

Considering Network Demand Issues in GIS Transportation Data Modelling

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Abstract

Aim of the research presented in this paper is to assist Transport Planners manipulate spatial information involved in Travel Demand Modelling (TDM) by exploiting the advances of contemporary Geographic Information Systems (GIS) tools. This may be achieved by establishing a standard data model prototyping the transport entities used in transportation related activities. Significant amount of information related to Urban Transport Planning System (UTPS) models could be exchanged with GIS management systems. Identifying this kind of data exchange may lead to refining the design of existing transportation data models. In this respect, EMME/2, an interactive-graphic state-of-the-art multimodal UTPS, being used by numerous transportation authorities worldwide as well as by the Athens Metro Authority in Greece, has been employed as a reference example, to provide valuable experience toward this direction.

1. Introduction

Demand forecasts for transportation resources under various conditions, was always a significant means for transportation professionals to plan future transportation needs in their areas of jurisdiction. In 70's the standard four-step transportation planning process implemented by the so-called Urban Transport Planning System (UTPS) models (trip generation/attraction, trip distribution, mode choice, road and transit assignment) was the accepted method for carrying out planning studies. Since then, this process evolved considerably incorporating new modelling approaches such as mode and route choice models, dynamic modelling, etc. enabling better forecasts for travel demand and more sophisticated simulations for route choice on road and transit networks. In general, Travel Demand Modelling (TDM) consists of a set of forecasting models aiming to predict the required amount of transportation use in response to changes in regional development, demographics, and transportation supply. TDM in this respect refers to strategic level planning rather to meso or micro level traffic management

During the last decades a number of computer models, that implement these modelling procedures providing to transport planners high capabilities on running alternative transport-planning scenarios have been developed. Considering that transportation network is one of the principal components of TDM software, one realises the enormous amount of spatial information involved. Traditionally, this kind of information was prepared externally, either manually or by use of other special software, in order to feed the transport or traffic simulation models. A great deal of the output data also has spatial nature and can only be displayed rather than manipulated by the TDM software or again can be handled by external specialised software packages. In other words, the core of these models focuses on traffic assignment and simulation, rather than on advanced spatial representations and manipulations of the input/output involved data.

Hardware evolution, reflected to processing capacity, has provided the capability of storing, processing and manipulating large datasets of spatial information as well as managing and visualising large image files. However such capabilities are directly provided by Geographic Information Systems (GIS) related software and, as stated before, are beyond the main scope of UTPS computer models.

Nevertheless, these models provide separate tools for displaying and representing their results but in any case their cartographic capabilities could never compete those provided by GIS tools unless GIS capabilities are built in them. Contemporary transport planning and traffic simulation software has just begun exploiting the rapid advances in computing that have characterised the last decade. TransCAD is a representative software package combining a complete and ever-expanding set of tools for travel demand modelling that are fully integrated with unique GIS for transportation (GIS-T) capabilities for digital mapping, spatial analysis, geographic database management, graphics presentation and application of sophisticated transportation, operation research and statistical models. (Caliper Corporation, 2004) Alternatively, the above objective may be achieved by creating special GIS software modules/extensions with UTPS related activities embedded in them.

Either perspective provides valuable assistance to transport planners but the concept of developing a standard GIS data model for transportation networks has a totally different fundamental basis and goal:

- A prototype data model serves as a standard independently of operating systems, platforms, programming languages, database management systems and GIS management systems.
- Transport planners continue working the way they are used to with the models they are already familiar, but traffic model vendors are enforced to develop the appropriate communication protocols to the geographic database implementing the prototype GIS transportation data model.
- In the case of Transportation an ideal GIS data model might establish communication between GIS software packages and any kind of traffic related models. Furthermore, various traffic models might communicate between each other through a GIS data model implemented in a spatial database and appropriate communication protocols, developed for example through Extensible Markup Language (XML).

Over the past two decades numerous standards, specifications and network representation models have been developed concerning the primary transportation entities constituting the underlying basic network and their connectivity (topology), linear referencing and dynamic segmentation techniques etc. Very recently, most GIS Management Systems adopted the use of an object-oriented data model called the geographical database, also known as geodatabase, data model. In this respect, a series of “essential data models” notated through Unified Modelling Language (UML), (Rumbaugh et al., 1999) were introduced by Environmental Systems Research Institute (ESRI) in collaboration with a wide range of professionals in various fields of expertise. (ESRI, 2005) In the field of Transportation the ArcGIS Transportation Data Model also known as UNETRANS (Unified NETWORK TRANSPORTation) is under development aiming to address the needs of transportation professionals. The basic network structure can generate multiple views of the transportation network in order to accommodate: multiple linear referencing methods, multiple transportation modes for routing and analysis, and multiple cartographic representations for output at different scales. (Curtin K. et al., 2001) As far as TDM is concerned, UNETRANS can only be used to display the results of four-step traffic demand models. However, a great deal of information included in UTPS models as well as any kind of sub models involved in managing transport demand (gravity models, logit models, residential models, multiple regression models etc.) is not directly included. (Curtin K. et al., 2001) Consideration of such information may lead to enhancing existing transportation data model design and to providing high capabilities for future integrations with UTPS computer models.

Design throughout the present study refers to trip assignment procedures, for two significant reasons: a) this kind of procedures are strongly related to the transportation network and b) the involvement of many specialists in most of the above mentioned planning steps is necessary however, the role of traffic engineers is mostly significant in modelling the road network and in trip assignment procedures.

2. Travel Demand Modelling

Travel Demand Modelling (TDM) “has evolved over a fifty-year period as an art and a science with a growing professional foundation and technical literature”. (Caliper Corporation, 2004) Developments in other scientific fields such as econometrics and operations research induced many advances to TDM in both theoretical and practical level. Much of the software that has been used in the past two decades for urban travel forecasting has been derivative from the UTPS mainframe and its predecessors without significant modification or enhancement. (Caliper Corporation, 2004) UTPS was developed by the Urban Mass Transportation Administration of the US Department of Transportation in the 1970’s. UTPS is also referred as the Urban Transportation Modelling System (UTMS), a system of models employed by transportation professionals as the standard approach to urban TDM.

UTPS or UTMS calculates the number of trips made within an urban area by type (e.g. home, work etc.), time (e.g. peak period) and origin-destination pair, the mode by which these trips were made as well as the routes of the transportation network used by the travellers. The final output of UTPS modelling procedures is a predicted set of modal flows on links in a network. The major inputs to UTPS are the factors specifying the activities generating trips and the characteristics of the transportation system serving these trips. Therefore, through travel demand forecasting procedures, the demand for transportation use is assigned to the supply of the transportation network and the modal sub networks, which comprises, and these two critical concepts, demand and supply, form an “equilibrium” procedure. (Meyer M. D. and Miller E.J., 1984) Because UTPS consists of four major stages, it is often mentioned as the four-step model, as shown in Figure 1.

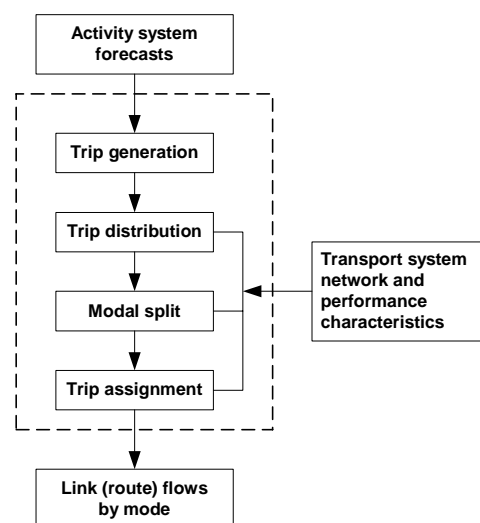


Figure 1: The urban transportation modelling system (Meyer M. D. and Miller E.J., 1984)

3. Existing GIS Transportation Data Modelling

Contemporary GIS Management Systems (e.g. ESRI’s ArcGIS) have adopted the use of an object-oriented data model called the geographical database, data model. A geographic database (geodatabase) provides the capability of making the spatial or attributed objects, participating in a GIS dataset, smarter by endowing them with natural behaviours and allowing any sort of relationship to be defined among these objects. (Zeiler M., 1999) Prior to its implementation a geographic database data model is conceptually designed by use of a high-level conceptual object-oriented data model. Through object-orientation a System is modelled by entities (objects) and the relationships among those entities. Objects hold state, behaviour and identity and along with other similar objects are members of classes sharing their properties. Such an analysis can be notated by UML, an industry standard language that

identifies the specific properties of the classes and objects, specifies attributes and codes relationship parameters. (Rumbaugh J. et al. 1999) In ESRI's ArcGIS terminology, classes storing information with spatial representation are called Feature Classes and may be related to other Object Classes (tables) containing attributes with no explicit spatial representation of their own. In addition, current versions of ESRI products provide capabilities for transforming UML data models into relational geodatabases.

In the area of Transportation the ArcGIS Transportation Data Model (UNETRANS), may be characterized as the most significant generic transportation GIS data model. The following provide a brief description of the major UNETRANS features.

A. Packages

Packages are logical groupings of objects. Six packages are identified inside UNETRANS data model:

1. *Reference Network*: its primary building blocks are the two abstract classes, TransportEdges and TransportJunctions, which correspond to the Framework Transportation Segment (FTSeg) and Framework Transportation Reference Point (FTRP) components of the Federal Geographic Data Committee (FGDC) transportation standard, respectively. (Ground Transportation Subcommittee, 2000) Beyond the transportation features themselves the Reference Network is specified by the way these features are segmented (Network Segmentation), the way they are connected to form a transportation network (Network Topology) as well as the Linear Referencing approach followed. In all cases UNETRANS is conformed to the FGDC Framework transportation standard.
2. *Routes and Location Referencing*: its Object Classes (Tables) support turns, routes, mode restrictions, and other essential aspects of transportation network operations. Its Feature Class (RouteFeatures) can be used to represent all types of linearly referenced objects from the rest packages (Assets, Incidents, Activities, or Mobile Objects).
3. *Assets*: its objects represent physical features that are not part of the network but are related to it (e.g. traffic lights, barriers, parking lots etc.). Assets can be Objects not having a shape or extent that are displayed through linear referencing and are represented by points or lines, or can be features represented by polygons. Assets can also have more than one appropriate spatial representation.
4. *Activities*: similar to Assets as regards linear referencing to the network and capabilities of multiple spatial representations. They differ from Assets in that they may only have a temporary physical relationship to the network (e.g. road construction or improvement project).
5. *Incidents*: similar to Assets or Activities package as regards linear referencing to the network and capabilities of multiple spatial representations. Refers to occurrences such as traffic accidents, citations, or spills.
6. *Mobile Objects*: they have no explicit spatial representation and they are modelled as a subclass of the basic object class. They can be transported across the Reference Network (e.g. Automobiles, Trucks, Railcars, etc.).

B. Topology

Topology specifies spatial relationships between network transportation features. Previous versions of UNETRANS data model made use of the so-called Geodatabase Geometric Network, while last version adopts topology rules. Both cases are provided by ArcGIS software package.

The following topology rules applicable to transportation networks were identified inside UNETRANS geodatabase:

- *Point must be covered by endpoint of line:* road intersections must be covered by endpoints of street centerlines.
- *Line must not self-overlap:* road segments constituting a road should never occupy the same space as another segment of the same road.
- *Line must be single part:* an individual line feature (e.g. metro line) should not appear as a series of non-connected segments.
- *Line must not self intersect:* a line feature (e.g. road) can only touch at its ends without intersecting or overlapping itself.

C. Linear Referencing

As mentioned above the Routes and Location Referencing package provides a system to generate and store references with the elements of the other packages. The RouteFeature class with its two related special cases, the AnchorPoints and AnchorSections, defines the fundamental linear referencing space.

D. Relationships

Relationships identified in current version of UNETRANS data model refer to a) locating activities occurring in the transportation network, b) naming streets and assigning address ranges to roads and c) routings.

E. Travel Demand Modelling

Transportation-related data involved in UTPS sub models are not directly included in the UNETRANS data model. Table 1 provides the geographic elements of TDM processes and their relationships to objects in the UNETRANS data model.

Table 1: UTPS Elements reflected to UNETRANS Classes

UTPS Elements	UNETRANS Object or Feature Classes
Analysis Area	Transportation-AnalysisZone
Annual Element	A group of Capital-Improvement-Projects
Census Tract	Admin Boundaries Data Model
Central Business District	Admin Boundaries Data Model
Centroid	Defined by the GIS
Destination	AssetPolygon or AssetPoint or Transportation-AnalysisZone
District	Admin Boundaries Data Model
Dwelling Unit	AssetPoint or AssetPolygon
Forecast Zone	AssetPolygon
Highway System	Reference Network
Inter-zonal Trip	ActivityLine
Intra-zonal Trip	ActivityLine
Link	TransportEdge
Mode of Travel	Mobile Objects
Origin	AssetPolygon or AssetPoint or Transportation-AnalysisZone
Route	Route
Sectors	AssetPolygon
Special Generators	ActivityPoint
Study Area Boundary	AssetPolygon
Subarea or Subregion	AssetPolygon
Transportation Improvement Program	Capital Improvement Project
Transportation System	Modified UNETRANS UML Model
Trip	Trip
Trip End	AssetPoint or Junction

4. GIS Transportation Data Modelling Enhancement

The major objective of the present research is to extend the capabilities of existing GIS transportation data modelling to TDM related issues so that communication between UTPS models and a transportation geographic database is assisted. This may be achieved through a thorough study of data exchange occurring during critical transport planning procedures. As such, are considered travel demand forecasting procedures, through which the demand for transportation use is assigned to the supply of the transportation network and the modal subnetworks which comprises. Considering such information may lead to enhancing existing transportation data model design and to providing high capabilities for future integrations between geodatabases implementing transportation data models and UTPS computer models.

For the purposes of this pilot data model design two specific choices were made: a) EMME/2, (INRO Consultants Inc., 1999) a multimodal UTPS, being used by Athens Metro Authority in Greece, has been employed to represent traffic assignment models and b) fixed-demand, single-class auto assignment has been considered as the typical traffic assignment procedure to be used during design phase. The methodological approach comprised the following tasks:

- *Data Filtering and Classification:* datasets are filtered and classified with regard to a) their involvement to TDM procedures as well as b) their eventual contribution to GIS data model refinement. Information regarding data definition and utility is also identified.
- *Tracking of UTPS Data Exchange:* any input/output data involved during TDM and more specifically during network assignment procedures, is being tracked.
- *GIS Transportation Data Model Enhancement:* TDM information identified during the previous tasks is considered during GIS data model design and optimisation.

4.1 Data Filtering and Classification

Three main categories of UTPS related data exist in the so-called EMME/2 data bank:

- *Network*
- *Matrices*
- *Functions*

Data interaction between the above categories can be briefly stated as follows: a complete Network data set comprising modes, turns, base and transit network specifies a scenario. Many scenarios may exist, each one representing a specific transportation planning decision. Given a scenario the relevant Matrices to be used with it are specified. A Matrix contains the data needed for an assignment or stores the results from it. Scenarios share functions defining delays in links, turns or transit lines to be used for auto or transit assignment.

A. Network

EMME/2 stores network data in a file, according to certain scenarios. A scenario includes datasets related to:

- *Modes*, which are divided into the following types:
 - auto modes: their links specify the network accessible to private vehicles,
 - transit modes: their lines consist of links accessible to transit vehicles,

- auxiliary transit modes: their lines consist of links used to achieve access to transit lines or transfer between lines that do not pass through the same node,
- auxiliary auto modes: their links specify the sub networks accessible to various user classes.
- *Base network* which consists of:
 - nodes, which may be centroids in case they are associated with zones, or regular nodes and
 - links, which represent a directional connection between two nodes and refer to any mode type.
- *Turns*, which are defined as a link to link movement occurring at an intersection node,
- *Transit vehicles* that may be used by a transit line.
- *Transit lines*, which represent a regular transit service defined as a sequence of transit segments, each of them corresponding to a link in the base network.

Figure 2 illustrates network entities and their hierarchy. Arrows represent entities' hierarchy and imply that an element should be added only if a relative element of higher hierarchy exists.

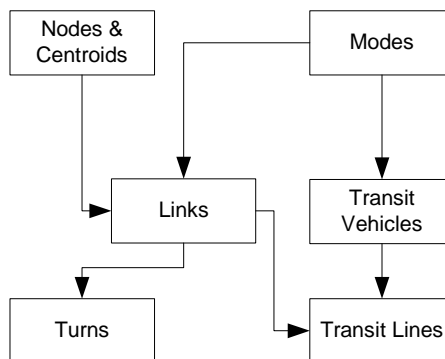


Figure 2: Network entities and their hierarchy in EMME/2

B. Matrices

Matrices host zone-related data and they might be used either as input (e.g. a demand matrix) or output (e.g. a matrix containing the results of calculation). Matrices in EMME/2 are classified to four classes:

- *Full matrices*, containing a value for every O-D pair.
- *Origin matrices*, containing origin-related values.
- *Destination matrices*, containing destination-related values.
- *Scalar matrices*, containing one value only.

C. Functions

EMME/2 allows the following classes of functions:

- *Auto volume-delay functions*, used for calculating auto times on links of the auto network.
- *Turn penalty functions*, used for calculating auto times on turns at intersection nodes.
- *Transit time functions*, used for calculating transit time on segments of transit lines.
- *Auto demand functions*, used for calculating auto demand for origin-destination pairs.
- *Transit demand functions*, used for calculating transit demand for origin-destination pairs.
- *User functions*, used for calculating tables and function plots of arbitrary functions.

4.2 Tracking of UTPS Data Exchange

A great deal of information is exchanged between the datasets described above and the core traffic model, during network assignment procedures. This information is usually manipulated by external software specialised in advanced data processing and analysis (e.g. spreadsheets, database management systems etc.), in spatial analysis and representation (e.g. GIS) etc. A deep understanding of this data exchange is going to assist GIS data modelling.

Table 2 provides the incoming to and the outgoing from, a fixed-demand, single-class auto assignment procedure data.

Table 2: Data exchange during a fixed-demand single-class auto assignment procedure

INCOMING DATA	A u t o A s s i g n m e n t	OUTGOING DATA
<ul style="list-style-type: none"> ▪ Network <ul style="list-style-type: none"> - Centroids, nodes, links and turns (with their attributes) - Source for additional volumes ▪ Matrices <ul style="list-style-type: none"> - Demand (in persons) - Vehicle occupancy (in persons/vehicle) - Additional demand (in vehicles) ▪ Functions <ul style="list-style-type: none"> - Link volume-delay - Turn penalty - Extra function parameters ▪ Parameters <ul style="list-style-type: none"> - Stopping criteria 		<ul style="list-style-type: none"> ▪ Network <ul style="list-style-type: none"> - Auto volumes on links and turns - Auto times on links and turns - Additional volumes on links and turns ▪ Matrix <ul style="list-style-type: none"> - Travel times

4.3 GIS Transportation Data Model Enhancement

Much of the information attributing UTPS elements identified in EMME/2's databank exists in the current transportation GIS data modelling as this is well represented by ArcGIS Transportation Data Model (Table 1). However significant amount of transportation-related data involved in the assignment planning step of the four-step travel demand modelling is not directly included.

In this section we identify travel demand modelling elements to be considered in GIS transportation data model enhancement, and propose a data model referring to traffic assignment, able to be superimposed on existing data models. This is achieved by comparing the principal components of existing transportation GIS data models (represented by UNETRANS) with those captured during previous subsections.

A. Base Network

The Base Network consisting of Nodes and Links is faced as Reference Network consisting of TransportEdge and TransportJunction ESRI Feature classes through UNETRANS data model.

However, a significant amount of information involved in network assignment procedures is not included and might be considered during GIS transportation data model enhancement. This information includes:

- *Transit assignment results*, including initial boardings and final alightings identified in Node entity.
- *Auto assignment results*, including volumes and travel times identified in Link entity.
- *Volume delay functions*, used to calculate travel times in links during assignment process.

B. Transit Network

Transit Network consists of Transit Lines formed by their Transit Segments. These elements identified in EMME/2 data bank, are modelled in UNETRANS through TransportRoute ESRI object class in conjunction with RouteFeature ESRI feature class.

Valuable information to be considered during existing GIS data modelling includes:

- *Transit assignment results*, including volumes, travel times and boardings identified in Transit segment entity.
- *Transit time functions*, on links and turns participating in transit assignment procedures.
- *Operating Costs and Energy Consumption attributes*, identified in Transit Vehicle entity.
- *Transit Modes Capacity Restraint*, issues.

The present work as being an initial approach to GIS transportation data model enhancement with UTPS related elements does not deal with transit assignment. However findings related to auto assignment may similarly be extended to transit assignment considerations.

C. Modes

Mode of travel is faced in Mobile Objects package through UNETRANS data model. Information related to operating costs and energy consumption could be included enhancing existing data modelling. Since the present focuses on a specific auto assignment procedure possible enhancements on transportation GIS data modelling with regard to Modes are not examined.

D. Linear Referencing and Topology

Travel Demand Modelling considerations do not affect or modify these two critical subsystems of existing geographical data models.

E. Relationships

A set of relationships compose a UML data model representing the specified assignment procedure. Table 2 combined with basic transport planning principles format this data model which can be then merged with existing GIS transportation data models. The following define the various types of relationships, the classes and the relationship classes participating in the UML class diagram:

Travel times on links and turns of the auto network are given by the volume-delay functions (*VDF*) associated with the links, and the turn penalty functions (*TPF*) associated with the turns. A parent class termed *Function* is the generalisation of the two function classes. A specific volume delay function may be applicable to many links, while one link's travel time is defined by one function. The same happens for turns and turn penalty functions. The association relationships implementing this kind of interaction are the *FunctionIsApplicableToLink* and the *FunctionIsApplicableToLink* relationships.

A *Scenario* consists of a complete network data set consisting of modes, turns, base and transit network. Many scenarios may exist each one representing a specific transportation planning decision, or corresponding to different reference year. Input for a fixed demand, single class auto assignment Scenario may contain:

- Auto demand matrix (*Demand*) specifying the number of persons travelling by auto for each Origin-Destination pair.
- Vehicle occupancy matrix (*VehicleOccupancy*) specifying the average number of persons per vehicle for each Origin-Destination pair.
- Additional demand matrix (*AdditionalDemand*) in auto equivalents (for example truck traffic) to be added to the auto demand.

The above types of matrices could only exist under a specific *Scenario*, thus defining an association relationship of type aggregation relating *Scenario* to *Matrix* class (*ScenarioIsAssociatedWithMatrix*). Additional generalization relationships are also defined between the *Matrix* class and its above-mentioned subclasses.

Beyond the volumes calculated through auto assignment, extra data sources may provide input regarding additional link and/or turn volumes. Such volumes may represent fixed background values of the network and may be expressed in auto equivalents of transit vehicles. This kind of volumes are modelled through *LinkVolume* and *TurnVolume* classes which are subclasses of *Volume* class and are associated with Links and Turns through the *FixedBackgroundVolumesAppliedOnLink* and *FixedBackgroundVolumesAppliedOnTurn* association relationships respectively. The class *Volume* is also associated with *Scenario* through an association relationship of type aggregation (*ScenarioIsAssociatedWithVolume*). Extra attributes are scenario specific and are defined by the user. Different scenarios may have different sets of extra attributes.

The results of this kind of auto assignment are stored in special association classes:

- A link may be part of transportation network supply in many auto assignment scenarios defined by specific demand components while a scenario may be applied to many links of the network. The relevant to a link output of auto assignment is stored to the *LinkAssignment* association class, which is formed through the above-mentioned association relationship. This assignment output data refers to auto and additional volumes as well as auto times on links.
- Accordingly, the relevant to a turn output of auto assignment is stored to the *TurnAssignment* association class, which is formed through the Scenario-Turn association relationship. This assignment output data refers to auto and additional volumes as well as auto times on turns.

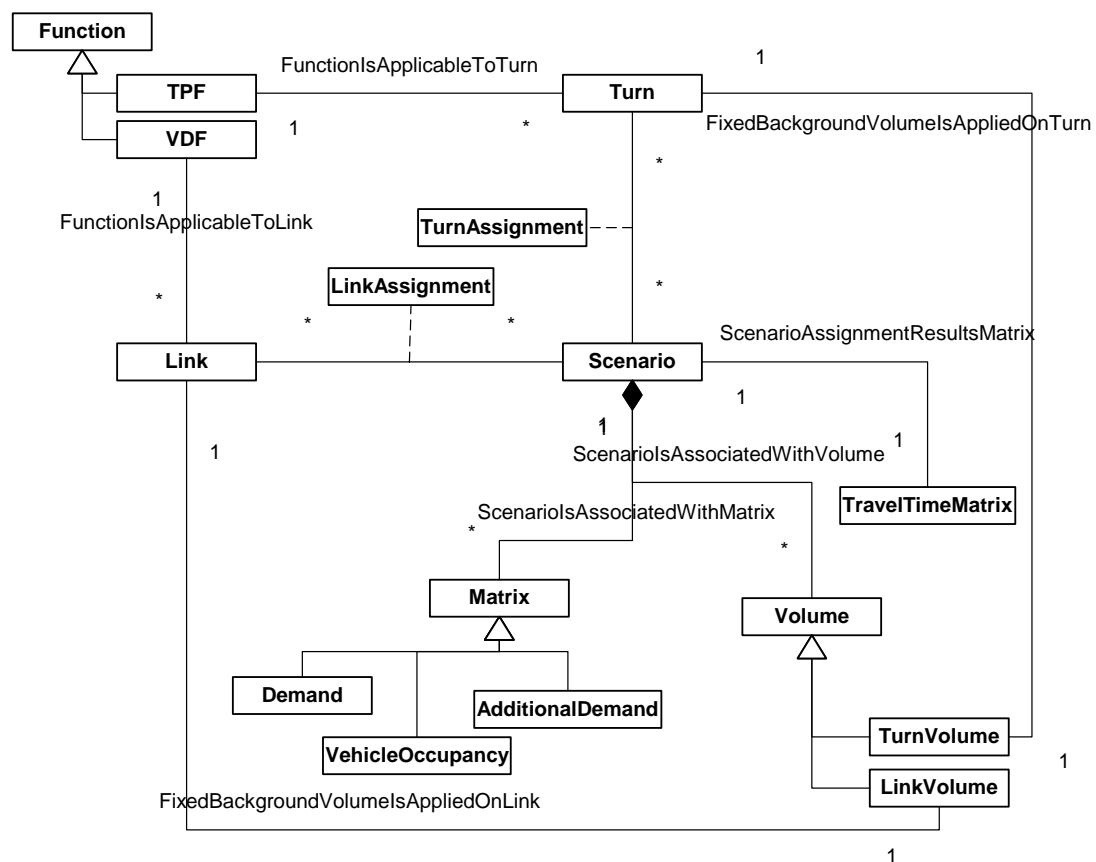


Figure 3: The proposed data model for fixed-demand single-class auto assignment

Finally, a matrix, containing travel times for each Origin-Destination pair as obtained by auto assignment procedure is represented by the *TravelTimeMatrix* class. This is associated with *Scenario* class through the *ScenarioAssignmentResultsMatrix* association relationship.

Figure 3, collects the data entities involved during the examined traffic assignment procedure into a UML class data model.

5. Geographic Data Base Design

Prior to implementing the proposed data model to a geographic database, the underlying base network along with the topology governing its components and the linear reference system, have to be specified and implemented. The geographic data base is implemented in ArcGIS version 9.0 which provides advanced geoprocessing tools and special CASE tools for transforming a UML data model to a geodatabase.

5.1 Base Network, Linear Reference System and Topology

The Base Network is deployed similarly with the Reference Network provided in ArcGIS Transportation Data Model. The BaseNetwork feature dataset provides the spatial reference that is shared by all of its feature class components.

Base Network physical design includes the development of its two major feature classes, the linear feature class Link and the point feature class Node along with their subclasses: the AutoSegment, LineSegment, AuxiliaryAutoSegment and AuxiliaryTransitSegment linear feature subclasses of the Link feature class and the RegularNode and Centroid point feature subclasses of the Node feature class.

The Linear Reference System is initially defined by the linear feature class Route. Its development is based on the fundamental linear base network component that is the linear feature class Link. The linear feature class Route along with the linear feature class AnchorSection and the point feature class AnchorPoint define the fundamental linear reference space upon to which any kind of point or line event will be referenced.

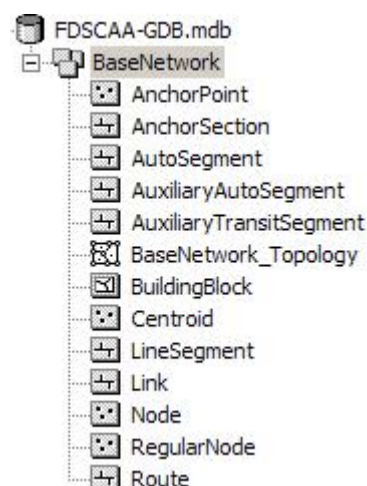


Figure 4: The BaseNetwork feature dataset

Topology rules are included inside BaseNetwork_Topology geodatabase component and are synopsised to the following:

- The linear feature classes Link and Route must a) be single part, b) not self-intersect and c) not self-overlap
- The linear feature class Link must be covered by the linear feature Class Route

- The point feature class Node and its subclasses must be covered by endpoint of the linear feature class Link

Figure 4, illustrates the part of the fixed-demand, single-class, auto assignment geodatabase (FDSCAA-GDB) implementing the base network along with its principal components.

5.2 Traffic Assignment

During physical design the proposed data model representing the selected traffic assignment is transformed to a number of object classes and relationships classes between object classes, inside the FDSCAA-GDB geodatabase. The following database components are identified:

A. Object Classes

Feature classes have been designed during BaseNetwork feature dataset design. Non spatial Object Classes (Tables) are obtained from non spatial UML classes. The following object classes representing non spatial entities are identified during geodatabase design:

- Table *Turn* as a result of Turn class representing turns on the transportation network.
- Table *Scenario* as a result of the Scenario class representing a transportation planning scenario.
- Table *TravelTimeMatrix* as a result of the TravelTimeMatrix class representing a part of the assignment output.
- Tables *DemandMatrix*, *VehicleOccupancyMatrix* and *AdditionalDemandMatrix* as a result of the UML generalization relationships associating the corresponding subclasses to the Matrix class representing transport demand.
- Tables *VDF* and *TPF* as a result of the UML generalization relationships associating the corresponding subclasses to the Function class representing function applied on links and turns respectively of the transportation network to provide travel times.
- Tables *LinkVolume* and *TurnVolume* as a result of the UML generalization relationships associating the corresponding subclasses to the Volume class representing additional volumes considered during assignment execution.

B. 1-1 Relationships Classes

During geodatabase design 1-1 relationship classes are obtained from 1-1 UML associations. The primary key field of the class to the one side of the association is designed as foreign key of the class to the other side. The following 1-1 relationship classes are identified during geodatabase design:

- Relationship class *FixedBackgroundVolumeIsAppliedOnLink* between feature class Link and object class LinkVolume as a result of the homonymous UML association.
- Relationship class *FixedBackgroundVolumeIsAppliedOnTurn* between the object class Turn and the object class LinkVolume as a result of the homonymous UML association.
- Relationship class *ScenarioAssignmentResultsMatrix* between the object class Scenario and the object class Matrix as a result of the homonymous UML association.

C. 1-M Relationships Classes

Figure 5 illustrates the final geodatabase as implemented from the proposed UML data model according to the design rules described below.

During geodatabase design 1-M relationship classes are obtained from 1-M UML associations. The primary key field of the origin class is designed as foreign key to the destination class. The following 1-M relationship classes are identified during geodatabase design:

- Relationship class *VolumeDelayFunctionIsApplicableToLink* from the object class VDF to the feature class Link where VDF table primary key field is designed as foreign key to the Link table,
- relationship class *TurnPenaltyFunctionIsApplicableToTurn* from the object class TPF to the object class Turn where TPF table primary key field is designed as foreign key to the Turn table,
- three relationship classes:
 - *ScenarioIsAssociatedWithDemandMatrix*,
 - *ScenarioIsAssociatedWithAdditionalDemandMatrix* and
 - *ScenarioIsAssociatedWithVehicleOccupancyMatrix*

from the object class Scenario to the object classes DemandMatrix, AdditionalDemandMatrix and VehicleOccupancyMatrix respectively, where Scenario table key field is designed as foreign key to the three lastly mentioned destination tables,

- two relationship classes:
 - *ScenarioIsAssociatedWithLinkVolume* and
 - *ScenarioIsAssociatedWithTurnVolume*

from the object class Scenario to the object classes TurnVolume and LinkVolume respectively, where Scenario table key field is designed as foreign key to the two lastly mentioned destination tables.

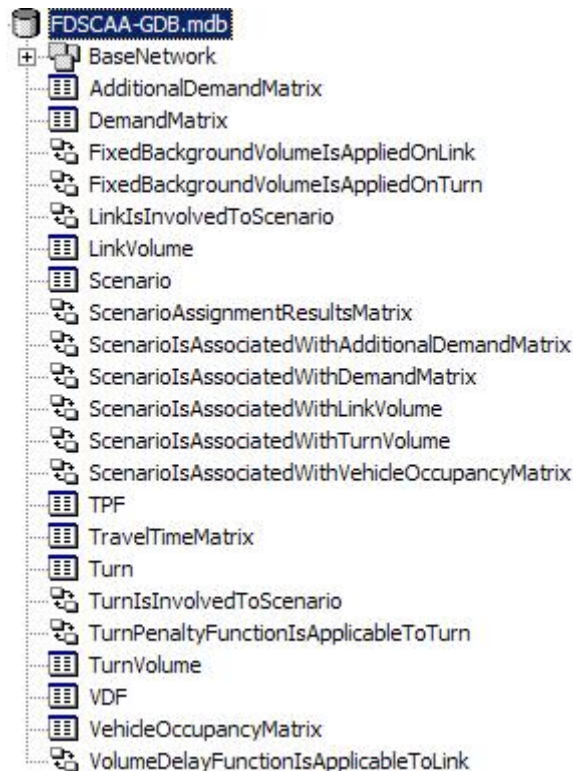


Figure 5: Data model transformation to geodatabase components

D. M-N relationship classes

During geodatabase design M-N relationship classes are obtained from M-N UML associations. The association classes resulting from such kind of UML association is designed as separate tables with

primary key field the combination of the primary key fields of each origin class designed as foreign key in the destination class. The following M-N relationship classes are identified during geodatabase design:

- attributed relationship class *LinkIsInvolvedToScenario* between feature class Link and object class Scenario with the combination of foreign keys coming from tables Link and Scenario to form the primary key of the attributed relationship and a number of fields designed to store assignment results on the links of the transportation network and
- attributed relationship class *TurnIsInvolvedToScenario* between object class Turn and object class Scenario with the combination of foreign keys coming from tables Turn and Scenario to form the primary key of the attributed relationship and a number of fields designed to store assignment results on the turns of the transportation network.

A demonstration of event layers displaying assignment results is illustrated in Figure 6. Tables *LinkIsInvolvedToScenario-1* and *LinkIsInvolvedToScenario-0* store the assignment results referring to traffic volumes on links with traffic flow determined by the digitized direction and opposite direction respectively. Combining the Route feature class which sets the location reference system with the above assignment results tables leads to the addition of route event layers providing valuable representations of traffic assignment results.

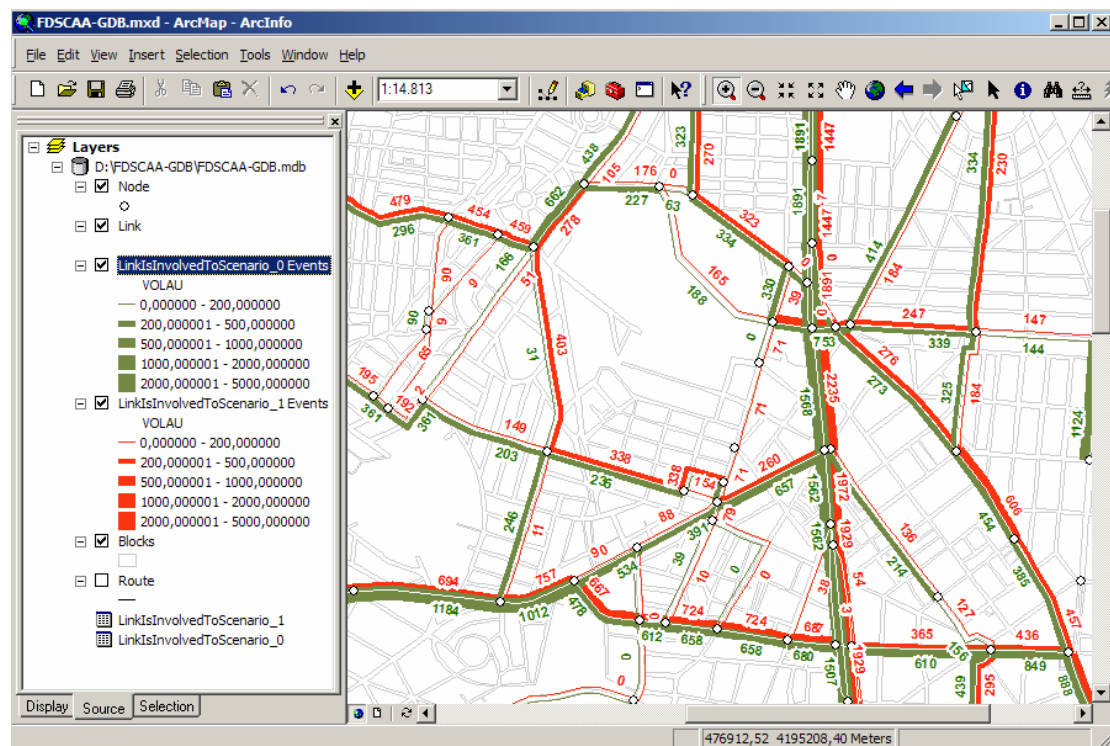


Figure 6: Using the linear reference system to add special assignment route events

6. Conclusions

The present paper attempted to provide a way for incorporating in existing GIS data models some travel demand elements as they are traditionally examined in UTPS. However much more such elements need to be examined and incorporated. Some of them include non-conventional modes, such as demand car for pooling, and network-demand interactions like those of High Occupancy Vehicle (HOV) - High Occupancy Toll (HOT) lanes with HOV and or toll users. Other important issues are those of Intelligent Transport Systems (ITS) that pertain to both the network system and its users and definitely are demand relates, especially when the system operates at capacity and/or congestion levels. Finally, it is quite interesting to look at the UNETRANS model usability in terms of the new

philosophies that have to do with the Demand Management approaches in the restriction of trips and the employment of innovative ways to exploit transport infrastructure.

Findings of the present work refer to a specific TDM assignment procedure. However these might be similarly extended to consider other types of auto assignment as well as transit assignment considerations. An enhanced GIS transportation data model implemented as a geographical database is expected to serve existing UTPS computer models in terms of data management and exchange during all stages of TDM. This also requires the development of the appropriate communication protocols between computer models and geodatabase data model. Furthermore, travel demand related objects might be linearly referenced providing critical views of the transportation network.

Finally, the travel demand related regulations governing the enhanced transportation data model are expected to enforce data validity and consistency and provide a common starting point to application developers in the area of transport planning.

7. References

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