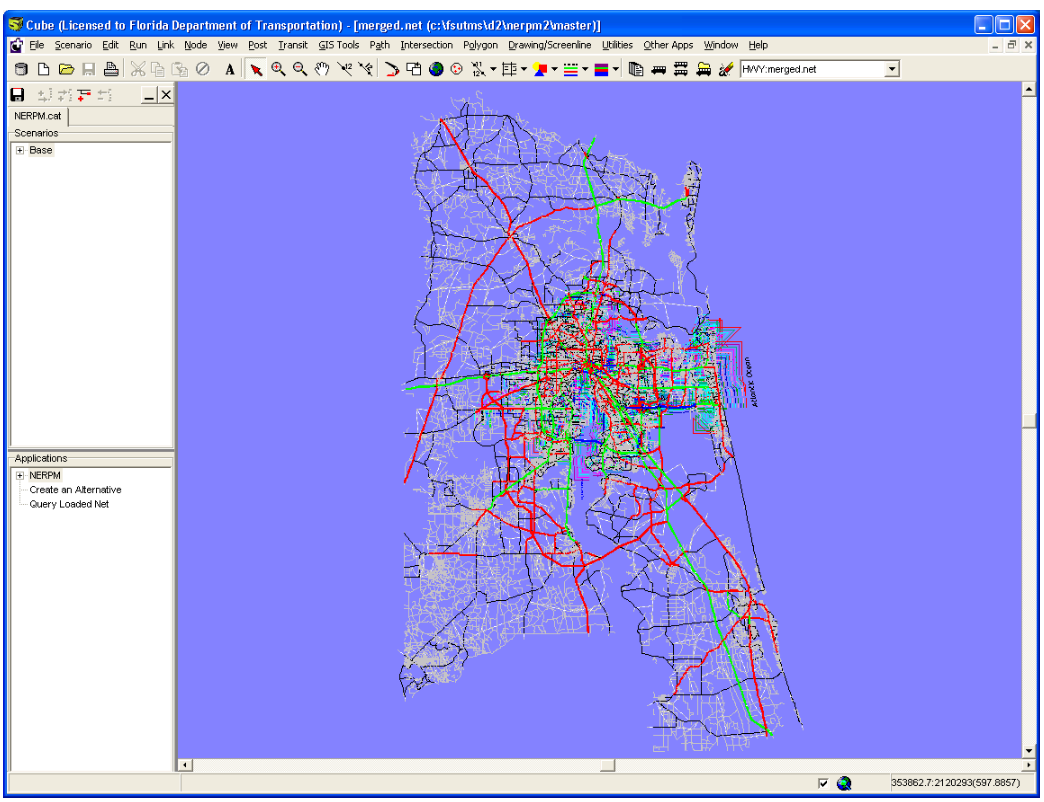

Figure 2-2. NERPM Master Network Displayed in Cube 5.0.

2.1.2. Network Attributes

The attributes in NERPM master network not only store the link information, but also distinguish each scenario network with others. These attributes are classified as either scenario-specific or universal. Scenario-specific attributes are specific to each scenario network in the master network. These attributes are identified by the presence of catalog keys designating the scenario model year and alternative letter. For example, the attribute for facility type FTYPE_{year}{alt} for the base year scenario network is named FTYPE_00A, whereas FTYPE_10A is the facility type for model year 2010 network. The scenario-specific attributes include the following:

- FTYPE_{year}{alt} – An attribute for the facility type.
- ATYPE_{year}{alt} – An attribute for the area type.
- LANES_{year}{alt} – An attribute for the number of directional lanes on any given link.
- IMPROV_{year}{alt} – An attribute indicating where a particular link is a roadway improvement project that first becomes active in this scenario.
- AGENCY_{year}{alt} – An attribute identifying the agency responsible for making the roadway improvement.
- DESC_{year}{alt} – An attribute describing the nature of the roadway improvement.

Universal attributes in the NERPM master network pertain to all scenario networks. They include (Cambridge Systematics, Inc., 2006):

- DISTANCE – This attribute contains the link distance. Values are in feet in the master network but are later converted into miles for the scenario networks and the loaded networks.
- NAME – This attribute contains the roadway name of the facility represented by any given link.
- ALT_NAME – This attribute contains an alternate name or route number of the facility represented by any given link.
- COFIPS – This attribute indicates the county FIPS code as follows: Clay-19, Duval-31, Nassau-89, and St. Johns-109.
- COUNTY – This attribute identifies links numerically by county as follows: 1-Nassau, 2-Duval, 3-St. Johns, 4-Clay. This attribute functions as the geographic location code for the TRANPLAN version of NERPM.
- DISTRICT – This attribute identifies in which planning district any given link is located. Values range from 1 to 32.
- SCREENLINE – This attribute identifies which screenline, if any, a particular link is part of. Values can range from 1 to 98. Currently, screenlines 1 through 39 have been designated as part of the base year validation. Links with a screenline equal to 0 or 99 are not part of any screenline.
- PSCF – This attribute is the Peak Season Conversion Factor. This factor is applied to AADT count values in order to derive Peak Season counts to compare against model estimates. The inverse of PSCF is the Model Output Conversion Factor (MOCF). The MOCF can be applied to model estimated volumes to derive AADT. Though the network does not possess a default MOCF attribute, one can be added to the network and calculated as follows: MOCF = 1/PSCF. The PSCF varies by facility and geography and is based off

of the 2000 FTI Traffic Count CD produced by FDOT.

- CNT_SRCE – This attribute identifies the source of the traffic count, if any, on any given link.
- STATION_ID – This attribute identifies the traffic count station number that recorded the traffic count, if any, on any given link.
- ROADDIR – This attribute indicates the cardinal direction of any given link. Values are NB, SB, EB, and WB.
- LEVEL – This attribute indicates grade separated links that appear to intersect with cross streets, but do not. This attribute was used in converting the original NERPM shape file to Cube. EECODE – This attribute indicates links that external-external (EE) trips are prohibited from using. This EE trip prohibition was deemed necessary during model validation to correct illogical EE movements. Values are 0 and 1. Values of 1 indicate that EE movements are prohibited through the specific link.
- COUNT – This attribute is the converted peak season base year traffic count, if any, for any given link.

2.1.3. Master Network Structure

The attributes described in the last section provide much of the information on the structure of the NERPM master network. By using scenario-specific attributes, each scenario network has its own attribute values besides the universal attributes. On the other hand, the key to distinguishing scenario network links from the master network links, or from each other, lies in the facility type field. By default, links that are a part of any given scenario network will have a facility type value not equal to zero for that particular scenario. Thus, all links for a base-year network are identified by the attribute FTYPE_00A with a non-zero value. In other words, all base-year links have FTYPE_00A<>0, and all other links with FTYPE_00A=0 belong to other scenario networks. Similarly, if the network for model year 2020 alternative 'A' network is to be selected, "FTYPE_20A<>0" will be used as the filter condition.

Cube allows the users to use the layer control window to establish a query that will filter out other network links not belonging to a scenario network. Figure 2-3 displays the layer control window. In this window, a sample query for the base year network (FTYPE_00A<>0) is defined using the **Change** button. Figure 2-4 shows only the links of the base year network for NERPM model in Cube 5.0.

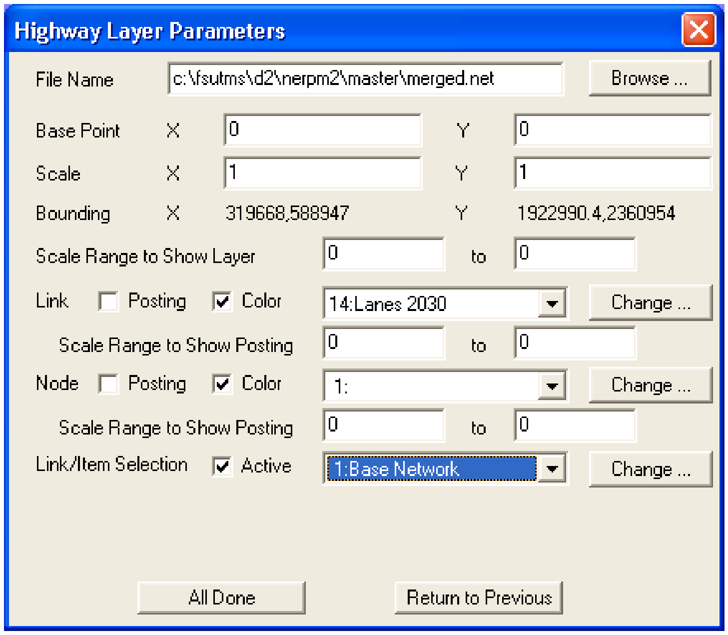

Figure 3-3. Layer Control Window in Cube 5.0.

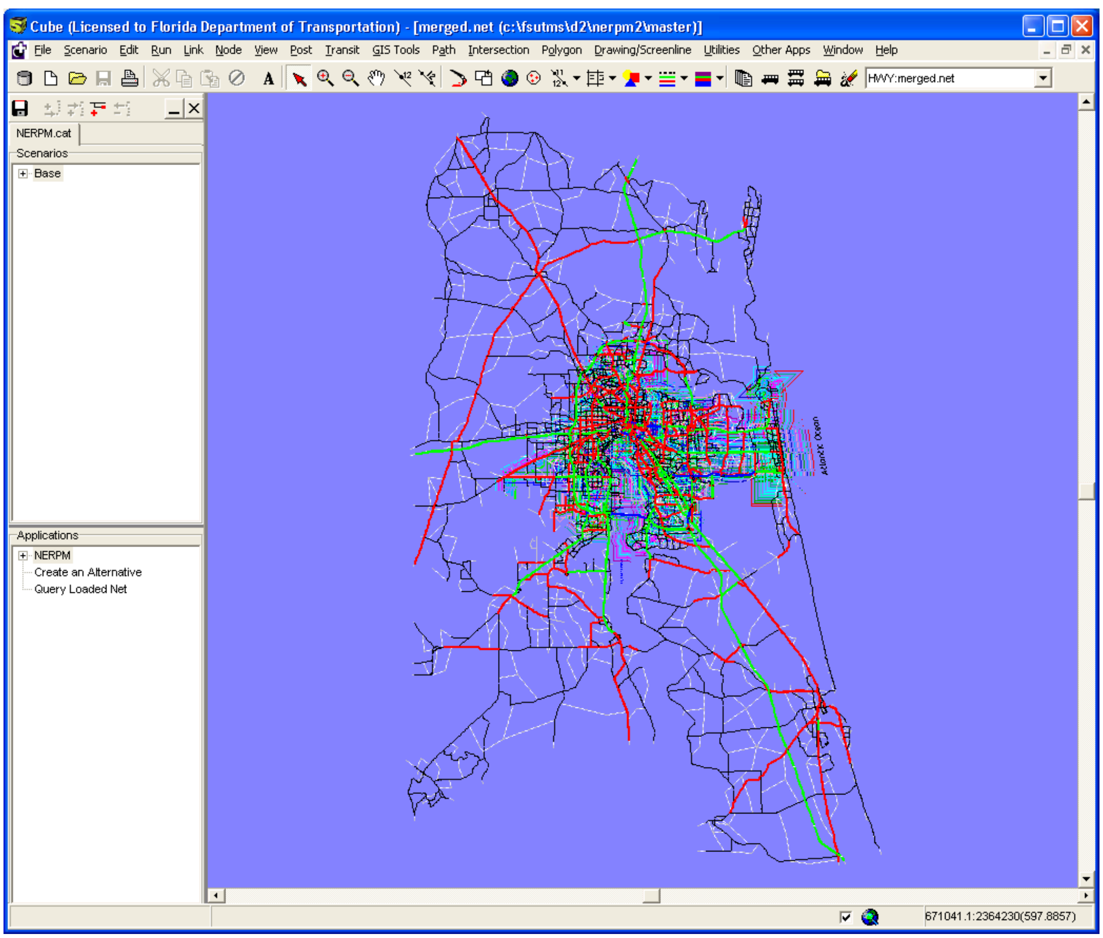

Figure 4-4. Base Year Network for NERPM Model.

2.2 BMC Master Network

The first Baltimore Metropolitan Council (BMC) master network project was originally undertaken by BMC staff in 1998 using MapInfo GIS software. BMC adopted and customized a master network system approach developed by the Delaware Department of Transportation (DelDOT) in 1996. The version of the master network reviewed was named MNet-ArcGIS and it was based on ESRI's ArcGIS platform. This system uses a Geodatabase to store all scenario network links and nodes. MNet-ArcGIS includes both a personal Geodatabase version and an ArcSDE Geodatabase version. Personal Geodatabases allow simultaneous viewing by multiple users but can be edited by one user at a time. On the other hand, ArcSDE Geodatabases support both data viewing and editing by multiple users simultaneously. These databases use ESRI ArcSDE software and store GIS data in an enterprise DBMS, such as IBM DB2, Microsoft SQL Server, Oracle, etc. (Baltimore Metropolitan Council, 2006).

2.2.1. Master Network Framework

A diagram of the MNet–ArcGIS application framework is shown in Figure 2-5. The main component of the system is an ArcMap document template (*MNet2005.mxd*). This document is supported by the MNet_Geodatabase.sde Geodatabase where all operative and most background data sources are stored.

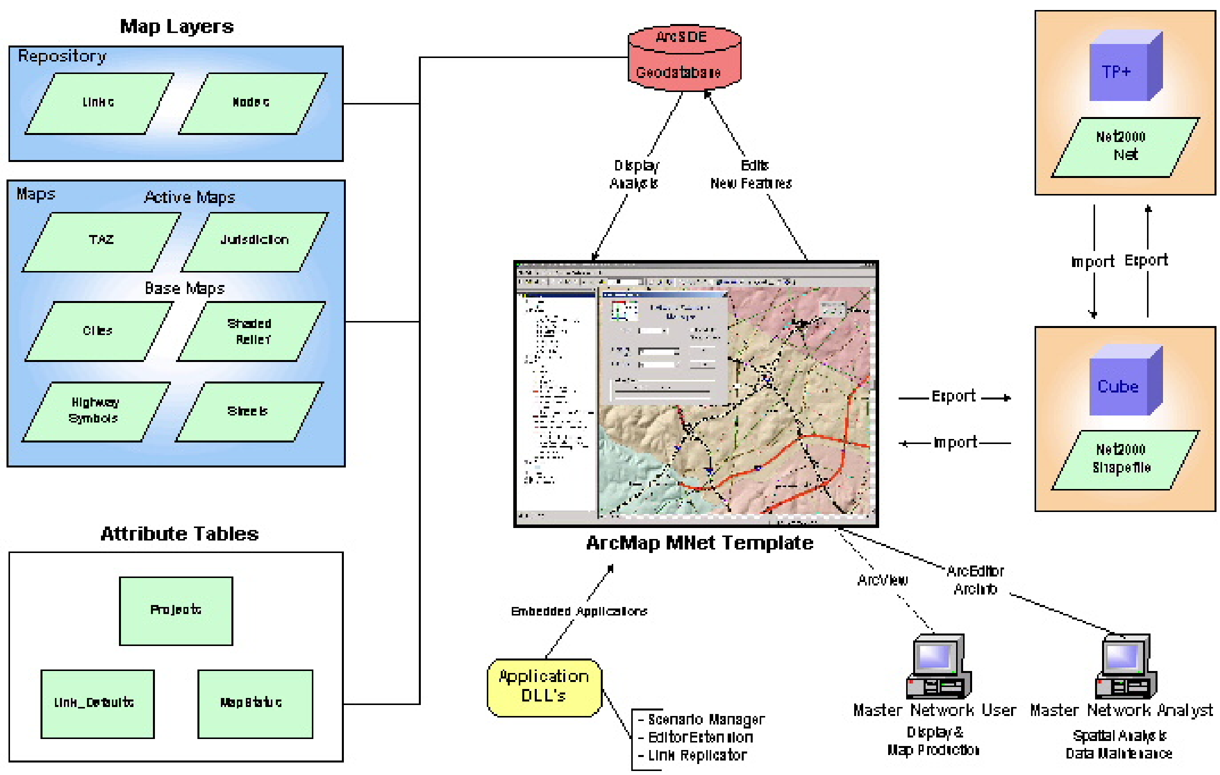

Figure 2-5. BMC Master Network Application Framework.

2.2.2. Master Network Structure

The BMS master network system includes not only highway networks, but also other networks such as transit networks. This is implemented using the FT (functional type) field of the link feature class. All link features in the link feature class are categorized by sub-type values (see Table 2-1) of FT field. Each scenario network is identified from the master network with FT field and the other four fields (Baltimore Metropolitan Council, 2006):

- EffYear – An attribute field defining the effective year of a link or a node;
- ExpYear – An attribute field defining the expiration year of a link or a node;
- Project – An attribute field identifying a improvement project; and
- Status – An attribute field used to choose links based on their project status (committed/uncommitted).

Table 2-1. Link Sub-Types.

Sub-Type Value	Sub-Type Description
1	Interstate
2	Freeway
3	Principal Arterial
4	Minor Arterial
5	Collector
6	Interstate High Speed Ramp
7	Interstate Medium Speed Ramp
8	Interstate Low Speed Ramp
9	Freeway Medium Speed Ramp
10	Freeway Low Speed Ramp
11	Centroid Connector
12	Special Older Freeway
13	Drive Access to Transit Connectors
14	Business Routes
33	Bus Rapid Transit
34	Light Rail
35	Subway
36	MARC

2.2.3. BMC Master Network Core Applications

The BMC master network includes its own editing environment. The system includes the following three main ArcGIS applications (Baltimore Metropolitan Council, 2006):

- The Scenario Manager (see Figure 2-6) allows master network users to manipulate data displays, query a network, and export network data to a personal Geodatabase or a shapefile. This application is developed inside ArcMap as an ArcMap document template.

- The Editor Extension is used for managing and modifying data within ArcGIS edit sessions. It is used to assist master network users to finish common edit tasks and ensure compliance with master network database design standards, rules, and feature ID conventions.

- The Link replicator can be used with an ArcMap edit session when the Editor Extension is active. Its purpose is to set default link attributes by functional type so that links can be "cloned" when creating a new link or modifying existing links.

Figure 2-6. Scenario Manager Interface

2.3 Summary of Review Findings

In this chapter, the NERPM and BMC master network models were reviewed for their functionalities and design approach. Their main design features are summarized as follows:

- Both NERPM and BMC master networks store all network links and nodes in one data file. For the NERPM master network, this data file can be either a Cube .NET file or an ESRI GIS shapefile. The BMC master network are stored in both a Personal Geodatabase and enterprise DBMS database that is accessed using the ESRI ArcSDE software.

- The NERPM master network uses scenario-specific attributes and the facility type field named FTYPE_{year}{alt}, which is also a scenario-specific attribute, to identify each scenario network in the master network. The BMC master network uses five attribute fields: FT, EffYear, ExpYear, Project, and Status to identify a scenario network in the master network.

- Compared to the NERPM master network, which is operated and edited within Cube, the BMC master network has developed its own management environment to support network editing and integration.

Both NERPM and BMC master networks were found to share the following limitations:

- *Data Redundancy:* The scenario-specific attributes defined in the NERPM master network structure results in significant data redundancy. For each new scenario network, all scenario-specific attribute values are completely replicated in the database, even if there is only one change in the network in relative to the others. This structure can increase the master network file size quickly and become burdensome when a large number of scenario networks exist.

- *Network Data Operation:* When editing a scenario network, both models load the entire master network into their network editors. Although the editors allow other network links to be filtered out through layer control, they can be overburdened. When a large network is used, the editing operations are slowed down significantly. The editing is also inconvenient. In the NERPM master network, if a new link is added to a scenario network, all scenario-specific attributes for other networks must be filled out with values even if they do not have and need this link.

- *Structure Expandability:* Both master network structures are specific to their own regional transportation planning models and cannot be easily adapted for other models. For example, both attribute fields EffYear and ExpYear in the BMC master network are not appropriate for most planning models in Florida.

- *Network Change Propagation.* Both models do not support automatic propagation of network changes to other networks. Automatic change propagation is perhaps the most important function of a master network. It is needed to significantly reduce network maintenance time and avoid inconsistencies among different scenario networks.

CHAPTER 3
FSUTMS MASTER NETWORK SYSTEM

This chapter describes the framework of the FSUTMS master network system, which consists of two major system components: the master network program and the master network databases. Also described in this chapter are the system installation and requirements. The functionalities of the master network program and its user interface for executing these functionalities will be described in Chapter 4, and the design and inner workings of the master network database will be described in Chapter 5.

3.1. System Framework

3.1.1. System Functionalities

Figure 3-1 shows the components of the master network system and their relationships. At the heart of the system is the master network program, which interacts with the master network database to accomplish two main functions:

1. Extract a scenario network database from the master network database.
2. Merge a modified scenario network database into the master network database.

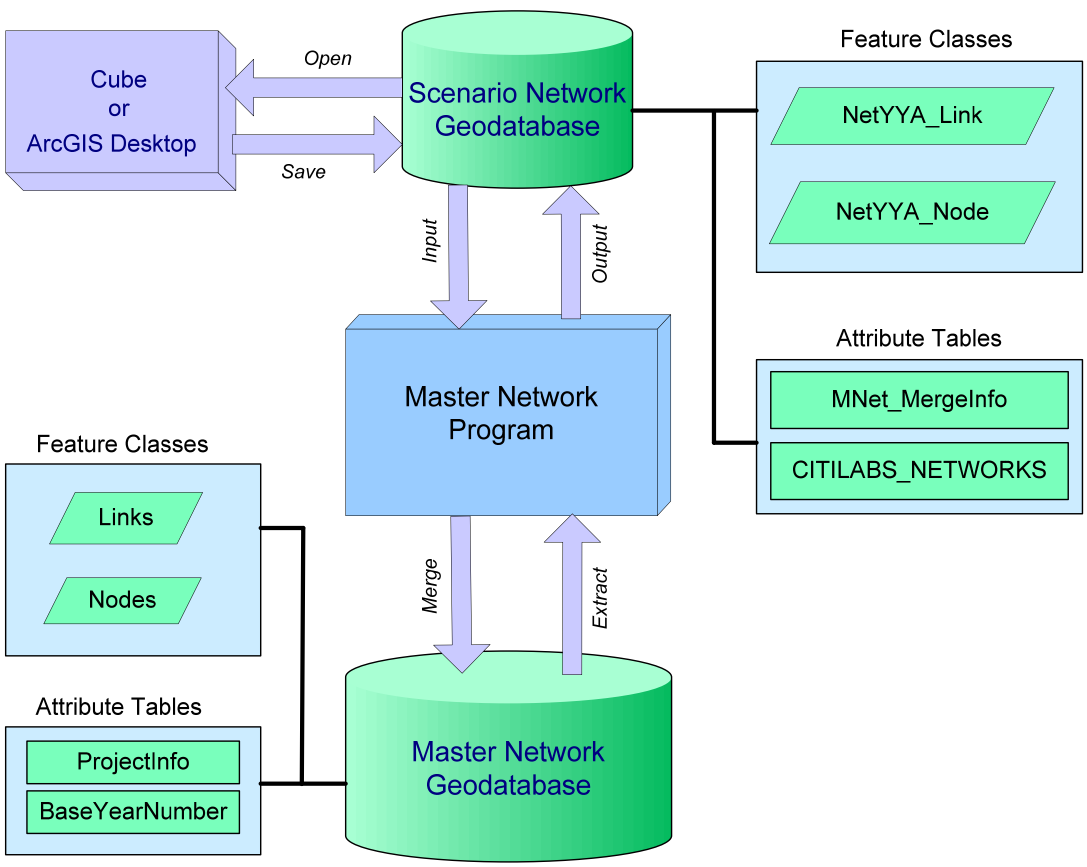

Figure 3-1. FSUTMS Master Network System Framework.

3.1.2. Database Components

All master network and scenario network databases are stored in the Geodatabase format. Master network databases are stored in standard ESRI's Personal Geodatabase and extracted scenario network databases are stored in the so-called Cube Geodatabase format. A "Cube Geodatabase" is a Personal Geodatabase that includes some additional system attribute tables that Cube uses.

3.1.3. Scenario Network Databases

As shown in Figure 3-1, a scenario network Geodatabase contains a node feature class named NetYYA_Node and a link feature class named NetYYA_Link, where YY is a two-digit model year and A is a one-character alternative letter. For example, **Net20B_Link** contains the network data for the link feature class in a 2020 future-year alternative 'B' scenario network. In addition to the node and link feature classes, a scenario network Geodatabase also contains two major attribute tables: **MNet_MergeInfo** and **CITILABS_NETWORKS**.

The **MNet_MergeInfo** attribute table is used to record the model year and the alternative of the scenario network and to keep track of some merging status information to ensure consistencies between a scenario network database and its master network database. More details on the later are provided in Section 5.3.

The **CITILABS_NETWORKS** attribute table is used by Cube to store information that allows the link and node feature classes to form one integrated network (as opposed to two separate feature class layers) to ease network editing in Cube's GIS window. An integrated network allows the nodes and links to be edited simultaneously and, thus, they remain consistent. For example, when a node is moved from point A to point B, all of the links attaching to the node will be automatically moved, thus preventing potential spatial data inconsistencies. However, an ArcGIS desktop system such as ArcMap could still be used to edit a Cube Geodatabase, especially when a modification does not involve any network geometry, such as changing the number of lanes from 2 to 4.

3.1.4. Master Network Databases

Similar to scenario network databases, master network databases also contains the node and link feature classes. However, their feature class names are not associated with any specific model year and alternative, as they are used to store all available model years and all alternatives. Again, these databases also include the following two attribute tables: **ProjectInfo** and **BaseYearNumber**. The **ProjectInfo** attribute table is used to store the project description for each scenario network in the master network database and the **BaseYearNumber** attribute table has only one field that is used to store the base-year number.

3.2. System Installation and Requirements

The master network program was packaged using Windows Installer 3.0. To install the program, simply double-click on the **setup.exe** file. After a few seconds, the setup program will display a welcome screen as shown in Figure 3-2. The user can simply follow the instructions on the screen to complete the installation. If an older version of the program is detected on the user's computer, it will be automatically removed and replaced with the new version.

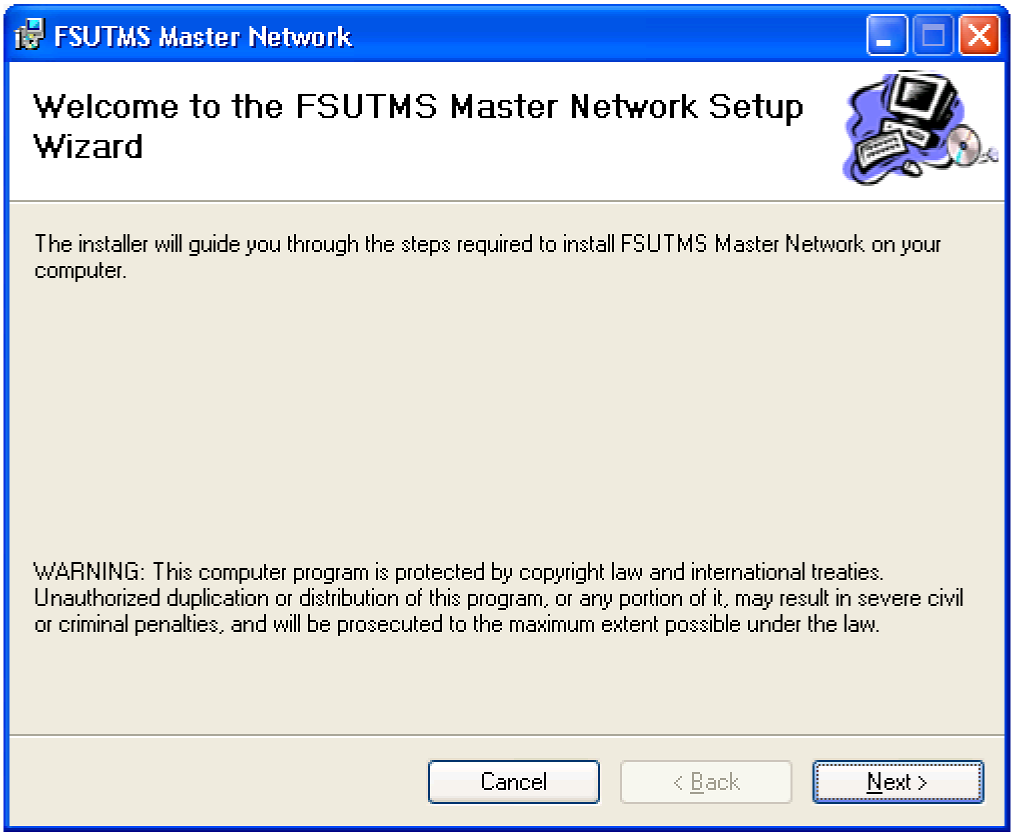

Figure 3-2. Welcome Screen for Master Network Setup Program.

To run the master network program, the computer must be installed with the following additional software:

1. Microsoft .NET Framework 2.0 Runtime
2. ArcGIS Engine 9.2 (or above) Runtime or ArcGIS Desktop 9.2 (or above) licenses authorized

The master network install package includes the install program for the Microsoft .NET Framework 2.0 Runtime. During the install, the .NET Framework 2.0 Runtime will be automatically installed if one is not already installed on the computer. However, the install package does not come with the install program for ArcGIS Engine 9.2 Runtime. In lieu of ArcGIS Engine 9.2 Runtime, the program will also run on any computers installed with ArcGIS Desktop 9.2 (or above).

CHAPTER 4
FSUTMS MASTER NETWORK PROGRAM

As mentioned in Chapter 3, the FSUTMS master network system consists of two major components: the master network program and the master network database. This chapter focuses on the functionalities of the FSUTMS master network program and its user interface for executing these functionalities.

4.1. Program Overview

The master network program was developed as a standalone desktop application using the C# language in Microsoft Visual Studio 2005. The program interacts with the master network database, which was designed in the ESRI Personal Geodatabase structure, using Application Programming Interfaces (APIs) provided by ArcGIS Engine 9.2.

The master network program implements two basic functions. The first is to allow the extraction of a highway network for a particular scenario from a master network database and then save it as a Cube Geodatabase. An extracted scenario network can be either for the base year or for a design alternative of a particular planning year. The second function of the program is to allow an extracted network, after it was modified in Cube, to be merged back into the master network database for storage. A network being merged can either replace an existing network or be added as a new scenario network in the master network database.

An important capability of the master network program is the automatic propagation. It allows the user to apply the same modifications to select networks stored in the master network database. This capability does not only save the time needed to edit individual networks repetitively for the same network modifications, but more importantly, ensure that the modifications will be consistent among the affected scenario networks.

It is noted that a network modification can involve a change in an attribute value or a change in a geometric feature (i.e., a link or a node). An attribute change can be for a node attribute or a link attribute. Similarly, a change in geometric feature can involve a node, a link, or both. Since links are defined by nodes, a geometric change would typically involve both nodes and links. A change to a link, for example, can be to merge two links into one, split a link into two, move a link from one location to another, add a new link, or remove an existing link. The master network program is capable of incorporating all of these changes.

It should also be noted that a modified scenario network can be merged into a master network database only if it was originally extracted from the same master network database. This ensures that the two databases being merged are of the same structure and with the same set of attributes. The master network program will verify that this requirement is met before merging a scenario network into a master network database.

4.2. Program User Interface

The user interface for the master network program is relatively simple. It only consists of two input screens: one for specifying the options for extracting a scenario network from a maser network database, and another for specifying the options for merging a modified extracted scenario network back into its master network database. The two screens are accessible from the two tabs shown in Figure 4-1. By default, the screen for the first tab is shown when the program is first entered.

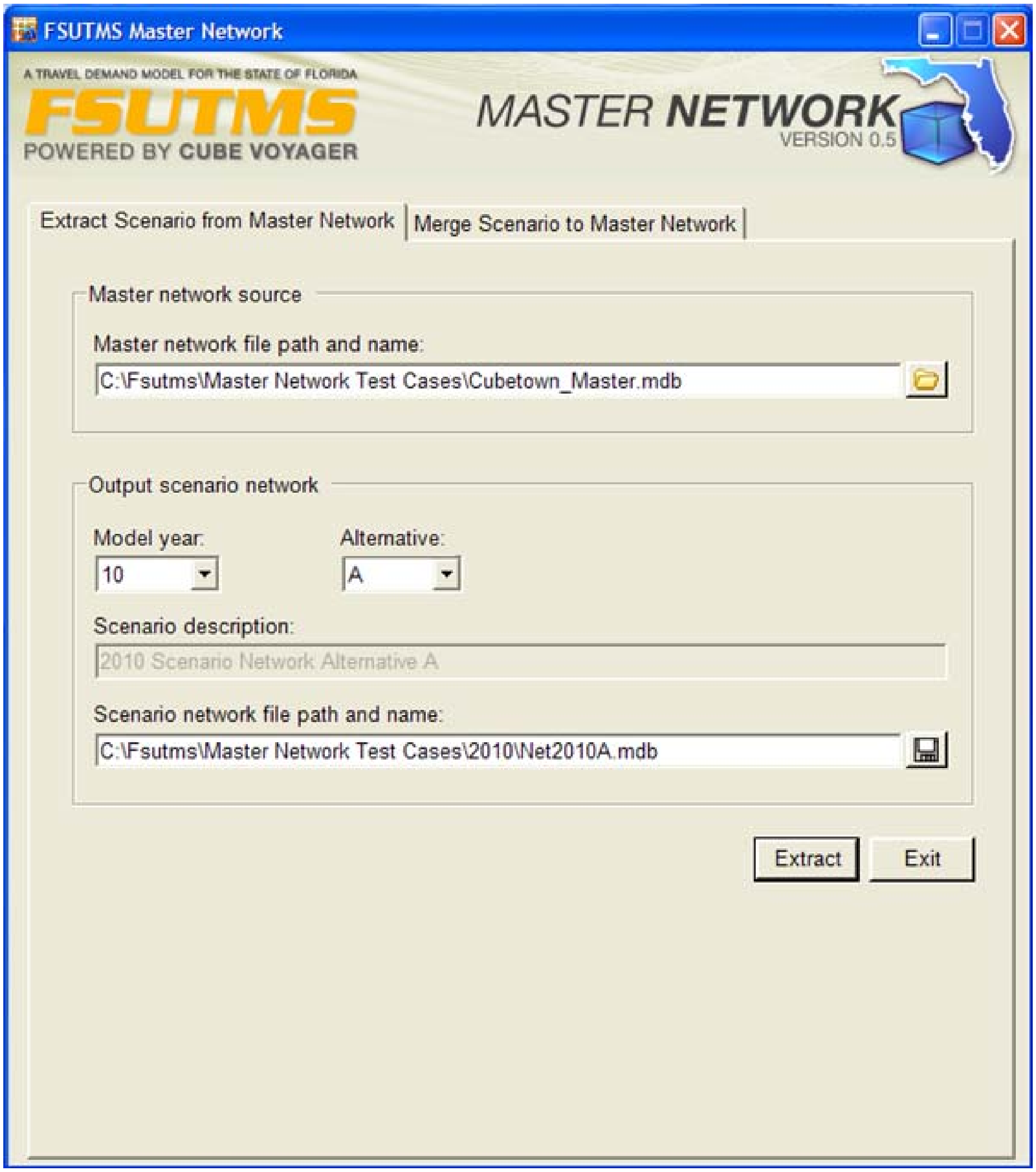

Figure 4-1. Main Screen for Network Extraction.

4.2.1. Network Extraction

As shown in Figure 3-3, the screen allows the user to specify the following options:

1. The **Master network source** allows the user to select a master network database from which an available scenario network is to be extracted. Once the master network database is selected, the name of the database file, together with its file path, will be displayed.

2. As soon as a master network database is selected, all of the model years stored in the database will be listed under the **Model year** dropdown list. Only the last two digits of a scenario year will be displayed, as is standard of FSUTMS/Cube. For example, '00' represents model year 2000 and '10' represents model year 2010.

3. Depending on the specific model year selected, all model alternatives for the selected model year will be listed under the **Alternative** dropdown list. An alternative is always expressed in one sequential alphabet, starting from "A", as is standard of FSUTMS/Cube.

4. In addition to model year and model alternative, a **Scenario description** for the network to be extracted is automatically displayed. This description is entered when the scenario network is first created or updated in the master network database (see next subsection).

5. The final user input is to name the output **Scenario network file path and name**. By default, the program will save the extracted scenario network database file to the same folder as that of its master network database and it will name the database using the selected four-digit model year followed by the selected one-character model alternative. The file type has to be of the ".mdb" type. Optionally, the user can click on the save button () to browse to a different folder and then optionally specify an output database file name.

Once the above inputs are completely specified, the user can click on the **Extract** button at the bottom of the screen to start extracting and saving the selected network. The process should take only a few seconds to complete.

After a scenario network is extracted from the master network database, it can be loaded into Cube and be edited in its GIS window. The user will first open the extracted network database file by selecting Cube's **File|GeoDatabase Manager** menu item. This will open the Geodatabase Manager screen shown in Figure 4-2. In this window, a scenario network named Net10A will be automatically listed after the extracted scenario network Geodatabase Net2010A.mdb is opened by clicking the **Open Other GDB** button at the bottom (which opens the screen shown in Figure 4-3). Double-clicking on **Networks** on the screen in Figure 4-2 will load both the link and node feature classes into Cube's GIS window where the attributes and geometric features can be edited. Figure 4-4 shows a loaded scenario network in Cube 5.0.

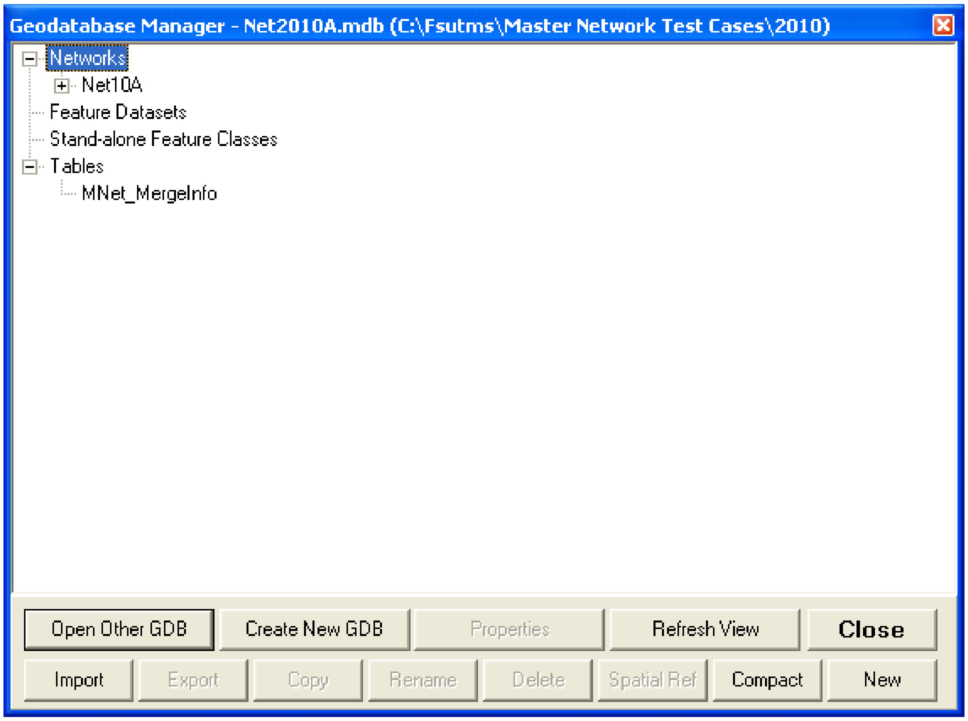

Figure 4-2. Cube 5.0 Geodatabase Manager.

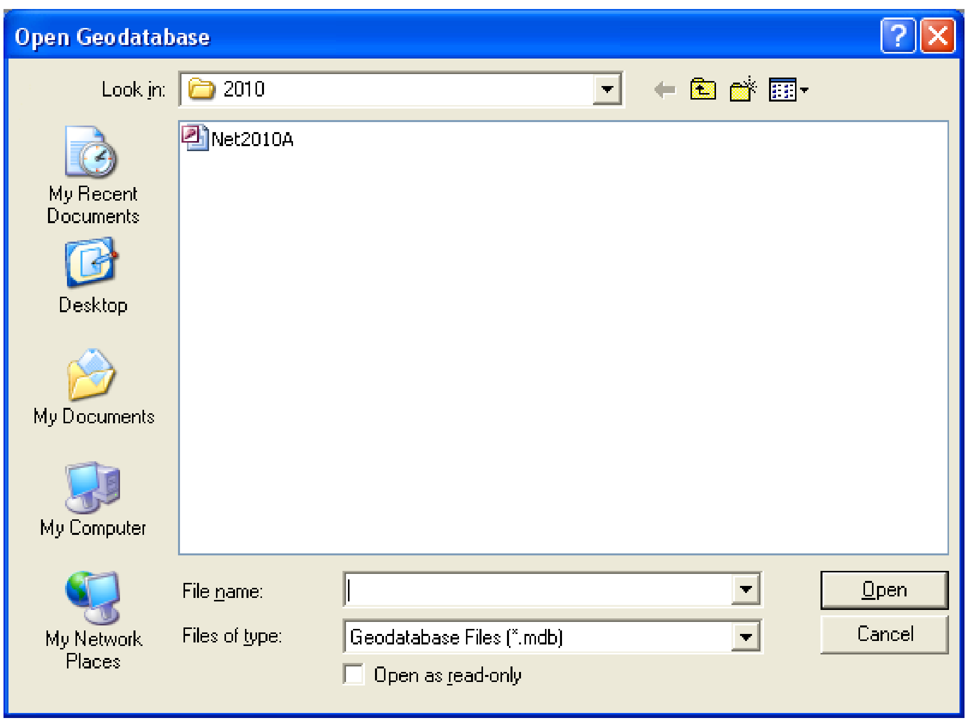

Figure 4-3. Cube 5.0 Geodatabase Open Screen.

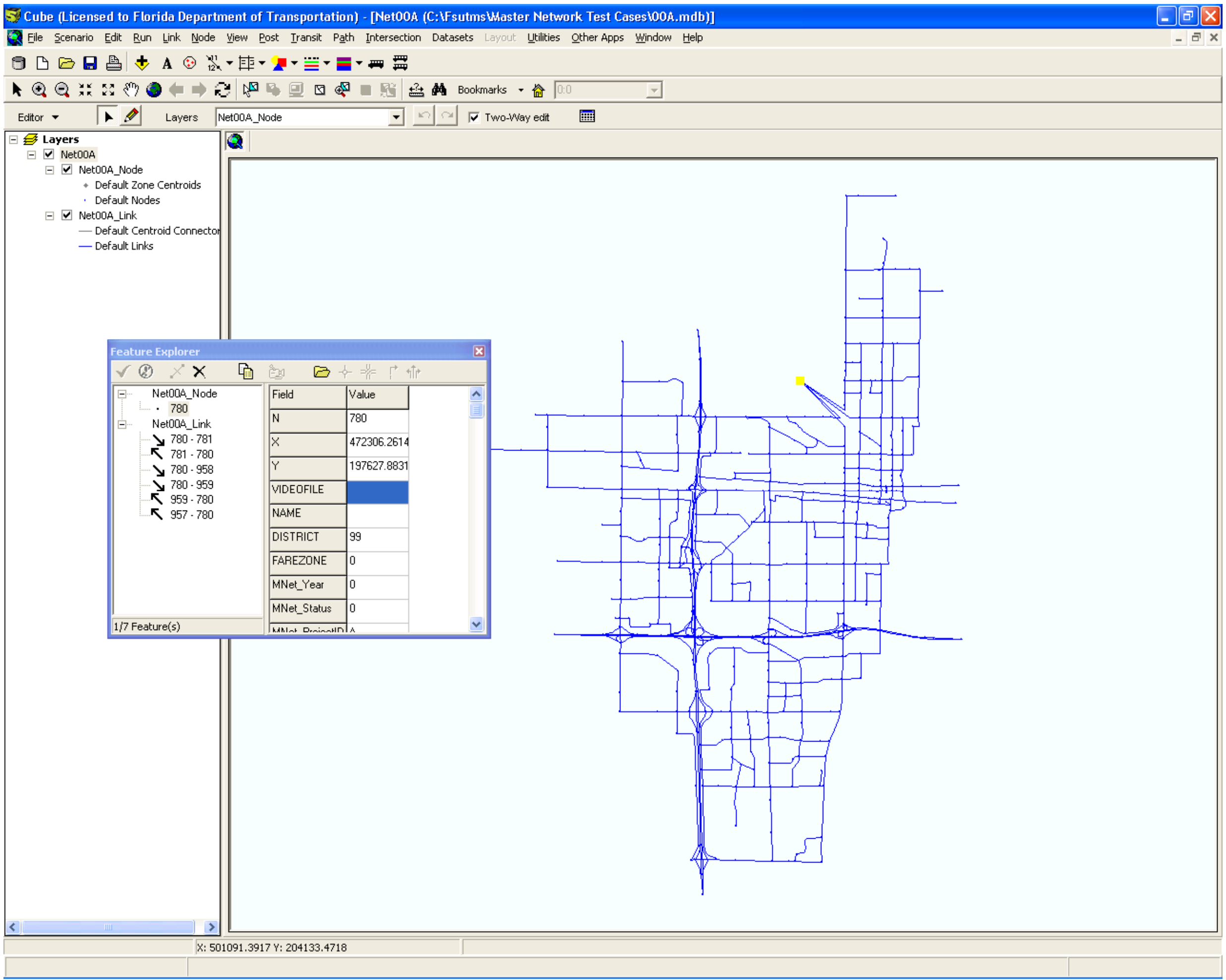

Figure 4-4. Scenario Network Loaded in Cube 5.0 GIS Window.

4.2.2. Network Merging

Figure 4-5 shows the input screen for merging a modified scenario network back into its master network database. The user first selects a scenario network database to be merged by browsing to the database file. The selected file path and name will be displayed under the **Scenario network file path and name** text box. The user will then select a master network database to merge the modified scenario network to. Again, this is done by browsing to the master network database file. The selected master network file path and name will be displayed under the **Master network file path and name** text box. The user must then select either to save the scenario network as a new scenario or to update the scenario from which the modified scenario network originated.

As an example, Figure 4-5 shows that the scenario network is to be saved as a new alternative under the same planning year of 2010. Since there are already two scenarios in 2010, the program automatically assigns "C" as the alternative letter. The user can select to save to an existing planning year by selecting from the **Model year** dropdown list. In the case when a scenario network is to be saved as a new alternative of a new planning year that is not already in the master network database, the user can enter the last two digits of the new planning year in the same dropdown list. Following this, the user can enter a description to identify the new scenario under the **Scenario description** text box.

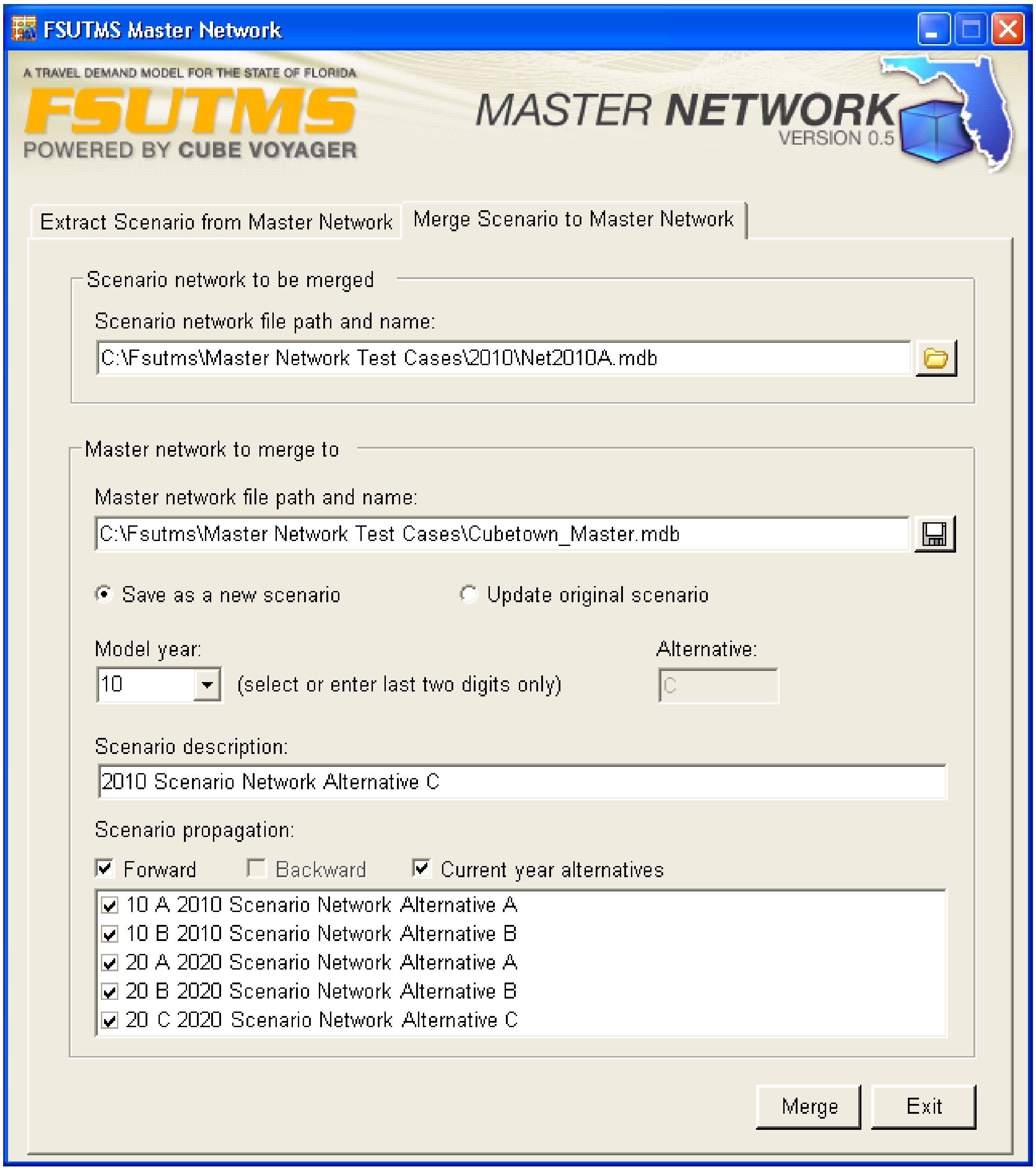

Figure 4-5. Main Screen for Saving a New Scenario Network.

Again, as an example, Figure 4-6 shows that the user has chosen to update the scenario from which the modified scenario network originated, in this case, for model year 2010 and alternative "B". The program will automatically retrieve and display the model year and alternative from the modified scenario network file. The program will also automatically list the original project description. Since the scenario network is supposed to have been modified in Cube, the user is allowed to update the scenario description.

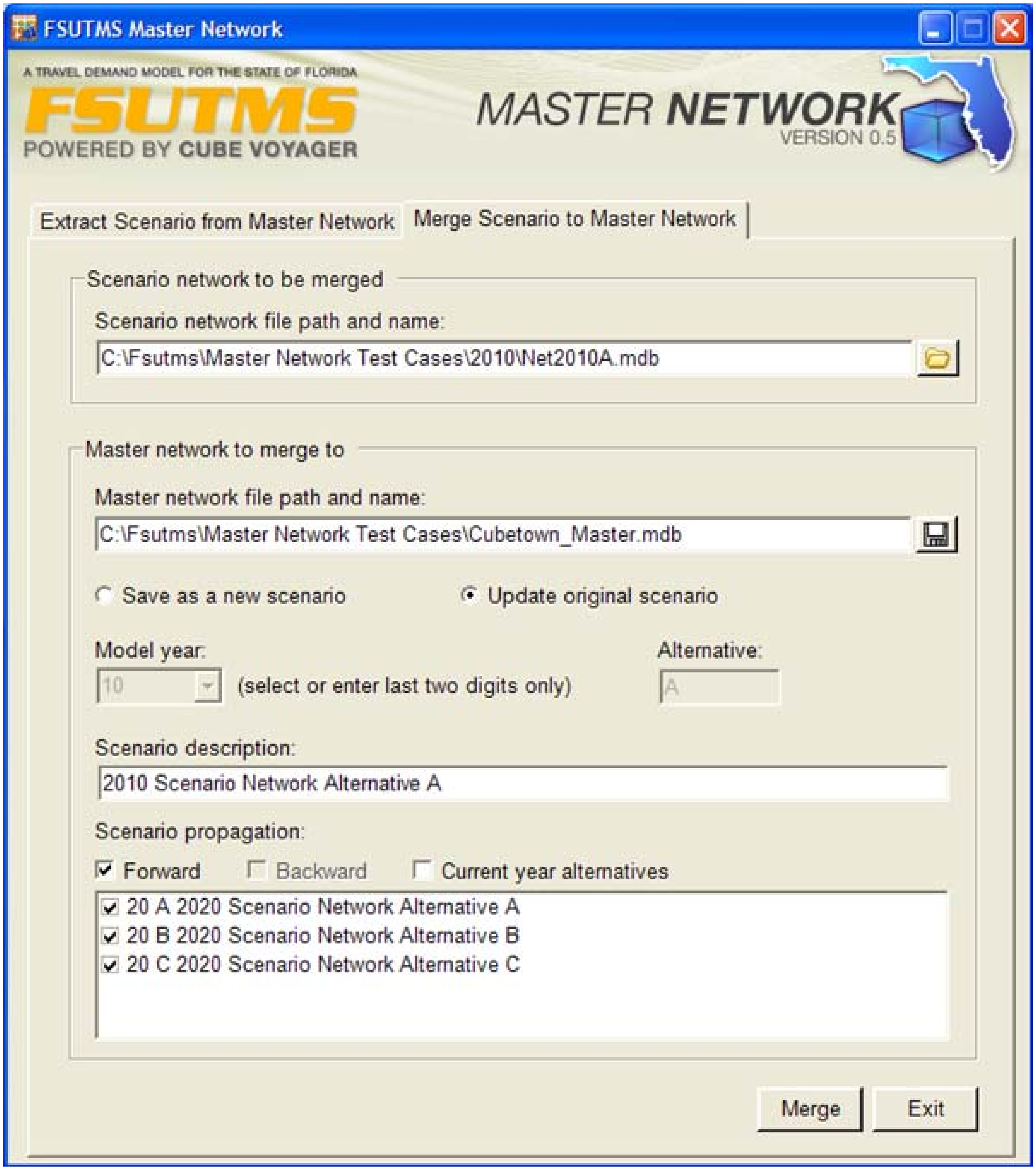

Figure 4-6. Main Screen for Updating the Original Scenario Network.

The final user input as shown in Figure 4-5 (and also 4-6) is to select the existing scenarios in the master network database to apply the same modifications in the network being merged. As mentioned earlier in this chapter, this is perhaps the most important capability of the master network program, as it can provide significant time savings from not having to manually modify individual networks for the same modifications. This also ensures consistency among the scenario networks. The screen allows the user to quickly select the scenarios to be applied for the same modification by checking one or more of the following three options:

1. Checking the **Forward** checkbox allows all future-year scenarios to be selected.
2. Checking the **Backward** checkbox allows all past-year scenarios to be selected.
3. Checking the **Current year alternatives** checkbox allows all current year scenarios to be selected.

Future and past years are defined with respect to the model year of the scenario being merged. All selected scenarios are listed on the list box below the checkboxes. The user can further choose to deselect any of the listed scenarios by unchecking the checkbox preceding a scenario name.

CHAPTER 5
MASTER NETWORK DATABASE STRUCTURE

This chapter describes the design and inner workings of the FSUTMS master network database. Also described are the advantages of the database design and the system as a whole.

5.1. Database Overview

As mentioned in Section 3.1, the master network database is designed in ESRI's Personal Geodatabase structure, which is a Microsoft Access database containing a set of tables as defined by ESRI for holding metadata, spatial, and miscellaneous other system information (Arctur and Zeiler, 2004). A number of data elements exist in a Geodatabase. Two of these data elements are the attribute tables and the feature classes. These two data elements form the core components of a master network database and are thus the focus of this chapter. As the name implies, an attribute table is a data table that is used to store attribute data. A feature class, on the other hand, is a collection of features representing some geographic elements, in this case, roadways, intersections, and transitioning locations.

5.2. Feature Classes

The master network database structure includes two feature classes: nodes and links. The Nodes feature class stores the nodes for the base-year and all future-year scenario networks. Similarly, the Links feature class stores the network links for the base-year and all future-year scenario networks.

Tables 5-1 and 5-2 list some sample records for the Nodes and Links feature classes, respectively. These records are based on a sample master network database structure that was converted from the Cubetown example model of Cube 5.0. The tables list the required fields for each feature class as well as some sample attribute fields. The fields can be classified into following three categories:

1. Feature class built-in fields: They include OBJECTID, SHAPE and SHAPE_Length. These fields are used for system indexing and geometry display, and are automatically generated by the system when the Nodes and Links feature classes were first created. SHAPE_Length stores the length of each link in the Links feature class.

2. Master network key fields: They include N, A, B, MNet_Year, MNet_Status, and MNet_ProjectID. These fields are summarized in Table 5-3. They are key to implementing the structure of the master network database and must not be modified or deleted by the user. The "N" key field is used to record the node numbers for the Nodes feature class. The "A" and "B" key fields are used to store the begin (i.e., A-node) and end (B-node) node numbers that define a link for the Links feature class. Finally, the three key fields, MNet_Year, MNet_Status, and MNet_ProjectID, are used to track the modifications in the nodes and links in the master network database and they are further detailed below:

   a. MNet_Year is an integer field that stores the last two digits of the model year of each feature. For examples, “0” is stored for a 2000 feature and “20” stored for a 2020 feature. Obviously, “0” instead of “00” is stored in the first example because the field is of the integer data type.

b. MNet_Status is an integer field that indicates if there has been a modification to the feature: “0” if not modified and “1” if modified.

c. MNet_ProjectID is a character field that is used to store a scenario network alternative letter, e.g., ‘A’ for alternative A, ‘B’ for alternative B, etc.

3. Attribute fields: They include fields for data pertaining to a specific model and may include such fields as functional class, posted speed, number of lanes, etc. The master network database has an open structure that allows any number of such attributes to be included for both the Nodes and Links feature classes.

Table 5-1. Sample Node Features.

OB-JECTID	SHAPE	N	X	Y	NAME	DIST-RICT	FARE ZONE	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1	482451.31	204001.82		1	0	0	0	A
	Long binary data	2	476594.40	203485.70		1	0	0	1	A
474	Long binary data	2	476594.40	203485.70	Carl	1	0	10	0	A

Table 5-2. Sample Link Features.

OBJECTID	SHAPE	SHAPE_ Length	A	B	SPEED	NUM LANES	FUNC_ CLASS	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1617.87	1	1153	25	2	10	0	1	A
1146	Long binary data	1617.87	1	1153	25	3	10	10	0	A
2	Long binary data	1586.84	2	954	25	2	10	0	0	A

Table 5-3. Key Fields.

Field Name	Data Type	Description	Feature Class
N	Long integer	Node number	Nodes
A	Long integer	Begin node number of a link	Links
B	Long integer	End node number of a link	Links
MNet_Year	Integer	Base-year or future-year number	Both
MNet_Status	Integer	1 if a link or node is updated; 0 otherwise	Both
MNet_ProjectID	Character	Scenario network project alternative letter	Both

The master network Geodatabase structure stores all scenario network links or nodes, including the base-year network, in one feature class. An important design of the structure is that it stores only the base-year feature records plus those feature records that were modified for a specific scenario (except for those feature records for which the corresponding links/nodes were deleted). In other words, feature records that are unmodified throughout the base-year and scenario networks are stored only once in the database to minimize data redundancy.

5.3. Scenario Network Merging Process

The master network program relies on three key fields, i.e., MNet_Year, MNet_Status, and MNet_ProjectID, as described in the previous section, to implement the scenario network merging process. The process for merging a modified feature record into a master network database consists of the following four steps:

1. *Change MNet_Status in corresponding base-year feature record.* When a feature record in a scenario network being merged is found to have been modified, the MNet_Status field of the corresponding feature record in the base-year network is changed from 0 to 1. This is done regardless of whether the change is for an attribute value or a geometric shape. It is noted that whether a feature record has been modified is detected by comparing each feature record in the scenario network being merged with the corresponding record in the original scenario network (from which the scenario network being merged was created).

2. *Copy corresponding base-year feature record to all other scenario networks.* If the feature record in the base-year network corresponding to the modified feature record has not been modified before, copy this feature record to all scenario networks other than the scenario network being merged. This causes all existing scenario networks to have the unmodified original feature record.

3. *Merge modified feature record.* The merge can be to create a new scenario network or to update an existing scenario network. If it is to merge as a new scenario network, the modified feature record will be inserted as a new record in the master network database for the new scenario network. If it is to update an existing scenario network, the program will simply replace the same feature record in the scenario network being updated. A special case of a modified feature record involves one that has been deleted. A deleted record is detected when an existing record in the scenario network being updated is not found in the scenario network being merged In this case, the program will delete the feature record in the scenario network being updated.

4. *Propagate modifications to other scenario networks.* This step is applied only when the user selects to propagate the modifications to the other scenario networks in the master network database. In this step, if a feature record in a scenario network selected for propagation is found to have the same node number(s) as those of the modified feature record being merged, the feature record will be updated with the modifications. This process is repeated for all scenario networks selected for propagation. It is noteed that, instead of replacing the entire modified feature record, only the specific attributes and/or geometric shapes within the record that were modified are replaced.

The above process is repeated for each modified feature record individually until all modified feature records are merged into the master network database.

To further illustrate this four-step merging process, Table 5-4 provides a simple example with two link records in a master network database. The links are link 1-1153 and link 2-954 for base year 2000. No other future-year scenario networks exist in this master network database. Assume that a scenario network has its number of lanes (field NUMLANES) for link 1-1153 changed to 3 from 2 for a future year 2010 alternative 'A'. In step 1, the MNet_Status field for link 1-1153 for base year 2000 is changed from 0 to 1, as shown in Table 5-5. Because there are no other scenario networks in the current master network database, step 2 does not apply. As part of step 3, a new link, 1-1153, with an OBJECTID of 1146 for the future year 2010 scenario network alternative 'A' (i.e., MNet_Year = 10, and MNet_ProjectID = 'A') is added. Note that link 1-1153 with an OBJECTID of 1 for the base year,network is left unchanged. Also link 2-954 that is also unchanged,belongs to not only the base-year network, but also 2010 scenario network alternative 'A'. Following the above merging process, the current master network database now has one scenario network for future year 2010 scenario network alternative 'A', in addition to the base year network.

Table 5-4. Original Base-Year Link Records in Master Network Database.

OBJECTID	SHAPE	SHAPE_ Length	A	B	NUM LANES	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1617.87	1	1153	2	0	0	A
2	Long binary data	1586.84	2	954	2	0	0	A

Table 5-5. Link Records in Master Network Database After Merging a Modified Record.

OBJECTID	SHAPE	SHAPE_ Length	A	B	NUM LANES	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1617.87	1	1153	2	0	1	A
1146	Long binary data	1617.87	1	1153	3	10	0	A
2	Long binary data	1586.84	2	954	2	0	0	A

Assuming that scenario network alternative 'A' is extracted from the current master network (using the process to be described in Section 5.4), and the number of lanes for link 2-954 from this extracted network is to be modified from 2 to 4. If this modified network is to be merged back to the master network as a new scenario network alternative 'B' for the same future year, as part of step 1 the MNet_Status field for the link 2-954 is changed from 0 to 1, as shown in Table 5-6, to reflect the fact that this base-year link record has been changed.

Table 5-6. Base-Year Link Updated in Master Network Database.

OBJECTID	SHAPE	SHAPE_ Length	A	B	NUM LANES	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1617.87	1	1153	2	0	1	A
1146	Long binary data	1617.87	1	1153	3	10	0	A
2	Long binary data	1586.84	2	954	2	0	1	A

Because the base-year record for link 2-954 has not been modified before, and the current master network already has one future-year 2010 scenario network alternative 'A', step 2 must be applied. In this case, a copy of the base-year record for link 2-954 for 2010 scenario network 'A' is made.

As Table 5-7 shows, this record has an OBJECTID of 1148. As part of step 3, a new record for link 2-954 with an OBJECTID of 1149 is inserted. This new record has a new number of lanes of 4. For link 1-1153 that was modified for scenario network alternative 'A', it was copied as a new link for alternative 'B' with an OBJECTID of 1147. Table 5-7 shows the complete set of link records in the master network database after the first three steps of the merging process.

Table 5-7. Complete Link Records After Merging a New Scenario Network.

OBJECTID	SHAPE	SHAPE_ Length	A	B	NUM LANES	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1617.87	1	1153	2	0	1	A
1146	Long binary data	1617.87	1	1153	3	10	0	A
1147	Long binary data	1617.87	1	1153	3	10	0	B
2	Long binary data	1586.84	2	954	2	0	1	A
1148	Long binary data	1586.84	2	954	2	10	0	A
1149	Long binary data	1586.84	2	954	4	10	0	B

The link records given in Table 5-7 did not involve any propagation. If the change in the number of lanes from 2 to 4 in scenario network alternative B is to be automatically propagated to scenario network alternative 'A', the resulting link records in the master network database will be those shown in Table 5-8. The table shows that the attribute value for NUMLANES for the record with an OBJECTID of 1148 will be changed from 2 to 4.

Table 5-8. Links in Master Network Database after the Propagation.

OBJECTID	SHAPE	SHAPE_ Length	A	B	NUM LANES	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1617.87	1	1153	2	0	1	A
1146	Long binary data	1617.87	1	1153	3	10	0	A
1147	Long binary data	1617.87	1	1153	3	10	0	B
2	Long binary data	1586.84	2	954	2	0	1	A
1148	Long binary data	1586.84	2	954	4	10	0	A
1149	Long binary data	1586.84	2	954	4	10	0	B

During the merging process, a rare but potential conflict may arise when a user tries to merge a scenario network database that includes one or more new node numbers that are already used by another scenario network. Merging such a new node number into the master network database will create conflict when the user chooses to propagate the new node to the scenario network that already uses the same node number for another network entity. This causes that scenario network to have two nodes that represent two separate network entities but with the same number. When this scenario network is extracted, a network error will occur when it is imported into Cube.

To prevent this conflict, the system will scan the master network database during the merging process to ensure that none of the newly added nodes in the scenario network database being merged are already in use by another scenario network. When a conflict is detected, the system will automatically assign another number that is not already in use to the conflicting node. The system will pop-up an information message to inform the user of the conflict. The same message will also list all the node numbers that were changed and the new numbers they changed to. Figure 5-1 shows an example of the message.

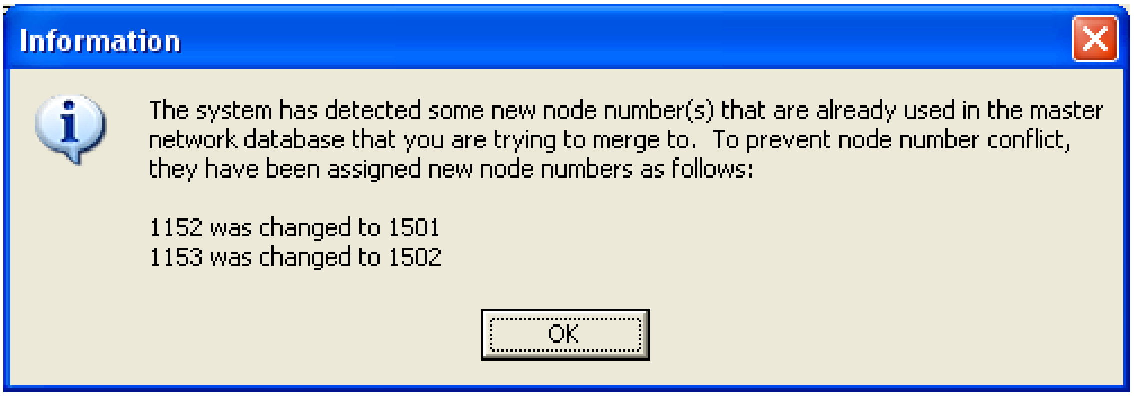

Figure 5-1. Message Informing User of Node Number Conflict and Assigned New Node Numbers

After a scenario network with conflicting new node numbers are merged into the master network database, the master network program will insert a code into the scenario network database to stop it from being merged again. When a user tries to merge such a scenario network database, an information message shown in Figure 5-2 will pop-up informing the user to re-extract the merged scenario network from the master network database so that it will contain the assigned node numbers.

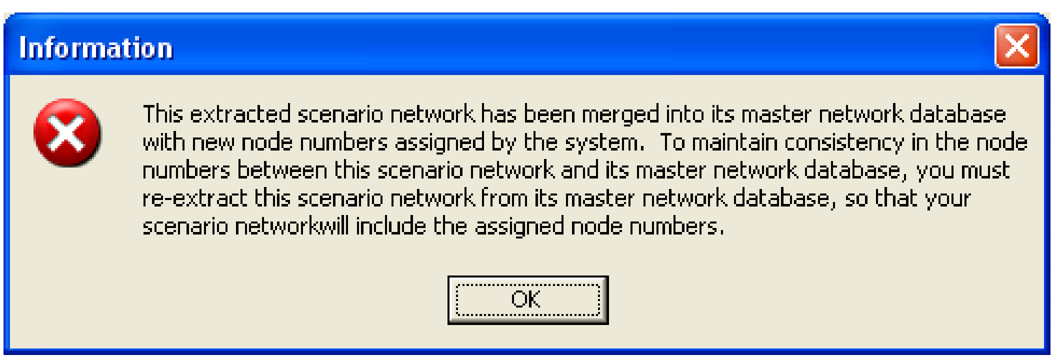

Figure 5-2. Message Informing the User to Re-extract a Merged Scenario Network Involving Assigned Node Numbers

5.4. Scenario Network Extraction Process

Extracting a scenario network from a master network database is a relatively straightforward process. Because the master network database stores all the links and nodes in one feature class, the extraction can be done using a query with a simple SQL **where** clause. To extract the base-year scenario network, the condition for the **where** clause is simply expressed as "(MNet_Year=0)". To extract a non-base-year scenario network, for example, for future year 2010 alternative 'A', the conditions for the **where** clause will be "(MNet_Year=0 and MNet_Status=0) or (MNet_Year=10 and MNet_ProjectID='A')". Using the sample links in Table 5-5, the sample records for the extracted scenario network for the base year are as listed in Table 5-9. Similarly, for model year 2010 alternative 'A', the sample records are as listed in Table 5-10.

Table 5-9. Extracted Base Year Network.

OBJECTID	SHAPE	SHAPE_ Length	A	B	NUM LANES	MNet_ Year	MNet_ Status	MNet_ ProjectID
1	Long binary data	1617.87	1	1153	2	0	1	A
2	Long binary data	1586.84	2	954	2	0	0	A

Table 5-10. Extracted Model Year 2010 Network Alternative 'A'.

OBJECTID	SHAPE	SHAPE_ Length	A	B	NUM LANES	MNet_ Year	MNet_ Status	MNet_ ProjectID
1146	Long binary data	1617.87	1	1153	3	10	0	A
2	Long binary data	1586.84	2	954	2	0	0	A

5.5. Advantages

In addition to the general advantages of master network on network maintenance and consistency, the master network database structure developed in this project offers the following additional advantages:

1. *The structure minimizes the network storage space*. This was accomplished by storing only the modified records (with respect to base-year network) of each scenario network without storing those that were not modified. It takes advantage of the fact that the differences between a base-year network and a future-year scenario network generally represent only a very small percentage of the total links and nodes. While storage space is generally not a major concern today, the fact that a more efficient storage structure minimizes the chances of reaching the 2 GB file size limit of Microsoft Access data file (of which Geodatabase is based) clearly increases the significance of this advantage. In addition, a smaller database also improves the data I/O speeds and makes file transfers easier.

2. *The structure keeps the network links consolidated*. Because the structure stores only the original base-year network plus only the modified links/nodes of each scenario network, the base-year network is kept intact and is not affected by the number of scenario networks or the number of link/node modifications in each scenario network. The same is extended to the individual scenario networks, as each is stored as the base-year network plus any

network changes that define the particular scenario. Thus, each scenario network is not affected by changes from the other scenario networks. A network with consolidated links (i.e., links with the same attributes are not unnecessarily broken down into multiple links) allows the model to run more efficiently.

3. *The structure supports change propagation.* The structure provides full support for both forward and back propagation. The propagation can be applied to any of the selected scenario networks, and can be for either data attributes or geographic features. As noted, change propagation is the most important capability of a master network as it saves time from having to manually edit each scenario network for the same changes. By doing so, it helps to maintain network consistencies.

4. *The structure was designed for extendibility*. The master network structure uses an open database structure. First, the two feature classes are not restricted to a certain set of attributes. The system will recognize and accept any number of attributes a model wishes to include. In addition, the structure is also not restricted to specific attribute names. These are important features as the master network system was not designed for potential implementation by a specific agency, but different agencies with different FSUTMS models. The structure can be extended to any other networks that are represented using a series of nodes and links, including transit lines. The structure can also be extended to GIS polygon areas such as TAZ.

In addition, the entire system works as a standalone program. This allows the system to be updated as needed independent of the FSUTMS/Cube releases.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Network maintenance in travel demand modeling is a very time-consuming process. The four-step demand model on which the Florida Standard Urban Transportation Model Structure (FSUTMS) is based requires the use of highway, traffic analysis zone (TAZ), and transit (if applicable) networks. In a typical demand analysis, multiple versions of a network are usually created to represent the different network conditions associated with different model years and alternatives. Traditionally, these networks are modified individually and stored in separate network files. The process is cumbersome and is prone to network coding errors that result in network inconsistencies. For example, a simple link split in a network will require that the same action be performed individually for all the networks affected by the split. The process is both cumbersome and is prone to coding inconsistencies. This has led to an increased interest in the modeling community to use the master network approach of building and maintaining modeling networks.

Unlike a traditional network, a master network combines the base-year and all future-year networks in a single, integrated, and consistent spatiotemporal database. To work on a particular network, the user would simply indicate the timeline and the specific scenario network to extract from its master network. After an extracted network is modified, it can be merged back into the master network. During the merging process, changes to the network can be automatically applied to other networks in the master network. This not only saves time from repetitive manual network editing, but also avoids potential inconsistencies among the different scenario networks.

This report has described a successful effort in developing a robust standalone master network system that works with Cube Voyager—the modeling engine of FSUTMS. Stored in ESRI's Personal Geodatabase format, the master network database structure was designed to minimize data storage space, extract efficient networks with consolidated links, support open and unlimited data attributes, and implement both forward and backward network propagations.

As part of this research effort, the master network system was successfully tested on multiple model networks, including the relatively large network for the Northeast Florida Regional Planning Model (NERPM) and the Florida Statewide Model. The system is ready for deployment to other FSUTMS models, especially for those models that plan or are in the process of transitioning to Geodatabase to take advantage of Cube's GIS editing environment. The deployment for each model will involve converting the individual networks (base-year and scenario) currently being maintained separately by agencies to the master network database structure. A conversion program will need to be developed to not only combine and convert multiple existing networks, but also to detect and produce a list of existing network inconsistencies, both spatial and non-spatial, that need to be reconciled. In other words, it will be an opportunity to rid network inconsistencies from the existing networks. Once the networks are converted into the master network structure, network consistency can be guaranteed thereafter.

While the current structure was designed for only highway networks, it can be extended to transit and TAZ networks. The extension to transit line networks will be relatively straightforward as they are also represented by links and nodes. The extension to polygon networks such as TAZ is expected to require additional but not significantly more effort, thanks to the flexible design of the current master network database structure.

As noted previously, the current master network system has been developed as a standalone application. This gives the application the benefit of not having to tie its system updates to Cube releases. However, because the application works entirely independent from Cube, it requires additional time to detect network changes when a scenario network is merged to its master network. Currently, this additional time amounts to around one minute or less when merging a large network on a current personal computer. An alternative will be for the Cube developer to generate a log file that records all the network changes after each network editing session. This will reduce the network merging time to seconds if not near instant.

Further effort to integrate with Cube, if desirable, could be to execute all of the current functions within Cube. The will require that the functions of the current system be encapsulated as a set of APIs that can be called or programmed directly within the Cube software. This will also mean that the master network program interface described in Chapter 4 will not be needed and the user will experience a more seamless master network application in Cube.

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