Florida Department of Transportation
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Toward a More Efficient Network Structure for Travel Demand Modeling

Final Report

Prepared by:
University of Florida

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DISCLAIMER

METRIC CONVERSION CHART

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	Km
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

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16. Abstract

The travel demand models in Florida use different road networks even in geographically overlapping areas. Due to differences in network segmentation and details, currently, it is difficult to share information among models at different scales. Thus, this research examines the issues related to the network structure of travel demand models, with an emphasis on the Statewide model. It aims to identify a more efficient multi-scale network structure that will enable effective information sharing between the Statewide models and the district or local models, while preserving the detailed information provided by finer network segmentation. After considering previous research and practice in and out of Florida on this topic, this research proposes a framework for a planning network database to support efficient travel demand modeling for the state of Florida. The proposed planning network database uses a unified true-shape network, which includes all public roads, supports Linear Referencing System (LRS) to access the FDOT's Roadway Characteristics Inventory (RCI) data, and supports multi-scale travel demand modeling and eventually, multi-resolution transportation simulation modeling. The network structure supports different scales of models and the ability to store various planning scenarios. Travel-demand modeling projections can be stored in the database which can help planners and decision makers on future planning applications. Therefore, the database provides a unified network for modeling consistency and efficient data sharing at the network level. It supports various transportation data sources, increases the efficiency in preparing a network ready for modeling, and reduces the redundancy workloads among multiple transportation agencies. To ensure successful implementation and the long-term sustainability of the network database, we provide some recommendations regarding data sources, modeling software, organizational and database structures.

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EXECUTIVE SUMMARY

Travel demand forecasting helps decision makers formulate informed transportation plans and policies. It allows transportation planners to assess changes in travel modes and travel demand for passengers and freight in a specific future time frame and to evaluate the economic and social impacts of transportation improvements, given different assumptions in demographics and traveler behavior.

At present, Florida has several travel demand models that operate at various geographical scales. The Systems Traffic Modeling section of the Forecasting and Trends Office maintains the Statewide model while the seven FDOT districts maintain their own regional models for their areas. All these models use different networks even in geographically overlapping areas. Typically, Statewide models are coarser than those at regional scales. The Statewide model, consisting of high-level roadways, is used to analyze the impact of policies and trends that are implemented by state governments but not captured within local areas. By contrast, more detailed regional models are used to examine travel patterns within the district areas and evaluate local investments.

Although statewide and regional models serve different purposes and are often used by different agencies, they are connected in several aspects. For example, where their geographic areas overlap, both models share the same roadways in geometry and attribute, thus sharing roadway information could help reduce duplications in data collection, and most importantly, facilitate cooperation between agencies at different scales. Furthermore, a Statewide model provides regional areas with existing and forecasted interregional travel, which could then serve as input for external trips in regional models. Besides, the results of each model could be validated by comparing them with each other. Thus great opportunities exist to share information among models at different scales. To achieve this goal, there must be efforts to build the connection between the road networks of these models at various scales.

The purpose of this research is to examine the issues related to the network structure of travel demand models and to develop a framework towards a more efficient multi-scale and multi-resolution network structure. The proposed planning network database enables effective information sharing among the statewide and regional models, which can optimize model execution while preserving the detailed information provided by finer network segmentation. Such a network database allows modelers and planners to access roadway information from other models at different geographic scales with increased efficiency.

The research team started the project by conducting a broad survey of the efforts by other researchers and practitioners in and out of Florida to learn about their successes and challenges

in dealing with network inconsistency. The survey revealed that modeling network inconsistency is a critical issue that widely exists in most states. The reasons for the network data inconsistency include the presence of technical challenges in building an efficient database structure, lack of efficient data sharing and cooperative arrangement between agencies, and lack of awareness of the issues.

In addition, we conducted a close review of the Florida Standard Urban Transportation Model Structure (FSUTMS) models used in different regions in Florida. We found that the network inconsistency among the models remained as one of the barriers that prevent efficient data sharing. Currently, none of the networks in FSUTMS show any considerations for data sharing between different scales of models and the Statewide model. To better understand current issues and demands for networks in FSUTMS, the research team surveyed relevant stakeholders. A questionnaire was sent out through the district modeling coordinators to the model, developers and consultants. The survey results confirmed that much manual work is needed when the model developers or end-users add, modify or delete links and link attributes. The respondents also agreed that the true-shape network makes it easier to recognize, present, and compare the forecast results.

Our next step focused on reviewing practitioner's efforts in dealing with issues regarding network databases for travel demand modeling, which revealed that some efforts have been made within and outside of Florida. However, most of the reviewed database systems were originally developed for a specific agency and did not provide multi-model support. Overall, we found that by facilitating data sharing, an efficient network database with advanced tools can reduce most data editing tasks for the staff in different agencies.

To facilitate data sharing and consistent model development, Florida Department of Transportation (FDOT) has put a lot of effort into building FSUTMS standards, which allows different models to follow a consistent data preparation, modeling, and validation procedure. A review of the FSUTMS standards helped us understand the requirements for the proposed network, which requires the network data, and additional supportive data files, including the data structure (node-link structure, zones, turns, tolls, transit) and key attributes. Furthermore, to build a software independent network, the research team reviewed the Geographic Information System (GIS) capabilities of five mainstream travel demand software packages in handling the network. We found that although some modeling packages provide special features or tools and some work is needed for network preparation, these requirements are broadly supported by most of the software packages we reviewed.

The research team proposed a planning network database model to support efficient travel demand modeling for the state of Florida. The proposed database structure is software independent, uses a unified true-shape network, which includes all public roads, supports the Linear Referencing System (LRS) to access the FDOT's Roadway Characteristics Inventory (RCI) data, and supports multi-scale travel demand modeling, and includes provisions for future support of multi-resolution transportation simulation modeling. Outputs of various planning stages such as the long-range transportation plans (LRTP), the transportation improvement programs (TIP), the statewide transportation improvement program (STIP), and Work Program can be stored in the database. The network structure supports different scales of models and the ability to store various planning scenarios. Travel demand modeling projections can be stored in the database for further reference and model comparison. The availability of modeling results from different models can inform planners and decision-makers on future transportation planning.

The proposed planning network database is more comprehensive, inclusive, and integrated, compared to all the existing network databases that we reviewed. It achieves the availability of modeling information and data sharing at the network level through including various transportation data sources, it increases the efficiency to prepare a network ready for modeling, and it reduces the redundancy workloads among multiple transportation agencies. It also has the potential to be extended to support simulation modeling at different resolutions.

The proposed database was validated using a small study area in Gainesville, Florida. A proof of concept procedure demonstrated how the proposed network database structure maintains the planning information, supports the modeling network, and updates the network as planning information is updated during the dynamic process of the transportation planning. Specifically, this proof of concept was able: (1) extract data from the database for a specific scale network; (2) support scenarios in transportation modeling software using extracted data; (3) update the database when (a) a new plan/scenario is added, and (b) a new project is committed or implemented; and 4) compare different models' inputs and outputs in the database. The testing results show the following: (1) the adoption of All Road Basemap (ARBM) makes the multi-scale modeling network possible, which is easy for data sharing and model consistency; (2) using the proposed database framework, one can build a functional database to support multi-resolution and multi-scale modeling.

The planning network database can promote better information sharing, increase modeling efficiencies, improve accuracy, and remove duplications in data collection and processing. This requires continuous collaboration and coordination to support the planning network database that shares the data through all the related agencies and stakeholders. Therefore, it is recommended that the database manager should work in close coordination with each model owner who contributes to model maintenance and updates.

Special considerations should be given to network data source selection which is the basis for the network database. After examining four potential source networks, i.e., FDOT's basemap, FDOT's FDOT All Road Basemap (ARBM) network, Census Bureau's Topologically Integrated Geographic Encoding and Referencing Database(TIGER) streets, and Open Street Map, the research team recommends the ARBM(based on HERE streets) as the most promising network at present because (a) it includes all roads, (b) it contains the FDOT LRS system which makes it possible to access FDOT RCI attributes for modeling purposes, (c) it is updated every 2 to 3 years, and it may potentially be updated yearly in the future, and (d) it is available to be used by all government agencies in Florida without any licensing limitations.

In addition to the data source, the modeling software package should be able to handle the FSUTMS standard, true-shape GIS network data, and should have the ability to read and write to a relational geospatial database.

As next steps toward the implementation of this research, we recommend development of a pilot project to build a functional network database prototype, either statewide or for a selected study area with the least institutional barriers. We recommend partnering with the Turnpike district to create the network prototype that can support both the central's office Statewide model and the Turnpike model and potentially one regional model. Since transit use is an important part of travel demand modeling at the local level, we also propose to expand the database structure with transit information (and potentially some emerging travel modes) to support multimodal planning.

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LIST OF ACRONYMS

ARBM	All Roads Base Map
BMC	Baltimore Metropolitan Council
CFRPM	Central Florida Regional Planning Model
CRTPA	Capital Region TPA Model
CIM	Civil Integrated Management
D1RPM	District 1 Regional Model
DOT	Department of Transportation
DTA	Dynamic Traffic Assignment
ESRI	Environmental Systems Research Institute, Inc.
FAF	Freight Analysis Framework
FDOT	Florida Department of Transportation
FSUTMS	Florida Standard Urban Transportation Model Structure
GIS	Geographic Information System
GTCRPM	Greater Treasure Coast Regional Planning Model
LRS	Linear Reference System
LRTP	Long-Range Transportation Plans
MIXS	Model Information Exchange System
MPO	Metropolitan Planning Organizations
MSM	Microsimulation Models
MTF	Florida Model Task Force
NCTCOG	North Central Texas Council of Governments
NERPM	Northeast Regional Planning Model
NWFRPM	Northwest Florida Regional Planning Model
HPMS	Highway Performance Management System
RCI	Roads Characteristics Inventory
SCAG	Southern California Association Of Governments
SERPM	Southeast Florida Regional Planning Model
STIP	Statewide Transportation Improvement Program
TBRPM	Tampa Bay Regional Planning Model

TAZ	Transportation Analysis Zone
TIGER	Topologically Integrated Geographic Encoding and Referencing Database
TIP	Transportation Improvement Program
UTPS	Urban Transportation Planning System

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1. INTRODUCTION

1.1 Problem Statement

Generally, travel analysis is performed to help decision-makers formulate informed transportation plans and policies. To this aim, a travel demand forecasting model is used to assess changes in travel modes and travel demand for passengers and freights in a specific future time frame and to evaluate the economic and social impacts of transportation improvements, given different assumptions in demographics and traveler behavior. Modeling work is conducted at multiple geographic scales: statewide, regional / metropolitan planning organizations (MPO), and local scales. Normally, models that cover large geographic areas have a coarser spatial resolution than small area models. A Statewide model which consists of high-level roadways, i.e., freeways, arterials, and major urban collectors, is used to analyze the impact of policies and trends that are implemented by state governments but not captured within local urban areas. By contrast, more detailed regional models are used to examine travel patterns within the district areas and to evaluate local investments, which cannot be performed by a Statewide model due to its insufficient spatial resolution.

Although statewide, regional, and local models serve different purposes and are often used by different agencies, they are connected in several aspects. For example, where their geographic areas overlap, these models share the same roadways in geometry and attribute; therefore, sharing roadway information could help reduce duplications in data collection, and more importantly, facilitate cooperation between agencies at different scales (Bejleri et al., 2014). Furthermore, a Statewide model provides regional areas with existing and forecasted interregional travel, which can subsequently serve as input for external trips in urban models. Besides, the results of each model could be validated by comparing them with each other. These realities create opportunities to share information among models at different scales. In order to achieve this objective, there must be an effort to build the connection between the road networks of these models at various scales.

At present, several travel demand models at various geographic scales are operational in Florida. Many of these models have different representations and inconsistent attribute information for the same roadways, which impedes information sharing among them. In the past decade, considerable efforts have been made to promote network consistency. The Florida Model Task Force (MTF) has provided a standardized model framework to promote model integration, and Florida researchers have conducted several studies on network databases

(Bejleri et al., 2006; Bejleri et al., 2014; Gan et al., 2009; Gan et al., 2010). In 2011, FDOT selected NAVTEQ (now HERE street network) to create a unified approach to managing transportation data. Tools and procedures were developed to place FDOT's LRS on NAVTEQ Streets (Knoblauch, 2015). In 2015, the FDOT began to transfer the Statewide model to NAVTEQ. Unfortunately, that process was never fully completed due to limited and non-continuous resources.

On the other hand, there is a trend to model the entire state at the urban level due to the needs for increasingly fine-grained analysis (Donnelly et al., 2017). Due to the emergence of new mobility options and the potential of full-scale operations of autonomous vehicles, the FDOT has started to develop advanced models by exploring the possibility of using new techniques, like dynamic traffic assignments (DTA), activity-based analysis, and microsimulation models (MSM). Since these approaches are very sensitive to network data, creating a highly accurate network with detailed road and traffic information would help the FDOT to improve forecasting capacity in the light of emerging transportation technologies.

1.2 Project Objectives

The purpose of this research is to examine the issues related to the network structure of travel demand models, with an emphasis on the Statewide model. We also aim to identify a more efficient multi-scale and multi-resolution network structure that will enable effective information sharing between the district's or local models and optimize model execution, while preserving the detailed information provided by the finer network segmentation. Such a network will allow modelers to access information from other models at different geographic scopes with increased efficiency when executing travel demand models, while maintaining their model independence. This research develops a framework to reach these goals and explores and test its feasibility for implementation.

More specifically, this research is focused on the following objectives:

1. Conduct a review of the literature to understand better the state-of-the-art efforts for addressing the issues related to model network inefficiencies and examine current models to understand related network data requirements, implementation procedures, and challenges.

2. Explore viable solutions to provide FDOT and related stakeholders with proper methodologies for improving model network structures for more efficient travel demand forecasting. This will lead to better information sharing, increased modeling efficiencies, improved accuracy, and reduced duplications in data collection and processing.

3. Explore the criteria to optimize data from other sources, such as RCI, Safety and Operations, NPMRDS, Bluetooth speed data, etc.
4. Explore the functionalities of travel demand modeling and simulation software packages to test a software-independent network structure.
5. Propose a network database framework to support multi-scale and multi-resolution modeling and use a testing network to show the proof of concept.
6. Obtain input from the Florida Modeling Task Force and related committees, such as the Data Committee and the Advanced Modeling Committee.
7. Provide recommendations for the implementation of the findings and proposed solutions in the practice of travel forecast modeling in Florida to improve and streamline the Statewide model, and eventually, the future regional models.

Ultimately this research is expected to support FDOT's long-term goals and vision. Envisioned as an integral part of the Civil Integrated Management (CIM) framework, this research is expected to improve travel demand modeling and lead to the development and utilization of more effective transportation planning and accelerated project delivery.

1.3 Report Organization

The next chapter presents a review of existing literature to understand the efforts of developing a modeling network framework supporting data sharing. Also, the review includes the previous efforts on the network research supporting multi-scale and multi-resolution modeling. Chapter 3 presents the surveys of the existing practice in Florida and the agencies from other states, as well as the surveys of the needs for a unified modeling network. Chapter 4 proposes the solution of the planning network database that facilitates the multi-scale and multi-resolution modeling. Chapter 5 uses a test network to demonstrate the proposed solution as a proof of concept. Chapter 6 provides conclusions and recommendations for the implementation of the proposed network database framework and discusses concrete next steps toward its full implementation.

2. LITERATURE REVIEW

This chapter consists a review of academic research literature and practitioner's effort in other states and organizations in issues regarding network databases in travel demand modeling, and a review on network conflation and multi-scale/resolution modeling.

2.1 **Modeling Network Research**

Developing an efficient network data management approach for modeling and data sharing has long been an issue of interest to transportation planners. Here we conduct a review of the academic research literature and practitioner's effort in other states and organizations in issues regarding network databases in travel demand modeling. Some of these databases are operational, while some are still in the research stage. We selected six databases, four of which are in Florida.

1. Northeast Regional Planning Model (NERPM) Master Network Database - Florida

The NERPM master network database is one of the first of its kind amongst the travel demand modeling community. Because of its simple structure, the database is found to have the following limitations:

1) Lack of support for advanced network operations (i.e., extract/merge/update). Users have to load the entire master network into the editor before using the filter.

2) Data redundancy: the usage of scenario-specific attributes leads to significant data duplicates.

3) Lack of support for multiple-model storage. As the database was designed to serve one model (NERPM), it is not able to store multiple models, as shown in Figure 2-1.

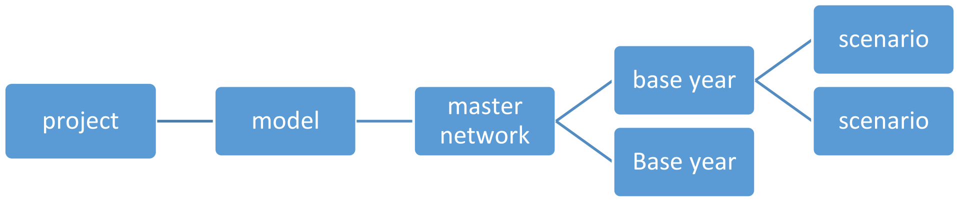


Figure 2-1 Model Structure Tree of the NERPM Master Network Database

2. Prototype Master Network System for FSUTMS – Florida

The master network system developed in the project offers some advantages:

(1) It stores base-year and multiple future-year networks in a single database to facilitate data maintenance and to promote data consistency across different scenarios.

(2) It developed an efficient database structure to manage link modifications, which helps reduce data redundancy. This is because the database only stores the original base-year network and the modified links for each scenario;

(3) The future-year projects could be turned on/off using SQL's "Where" clauses.

However, there are some limitations in the project:

(1) It stores only one base-year network (with its scenario networks) per database, as shown in Figure 2 2. Therefore, it is not able to deal with integrated multiyear base-year networks, nor networks for models at various geographic scales such as a local network and a regional network;

(2) It has no provision to save modeling results for each link in the scenario's network, which prevents the comparison of results.

3. Data Framework for FSUTMS - Florida

The project sets standards for all input data in FSTUMS, which facilitates data consistency and sharing among different models and prepares data for future master network research. However, the master network system used by the project stored networks in a personal geodatabase by model and base year. Multiple databases are needed for different models, as shown in Figure 2-2.

This kind of database structure will lead to data redundancy since the FSTUMS models share the same roadways in geometry and attribute where the geometric areas overlap.

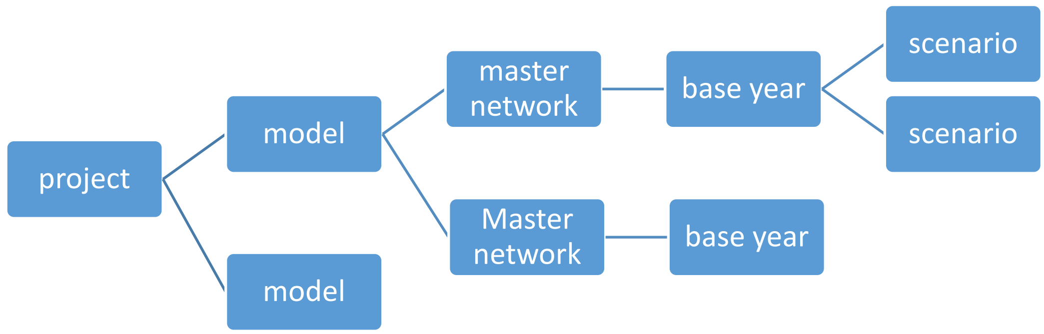


Figure 2-2 Model Structure Tree of the Data Framework for FSUTMS

4. Model Information eXchange System (MIXS) for Travel Demand Models (TDM) – Florida

MIXS is a collection of databases, tools, roles and operations designed to facilitate model information exchange by using a unified network approach.

It has multiple advantages. Specifically, it

(1) Designs a database framework which supports complex relationship and operations;

(2) Supports multi-scale models, multiple base-year networks, and scenarios stored in one master network, shown in Figure 2 5.

(3) Supports network extraction and upload, scenario result comparison.

(4) Reduces data redundancies and promotes data sharing;

(5) Uses a true-shape GIS network (e.g NAVTEQ streets) as the unified streets base map and converts it into a network suitable for travel demand modeling.

There are some limitations to the MIXS's proposal:

(1) Lack of node management. The project does not consider network node management, as nodes could be handled by the software. However, recording the endpoints, even the shape nodes, can help to better manipulate the networks;

(2) Although the upload process is expected to be automated, some manual work is needed in the upload process. Due to the complexity involved, a small percentage of

changes may not be successfully detected.

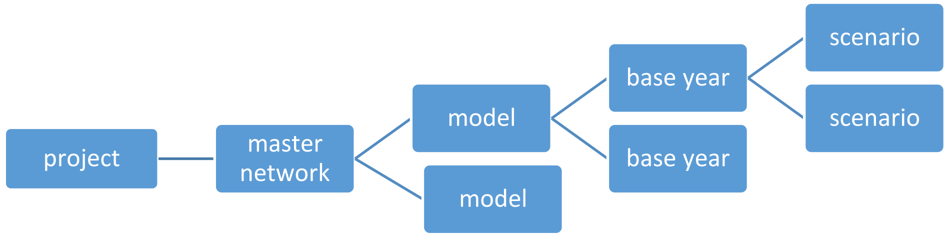


Figure 2-3 Model Structure Tree of the MIXS

5. Baltimore Metropolitan Council (BMC) Master Network system

The BMC master network system was originally designed for one specific model rather than for multi-model storage, as shown in the tree structure (Figure 2-4). It does not support advanced network operation (i.e., extract/merge/update). Users must load the entire master network into the editor before they can use the filter. However, there are some useful lessons to learn from this project:

(1) It uses two fields, "EffYear" and "ExpYear" to efficiently identify the effective links for each base-year network, which helps preserve the abandoned links by not directly deleting them from the database.

(2) Some advanced GIS applications were developed to manage data editing tasks and to keep them following database design standards.

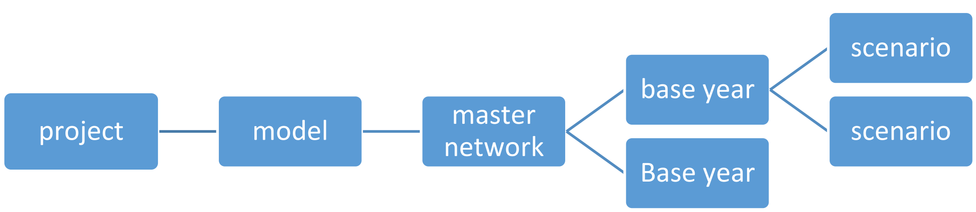


Figure 2-4 Model Structure Tree of the BMC Master Network System

6. North Central Texas Council of Governments (NCTCOG) Multi-Year Network Integrated Databases

The system was designed to support multi-year network integration, but not multi-model storage, as shown in Figure 2-5. Its advantages include:

(1) It proposes a procedure for exporting and merging selected links from the master network to a year-specific travel model network. For example, a highly segmented section of a road could be dissolved into fewer links for modeling. This functionality would help to reduce the run time of the model.

(2) It develops a multi-level structure to facilitate scenario management.

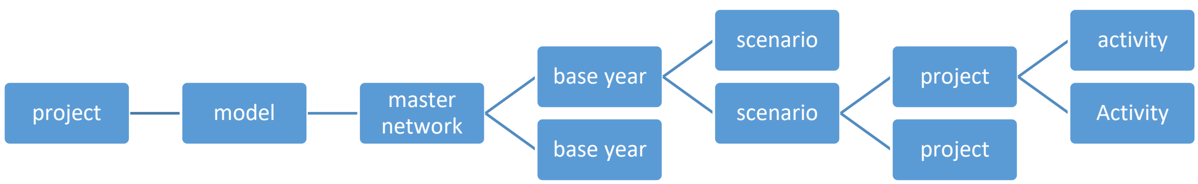


Figure 2-5 Model Structure Tree of the NCTCOG Master Network Database

Considering the complexity of network data maintenance, an efficient master network database with advanced tools is highly desirable to reduce most data editing tasks for the staff in an agency. Through an extensive literature review we found that some efforts have been made within and outside of Florida.

2.2 **Multi-Scale and Multi-Resolution Modeling**

2.2.1 Scales

After reviewing all modeling networks in the FSUTMS, the research team found that there are 9 regional travel demand models in Florida: District 1 Regional Planning Model, Northeast Regional Planning Model, Northwest Florida Regional Planning Model, Gainesville MPO model, Central Florida Regional Planning Model, Tampa Bay Regional Planning Model, Treasure Coast Regional Planning Model, Greater Treasure Coast Regional Planning Model, Southeast Regional Planning Model; 2 statewide travel demand models: Florida Statewide model and Florida Turnpike State Model. These models use their own modeling networks.

As shown in Figure 2-6, there are some overlapped areas among these regional models. For example, the Polk County is modeled in both Central Florida Regional Planning Model and District 1 Regional Planning Model. Also, a majority of links in the regional models are modeled in the Florida Statewide model, and the interstates and turnpike links in the regional models are modeled in the Florida Turnpike State Model.

Currently, no FSUTMS modeling network demonstrates any considerations of the geographically related model networks. The links in the statewide network do not necessarily correspond or overlap with the links at the same geographic location in other regional models or the turnpike model. The links of the overlapped areas in two regional models are built twice independently and may not share the same geometry. This overlap makes the data sharing and information exchange difficult between road networks at different scales. Double or even more efforts are needed for modelers in charge of different models to collect the same information for each model. Also, it is impossible to compare the modeling results such as the projected traffic volumes from the Statewide model and the regional model for the same link. Therefore, this research focused on a unified network supporting the multi-scale modeling for more efficiencies in travel demand models.

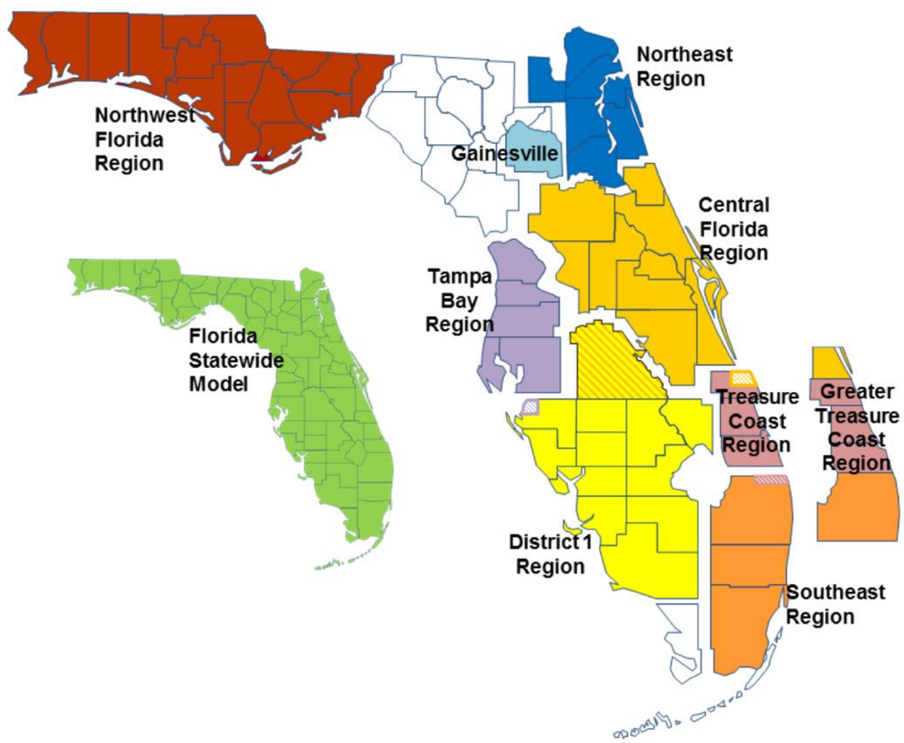


Figure 2-6 Statewide Regional Planning Model Coverage (updated in 2019)

2.2.2 Resolutions

All the models mentioned above are travel demand forecasting models, which use the macroscopic traffic flow relationships to relate the travel information to network links. We refer these travel demand models as the macroscopic models. They usually model the traffic impact link by link on the network, instead of considering the individual vehicle flows. Therefore, the macroscopic models are less complicated and less time consuming, and they require less information and generate less detailed results.

Mesoscopic and microscopic modeling analyze the network in a much-detailed level than the macroscopic models. Microscopic models usually simulate the movements of individual vehicles based on car-following, lane-changing and gap acceptance theories. More detailed information is needed to accommodate the microscopic models. Thus, the microscopic models are always limited within a relatively small network in size. Mesoscopic models need more detailed traffic information than macroscopic models but less detailed information than microscopic models. Mesoscopic models simulate individual vehicles or packets but calculate measures with the macroscopic traffic flow relationships.

Mesoscopic and microscopic models usually use their customized network that is highly dependent with the modeling software. To create a unified network supporting multi-resolution modeling is very difficult considering the detailed information that microscopic models need.

2.3 **Conflation Methods**

Generally, network conflation consists of two components: feature matching and feature transformation. Most literature focuses on the first component, which involves the identification of features in multiple datasets regarding their similarities of geometry, topology, attribute or their combinations (Li et al., 2011). In the past, several algorithms and methods have been proposed.

Sester et al. (1998) explored three approaches for matching features in different data sets, all of which depended on methodologies from artificial intelligence. Walter and Fritsch (1999) presented an automatic approach which constraints geometric similarity by an angle difference of less than 30^{o}. To annually facilitate congestion management, Li and Goodchild’s research (2010) formulated a new algorithm to link geographical features in different spatial datasets automatically and simultaneously, which could be solved by an optimization model with the objective function of minimizing the total distance of all pairs. Green et al. (2013) created a mechanism that aims to conflate networks between the commercial vendor network data and the HPMS network. The private vendor network data were converted into a point layer with all information, and then snapped to the transportation network. Unfortunately, the accuracy of feature matching was exchanged for simplification, which resulted in large losses of geometric information. Therefore, this method could not be used for networks with very complicated geometries. Beeri et al. (2005) investigated two location-based join approaches to conflate three spatial datasets, which could be applied to a join of any number of datasets. Safra et al. (2006) explored an approach that matches pairs of polylines merely on locations of their endpoints rather than whole lines. The method has high efficiency and low dependency on roadway attributes and topology. It works well for complete overlap and extension relationship of polylines, while containment or partial-overlap would not be well recognized.

In summary, most published feature-matching methods achieved very high percentage of correct identification. The successful matching rate of Li's (2011) test was 97.18%; Safra's (2006) research showed that the highest precision of the approaches was 100%. Probably, it is because those methods have adjusted based on the nature of the test datasets. In addition, considering that few of those methods has ever been tested on a variety of test datasets due to lack of resources, it is very possible that the precision will decrease if the method is applied to a dataset with different structure or source. Therefore, they cannot be used universally. In practice, fully automatic conflation, which could be applied to actual GIS datasets, cannot be completed yet. Some manual work or postprocessing steps are usually required.

2.4 **Summary of Findings**

This chapter presents the findings from an extensive literature review on the current research or practice in modeling network development and conflation methods. The research team reviewed a broad range of papers, reports, and other documents that are most relevant to issues the research team addressed in this project. Considering the complexity of network data maintenance, an efficient master network database with advanced tools is highly desirable to reduce most data editing tasks for the staff in an agency. Our review of the literature and practice indicates that some efforts have been made within and outside of Florida.

Six master network systems were reviewed in this chapter. Each of them has its own features, advantages, and limitations in functionality and design approach. Some of them can handle more advanced operations; for example, BMC's Editor Extension could help automatically keep design standards during the editing process; meanwhile, the MIXS supports modeling result comparisons among scenarios of multiple models. However, most of the systems were originally developed for a specific agency, which means many do not support multi-model storage. The MIXS is the only system designed for multi-scale modeling network integration. Furthermore, three of the systems use true-shaped GIS networks for modeling. The MIXS proposed a single unified master network for modeling purposes.

After reviewing the different models in Florida, the research team found that network inconsistency among the models is one of the barriers that prevents efficient data sharing. Building a unified master network will benefit different agencies by saving a lot of effort in data collection and maintenance. In addition, because mesoscopic and microscopic models require highly detailed network data and use of their customized networks usually depends heavily on the modeling software, this research focused on finding the core attributes for mesoscopic and microscopic modeling and connecting them to the unified modeling network data structure.
For network conflation, most published feature-matching methods achieved a very high percentage of correct identification. The successful matching rate of Li's (2011) test was 97.18%; Safra's (2006) research showed that the highest precision of the approaches was 100%. Probably, it is because those methods were adjusted based on the nature of the test datasets. In addition, considering that few of those methods have ever been tested on a variety of test datasets due to a lack of resources, it is very possible that the precision will decrease if the method is applied to a dataset with different structure or source. Therefore, they cannot be used universally. In practice, fully automatic conflation, which could be applied to actual GIS datasets, cannot be completed yet, and some manual work or postprocessing steps are still required.

3. SURVEYS OF CURRENT NETWORKS, MODELS, AND SOFTWARE

The research team made a broad survey of the efforts conducted by other researchers and practitioners in and out of Florida to learn about their success and challenges in dealing with network inconsistency. In addition, a survey on the existing practice in FSUTMS network was conducted to help broaden the understanding of and form a suitable solution for the issue in the Florida context. We also conducted a survey to gain a better understanding of the modeling network data structure used in some of the most common modeling software packages.

3.1 Existing Practice (Survey to Other States)

According to a survey conducted by Donnelly et al.(2017), 34 out of 46 the states that responded to the survey operated Statewide models in 2017. The research team contacted 20 state Department of Transportation (DOT) and 8 MPOs to collect information about the state of practice in statewide and regional travel demands' network development process. In addition, two agencies abroad were contacted to examine how their networks were developed. Several questions asked for information on data sources of the modeling networks, issues in using the data, updating cycle, maintenance of the network, and network integration between urban and Statewide models.

Most states and some large MPOs, like Oregon, North Dakota, Florida, Ohio, Michigan and Southern California Association of Governments (SCAG), have developed their own geographic databases, which contain a variety of the themes most commonly used by governmental agencies. As transportation is an important component, considerable efforts have been made to build statewide roadway networks in geodatabases. LRS-based networks support multiple purposes, such as supporting E911 (or NG911), road centerlines, geocoding services, and transportation asset management. As shown in Figure 3-1, 19 of 20 surveyed Statewide models use centerline layer for roadway geography, which are most often linear-referenced for Highway Performance Management System (HPMS), traffic monitoring, and other performance monitoring databases (Donnelly et al., 2017) to obtain network characteristics, such as lanes, speed, and facility type. Private vendors, like NAVTEQ maps and Caliper, are used as sources for network building.

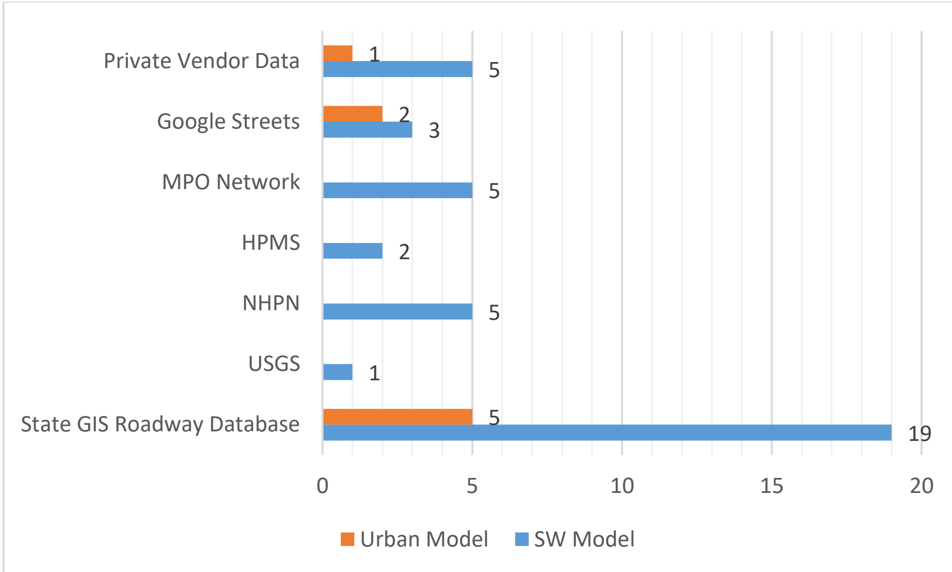


Figure 3-1 Modeling Network Data Sources in Other States

We selected four cases, three Statewide models and one urban model, to demonstrate typical practices of building the modeling network. The lessons learned from the case studies are summarized as follows:

1) Ohio's model is a traditional Statewide model based on the DOT's database. Currently, the agency is trying to build a master network to promote network integration. Their method is to build the network by integrating the MPO networks directly into the master network.

2) Massachusetts is a special case because its Statewide model is maintained by the Boston Region MPO. In addition, the two models have been integrated seamlessly, which made the Statewide model 100% compatible with the Boston Region MPO model.

3) The work for Virginia's Statewide model offers some insights about integrating DOT's database and private vendor's data. It shows that NAVTEQ data has some advantages regarding geographic shape and attribute accuracy. Instead of using MPO networks, building a brand-new master network was suggested.

4) Portland Metro, Oregon, is an outstanding example about successful data sharing and cooperative arrangement with local agencies. In addition, it is one of the few agencies that used private vendor's data as the network's main data source, which means that they have transferred their model to NAVTEQ Streets successfully.

Overall, the survey on the existing practice shows that network inconsistency exists widely across U.S. states and overseas. As discovered by Bejleri et al. (2006), even though considerable efforts have been made by most DOTs to develop unified reference systems of their roadway networks, efficient network data sharing among agencies at different levels has rarely been addressed. Still, there are lots of precious experiences that we could learn from, like Portland Metro's and North Carolina DOT's experience to make use of private vendor's true-shape network, and Ohio DOT' plan to develop a master network. Also, these lessons encourage us to find a more efficient and effective way to promote data sharing among models at multiple scales.

3.2 Existing Practice: FSUTMS Network (by Models)

FDOT has made great efforts to develop a standard structure (FSUTMS) for travel demand models and the corresponding networks at the state, regional and local scales. FSUTMS stands for Florida Standard Urban Transportation Model Structure. The first version of FSUTMS was built in 1978 and it was named the Urban Transportation Planning System (UTPS). This is the time when Florida started to develop networks for travel demand modelling. The method was described in the 1981 report entitled "Urbanized Area Networks Study Task A: Standard Highway Network Procedure Final Report" (Schimpeler-Corradino Associates, 1981). The network was built from scratch based upon the FDOT urban area maps and county maps. The second version was built as a framework using TRANPLAN (a transportation modelling software tool) in 1985. The network was called the TP+ network. Numerous improvements were made in the TP+ model and network. After 2000, FDOT selected Cube Voyage to replace TRANPLAN. The entire model was built from the TRANPLAN version with additional GIS data sources. The network became a Cube Voyager network.

To better understand models and networks in FSUTMS, the research team conducted a survey of stakeholders involved in the development and the use of FSUTMS. An in-depth questionnaire was sent out through the district modeling coordinators to the model developers and consultants. Questions addressed the procedures for obtaining the network data sources, processing the relevant data, building and updating the network, and the challenges of exchanging information among models of different scales. In this section we describe the results of the survey along with a summary of current issues of the FSUTMS networks.

The questionnaires were directed to the following stakeholders: district modeling coordinator, model developer / consultant and end user / planner.

3.2.1 Challenges with Data Sharing

Below is the summary of the questionnaire answers regarding data sharing among models of different scales.

1) Network Conflation

The biggest hurdle when sharing data across networks and scales is that model networks and GIS data sources don't always represent the same link in the same way. One network may represent a link which is two miles long, where the other represents the same link as two one-mile links with an intersecting road that the first model does not include. Furthermore, very rarely will one linear shape overlay exactly on top of the other with the same shape points. In GIS, this is best handled through a conflation technique. Nevertheless, conflation techniques are still very rarely performed in a fully automated manner with great results, unless the two sources are closely related, such as one being a spatial copy of the other with only minimal link break differences. When two networks are nearly identical spatially, conflation techniques must still look for the nearest matching link in order to share its information. A crossover link id shared by both sources is about the only way to directly share data through a common process. In the absence of these, buffering the links and using automation to eliminate undesirable matches may also be a possible conflation technique, but manual edits would still be needed to ensure the best matches.

2) Need to Incorporate the Statewide model

Some modelers and consultants showed skepticism about the need to incorporate the Statewide model, or other models from different scales, because the regional models are more detailed and refined and therefore don't have much to benefit from the Statewide model.

3) Preferred Data Format for Data Sharing

The best format is still the most relevant GIS data that can be thematically color coded for visualization of new data locations or changes in attributes across multiple layers. Using GIS tools for overlaying and matching data layers go a long way to making any necessary corrections to existing networks, but the final edit is still usually best judged by the model developer.

3.2.2 Efforts in Using NAVTEQ Network for Modeling

The research reviewed some efforts by FDOT to develop the Statewide model network using the NAVTEQ/HERE basemap in the past.

Adoption of NAVTEQ as the modeling network presents some benefits in comparison to the stick-network that most models are using in FSUTMS. NAVTEQ is a true-shape network and it is updated quarterly. It can be integrated with other GIS based datasets such as FDOT RCI data, Florida Traffic Information System data, INRIX speed data, and Freight Analysis Framework (FAF) data. Additional restricted turning movements, roadway elevations, and points of interests are included in NAVTEQ's data package. Finally, it is a lot cleaner, simpler to update, and more accurate regarding existing and future roadway conditions.

The process was designed to convert a NAVTEQ network for use in the Cube modeling environment and then back to its original format for use in a GIS environment, with the modeled forecasted traffic. The development of the NAVTEQ network involved consultants from several private companies, including BCC Engineering, AECOM, and Moffat & Nichol. However, the Statewide model has not been successful in completely adopting the NAVTEQ network as the modeling highway network. Most of the district modelers only use the NAVTEQ basemap as a source for manually editing the links or verifying their networks. A limitation of using NAVTEQ is the high cost of the conflation from NAVTEQ to a Cube modeling network and the data updates are not efficient. The purpose of the NAVTEQ is for mapping and navigating, but it is not fitted for transportation forecasting. Based on these limitations, some of the modelers do not prefer to use NAVTEQ as the modeling network in travel demand models.

3.3 Modeling Network Survey (District)

The research team conducted a review of all the relevant networks in the FSUTMS models. The table (Table 3-1) below presents a summary of the information collected.

3.3.1 Network of the Statewide model (FLSWM)

Connecting zones together is a representation of the transportation network in FLSWM within and around the state. Including all minor roads is unnecessary, because there is insufficient detail in the Transportation Analysis Zone (TAZ) to support assigning traffic counts to minor streets. Details about the included roads (e.g., speed limit, number of lanes, tolls, etc.) are also attached to the road network for the base year as well as any forecast scenario years, although in many cases the attributes will not change over time. Additionally, roads can be flagged to be added or removed from the network for future scenarios and for membership in a variety of categories for summary analysis (e.g., by District, County, or Corridor) (Cambridge Systematics, Inc., 2018).

Table 3-1 Summary of Networks in FSUTMS Models

District	Model	Alias	Level	Covered Area	Key Features
State	Florida Statewide model	FLSWM	statewide	statewide	
State	Florida Turnpike State Model	TSM	statewide	statewide	
1	District 1 Regional Planning Model	D1RPM	regional	12 counties	
2	Northeast Regional Planning Model	NERPM	regional	4 counties	Activity based model
2	Gainesville MPO Model	--	local	1 county	
3	Northwest Florida Regional Planning Model	NWFRPM	regional	All 16 counties in District 3	
3	Capital Region TPA Model	CRTPA	local	4 counties	
4	Greater Treasure Coast Regional Planning Model	GTCRPM	regional	5 counties	Accident analysis based
4 & 6	Southeast Florida Regional Planning Model	SERPM	regional	3 counties	Activity based model
5	Central Florida Regional Planning Model	CFRPM	regional	9 counties; 2 counties parts	V5 true-shape network
7	Tampa Bay Regional Planning Model	TBRPM	regional	5 counties	True-shape network

3.3.2 Network of the Regional Models

1) District 1 Regional Model (D1RPM)

The District 1 Regional Planning Model (D1RPM) is one of the larger models in the state. The most updated D1RPM V1.0.3 covers 12,400 square miles in a twelve-county area. It represents the travel characteristics of a population of approximately 4.1 million. It is a traditional four-step trip-based model. Since all of District 1 is in one model, it is possible to forecast regional highway and transit alternatives by all MPOs in District 1 for their LRTPs (Collier Metropolitan Planning Organization, 2016).

Some unique features of the network include a cost-feasible future scenario that contains all the roadway improvements proposed in the LRTP. The attribute “LRTP_KEY” allows the users to include or exclude proposed roadway projects over the lifetime of the model. This has proved to be a great time-saver allowing proposed improvements to be easily shown graphically. The D1RPM also made some efforts to incorporate autonomous vehicles (FDOT Forecasting and Trends Office, 2017).

2) Northeast Regional Planning Model: Activity-Based (NERPM-AB)

The Northeast Regional Planning Model: Activity-Based V1.0 (NERPM-AB) is a new and sophisticated regional model to help the North Florida TPO and its partners develop more insightful analyses. Based on the DaySim activity-tour framework, NERPM-AB v.1.0 has a more complicated structure than a traditional trip-based model. For instance, the model has many more components that need to be calibrated, and requires greater levels of data segmentation.

NERPM-AB V1.0 covers 4 counties in Jacksonville Metropolitan Area. The AB model is more sensitive to changes in networks. To incorporate the network in the AB model, the highway network needs to be recorded for the link attributes, intersection turning penalties, and speed-capacity tables. The highway network, referred to as the all-streets network, is a detailed GIS network developed from NAVTEQ data. Land-use parcel and transit-stop locations are associated with the nearest node in the all-streets network. The enhanced all-streets network with transit stop locations is then combined with the land-use parcel file, which also includes employment data by various industry types. This combined network creates a variety of urban form variables that measure the accessibility of parcels to households and employment. The AB modeling software DaySim uses these variables in different parts of the modeling process (Resource Systems Group, Inc., 2015).

3) Northwest Florida Regional Planning Model (NWFRPM)

The NWFRPM has been updated to include all 16 counties in District 3. This NWFRPM V3.0 includes updated socio-economic data, networks and the inclusion of mode choice and transit (FDOT Forecasting and Trends Office, 2017). The previous versions of networks in NWFRPM all followed the FSUTMS standards.

4) Greater Treasure Coast Regional Planning Model (GTCRPM)

The networks in GTCRPM follow the FSUTMS standards. GTCRPM V3.4 includes a safety analysis based on crash reports provided by the FDOT Traffic Operation Office. Two additional attributes "COR_ID" (corridor number) and "MEDIAN" (median type) are included in the highway network (FDOT Forecasting and Trends Office, 2013).

5) Southeast Florida Regional Model (SERPM)

SERPM V7 started to incorporate ABM in the traditional four-step trip-based model. The ABM operates on smaller micro-zones, which relied on TAZs. SERPM V7 completes a series of network processing routines to prepare the network for modeling. Included in the network processing step is the identification of transit access point nodes. The highway and transit networks are then skimmed to produce network level-of-service matrices for use in the model (Parsons Brinckerhoff, Inc.; The Corradino Group, Inc., 2016). The most current SERPM V8 Model and the network are in development. The NAVTE /HERE data is used as one of the GIS data sources for the speed data in the model (Milkovits & Liu, 2017).

6) Central Florida Regional Planning Model (CFRPM)

CFRPM V5 utilizes the true-shape network for modeling. The network was built as a true-shape GIS-based network, improving the accuracy of the model in terms of the calculated distances of roadways. This improvement results in a travel demand model that performs better and produces more reasonable forecasts. The development of the true-shape network began with the CFRPM V4.5 network in 2000 and included cooperation between FDOT District 5 and MPOs/TPOs to include all roadway capacity improvements that were added to the system between 2000 and 2005 to update the highway network to reflect 2005 roadway conditions. These improvements were then used to develop input speeds and capacities for the model. (Gannett Fleming, Inc., 2010).

7) Tampa Bay Regional Model (TBRPM)

TBRPM V8.0 developed the network for speeds and link travel times using the true-shape distances derived from the ArcGIS shapefile. The associated Base Network shapefile "Base_YYA.shp", is needed in each scenario input directory which holds the original true-shape coordinates and distances. These distances are transferred to the highway network when the network is built from the shapefile. The "True Shape" option in the Cube Network window should be used during network editing for proper display of the network link geometry. This allows for proper graphical display in Cube and helps keep the network to a minimal number of links for efficiency (FDOT Forecasting and Trends Office, 2015).

3.3.3 Network in Local Models

1) Gainesville MPO Model

The Gainesville MPO Model was one of the first four-step trip-based Cube models developed in Florida. Private consultants and MPO staff built the highway and transit network, edited the geometry and attributes from GIS database to Cube. The current version of the Gainesville MPO model was updated and validated in 2015. Network characteristics (number of lanes, area type, and facility type) were updated to reflect 2010 conditions of the roadway system throughout

Alachua County. Based on the feedback received, a series of network alternatives were developed and tested to determine how the future transportation network might function under various scenarios reflecting different strategies for improving mobility (HDR, Inc., 2015; The Corradino Group, Inc., 2005).

2) Capital Region TPA Model (CRTPA)

The CRTPA model is a four-step trip-based model. The network was built by consultants using the existing base year model and updating the network. Roadways outside of the CRTPA boundary are coded at a lower level of detail than those inside the boundary. In general, local roads are not included in the highway network outside of the CRTPA boundary (RSH, Inc., 2010).

3.4 **Software**

Although the focus of this research is to develop a software-independent efficient modeling network that that can support for the demand modeling and planning, we conducted a review to help us develop a better understanding of the modeling network data structure used in some of the most common modeling software packages. Knowing the most typical modeling network characteristics commonly used in such software packages will inform the rest of our research to find solutions that are feasible to be implemented in modeling practice in the state of Florida and sustainable in the long run as modeling packages could change over time. To accomplish this goal, we selected five modeling packages. We were not able to examine some features of interest of the trial packages, and so we supplemented our review by using additional sources, such as software's user guide and online community. Table 3-2 presents a summary of the review in terms of the software features of interest.

1) Cube (student version)

As shown in the table, Cube supports the FSUTMS standard in every aspect because it was chosen as the software package to develop the FSUTMS standard by FDOT. Cube uses the node-link structure, and all the additional files required by FSUTMS, such as turn penalty, toll, and transit, are consistent with this data structure. The additional files are all supported by text editors, making it easy for viewing and editing. Cube develops the GIS window, creating a seamless data editing process between GIS and Cube files. GIS files can be directly edited in the Cube GIS window and edited using Python scripting. The true-shape display capability connects the stick network from Cube with the original GIS data, making the modeling computation more accurate.

2) Visum (fully licensed)

Visum supports the node-link structure that is defined in the FSUTMS standard, as well as the reference tables, including turn penalties/prohibitors and tolls. One of their differences is that Visum treats centroids and centroid connectors separately from nodes and links. Moreover, Visum uses a new concept, the permitted transport system, to manage the network objects, including links, centroid connectors, and turns. Therefore, additional information is needed before they are used in Visum. Furthermore, with the increasing use of disaggregated networks, Visum's main node is used to handle intersections with dual-centerline roads. In terms of transit, Visum can manage more complicated transit systems than that defined by the FSUTMS standard. In addition, it has been found that a true-shape GIS-based network can be imported into Visum and be displayed well for modeling.

3) TransCAD (demo release)

TransCAD has the same node-link structure as the FSUTMS standard. Like FSUTMS, it treats centroids and centroid connectors as special nodes and links and uses reference tables to manage turn penalties/prohibitors. TransCAD handles intersections with dual-centerline roads by simplifying them directly; however, this causes valuable network information for multi-resolution analysis to be lost. In the context of transit, TransCAD supports the network structure defined in the FSUTMS standard and reads a transit system in the GTFS format.

4) Emme (trial version)

Emme supports the same node-link structure as required in FSUTMS standard. The Emme *.in files are created to store the network information. Like Cube, the Emme *.in files, which are largely used in network and other files, can be viewed and edited in any text editors. This data structure creates considerable flexibility if the Emme network were to adopt the FSUTMS standard. In addition, Emme would create a vivid display for the turns, transits, and other network elements. With the Emme GIS add-on tool, users can view the GIS files directly in Emme.

5) Aimsun Next (trial version)

Aimsun Next differs significantly from the other software packaged, given its focus on the transportation simulation at microlevel. It uses the junction nodes and road sections structure rather than the familiar node-link structure. The Aimsun network allows for more detailed information such as the manipulation of shape of a lane to create a more realistic way to represent the existing network. Aimsun Next prefers users to build the network within its interface. When a network is imported from other data sources, a lot of manual editing is needed to construct every true-shape road section and to manage turns in every junction node.

Table 3-2 Summary of Network Data Structures of Modeling Packages

	Node-link structure	Centroids& connectors	Turns	Tolls	Transit	Special features	Data exchange	Scenario management	GIS data management capability	True Shape
FSUTMS	• Use node-link as the basic structure •Code FromNode and ToNode in link file;	• Treat as special nodes and links	• Use turn penalty table referenced by node-to-node	• Use toll link table reference by link id	• Use the sequence of node numbers to represent transit routes include other related data such as fares	---	---	---	---	---
Cube	• Use *.net file to store coordinates and attributes of nodes and links	• Treat as special nodes and links	• Use turn penalty *.pen file to represent the turning location and restriction	• Use toll file to represent the location and attributes of the toll	• Use *.lin file to store a sequence of node numbers for transit routes Add a hyphen in front of the node id indicating a stop	---	• Allow the Build network from Shape tool to exchange data between shapefile and Cube network	• Store each scenario in an independent folder Organize the scenario files in subfolders: input and output folder	• Have Cube GIS windows to edit GIS files directly Allow Python script for customized tool	• Have true-shape tool to connect the GIS shapefile and display the true-shape network
Visum	• Use nodes as the endpoints of links; • Code FromNode and ToNode in link file • Define a link always with two directions; • Block a link direction for one-way link;	• Treat separately with links and nodes;	• Treat as a network object with attribute table; • Create Automatically with nodes; • Visually display in the map; • Overwrite attributes using turn penalties/ prohibitors table;	• Code toll amount in link attribute table; • Support using toll link table;	• Use stops and routes as basic objects; • Use Stop hierarchy and line hierarchy to model complicated transit system;	• Use main nodes to handle intersections in disaggregated networks;	• Us shapefile interface to exchange data with GIS	• Consist of project, modification and scenario; • Create scenarios based on various combinations of modifications • Store each scenario result in specific folder;	• have various ways to deal with GIS objects and facilitate network processing for presentation	• Use a tool to facilitate the accuracy of geometry editing

TransCAD	• Use nodes as the endpoints of links; • Code FromNode and ToNode in link file • Close associate links with nodes; • Define two duplicate links for aggregated two-way road;	• Treat as special nodes and links;	• Use turn penalties/prohibitors table identified by link-to-link;	• Code toll amount coded in link attribute table;	• Use stops and routes as basic objects; • Use milepost to allocate stops on routes;	• Deal with linear referenced data; • Simplify intersections in disaggregated networks;	• Us shapefile interface to exchange data with GIS	• Export scenario, and stores the result in a specific folder with its network;	• have numerous technical advances in geographic data management, display, and analysis;	• Use a tool to facilitate the accuracy of geometry editing
Emme	• Use *.in file to store coordinates and attributes of nodes and links	• Treat as special nodes and links	• Use *.in file to store the turning locations and attributes • Visualize turning restrictions on map	• Provide the toll tool with the input of the tolling features as a sequence of node numbers	• Contain transit vehicle, transit line, transit segment Use *.in file to store the transit information	• Use mode as an indispensable network element defined when building the network	• Provide the import/export tools for data exchange between shapefile and Emme network • Support GTFS for transit	• Provide the scenario management toolbox Export scenario and create an independent scenario folder with the network file	• Provide the GIS add-on tool to view the GIS files in Emme	• Allow true-shape editing by manually adding control vertices
Aimsun Next	• Use junction nodes and road sections as node-link structure	• Separate from junction nodes and road sections	• Need manual work to edit turns; Have additional elements such as stop lines and meters	• Allow the toll lane defined with e-pass feature or the barrier added	• Contain stops, transit line, transit plan	• Use junction nodes and road section for better micro simulation	• Provide the importer/exporter tools for data exchange between shapefile and Aimsun network • Support GTFS for transit	• Require the scenario type fixed Allow one scenario with multiple experiments	• View GIS files as the base map when building the network	• Allow true-shape editing by manually adding curve points on road sections Allow editing side lanes

3.5 **Summary**

This chapter presents the findings from a broad survey of existing practice of modeling network development across different agencies in the state of Florida and in other states. In addition, the research team conducted a review of the FSUTMS definition and selected five transportation modeling software focusing on network structure.

We found that modeling network inconsistency is a critical issue that widely exists in most U.S. states. The reasons for the network data inconsistency are summarized as follows:

1. Presence of technical challenges in building an efficient database structure that could offer standardized, comprehensive and updated network data specific to modeling at all geographic levels of the state.
2. Lack of efficient data sharing and cooperative arrangement between agencies. Some agencies, especially at the regional or local levels, maintain their network independently, and share data only based on requests, leading to modeling inaccuracy at the upper levels.
3. Lack of awareness. Some agencies are not aware of the existence of this issue or the necessity to solve it due to different purposes between statewide and urban models. As a result, no efforts have been made to address the issue.

After reviewing the highway networks from different scales and extents in FSUTMS, we summarized some common issues among these models in the process of building, updating and validating the network share as follows:

1. A lot of manual work is needed when the model developers or end users add, modify or delete links and link attributes. This is due to the existing data sources not satisfying the modeling requirements. Currently, aerial photography and GIS data are used for reference or alignment in modeling development. In addition, when a new TAZ structure needs to be adopted in the model, the developers need to update all the TAZ connectors manually. This editing work must be done either through ArcGIS or in the Cube environment. Some of the bulk changes can be done through scripting, but inevitably manual adjustments are needed.

2. Disconnection of nodes and links in the highway network that overlaps a transit network easily creates errors in modeling. When the highway network is changed, the transit network needs to be changed accordingly. Currently, these changes are manually performed by the developers or end users.

3. The conflation from NAVTEQ (HERE) basemap to Cube modeling network of the Statewide model has not been completed. Though the NAVTEQ network is cleaner, simpler to

update, and more accurate regarding the existing and future roadway conditions, it is time consuming and the cost could be high.

4. We observed that network data independency has widely existed among travel demand models. Although various efforts have been made to share data, the outcomes are still unsatisfying. Currently, none of the networks in FSUTMS show any considerations for data sharing between different scales of models and the Statewide model. Since the networks were built independently by the model developers at the state, districts or MPOs, model networks and GIS data sources at different scales don’t always represent the same link in the same manner (i.e., the shapes and the segmentations of the same roadway may differ between networks). This discrepancy has been one of biggest challenges for the direct use of GIS networks. Network conflation and manual work is required before sharing the data and exchanging information between models at different scales.

5. Most of the stakeholders in the survey agreed that the true-shape network makes it easier to visually recognize, present and compare the forecast results. Another advantage is that having the true-shape network allows a more accurate computation of link distances, which leads to a more meaningful modeling result. It is better for the multi-resolution modeling as well so that data can flow in both directions among macro, meso, and micro scales. The modeling process doesn't really make much of a difference between using true-shape networks and stick-networks.

In addition, the research team conducted a review of the FSUTMS definition and five broadly used transportation modeling software. We found that these software packages support the data structure required by FSUTMS. In addition, we proposed recommendations to develop an efficient a network structure for demand modeling purpose that should satisfy the following:

(1) The network should be consistent with the FSUTMS standard.

(2) The network should be independent of demand modeling software packages. Additionally, it should be easily viewed and edited in GIS.

(3) The network should support multi-scale and multi-resolution modeling.

(4) The recommendations are included in the last chapter.

4. PROPOSED SOLUTION

In Chapter 4, the research team proposes a planning network database structure to support the multi-scale and multi-resolution modeling. The network stored in a database following our proposed structure is hereafter referred to as a planning network. It is firstly conflated from the ARBM and the previous models. The network database is also updated from different sources, such as HERE links and FDOT RCI attributes. Planning stages such as LRTP, TIP, STIP, and Work Programs are also reflected in the database. The database can export the networks for different scales of models. The network contains the required modeling information and supports transportation modeling in any software packages for building models and scenarios. After the running the models, the modelers can export useful modeling results of the network links back to the geospatial database. The comparisons of modeling results from different models can inform planners and decision-makers on future transportation planning. In this chapter, we will discuss in detail how the network in the geospatial database can support the multi-scale and multi-resolution modeling and how it works with the modeling software.

4.1 **Planning Network Database Framework**

Below (Figure 4-1) is the schema of the geospatial network database. At the core of the database is the Link file, the fundamental element of the database, and represents the proposed unified master network. The Link file is a spatial file that contains the conflated ARBM streets, whose attributes are stored in the Link Attribute table. Also, the Link file is connected to the Project-Link table, which contains the links involved in the transportation planning projects such as the LRTP, TIP, STIP, and Work Programs. The links of a committed/completed project will be updated to the Link and Link Attribute table. The Project table contains the planning projects in LRTP, TIP, STIP, and Work Programs. Modelers can query the links based on the action and effect date from the database and export the network as needed.

After the models are run in the modeling software, the modeling results are returned into the geospatial database for view and further comparison among different models. Therefore, the Scale and Resolution table contains different scenarios built by modelers in modeling software. The link-level modeling results are stored by link ID and scenario ID in the Link Performance table. The Link Performance table is for the planners to query the links based on the scale/model/scenario and compare the modeling results of the same links from different models. The Scenario Link Add file and Scenario Link Attribute Change table contain the temporary network editing in scenarios. The Scenario Link Add is a spatial file as the newly

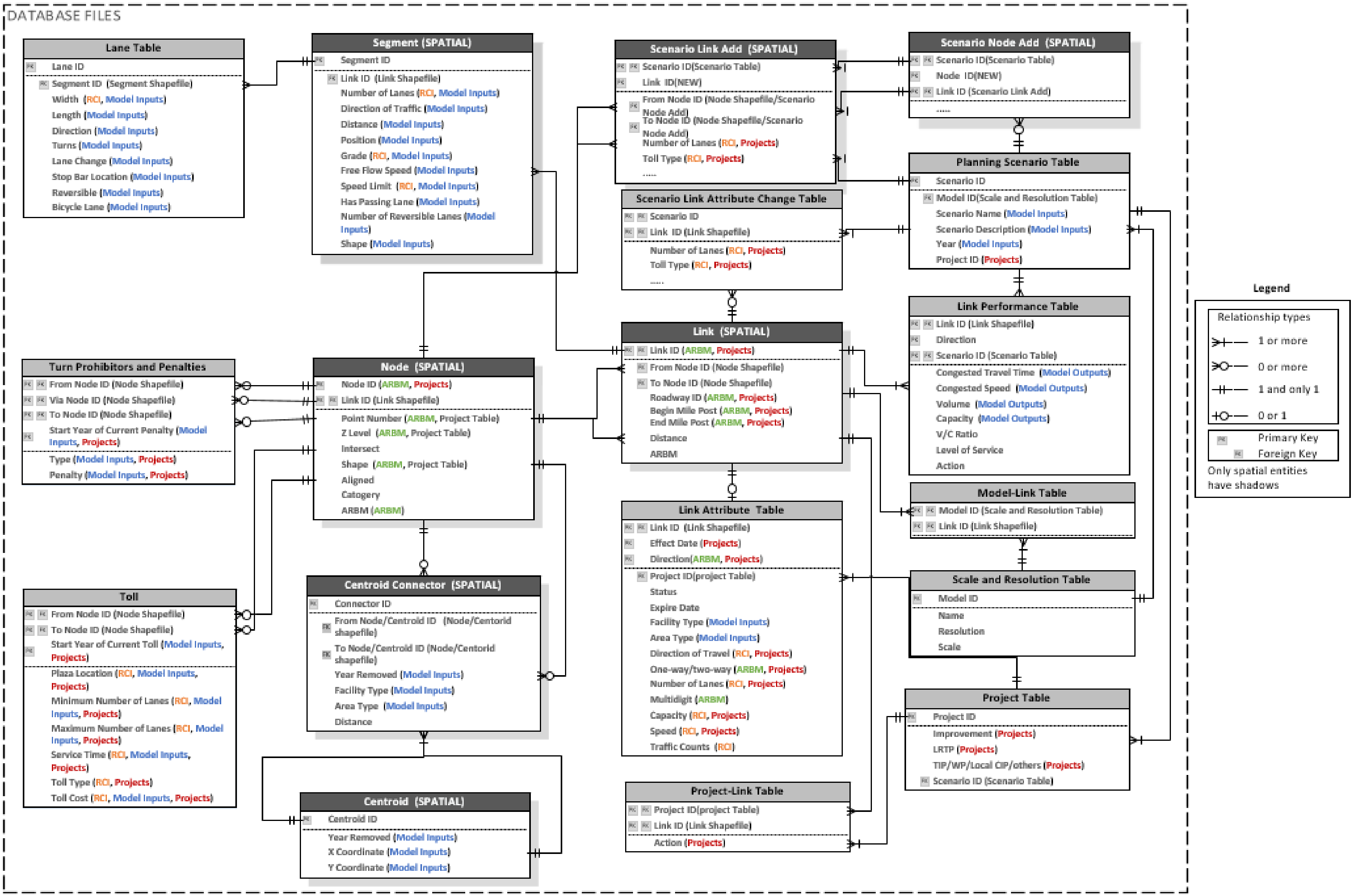


Figure 4-1 ER Diagram of the Geospatial Network Database

added links have new link ID and geographical information different from the links in the Link file.

The Node file is also a spatial file. Even though most mainstream software packages can create nodes automatically when links are imported, the research team still suggests maintaining the node information as the node-link structure. It is because the Toll and Turn Prohibitors/Penalties tables are dependent on nodes and keeping nodes will help data share for multi-solution modeling. The centroids and connectors are stored independently in the Centroid and Connector files, respectively. The Centroid Connector file connects the Centroid file and the Node file. The proposed database structure suggests that these data elements are stored in the geospatial database, but mainly maintained and updated by modelers when they export the selected network for modeling.

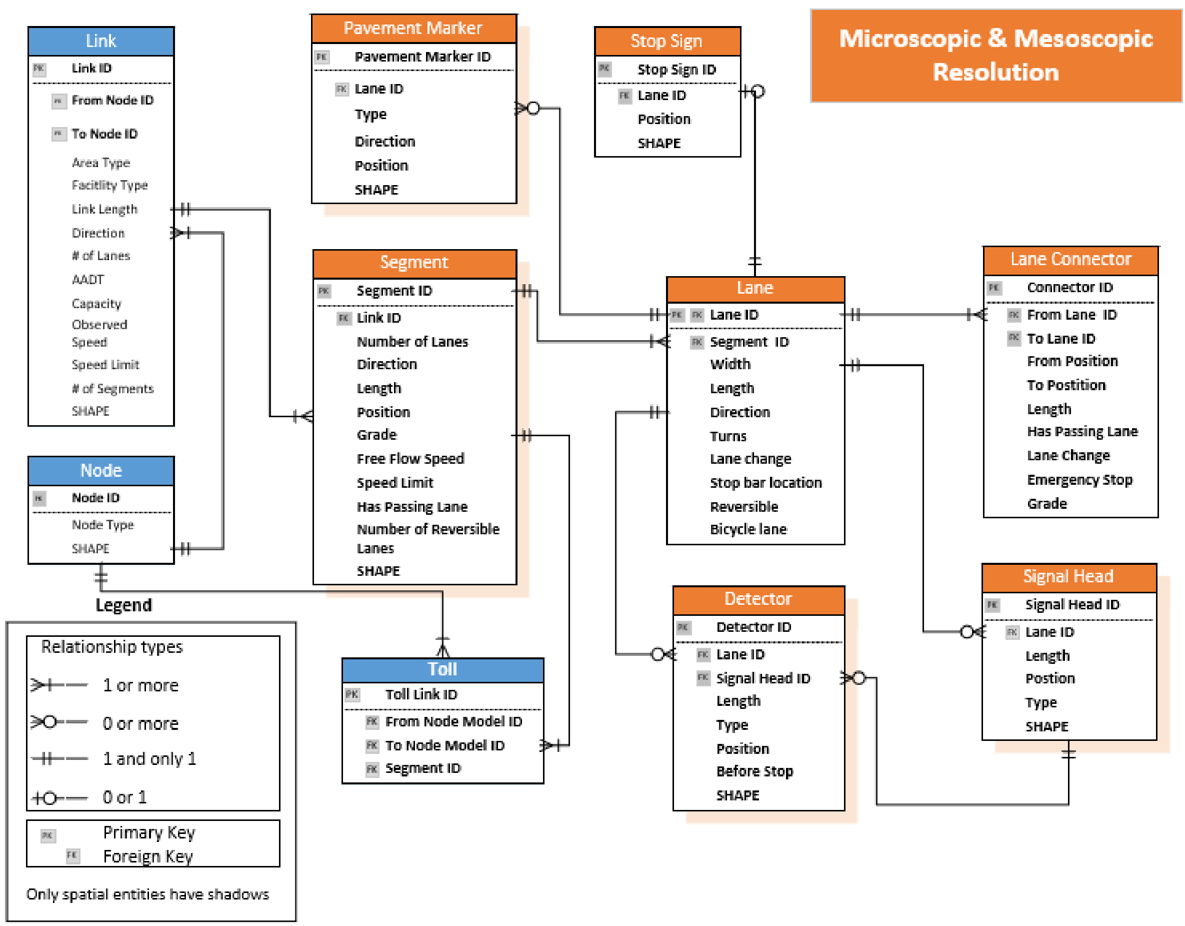


Figure 4-2 ER Diagram of the Microscopic/Mesoscopic Resolution Modeling

4.2 Information Flow between Geospatial Network Database and Modeling Software

The following diagram, as shown in Figure 4-3, shows the information flow between the geospatial network database and the modeling software. The network database supports the multi-scale and multi-resolution modeling. The unified network is stored in GIS format in the geospatial database. It is firstly conflated from the Florida ARBM for the network link shapes and the previous models for the necessary attributes for modeling. The database can export the network for different scales and resolutions of models. Then, in the modeling software, the network can be edited to build the model and scenarios. After running the model, the modeling results stored in the network links can be returned to update the database. Planners can review the modeling results to guide future transportation planning. The network database can be also updated from different sources such as HERE (NAVTEQ) street links and FDOT RCI attributes. Also, planning stages such as LRTP, TIP, STIP, and Work Programs are also reflected in the database.

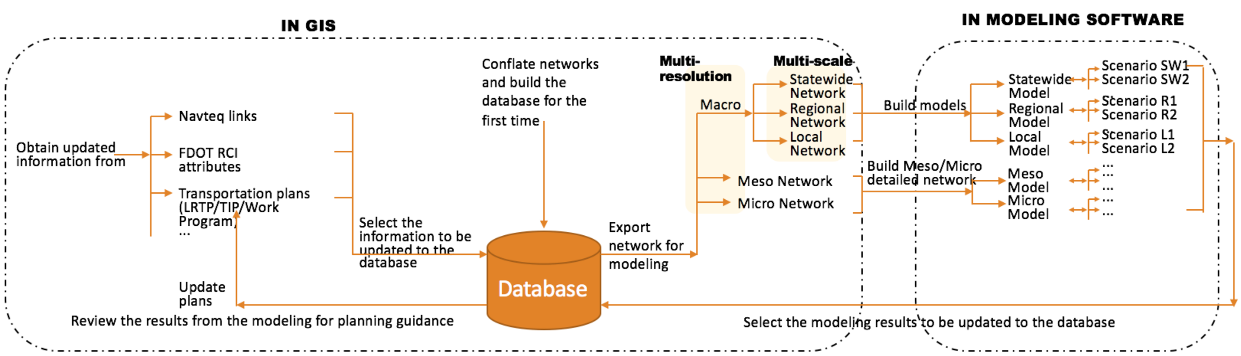


Figure 4-3 Diagram Showing the Information Flow in the Geospatial Network Database

Figure 4-4 further demonstrates the information flow through the GIS database and the modeling software at the macroscopic level. The input files are those extracted from the database, while the output files include the information exported from the modeling software and will be updated to the database. Also, the output, namely the future projections, can provide data support for meso/microscopic modeling.

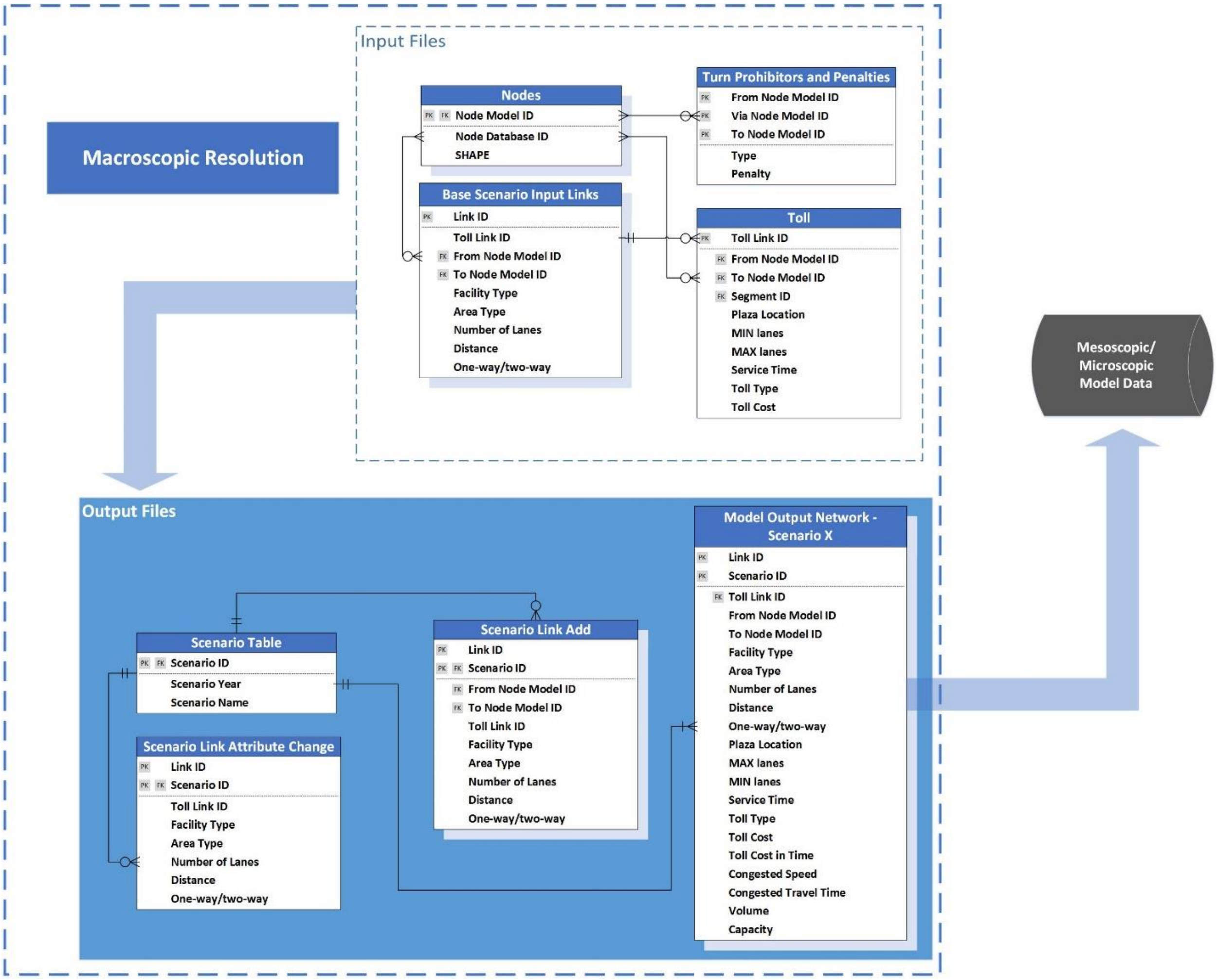


Figure 4-4 Information Flows through Geospatial Database and the Modeling Software at the Macroscopic Level

The update cycle should be considered, as shown in the following diagram. There should be a one-time conflation process to build the geospatial database for the first time. On the modeling side, there is an update cycle that should be every five years for LRTP, annually for TIP/STIP/Work Program, or just on demand when there is a new model built for some area. On the information source side, there are some different cycles, for example, the FDOT updates RCI regularly, and the HERE (NAVTEQ) updates the basemap quarterly.

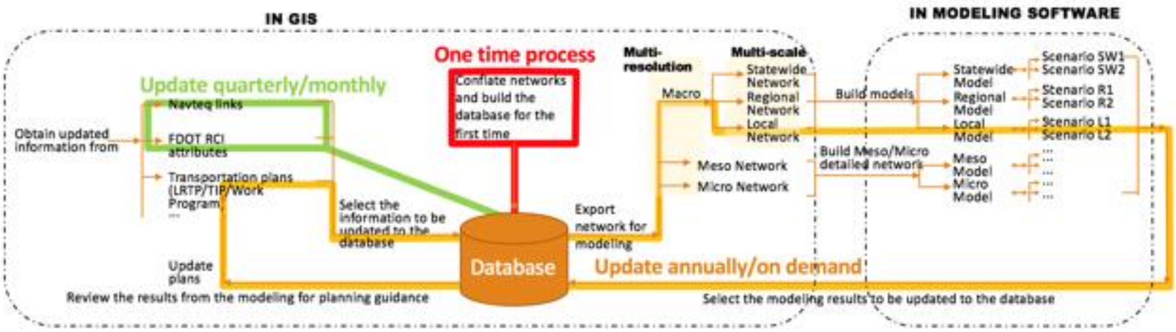


Figure 4-5 ER Diagram of the Update Cycle in the Network Database

4.3 **Database Management Roles and Responsibilities**

Roles need to be set for managing, maintaining, and updating the database. Three essential roles are defined here: database manager, modeler and planner, as shown in the following diagram. Database managers build the database, acquire updated information from various sources, and receive the modeling results from the modelers to maintain and update the database. Modelers export the network from the database and build some specific models at different scales and resolutions. Planners query the modeling results in the database and view and compare results from different models to facilitate transportation planning.

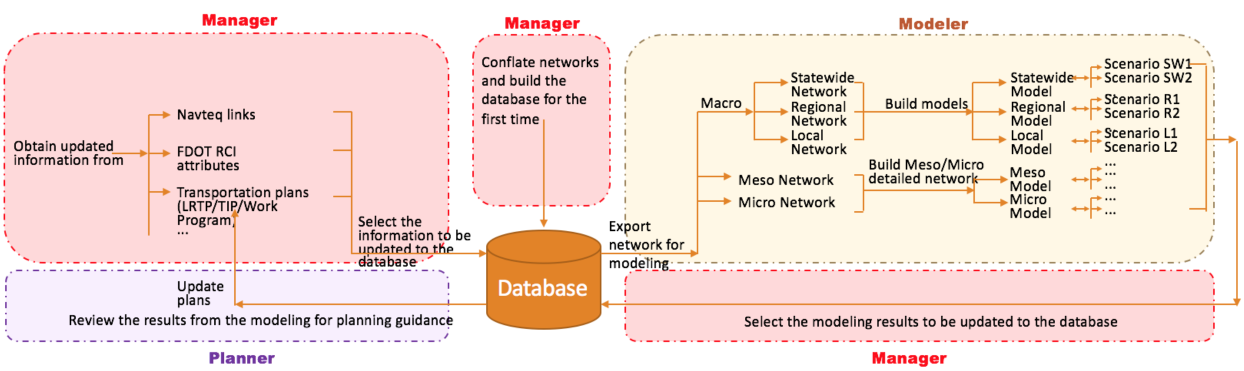


Figure 4-6 ER Diagram of the Management Roles in the Network Database

Here is the list of responsibilities of management roles in the network database:

Database managers are responsible for the management and maintenance of the database. Their responsibilities include:

- Import the conflated ARBM streets to the network database for the first time.

- Update the network database when the new version of ARBM is released.
- Update the network database when the new RCI attributes are updated.
- Update the network database according to transportation plans. The network database should be updated according to new committed/completed projects.
- Modify the attributes in the database if any error is recognized.
- Upload the selected scenarios from travel demand models and results to the database.

Modelers are responsible for model development and maintenance of the modeling related information. Their responsibilities include:

- Query the necessary network for building the models and run multiple scenarios after the one-time conflation is completed.
- Populate the necessary attributes of modeling related data elements (turns, tolls, centroids, connectors, etc.) associated with their models.
- Update the modeling network if the network database has been updated.
- Revise the scenarios based on the feedback from stakeholders. Modelers need to work closely with planners.

Planners review the models and the scenario results to gain planning insights. They have read-only access to the database but cannot modify it. Their privileges include:

- View/Explore the network and modeling results. Planners can view the attributes of each model and compare the results of different scenarios of a given model. They can also compare the future projections of the overlapped network links of different models.
- Extract and download the network and the models/scenarios. They can import the network to ArcGIS or modeling software for further analysis.

4.4 **Summary**

The proposed planning network database uses a unified true-shape network, which includes all public roads, supports LRS to access FDOT's Roadway RCI data, and supports multi-scale travel demand modeling and multi-resolution transportation simulation modeling. The planning network database is more comprehensive, inclusive, and integrated, compared to all the existing network databases that serve as the basis for travel demand modeling. It achieves the data sharing and information exchange on the network level through various transportation data sources, increases the efficiency to prepare a network ready for modeling, and reduces the redundancy workloads among multiple transportation agencies. It also has the potential to be extended to support simulation modeling across various scales.

5. PROOF OF CONCEPT

As a proof of concept, this chapter first demonstrates how to conflate a modeling network to a planning network and how to use and update a planning network database, and then summarizes the main barriers for future implementations.

5.1 **Network Conflation**

Section 5.1 demonstrates how to conflate a modeling network to a planning network. To test the feasibility and explore solutions for network conflation, we completed network conflations for both the 2015 network in Gainesville FSUTMS model and in the Statewide model (only the portion within Alachua County).

Currently, ARBM is the most promising source for modeling network development, so the ARBM links within Alachua County's boundary is extracted and used as the starting point of our planning network. The goal of network conflation is to associate links in the planning network with the corresponding links in the modeling network, so one can transfer attributes between the two networks later. It is a three-step process:

- Step 1

For each planning network link, spatially join all the Cube links within 10 meters' distance of its midpoint.

- Step 2
  - Scenario 1

    If at least one link is successfully joined, associate qualifying link(s) to the planning network link (have the same road name or the angle between them is smaller than 15 degrees). If no qualified link is found, go to Scenario 2

  - Scenario 2

    If no link is spatially joined, find the closest Cube links of the midpoints and check if they have the same road name or the angle is smaller than 40 degrees.

- Step 3

Compare two networks to manually correct errors.

5.2 **Use Database to Support Planning**

Section 5.2 aims to demonstrate how one can extract data from a functional planning network database and then update it as the planning process proceeds. Specifically, this proof of concept is designed to demonstrate the following processes:

- Extract data from the database for a specific network
- Build scenarios in transportation modeling software using extracted data
- Update the database when (1) a new plan/scenario is added (2) a new project is committed or implemented

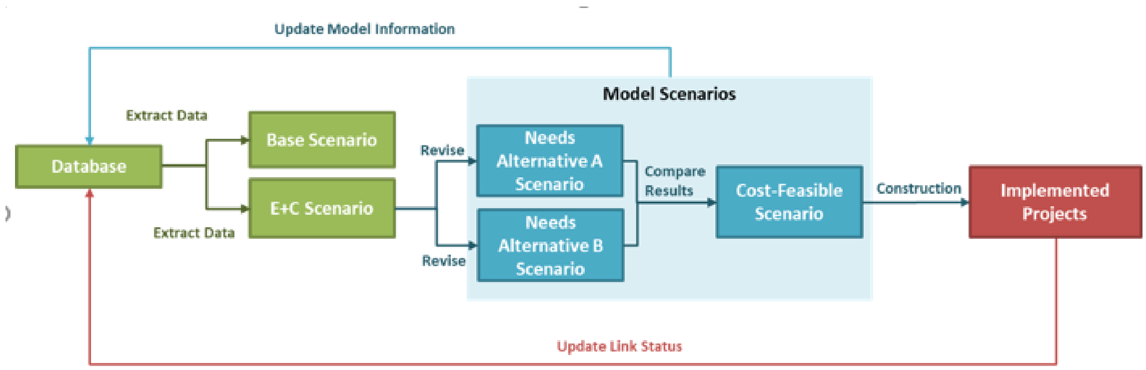


Figure 5-1 Project Design

- Compare different models' inputs and outputs in the database

5.2.1 Project Design

For this proof of concept mini project, the research team selected a small study area located in the northwest of Gainesville to present the following items:

- A review of key database files' existing statuses
- Extracting information for 2015 Base network and 2024 E+C network (2019E & 2020-2024C)
- Importing data into Cube Voyager and build scenarios for 2045
- Database Update
- Comparison of inputs/outputs of the Statewide model and the Gainesville Model

The database framework can also support multi-resolution models, but due to data availability, this proof of concept project only considers two macroscopic models – the Statewide model and the Gainesville model.

5.2.2 Key Database Files in 2019

This demonstration only presents the abovementioned processes using some key database files containing basic link information, project information, and model and scenario information. Other information in the database, such as turn prohibitors/penalties and mesoscopic/microscopic model inputs/outputs can be extracted and updated in a similar manner.

The key database files included in this demonstration are:

(1) Link Feature Class (Figure 5-2)

- Each link is represented by a polyline and has only one record

(2) Link Attribute Table (Figure 5-3)

- Each record contains the attributes of an existing or committed link during a certain time period
- The status/expected status of a link at a given year can be identified based on three attributes: STATUS, EFFECT DATE and EXPIRE DATE.

(3) Project Table (Figure 5-4)

The project table describes the information of projects from TIP, Work Program, local government Capital Improvement Program, and others. For example, Link 1076888185 belongs to Project 2040001, which was committed in LRTP 2040 in 2015 and committed for construction by TIP 2016-2021 in 2016.

(4) Project-Link Table (Figure 5-4)

This is an association table to connect the Project Table and the Link Attribute Table because they have a multiple-to-multiple relationship

(5) Planning Scenario Table (Figure 5-4)

This table stores information on projects committed in LRTP. The attribute TIP_WP_CIP_OTHER indicates whether the project has been committed in TIP, Work Program, local government Capital Improvement Program, and other similar programs.

(6) Scale-Resolution Table (Figure 5-5)

This table stores information on models of various resolutions and scales.

(7) Model-Link Table (Figure 5-5)

This table associates link IDs with model IDs.

Links

OBJECTID *	Shape *	LINK_ID *	FNode	TNode	ROADWAY	BMP	EMP	Shape_Length	ARBM
1	Polyline M	1071065465	207500624	1060224994	26000025	1.0072	1.0471	64.280249	Y

Figure 5-2 Link Feature Class in 2019

Link_attributeT

	LINK_ID	DIRECTION	LANES	EffectDate	ProjectID	Status	ExpireDate	Speed
	105923030	2	2	1/1/1998	<Null>	Existing	<Null>	50
	105923054	2	2	1/1/1999	<Null>	Existing	<Null>	50
Two active records	941945247	2	2	1/1/1946	<Null>	Existing	<Null>	35
	941945247	2	2	1/1/2015	2040002	Committed in LRTP2040	<Null>	30
Inactive record	1076888185	2	3	1/1/2015	2040001	Committed in LRTP2040	1/1/2016	50
	1076888185	2	3	1/1/2016	2040001	Committed in TIP 2016-2021	<Null>	50

Figure 5-3 Link Attribute Table in 2019

Project_LinkT

OBJECTID *	PROJECT_ID *	LINK_ID *	ACTION
1	2040001	1076888185	ADD
2	2040002	941945247	ATTRIBUTE CHANGE

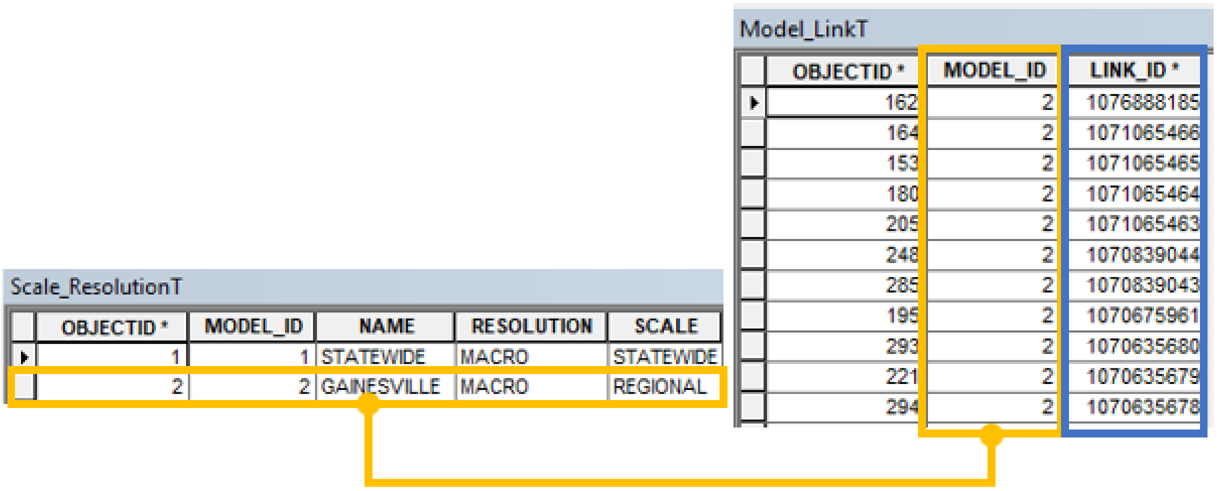
ProjectT

OBJECTID *	PROJECTID	Improvement	LRTP	TIP_WP_CIP_OTHER	SCENARIO_ID
1	2040001	Add a New Road	2040	TIP 2016-2021	2204001
2	2040002	Speed change	2040	<Null>	2204001

Planning_ScenarioT

OBJECTID *	SCENARIO_ID	NAME	DESCRIPTION	YEAR	MODEL_ID
1	2204001	Cost feasible	<Null>	2040	2
2	2204501	Base	<Null>	2015	2

Figure 5-4 Project-Link Table, Project Table, and Planning Scenario Table in 2019



Scale_ResolutionT

OBJECTID *	MODEL_ID	NAME	RESOLUTION	SCALE
1	1	STATEWIDE	MACRO	STATEWIDE
2	2	GAINESVILLE	MACRO	REGIONAL

Model_LinkT

OBJECTID *	MODEL_ID	LINK_ID *
162	2	1076888185
164	2	1071065466
153	2	1071065465
180	2	1071065464
205	2	1071065463
248	2	1070839044
285	2	1070839043
195	2	1070675961
293	2	1070635680
221	2	1070635679
294	2	1070635678

Figure 5-5 Scale-Resolution Table and Model-Link Table

5.2.3 Extract Link Information from the Database

The first step to extract link information from the database is to identify the links associated with the chosen transportation model. In this example, one can retrieve a list of link IDs associated with the Gainesville Model using the Scale-resolution table and the Model-link table (Figure 5-5). Using this list of link IDs, one can then extract corresponding records from the Link Feature Class file and the Link Attribute Table. Because each link ID can have multiple records in the Link Attribute table, the following criteria were used to extract records for the Base 2015 network:

- LINK STATUS is "Existing"
- EFFECT DATE is earlier than 1/1/2015
- EXPIRE DATE is later than 1/1/2015 or is Null

Similarly, to extract link records for the 2024 E+C network, we can use the following conditions:

- 1. LINK STATUS is "Existing" or "Committed in TIP 2020-2024"
- 2. EXPIRE DATE is Null

Figure 5-6 shows the Base 2015 and E+C 2024 network extracted from the planning network database. E+C 2024 network includes two projects adopted in LRTP 2040: adding a new Link 1076888185 (highlighted in yellow) and updating the speed limit of Link 941945247 (highlighted in blue).

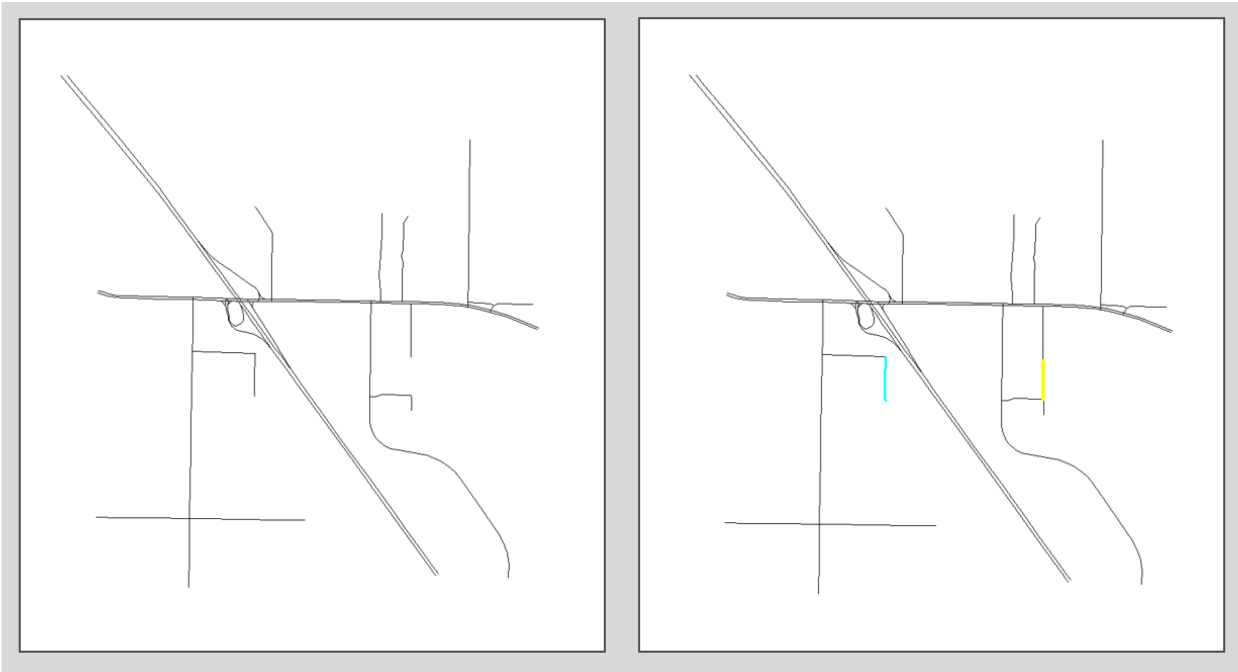


Figure 5-6 the 2015 Base Network (Left) and the 2024 E+C Network (Right)

5.2.4 Build Modeling Scenarios in Cube

Besides Scenario Base 2015 and E+C 2024, we also built two proposed scenarios based on E+C 2024: Scenario A2045 (Needs Alternative A) and Scenario B2045 (Needs Alternative B)

There are two ways to modify the networks for proposed scenarios:

(1) Edit the network in ArcGIS and then export modified network files.

(2) Import the E+C Scenario network into Cube first, copy the network file to new scenarios, and then modify the scenario networks in Cube.

We used the first approach in this demonstration.

Scenario A2045 adds two proposed projects based on E+C Scenario. In the first proposed project, we built a new link with LINK ID 1076888188. This new link has one node on Link 105923030, which splits Link 105923030 into two new links: Link 1076888186 and 1076888187. Link 105923030 is deleted from the network. The other proposed project requires adjustments on the curvature of Link 105923054. Because the link shape is changed, we deleted Link 105923054 and created Link 1076888189 with the proposed curvature.

Scenario B2045 includes one road-widening project on Link 105923030, which only requires a revision in the attribute table.

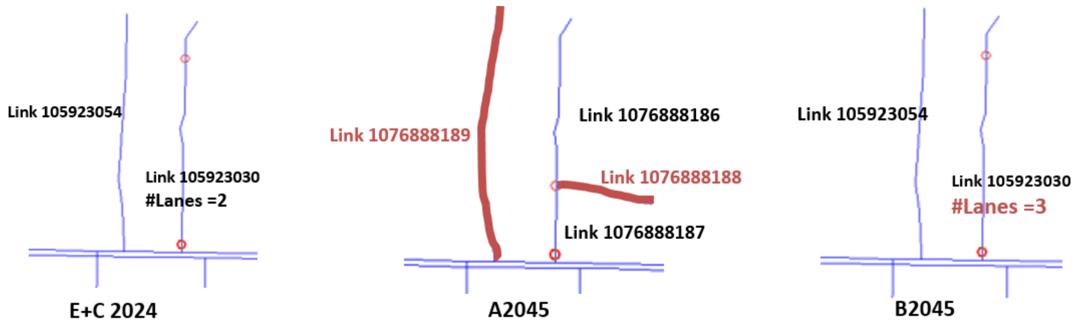


Figure 5-7 Proposed Projects in Scenario A2045 and Scenario B2045

Even though Cube has a True Shape Display tool, it does not use the true-shape network. Therefore, it is important to calculate link distance in ArcGIS before importing it into Cube.

Using the Build Network from Shape tool, we can easily import networks of different scenarios to Cube. To differentiate one-way and two-way links, as well as indicate travel directions on one-way links, we used an indicator field DIRECTION, which was calculated in ArcGIS following the requirements of Cube.

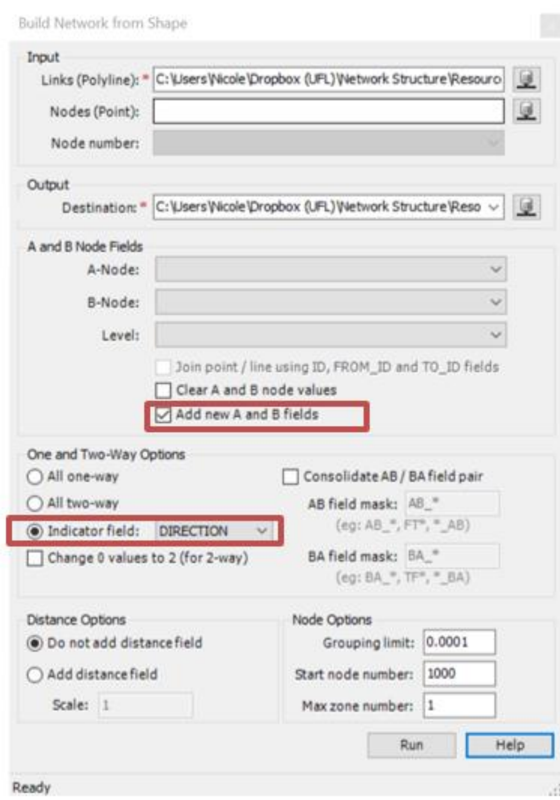


Figure 5-8 Create an Input Network for Cube

Once all network files are created, modelers can build the model and create scenarios.

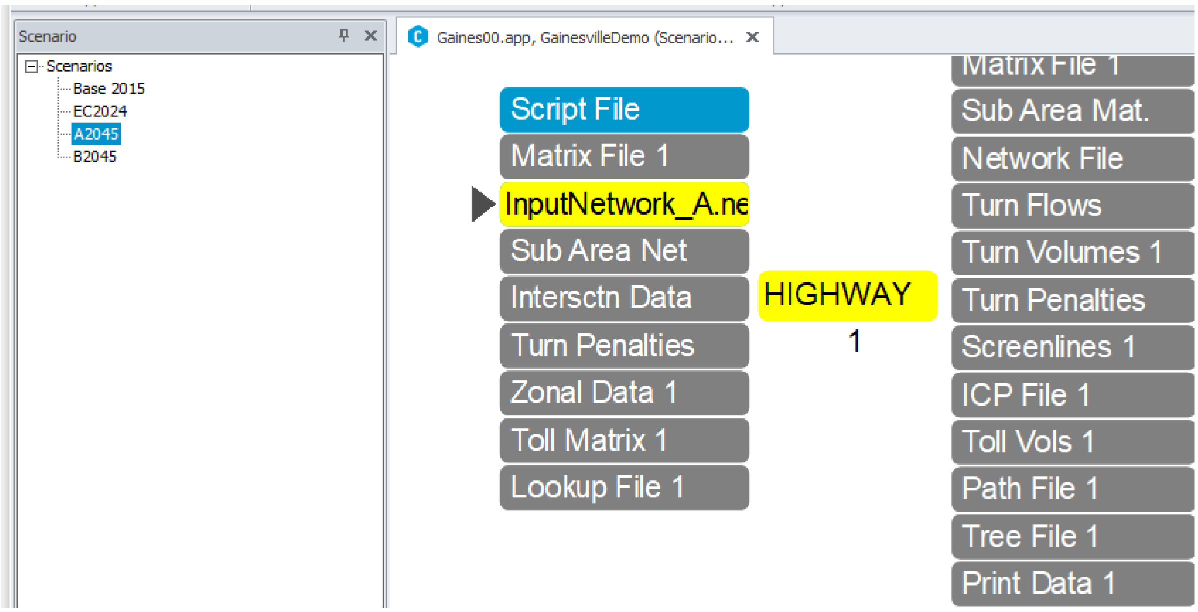


Figure 5-9 Create Scenarios and Link Each Input Network to the Corresponding Scenario

Assuming all other input files are available, and the modelers have successfully run the model, model results will show up in the output network files. For the purpose of this study, we manually created pseudo output network files by adding the fields that are typically generated in Cube. Assuming Scenario A yields better results than Scenario B and is adopted as the Cost-Feasible Scenario for the year 2045, we now have five scenarios in the model: Base 2015, E+C 2024, A2045, B2045 and Cost-Feasible 2045.

5.2.5 Update the Database

The first step to update the database is to exported output network files in Cube to shapefiles with all needed attributes. For instance, Figure 5-10 highlighted the essential attributes that are needed in the Link Performance Table.

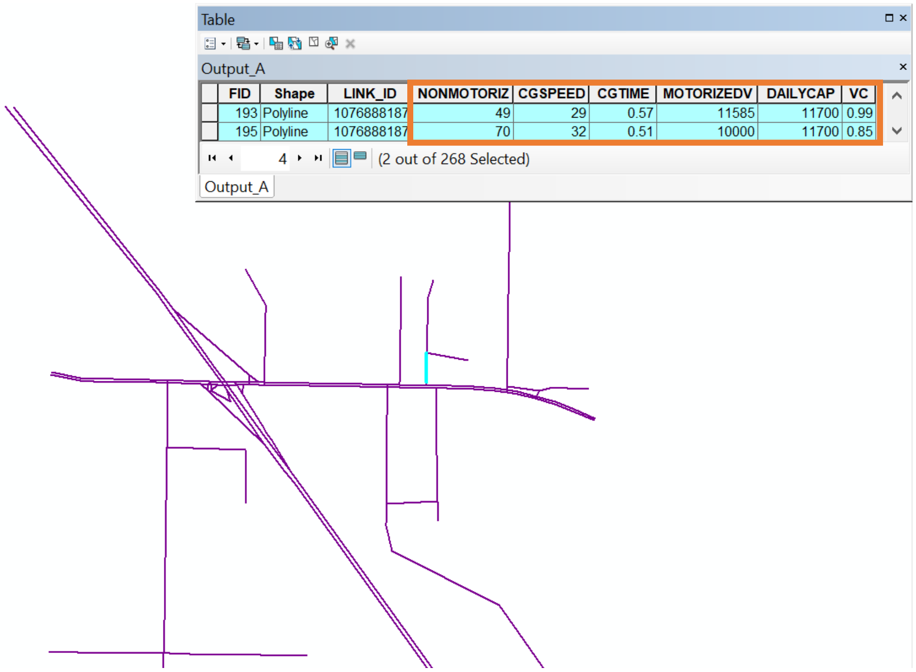


Figure 5-10 Each Two-Way Link Has Two Records in the Output Shapefile

The following tables need to be updated to incorporate information about the new scenarios created earlier:

- A new record needs to be added for each scenario in the Planning Scenario Table (Figure 5-11).

Planning_ScenarioT

OBJECTID *	SCENARIO_ID	NAME	DESCRIPTION	YEAR	MODEL_ID
1	2204001	Cost feasible	<Null>	2040	2
2	2204501	Base	<Null>	2015	2
3	2204502	E+C	<Null>	2024	2
4	2204503	A	<Null>	2045	2
5	2204504	B	<Null>	2045	2
6	2204505	Cost feasible	<Null>	2045	2

Figure 5-11 Planning Scenario Table in 2020

- Figure 5-12 shows some newly added records for Cost Feasible 2045 in the Link Performance Table. The Link Performance Table is designed to store all attributes related to link performance (only VC_RATIO is displayed in Figure 5-12)

Link_PerformanceT

SCENARIO_ID *	LINK_ID *	DIRECTION	ACTION	VC_RATIO
2202405	105923030	1	DELETE	<Null>
2202405	105923030	-1	DELETE	<Null>
2202405	105923054	1	DELETE	<Null>
2202405	105923054	-1	DELETE	<Null>
2202405	941945247	1	<Null>	0.67
2202405	941945247	-1	<Null>	0.67
2202405	1076888185	1	<Null>	0.69
2202405	1076888185	-1	<Null>	0.69
2202405	1076888186	1	ADD	0.75
2202405	1076888186	-1	ADD	0.75
2202405	1076888187	1	ADD	0.99
2202405	1076888187	-1	ADD	0.85
2202405	1076888188	1	ADD	0.74
2202405	1076888188	-1	ADD	0.74
2202405	1076888189	1	ADD	0.79
2202405	1076888189	-1	ADD	0.79

Figure 5-12 Link Performance Table in 2020

- A record needs to be added for each link with updated attribute(s) in the Scenario Link Attribute Change Table (Figure 5-13). The Scenario Link Add Table should be updated in a similar manner with information on new links (Figure 5-14).

Scenario_Link_Attribute_ChangeT

	LINK_ID	SCENARIO_ID	DIRECTION	LANES	Speed
Cost Feasible 2040	941945247	2204001	2	2	30
Needs Alternative B	105923030	2204504	2	3	50

Figure 5-13 Link Attribute Change Table

Scenario_Link_Add

	OBJECTID *	LINK_ID	SCENARIO_ID	LANES	Speed
Cost Feasible 2040	1	1076888185	2204001	3	50
Needs Alternative A	2	1076888186	2204503	2	45
	3	1076888187	2204503	2	45
	4	1076888188	2204503	2	45
	5	1076888189	2204503	2	45
Cost Feasible 2045	6	1076888186	2204505	2	45
	7	1076888187	2204505	2	45
	8	1076888188	2204505	2	45
	9	1076888189	2204505	2	45

Figure 5-14 Scenario Link Add Table

- In the Project table, only the projects in the Cost Feasible Plan are recorded, as highlighted in Figure 5-15.

ProjectT

OBJECTID *	PROJECTID	Improvement	LRTP	TIP_WP_CIP_OTHER	SCENARIO_ID
1	2040001	Add a New Road	2040	TIP 2016-2021	2204001
2	2040002	Speed change	2040	<Null>	2204001
3	2045001	Add a new road	2045	<Null>	2204505
4	2045002	Chage road curvature	2045	<Null>	2204505

Figure 5-15 Project Table in 2020

- The Link Attribute table needs to be updated whenever a link changes status. Figure 5-16 highlighted the links committed in LRTP2045. Assuming in 2021, the construction of Link 1076888185 is completed and Link 1076888189 (Project 2045002) is committed in TIP 2021-2045 for construction, the Link Attribute Table will need to be updated again with highlighted changes (Figure 5-17).

Link_attributeT

OBJECTID *	LINK_ID *	Status	EffectDate	ExpireDate	ProjectID	LANES	Speed
283	105923030	Existing	1/1/1998	<Null>	<Null>	2	50
284	105923054	Existing	1/1/1999	<Null>	<Null>	2	50
635	941945247	Existing	1/1/1946	<Null>	<Null>	2	35
1043	1076888185	Committed in LRTP2040	1/1/2015	1/1/2016	2040001	3	50
1044	941945247	Committed in LRTP2040	1/1/2015	<Null>	2040002	2	30
1045	1076888185	Committed in TIP 2016-2021	1/1/2016	<Null>	2040001	3	50
1046	1076888186	Committed in LRTP2045	1/1/2020	<Null>	2045001	2	45
1047	1076888187	Committed in LRTP2045	1/1/2020	<Null>	2045001	2	45
1048	1076888188	Committed in LRTP2045	1/1/2020	<Null>	2045001	2	45
1049	1076888189	Committed in LRTP2045	1/1/2020	<Null>	2045002	2	45

Figure 5-16 Link Attribute Table in 2020

Link_attributeT

OBJECTID *	LINK_ID *	Status	EffectDate	ExpireDate	ProjectID	LANES	Speed
283	105923030	Existing	1/1/1998	<Null>	<Null>	2	50
284	105923054	Existing	1/1/1999	<Null>	<Null>	2	50
635	941945247	Existing	1/1/1946	<Null>	<Null>	2	35
1043	1076888185	Committed in LRTP2040	1/1/2015	1/1/2016	2040001	3	50
1044	941945247	Committed in LRTP2040	1/1/2015	<Null>	2040002	2	30
1045	1076888185	Committed in TIP 2016-2021	1/1/2016	8/1/2021	2040001	3	50
1046	1076888186	Committed in LRTP2045	1/1/2020	<Null>	2045001	2	45
1047	1076888187	Committed in LRTP2045	1/1/2020	<Null>	2045001	2	45
1048	1076888188	Committed in LRTP2045	1/1/2020	<Null>	2045001	2	45
1049	1076888189	Committed in LRTP2045	1/1/2020	4/1/2021	2045002	2	45
1050	1076888185	Exsiting	8/1/2021	<Null>	2040001	3	50
1051	1076888189	Committed in TIP 2021-2025	4/1/2021	<Null>	2045002	2	45

Figure 5-17 Link Attribute Table in 2021

5.2.6 Compare Model Inputs and Results from the Statewide model And Regional Model

Using Scale_resolution Table and Model_link Table, one can identify the links associated with each model, and then compare both model inputs and outputs from different models.

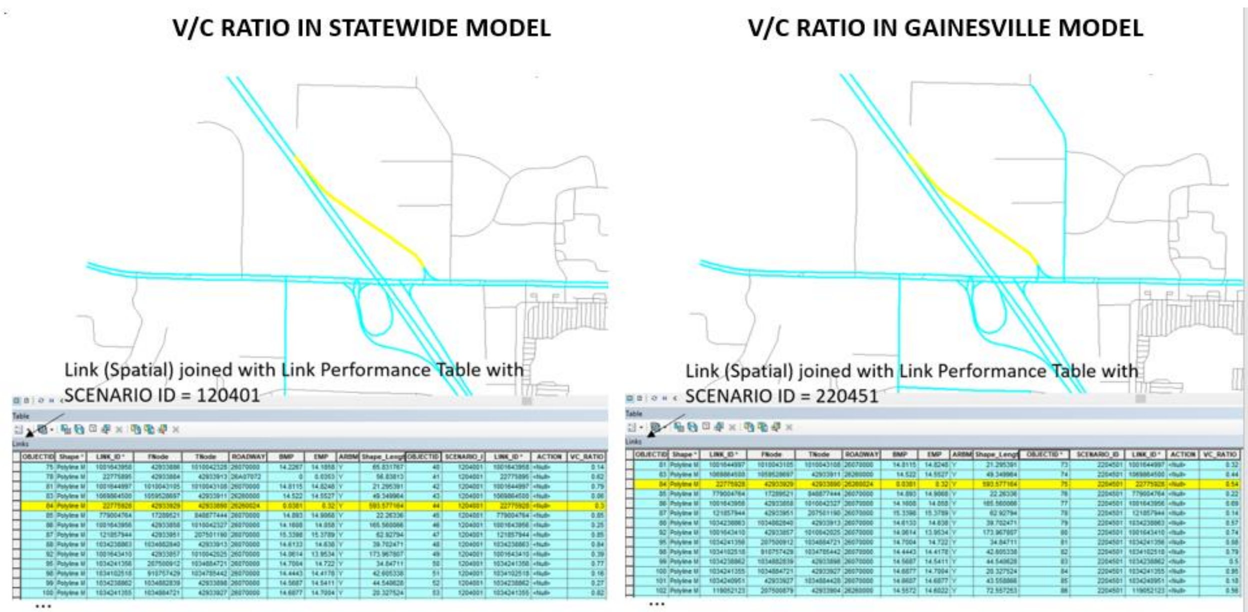


Figure 5-18 Compare Model Results from Two Models

5.3 **Challenges**

5.3.1 Inconsistent Link IDs and Node IDs

Link IDs and node IDs are the unique identifiers for links and nodes. This database compiles data from a variety of data sources, and each data source has its own mechanism to assign node IDs and link IDs. For example, the planning database needs to assign node IDs and link IDs to proposed links if these links are not included in ARBM. When a new version of ARBM is released, different node IDs and link IDs may be assigned to these new links by ARBM, which causes inconsistency and adds workload for updating the database with new information from ARBM.

5.3.2 Inconsistent Definitions of Data Elements

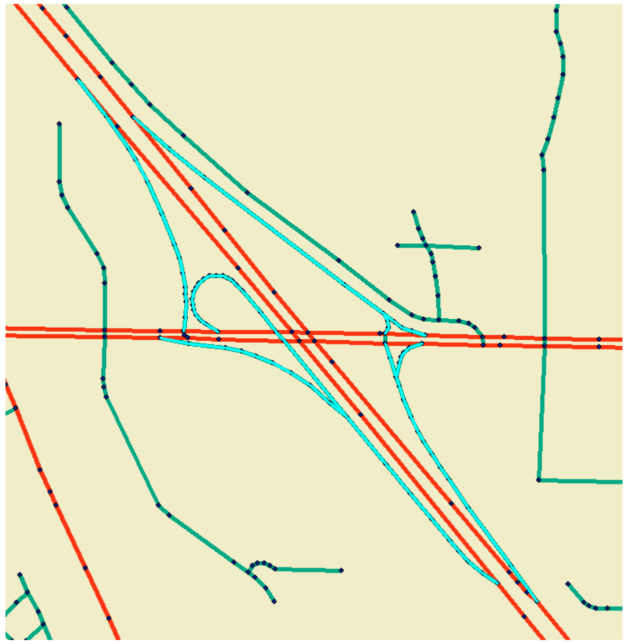
Different data sources (e.g., ARBM, RCI, modeling software) define links, nodes, and other attributes differently. One example is the attribute Number of Lanes: the RCI defines the number of lanes as the total number of through lanes on a roadway, while modeling software such as Cube defines as the number of lanes in each direction. The Cube network also tends to have less detailed information compared to ARBM. For instance, interchanges are simplified as a traditional 4-way intersection, while in ARBM, an interchange also includes several ramps, as highlighted in blue in 

Figure 5-19.

When we used GIS to automatically compile information from multiple sources in the database based on spatial relations or linear referencing system, this inconsistency of definition of data elements often leads to errors in the result. Therefore, a lot of manual work is required to validate and correct the result.

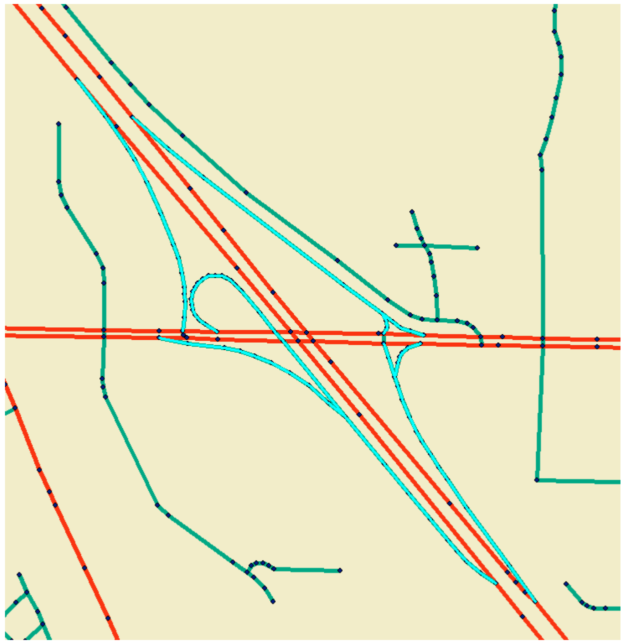


Figure 5-19 an Interchange Example from Gainesville MPO Model Network

5.3.3 Keep the Database Updated with the Most Accurate Information

The database manager needs to keep track of the updates in all data sources, identify the most accurate source of information for each table field, and then update the database accordingly. The workload of updating the database will increase as more data sources are added.

6. CONCLUSIONS AND RECOMMENDATIONS

A summary and the conclusions of the research are presented below, which are followed by some recommendations for database development and management.

6.1 Summary and Conclusions

The goal of this study was to develop a planning network database, using a unified true-shape network that includes all public roads, supports Linear Referencing System (LRS) to access the FDOT's RCI data, and supports multi-scale travel demand modeling and multi-resolution transportation simulation modeling.

To achieve this goal, the research first conducted a survey of the efforts carried out by other researchers and practitioners in and out of Florida to learn about their successes and challenges in dealing with network inconsistency. Next, the research conducted a close review of the FSUTMS models used in different regions in Florida as well as a survey of stakeholders involved in the development and the use of FSUTMS. We found that the network inconsistency among the models still remains as one of the barriers that prevent efficient data sharing. Currently, none of the networks in FSUTMS show any considerations for data sharing between different scales of models and the Statewide model. The model developers and consultants confirmed that because of insufficient data sharing, a lot of manual work is required during network maintenance. They also agreed that the true-shape network makes it easier to visually recognize, present and compare the forecast results. In addition, a review of the FSUTMS standards and the GIS capabilities of the mainstream travel demand software packages was conducted to better understand the requirements for the proposed network. We found that FSUTMS requires the network data and additional supportive data files, including the data structure (node-link structure, zones, turns, tolls, transit) and key attributes. These requirements are reflected and supported in most of the software packages that we reviewed.

Building on the findings from the literature review, the surveys of the current modeling practice, and the information from the software package reviews, the research team proposed a planning network database framework that supports multi-scale and multi-resolution modeling. The network is stored in a relational geospatial database. Existing travel demand models should first be conflated to the ARBM. The network database can be updated from various sources such as HERE and FDOT RCI attributes. Planning stages such as the long-range transportation plans (LRTP), the transportation improvement programs (TIP), the statewide transportation improvement programs (STIP), and Work Program are also reflected in the database. The database supports different scales of models. The network structure supports different scales of models and the ability to store various planning scenarios. Travel-demand modeling projections can be stored in the database for further reference and model comparison. The availability of modeling results from different models can inform planners and decision-makers on future transportation planning.

The proposed database was validated using a small study area in Gainesville, Florida. A proof of concept procedure demonstrated how the proposed network database structure maintains the planning information, supports the modeling network, and updates the network as planning information is updated during the dynamic process of the transportation planning. Specifically, this proof of concept was able to: 1) extract data from the database for a specific scale network; 2) support scenarios in transportation modeling software using extracted data; 3) update the database when (a) a new plan/scenario is added, and (b) a new project is committed or implemented; and 4) compare different models' inputs and outputs in the database. The proof of concept shows that the proposed planning network works and performs as expected.

6.2 Recommendations for Implementation

This research proposed transition from the current practice of using many disconnected, different, uncoordinated, and project-based travel demand modeling networks, toward a single, unified network data structure shared by all models at different scales. Achieving a single unified network and efficient data sharing across agencies and stakeholders in the state of Florida is expected to take a great deal of coordinated efforts. We suggest the following recommendations for the initial implementation phase of the proposed planning network database.

6.2.1 Database Structure

- The database should have Node and Link spatial files as the fundamental entities. The database is primarily designed for planning network. Since the network is based on node-link structure, links and nodes should be stored as the core entities and all the other entities in the database should be organized around links and nodes.

- The historical data, including spatial and non-spatial information, should never be deleted or overwritten in the database when it is no longer needed or after it has been updated. Therefore, any historical network could be queried and extracted.

- Non-spatial attributes and spatial information of links should be stored separately to avoid geometrical data redundancy.

- Lane and Segment files should be stored with a connection to the Link file for the database expansion to support multi-resolution modeling.
- Centroids and centroid connectors should be stored separately from nodes and links. The data format of the current planning network has centroids stored in the node file and connectors in the link file. However, since centroids and connectors come from different data sources and use different update cycles from nodes and links, separate storage is good for data maintenance and update.
- For links that contain both travel directions (direction of travel is defined as "B"), if the non-spatial attributes of both directions are the same, only one copy of the link is needed in the Link file. Otherwise, two copies of the link should be created to be associated to two different records in the Link Attribute file, respectively.
- Any network change, including addition, deletion, attribute change, and geometry change, in a scenario should be tracked and stored in the database to allow access to scenario information for viewing and future planning.

6.2.2 Data Sources

- A true-shape GIS network including all roads should be chosen as the basis for the network database. Various networks have some potential to be adopted for this purpose, such as FDOT GIS basemap (the RCI network), the TIGER streets, or the OpenStreetMap streets. However, they present many limitations that will need to be overcome before they can realistically be used for this purpose. Instead, at present, the FDOT All Road Basemap (ARBM) network provided by FDOT Safety Office (based on HERE streets) is currently the most promising network because (a) includes all roads, (b) it contains the FDOT LRS system which makes it possible to access FDOT RCI attributes for modeling purposes, (c) it is updated every 2 to 3 years and it will potentially be updated yearly in the future, and d) it is available to be used by all government agencies in Florida without any licensing limitations.
- The network should store different levels of data (state, regional, and local), according to the current Florida Standard Urban Transportation Model Structure (FSUTMS) models at different scales. The links should be tagged with the proper scales in order to represent different models they participate in.

6.2.3 Modeling Software

- The software package should have the ability to provide travel demand modeling based on the FSUTMS standard. FSUTMS requires the network data and additional supportive data files including the data structure (node-link structure, zones, turns, tolls, transit) and key attributes. These requirements are reflected and supported in most of the reviewed software packages in this research.

- The software package should have the ability to handle GIS network data and modeling using the true-shape network. In fact, Environmental Systems Research Institute's (ESRI) shapefile format can be imported in and exported from almost all of the travel demand software packages.

- It should have the ability to read the input network data from the proposed relational geospatial database, either by working on a GIS framework directly, or by extracting the network form the database.

- It should have the ability to write the modeling results back into the database, either directly or by exporting them in the same database format.

6.2.4 Organizational Structure

- Three basic roles are defined as database manager, modeler, and planners. Training should be provided based on the roles involved in the database operation.

- Contributing roles from FDOT offices can be data providers, and host/managers of the database to maintain the updates from various data sources.

6.2.5 Next Steps

- A pilot project to develop a network database prototype

The current proof of concept only considers a small testing area in two macroscopic models - the Statewide model and a regional model. The next step is to build an actual network database prototype, either statewide or for a selected regional geographic area that can include at least one regional model area. We recommend partnering with the Turnpike district to create the network prototype that can support both the Turnpike and the central's office Statewide model and potentially a regional model.

- Rules to handle object identification

Link IDs and node IDs are the unique identifiers for links and nodes. If the database uses the mechanism of its data source to assign node IDs and link IDs, ID conflicts may arise when the data source is updated. We recommend that new rules should be established to assign link IDs and node IDs included in the database.

- Rules to handle conflicted data sources

One of the benefits of building a unified network database is to share data among various model owners. However, data inconsistency might arise when multiple agencies try to update the same data. Therefore, new rules need to be established in the database to deal with such conflicts.

- Meso/micro simulation

Besides the core attributes for mesoscopic and microscopic modeling, other potential attributes and data sources should be explored and further included in the database to better support multi-resolution modeling.

- Multimodal planning

Transit system is an important part of travel demand modeling at the local level. Therefore, transit-related entities and new entity relationships should be created in the database to provide a comprehensive data service for transit-demand modeling. In addition, it is recommended to expand the network with data elements supporting emerging transportation modes, such as ride sourcing, e-scooter, moped and autonomous vehicles.

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