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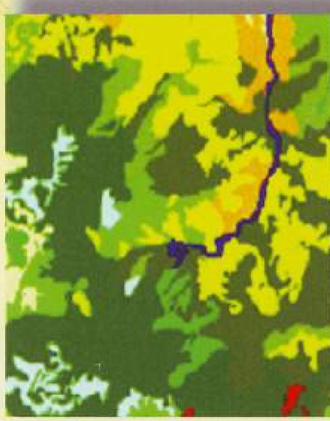

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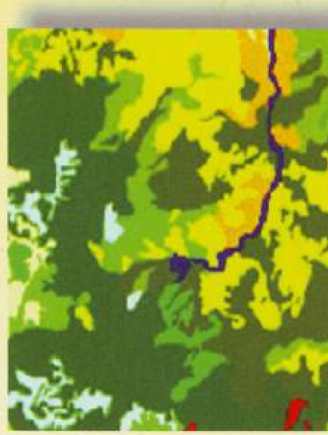

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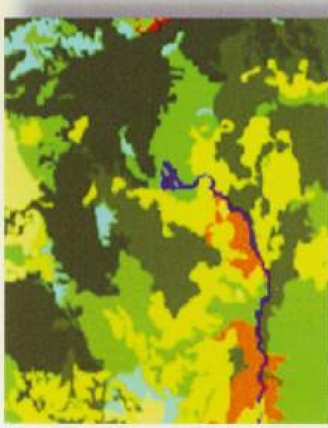

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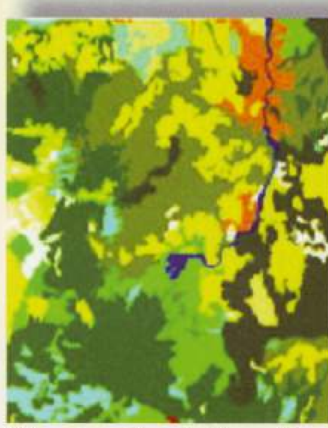

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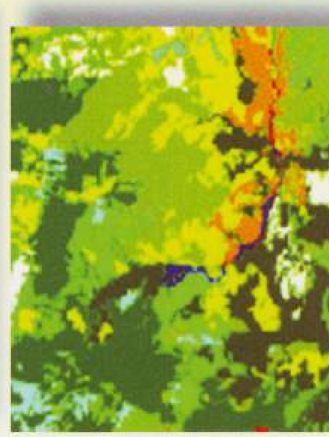

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Front Cover Page

Land covers maps at various resolutions and mapping scales (page 5)

Considering Network Demand Issues in GIS Transportation Data Modelling and Geographic Data Base Design

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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, 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 (Meyer and Miller, 1984 and Morlok, 1978). 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 (European Commission, 1999). 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 (Kanafani, 1983).

During the last decades numerous computer models that implement these modelling procedures providing to transport planners high capabilities on running alternative transport-planning

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scenarios have been developed (FHWA, 1982). 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 (Serra, F., 1999). 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 complete 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 (Caliper, Corp., 2004). Alternatively, the above objective may be achieved by creating special GIS software modules/extensions with UTPS related activities embedded in them (Rapidis, 2006). Both cases provides valuable assistance to transport planers 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 (Bourret, 2005).

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 (Miller and Shaw, 2001). Recent developments in GIS software packages include the adoption of geographic database as the main data structure maintaining spatial information, replacing the traditional georelational data structure (Zeiler, 1999). In this respect, a series of "Essential Data Models" notated through Unified Modelling Language, UML, (Rumbaugh et al., 1999) were introduced by GIS software companies in collaboration with a wide range of professionals in various fields of expertise (ESRI, 2006). In the field of Transportation the UNETRANS (Unified Network Transportations) transportation data model is under development aiming to address the needs of transportation professionals (UNETRANS, 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 (Curtinet al., 2001). Considering 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, Corp., 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. UTPS was developed by the Urban Mass Transportation Administration of the US Department of Transportation in the 1970's (USDOT, 1986). 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 (Stopher and Meyburg, 1975).

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 (Papacostas, 1987). 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.

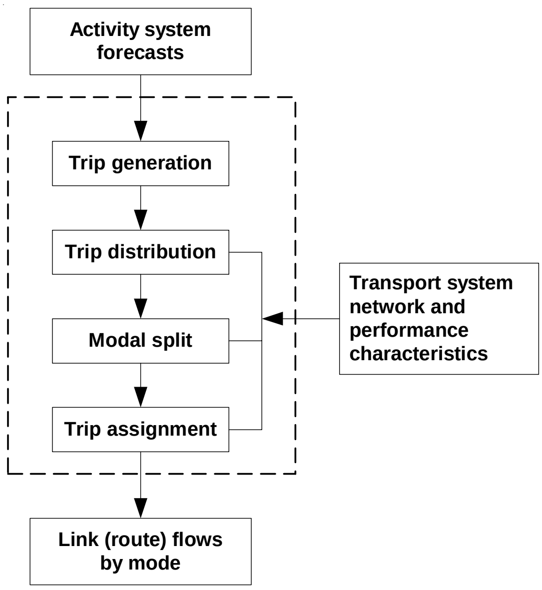

Figure 1: The Urban Transportation Modelling System (Meyer and Miller, 1984)

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 and Miller, 1984). Because UTPS consists of four major stages, it is often mentioned as the four-step model, as shown in Figure 1.

3. Existing GIS Transportation Data Modelling

Contemporary GIS Management Systems have recently adopted the use of Geographic (Spatial) Databases as the main data structure maintaining spatial and attributed information. A Geographic Database provides the capability of making the 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 can be 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 (OMG, 2000). 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 et al., 1999). In addition, special software products provide capabilities for transforming UML data models into relational Geographic Databases.

In the area of Transportation UNETRANS data model, seems to be the most significant generic transportation GIS data model. 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 et. al., 2001).

UNETRANS comprises six logical groupings of objects (packages). The fundamental structural components of the transportation system being modelled, are the packages described in the following:

- *Reference Network :* its primary building blocks are the two abstract object classes, 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 (GTS, 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.
- *Routes and Location Referencing:* its attributed objects support turns, routes, mode restrictions, and other essential aspects of transportation network operations. Its spatial objects can be used to represent all types of linearly referenced objects from the rest UNETRANS packages.

From the rest UNETRANS packages *Assets* package contains objects representing physical features that are not part of the network but are related to it (e.g. Traffic Lights, Barriers, Parking Lots etc.). It may also contain 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. Activities package is similar to Assets as regards linear referencing to the network with 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). Incidents package is similar to Assets or Activities package as regards linear referencing and multiple spatial representations capabilities and refers to occurrences such as traffic accidents, citations, or spills. Finally, Mobile Objects have no explicit spatial representation and they can be transported across the Reference Network (e.g. Automobiles, Trucks, Railcars, etc.).

Numerous transportation-related data involved in core UTPS processes (e.g. Demand Functions, Generalised Costs etc.) are not included in the UNETRANS data model as being, according to its creators "*Beyond The Scope Of The Unetrans Model*" (Curtin et al., 2001). Table 1 provides TDM elements 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-Analysis Zone
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 spatial databases 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, 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 : 1) Network, 2) Matrices and 3) 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.

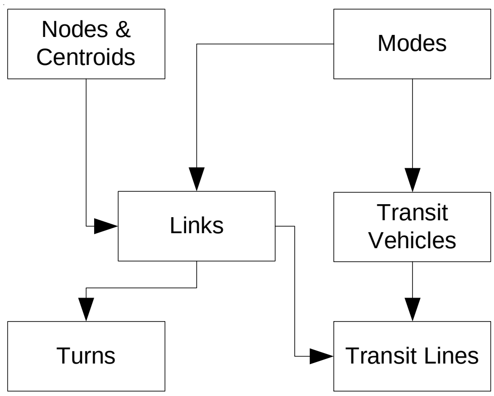

Figure 2: Network entities and their hierarchy in EMME/2

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		**OUTGOING DATA**
▪ Network - Centroids, nodes, links and turns (with their attributes) - Source for additional volumes ▪ Matrices - Demand (in persons) - Vehicle occupancy (in persons/vehicle) - Additional demand (in vehicles) ▪ Functions - Link volume-delay - Turn penalty - Extra function parameters ▪ Parameters - Stopping criteria	**Auto Assignment**	▪ Network - Auto volumes on links and turns - Auto times on links and turns - Additional volumes on links and turns ▪ Matrix - 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 UNETRANS (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 the travel demand modelling elements that need to be considered in GIS transportation data model enhancement are identified, and a prototype data model referring to the selected traffic assignment is proposed. The above objectives are 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 Transport Junction 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 Route Feature ESRI feature class. Extra information that needs to be considered in order to enhance the existing GIS transportation 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 trans portation 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 transportation data models.

E. Relationships

A set of relationships between TDM classes is defined during a fixed-demand, single-class auto assignment UTPS procedure. These relationships governed by object-oriented design rules, compose a UML static view class diagram as illustrated in figure 3. A thoroughly descriptive analysis documenting the UML data model design has been incorporated in Table 3.

Table 3: Descriptive Analysis Documenting UML Data Model Design

Class	Description
Function	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 *Function's Applicable to Link* and the *Function's Applicable to Turn* relationships.
Scenario	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.
Matrix	A *Matrix* may be auto demand matrix *(Demand)* in case it specifies the number of persons travelling by auto for each Origin-Destination pair, vehicle occupancy matrix *(Vehicle Occupancy)* in case it specifies the average number of persons per vehicle for each Origin-Destination pair or may represent additional demand matrix *(Additional Demand*) in auto equivalents (for example truck traffic) to be added to the auto demand. Thus, three *generalization relationships* are defined between the *Matrix* class and its above-mentioned subclasses. 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 *(Scenario's Associated with Matrix).*
Volume	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 *Fixed Background Volume is Applied on Link* and *Fixed Background Volume is Applied on Turn association relationships* respectively. The class *Volume* is also associated with *Scenario* through an *association relationship* of type *aggregation (Scenario is Associated with Volume).* Extra attributes are scenario specific and are defined by the user. Different scenarios may have different sets of extra attributes.
Link Assignment	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 *Link Assignment 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*.
Turn Assignment	The relevant to a *Turn* output of auto assignment is stored to the *Turn Assignment 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*.
Travel Time Matrix	Finally, a matrix, containing travel times for each Origin-Destination pair as obtained by auto assignment procedure is represented by the *Travel Time Matrix* class. This is associated with *Scenario* class through the *Scenario Assignment Results Matrix association relationship.*

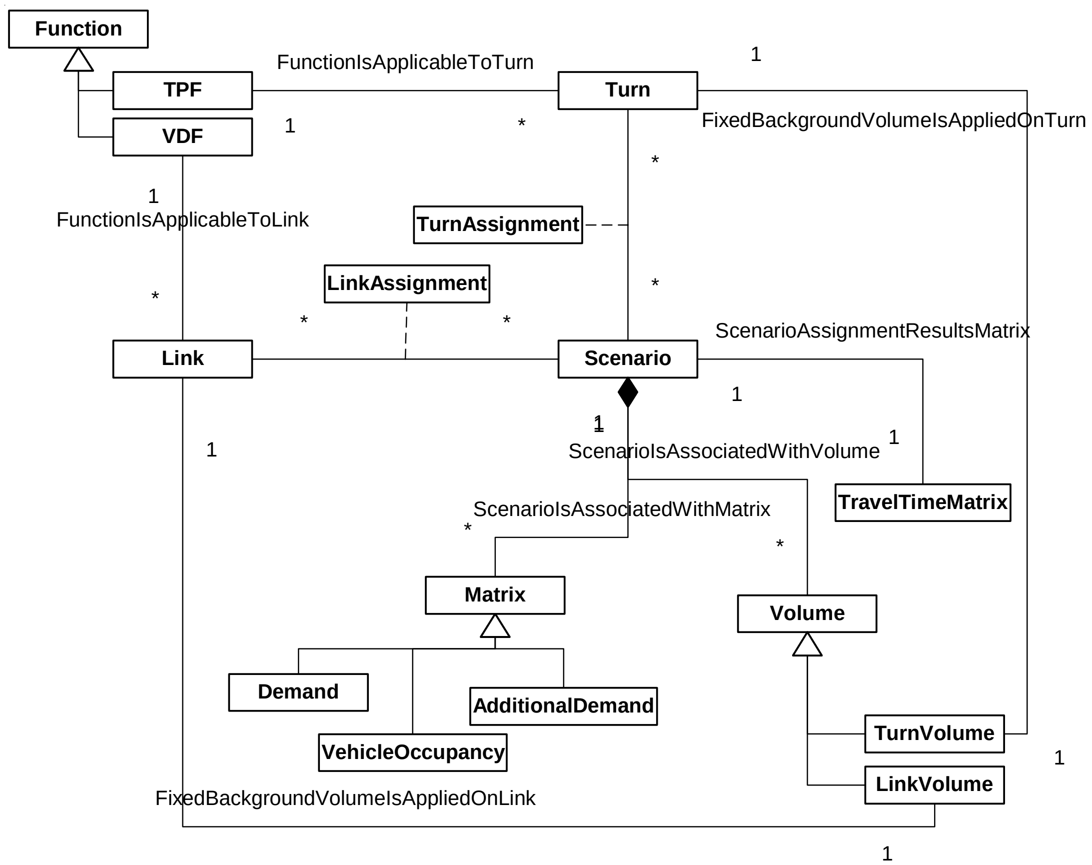

Figure 3: The Proposed Data Model for Fixed-Demand Single-Class Auto Assignment

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 was implemented in Arc GIS 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 UNETRANS 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, AuxiliaryAuto Segment 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 Anchor Section and the point feature class Anchor Point define the fundamental linear reference space upon to which any kind of point or line event will be referenced.

Topology rules are included inside BaseNetwork_Topology, geodatabase component and are synopsized 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, and

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

5.2 Traffic Assignment

During physical design the proposed data model representing the selected traffic assignment (Figure 3) is transformed to a number of object classes and relationship classes between object classes, inside the geographic database. Certain rules governing transformation of an object-oriented UML data model to a geographic database, along with critical physical design details are as follows :

- *Non spatial Object Classes (Tables) are obtained from non spatial UML classes.*
- *1-1 relationship classes are obtained from 1-1 UML association relationships:* 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.
- *1-M relationship classes are obtained from 1-M UML associations relationships:* the primary key field of the origin class is designed as foreign key to the destination class.
- *M-N relationship classes are obtained from M-N UML associations relationships:* 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

Table 4 depicts the correspondence between the UML and the geographic database components

Table 4: Mapping UML Data Model to a Geographic Database

UML Data Model Component	Geographic Database Component
Turn Class	*Turn* Table
Scenario Class	*Scenario* Table
TravelTimeMatrix Class	*TravelTimeMatrix* Table
Matrix-DemandMatrix Generalisation Relationship	*DemandMatrix* Table
Matrix-VehicleOccupancyMatrix Generalisation Relationship	*VehicleOccupancyMatrix* Table
Matrix-AdditionalDemandMatrix Generalisation Relationship	*AdditionalDemandMatrix* Table
Function-VDF Generalisation Relationship	*VDF* Table
Function-TPF Generalisation Relationship	*TPF* Table
Volume-LinkVolume Generalisation Relationship	*LinkVolume* Table
Turn-TurnVolume Generalisation Relationship	*TurnVolume* Table
FixedBackgroundVolumeIsAppliedOnLink Association Relationship	*FixedBackgroundVolumeIsAppliedOnLink* 1-1 Relationship class
FixedBackgroundVolumeIsAppliedOnTurn Association Relationship	*FixedBackgroundVolumeIsAppliedOnTurn* 1-1 Relationship class
ScenarioAssignmentResultsMatrix Association Relationship	*ScenarioAssignmentResultsMatrix* 1-1 Relationship class
FunctionIsApplicableToLink Association Relationship	*VolumeDelayFunctionIsApplicableToLink* 1-M Relationship class
	TurnPenaltyFunctionIsApplicableToTurn 1-M Relationship class
ScenarioIsAssociatedWithMatrix Association Relationship of type aggregation	*ScenarioIsAssociatedWithDemandMatrix* 1-M Relationship class
	ScenarioIsAssociatedWithAdditionalDemandMatrix 1-M Relationship class
	ScenarioIsAssociatedWithVehicleOccupancyMatrix 1-M Relationship class
ScenarioIsAssociatedWithVolume Association Relationship of type aggregation	*ScenarioIsAssociatedWithLinkVolume* 1-M Relationship class
	ScenarioIsAssociatedWithTurnVolume 1-M Relationship class
LinkAssignment Association Class	*LinkIsInvolvedToScenario* M-N attributed relationship class
TurnAssignment Association Class	*TurnIsInvolvedToScenario* M-N attributed relationship class

Figure 4, illustrates the physical design of the geographic database (FDSCAA-GDB) implementing a) the base network feature dataset and b) the fixed-demand, single-class, auto assignment.

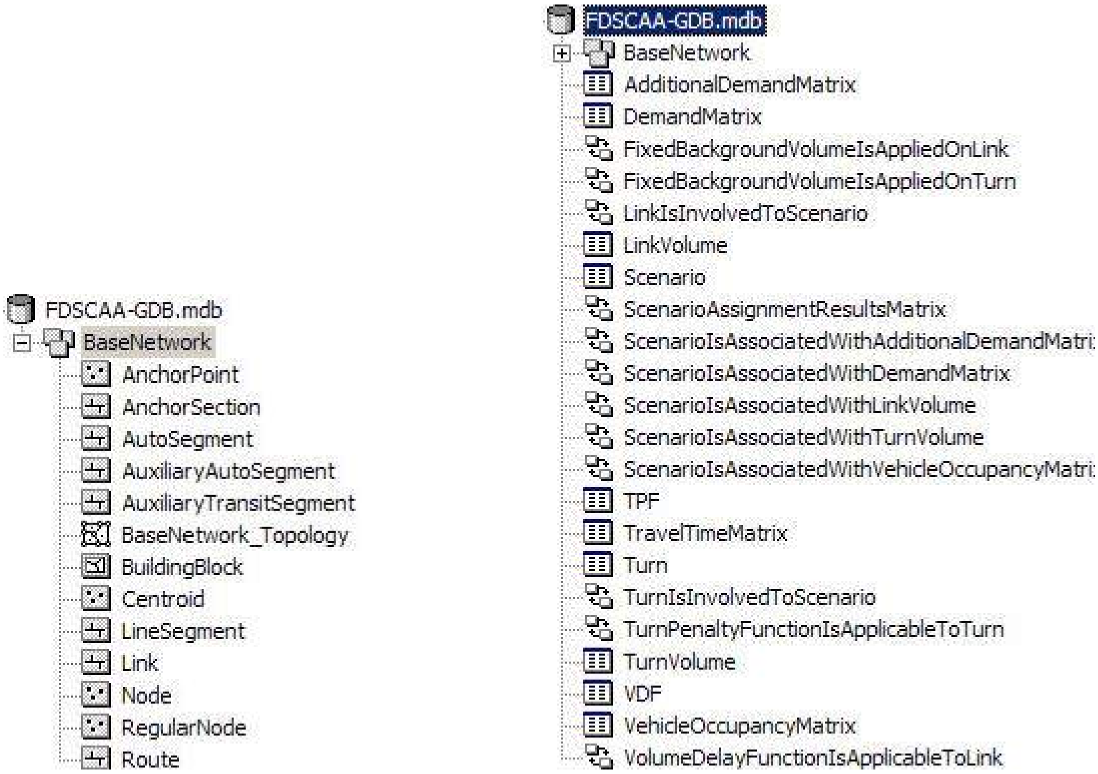

Figure 4 : Data Model Transformation to Geographic Database Components

A demonstration of event layers displaying assignment results is illustrated in Figure 5. 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 5 : 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.

It should be stressed once again that a UML data model serves as an open architecture standard independently of operating systems, platforms, programming languages, database management systems and GIS management systems. Certain implementation choices involving open source software may set new prospects as regards the future transportation data management and sharing, by encouraging individual developers and the research community to develop additional open source specialized applications.

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.

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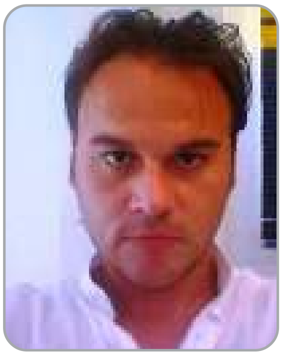

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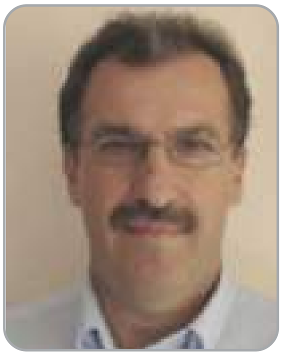

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