DOCTORAL ABSTRACT

# ENHANCED DATA MODELS FOR GEOGRAPHIC INFORMATION SYSTEMS

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**ABSTRACT**

*Geographic Information Systems (GIS) are becoming essential tools for analyzing and geographically transferring the information about the world. GIS incorporates, both spatial and non spatial data, and has the capability for searches, overlays, association and display output in 2D/3D incorporating non spatial data. In addition to spatial data a GIS systems contain geo referenced information which enables near true representation of geography and capability to provide measurements, variations etc. These features make the technology different from the CAD systems and conventional database applications. The capabilities of GIS have brought a paradigm shift in the approach to the presentation of information.*

*A GIS data contains spatial and attribute data. The spatial data models popularly use data in Vector and Raster forms. Both these data sets are complimentary to each other and have their significant roles in any GIS application. Storage/retrieval of raster models has their primary role in visualization while vector representations have focus on the analytical capabilities. The present research work is mainly focused on vector data management.*

*Vector data is basically represented using Point, line and polygons. The point data is primarily stored in a data base as X and Y co-ordinate or it could be lat/long in case of a geo referenced data. Stream of the points forms a line and a closed line is represented as polygon. The data models in geographic databases allows any geographic features in real world to be digitally represented and stored in a database so that they can be presented in map form, and can also be worked with and manipulated. The data base design incorporates real world data in the form of layers and each layer may further represent multiple aspects. For analytical capability of any system, the appropriate database designing will lead to efficient results. The data modeling process, which enables the database design consists of three levels namely, conceptual, logical and physical levels. The conceptual level defines the entities, their properties and relationship between entities, which are important for a particular application domain. The conceptual model is translated into a set of constructs supported by the target database management system (DBMS) at the logical level. At physical level, data are mapped onto the physical structure of the DBMS.*

*The present research has evolved an approach to represent spatial data at conceptual level and to design vector model at logical level for efficient vector data storage. Spatial data representations have been investigated further under two important aspects, namely geometric and topologic consistencies using the developed terzatto tool.*

*At conceptual level a Topo-Net Spatial Entity relationship model has been proposed for representing topological and network geo-primitives being required for GIS applications. A Triangular Pyramid Framework for enhanced object oriented data model for GIS applications has been proposed at logical level. The model covers the representation of complete information required by GIS application in three levels i.e. Object, Geometric and Location. Further to analyse the performance of the triangular pyramid framework, it was compared with the existing bi-level object oriented data model, whose vector data storage has been done using the developed Digitiz tool to digitize raster map to vector data. Triangular Pyramid framework has been implemented through Terzatto Tool. Using Terzatto tool Shape file data has been transformed into Triangular Pyramid Framework. The developed Terzatto tool assessed the effectiveness of the proposed model for removal of geometric and topological inconsistencies using the additional common reference table at location level. To evaluate the proposed Triangular Pyramid Framework for topological consistency of spatial objects a scene has been described. Topological consistency of a scene description means that there is no internal contradiction among the individual relations due to their properties. Properties such as the converseness of pairs of relations and the composition of relations have been considered in order to guarantee that a scene description is free of internal topological contradiction of relation. The object of concern in this research are spatial regions, which are defined as homogeneously 2-dimensions point sets with connected boundaries. The definition of binary topological relations between two spatial regions A and B, is based on the four intersections of A's boundary (A) and interior (A) with the boundary (B) and interiors(B) of B. The consistent integration of topological information relies inherently on the algebraic properties of the relations between the objects. A rigorous computational method has been adopted to infer the topological information consistency between spatial regions for the scene description.*


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## INTRODUCTION

GIS concepts today have brought a paradigm shift world over in the approach for developing the information system. GISs developed with incorporation of satellite/aerial images, survey maps, location information from GPS devices and their integration with data from management work flow systems are revolutionary in nature. Visualization of information has added immense power to resolve complex situations.

The power and potential of GIS, however, in India is not yet exploited thereby it could be attributed that there is need and scope to work in this area on various aspects. The primary motivation to undertake research in this area is to explore the core of spatial data model and database design which can be relooked at in terms of the relevance to a GIS application.

GIS is defined by Konecny, 2003 as, "A Computer System for the input, manipulation, storage and output of digital spatial data. It is a digital system for the acquisition, management, analysis and visualization of spatial data for the purpose of planning, administering and monitoring the natural and socio-economic environment".

Thus, GIS is a computer based information system used to digitally represent and analyze the geographic features present on the Earth's surface and the events (non-spatial attributes linked to the geography under study) that are taking place on it.

GIS has its application in wide number of areas including Engineering Mapping, Tax Mapping, Highway Maintenance, Event Mapping (accidents, fire, crime, facility breakages), Census and Statistical Mapping, Land use Planning and Management, Environmental Impact Studies, Natural Resource Mapping and Management, Urban and Regional Planning and so on(Albert and Yeung, 2009). Development of an efficient GIS application not only depends on the GIS product but also needs to develop suitable spatial /non spatial databases, adoption of standards, deployment of spatial data infrastructure (SDI) concepts etc.

The data models in geographic databases or the GIS data model allows the geographic features in real world locations to be digitally represented and stored in a database so that they can be presented in a map form, and can also be worked with and manipulated to address spatial analysis and decision making (Tadakaluru *et al.*, 2005). GIS data models can broadly be either vector data model or raster data model based on the data they use to represent and store.

Spatial data modeling is a precondition and key to the design and realization of spatial database which provides means for spatial data organization. The integrality and consistency of geographic data rely on how the data model represents, stores and manages the GIS data (Yen *et al.,* 2006).

The representation of data is done at conceptual level. The conceptual level defines the entities, their properties and relationship between entities, which are important for a particular application domain. The conceptual model is translated into a set of constructs supported by the target database management system (DBMS) at the logical level. At physical level, data are mapped onto the physical structure of the DBMS (Elmasri *et al.,* 2009).

Any GIS data model is implemented in layers. Data is organized by layers, themes, with each layer representing a common feature or its subsets (Zeiler, 1999).The data model represents a set of guidelines to convert the real world (called entity) to the digitally and logically represented spatial objects consisting of the attributes and geometry. The attributes are managed by thematic or semantic structure while the geometry is represented by geometric-topological structure (Lo and Yeung, 2009). The model designed should be geographically and topologically consistent. Geometric inconsistency refers to geometric part of geographical features (shapes and coordinates). Three kinds of geometric inconsistency errors are repeated point: two or more points in the same Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the Earth's surface and the events that are taking place on it. Further validation for topological inconsistencies have also to be taken care of.

The present research work deliberates on conceptual and logical designing of the spatial data models. The next section discusses the brief overview of various data models.

## LITERATURE SURVEY

### CONCEPTUAL MODELS

Conceptual database model represents the real world at a high level of abstraction that is independent of hardware and software. At this level objects/entities, their attributes and relationships are defined diagrammatically (Batini *et al.,* 1992).

### CONVENTIONAL CONCEPTUAL MODELS

Entity relationship(ER) model (Chen *et al.,* 1976), is used to represent the relationship between entities and is a basic tool in database design. This model does a good job of capturing and representing the basic semantics of many different situations. However , the model, is not capable to capture more domain semantics for modern applications(Badia, 2004, Peckham et al., 1988), hence more domain semantics are included in EER models(Badia, 2004) where an enhancement has been made through representation of generalization/ specialization, aggregation and classification in ER model. E-R models have a layered approach to organizing information in that the basic components of an E-R model, attributes, entities and relationships can only be combined in certain ways , on the other hand,the extended entity-relationship mode (Elmasri *et al.,* 2009) is decomposed according to a set of basic entity-relationship constructs, and these are transformed into candidate relations via entity relations, extended entity relations and relationship relations which reduce the number of data dependencies and maintains data integrity through normalization.

It has been observed that the above mentioned ER, EER models can represent traditional database design for conventional commercial applications and are not effectively suitable for GIS applications as they are incapable to represent spatial aspects.

**GIS SPECIFIC CONCEPTUAL MODELS**

MADS is a spatio-temporal data model. It is a framework suitable for vector data for use at different resolution levels. The MADS(Parent et al., 1999)(Christine et al., 1999) data modeling, data matching from different data sets, and data utilization supporting multiple representations. It belongs to the family of entity relationship data models extended to supports the main concepts of object oriented and spatio-temporal features to be represented in conceptual database design. Remodeling of ER models into MADS has reduced the number of object and relationship types by a factor of 23% compared to ER models.

Chrono GeoGraph(CGG)(Sandrine et al., 2004) is another spatio-temporal model that pairs the classical features of the EER model with a large set of spatial and temporal constructs . It introduces spatial attributes that take their value over a geometry type and can be associated with spatial and non-spatial entities. CGG model is being extended so that multiple representations of topological relations can be dealt with (Donatella et al.2008). Topological relations allow us to constrain the relationship between the geometries of pairs of spatial entities. Moreover it makes it possible to pair the spatial entity with multiple viewpoints, shapes and resolution by means of suitable primitives for cartographic specialization. Both MADS and CGG Model lacks to incorporate either the topological or the network or both the aspects of GIS applications.

Several models E.g. GeoOM(Tryfona et al.,1997), MODUL-R(Yvan et al., 1996), and SPATIAL E-R model(Li et al., 2006), Spatially Enhanced EER Model(SEER)(Firn, 1994) only supports the representation of spatial information, similarly temporal model e.g. Temporal Entity-Realtionship Model(TERM), Temporal EER Model(TEER)(Yvan et al., 1996),Relationships, Attributes, Keys and Entities Model(RAKE)(Ferg et al., 1985) supports the association of time with objects, relationships and attributes. Whereas, in a real life for a GIS application, apart from Spatial , temporal and spatio-temporal scenario, topological and network scenarios are also frequently encountered. GeoOOA(Kosters et al., 2006) Object-oriented Analysis for GIS overcomes the deficiencies of conventional spatio-temporal and object oriented analysis model by adding suitable domain tailored primitives such as topological, network etc. but is applicable for object – oriented analysis only.

In conclusion, none of the above mentioned spatial and temporal models satisfied the representation of topological and network Geo-primitives for relational GIS applications appropriately. This prompted the development of Topo-Net Spatial Entity Relationship model for representing topological, network and generalization features fulfilling the simplicity and comprehensiveness criterias, where simplicity of the model talks about easiness of use and understanding and comprehensiveness means the direct representation of topological and network aspects in the model. The Topo-Net spatial ER model (Bahl *et al.,* 2011) has been designed through the proposed notations for a GIS application.

**LOGICAL DATA MODELS**

At logical level, the conceptual schemas are translated into logical schemas. These schemas are represented through the logical models. These models give the designer a formal methodology and framework for the correct specification of the geographical information. Implementations at this level are based on conventional relational, object-oriented or object-relational approaches being discussed below:

**RELATIONAL DATA MODEL**

The power and elegance of the relational model stems from the fact that it uses a single construct, the relation(Gubiani et al., 2007). Five functional closed operations are defined in relations, namely, union, difference, selection, projection and Cartesian product.

For spatial applications, however, the resulting representation is inadequate.

For example, if layers are represented with plain relation, operations such as overlaying and reclassification cannot be derived from the fundamental relational databases.

In the relational model these operations are hidden in the physical level. As a result important information is lost and the system is tied to some specific implementation. Thus relations are inadequate as the sole modeling construct for geographical applications.

**GEORELATIONAL DATA MODEL**

Data representation for GIS applications includes the spatial and attribute component (Dangermond et al., 2008). Spatial data describes the location of spatial features, whereas attribute data describes the characteristic of spatial features. The Geo Relational data model stores spatial and attribute data separately in a split system. Spatial data is stored in graphic files and attribute data is in a relational database. A Geo Relational data model uses the feature label or ID to link the two components as shown in figure below. The two components must be synchronized using some ID so that they can be queried, analyzed and displayed in unison.

**OBJECT BASED DATA MODEL**

A fundamental requirement for spatial database design is the ability to model spatial properties, i.e., to associate parts of space with an attribute (Tadakaluru et al., 2005).

Parts of space are usually represented by points, lines and regions and are known as geometric features. Spatial applications deal with two, orthogonal, generalizations of spatial properties. One is association of the whole of space with an attribute and the other is associations of sets of attribute and geometric feature. The former is modeled with concepts oriented towards objects (Sauchyn et al., 2008). Object Based Data Model has been used as a means of conceptual structuring of geographic information. In particular it models real-world objects (or entities) with a precise and 'crisp' spatial location and extent.

The object based data model differs from the Geo Relational data model in two important aspects. First, the object-based data model stores both the spatial and attribute data of spatial features in a single system i.e. an object rather than a split system. Second, the object-based data model allows a spatial feature to be associated with set of properties and methods. Since both spatial data and attribute data is stored in a single system the problem of data synchronization is eliminated that is found in split system Geo relational data model.

**VECTOR LOGICAL DATA MODELS**

Vector data represents discrete features and its data types points, lines and polygons are stored and managed using vector data model. Various vector logical data models viz: the Spaghetti Model (Dangermond, 1982), Topology Model (Dangermond, 1982), Polyvrt (Peuker and Chrisman, 1975), Bi-level (Choi and Lub, 1991), Geo-relational (Morehouse, 1985&1989) and Geo-database (Twumasi, 2002) have been studied and explained below:

**THE SPAGHETTIE MODEL**

In spaghettie a digital cartographic data file is constructed referred to as a spaghattie file which is a collection of coordinates, strings heaped together with no inherent structure (Dangermond, 1982). This model is inefficient for most types of spatial analysis, since any spatial relationships must be derived through computation. On the other hand the lack of stored spatial relationships, which are extraneous to the plotting process marks the spaghetti model efficient for reproducing the original graphic image. Thus they are used for simpler forms of computer assisted cartographic production.

**TOPOLOGICAL MODEL**

In topological modelthe information allows the spatial definitions of points, lines, and polygon type entities to be stored in a non-redundant manner (Dangermond, 1982). The GBF/DIME (Geographic Base File/Dual Independent Map Encoding) model is built upon the topological concept. The model represents a directed graph. ,in which an explicit direction is being assigned by recording a from-node and to-node which automatically check for missing segments and other errors in the file. In this model the basic logical entity is a straight line , where street, river, etc is represented as a series of straight line segment which are spatially defined. The main problem with this model is that the individual line segment do not occur in any particular sequence order, so to retrieve all line segments which define the boundary of a polygon, an exhaustive search must be done as many times as there are line segments in the polygon boundary.

**POLYVRT**

Peucker and Chrisman (1975)developed POLYVRT(Christine et al., 1999). This model had overcome the very major retrieval and manipulation inefficiencies seen in simpler topologic structures by explicitly and separately storing each type of data entity in a hierarchical data structure. It made distinctions between types of entities both logically and topologically meaningful, so that a chain is denoted as the basic line entity. It facilitates easy search and retrieval and there is partitioned storage. Leads to storage overhead (pointers) and integrity of pointers. It is a multipurpose database model .

**GEO DATABASE DATA MODEL**

This model is built on arc-objects. It uses the geometries of point, polyline and polygon to represent vector-based spatial features (Egenhofer et al., 1994). The data structure of geo database distinguishes the feature classes and feature datasets. A feature class stores spatial data of the same geometry type and its datasets stores feature classes that share the same coordinate system and area extent. In this model, feature classes can be standalone feature classes or members of a feature dataset. The geo database constitutes a uniform repository of both spatial and attribute data in a single database system. Objects in the geo database can have behavior associated with them. Integration with object-oriented concepts and COM technology allows great level of customization and reuse of the model to create application-specifications, which may (in the figure) provide the framework for interoperability. The main problem we encountered was the custom domains, but this was not investigated. In addition, although the Arc Objects Library is extensive, more functionality needs to be added to allow high level of customization.

**BI LEVEL DATA MODEL**

There are two separate layers (Choi et al., 1991) in this model as mentioned below:

Higher level data model (Geographic object data model): This level consists of the geographic objects and a set of semantic spatial functions through which the topological relationships among objects can be defined or derived.

Lower level data model (Geometric object data model): This level consists of geometric objects which are actual spatial representations of the geographic objects. It also has a set of functions for retrieval, manipulation, computation of geometric objects. In this model, relationship between geographic and spatial objects is investigated, Spatial object is not PART-OF a geographic object , but is just a representation of the geographic object , similar to the mapping from one object to any other object(s). Where as Triangular pyramid model, the proposed model has three abstraction levels represented using three components – the object component, Geometric component and the location component. The details of the same have been discussed in the next section. In this model “uses” relationship type has been introduced, where the common reference table is used for representing the location component for various maps.

**SPATIAL DATA QUALITY ISSUES**

Spatial data quality like data accuracy, precision, consistency, completeness and so on are the key issues in Geographic Information System(Jeffrey et al., 1994)(Wand et al., 1996). Lot of research has been done in this direction. Various models, techniques, methodologies, tools and framework have been developed to meet the data quality dimensions(Wang et al., 2009). Dimensions are applied with different roles in models, techniques, tools, and frameworks. With reference to inconsistency dimension, it has been found that Geometric and topological inconsistencies have been handled either by using algorithms like node snapping(Liu et al.,2001) or through software written in AutoCAD LISP(Egenhofer et al.,1990). They are mainly discussing Geographical boundary inconsistency (Xie et al., 2010) caused when the geographical data are from different data sets or results of spatial analysis. The inconsistencies between two adjacent geographic boundaries are either because two boundaries have same number of vertices but not the same coordinates and secondly they have the different numbers of vertices. To resolve the mentioned inconsistency, node snapping generalized algorithm is used for finding matching vertexes, and standard formalizing of inconsistent boundaries by vertical projection. Topological inconsistencies like intersection ,separation and interlaced intersection have been corrected by using Delaunay triangulation (Ai et al., 2000). It is used for obtaining adjacent areas to remove topological inconsistencies.

Topological error correction of GIS vector data (Gubiani et al., 2008) has been accomplished by Autocad VE Autolisp. It eliminates Floating or short lines, overlapping lines, overshoots and undershoots, Unclosed and weird polygons , dangle nodes, nodes and pseudo nodes , slivers and gaps error etc. The software automatically checks the mentioned errors and makes the necessary corrections for accurate spatial analysis.

A Geo Expert- framework (Tadakaluru et al., 2005) has been proposed for data quality in Spatial database . It is a cleansing tool for spatial data that integrates the spatial data visualization and analysis capabilities of the ARCGIS Engine for an expert system.

All above mentioned anamolies refers to the inconsistencies that can be resolved either algorithmically or through the software design. However, the inconsistencies arising while digitization and due to multiple inputs may be best suited to be resolved at the data model level. The concept though has been recommended (Xie et al., 2010), its implementation details were not evident.

**MODELS FOR TOPOLOGICAL RELATIONS:**

Binary topological relations between two objects, A and B, are defined in terms of the four intersections of A's boundary(A) and interior(A) with the boundary (B) and interior (B) of B(Egenhofer and Franzose 1991). This Model is concisely represented by a 2*2 matrix, called the 4-intersection and is the basis for accessing the proposed Triangular Pyramid framework.

As mentioned in literature, for analytical capability of any system, data models have vital role. The appropriate data modeling will lead to efficient results. Hence, to overcome the mentioned gaps in the literature, the focus of the present research work is on the designing of an effective spatial data model at conceptual and logical levels and is being explained in the next section:

**MOTIVATIONS FOR THIS RESEARCH WORK**

Literature shows that various spatial and temporal models are available but none of them satisfied the representation of topological and network Geo-primitives for relational GIS applications appropriately. This prompted the development of Topo-Net Spatial Entity Relationship model (Bahl et al., 2011) for representing topological, network and generalization features fulfilling the simplicity and comprehensiveness criterias, where simplicity of the model talks about easiness of use and understanding and comprehensiveness means the direct representation of topological and network aspects in the model. The Topo-Net spatial ER model has been designed through the proposed notations for a GIS application.

One of the major challenges the Geographic Information System applications face today relates to quality of data. Better the quality of data, efficient is the application. Quality of data have multiple dimensions like completeness, validity, consistency, timeliness and accuracy, that makes data appropriate for a specific use. The rationale of quality refers to the degree of excellence exhibited by the data in relation to portrayal of the actual scenarios. Inconsistency issues in spatial databases have major concern for quality data as it results in data integrity. It has been observed that most of the inconsistencies are addressed through either algorithms or software's. However, the aspects arising at data collection and preservation phase is much recommended while designing the database and thereby handling the geometric and topological inconsistencies. Hence, the research also deliberates on quality concerns and its assessment through the tool development.

At Logical level various data models like spaghetti, polyvrt, bi- levels etc. are available but they suffer from one or another drawbacks as discussed above in the literature review. Hence, an approach to design a data model is evolved which can overcome the identifies gaps of various models being studied to overcome the identified gaps of various models being studied for a GIS application. An enhanced object relational dynamic data model has been proposed in which reusability and dynamicity has been introduced for the database. Reusability concept allows storage of distinct objects having same spatial representation onto a single storage space and dynamicity allows creation of relations on user's requirement. The conceptual data model for the same has been designed named Triangular Pyramid framework.

To prove that the proposed model can be used by the GIS community for vector data storage, its performance with respect to response time and quality parameter aspects related to inconsistencies have been compared with the similar type of existing bi-level data model which has been implemented using a manual digitizer tool named "Digitiz"(Bahl et al., 2011).

Large amount of spatial data is derived from map digitizing. In spite of availability of a large number of packages available for digitization, there is no complete automatic digitization software available, since every image is different and it has its own properties. In view of this, the practice of acquiring vector data continues to be by manual digitization. Existing Digitizers like Algolab R2V Toolkit, Vextractor and WinTopo are automatic raster to vector conversion software's but they suffer from drawbacks like inability to add data in the vector format, inability to handle queries, making modifications and storage of all the data in global database. Hence, to overcome the above mentioned drawbacks and to understand the structure of existing bi-level object oriented model, "Digitiz" tool based on bi-level model has been developed.

High level topological information about spatial objects can be described in terms of a set of binary topological relations between the objects, also called a scene description. The objects of interest are spatial regions, which are bounded objects that have a distinct identity. The consistent integration of topological information relies inherently on the algebraic properties of the relations between the objects. Properties such as the converseness of pairs of relations and the composition of relation must be fulfilled for any combination of relations in order to guarantee that a scene description is free of internal topological contradictions. To prove that the proposed model is free of internal topological contradictions a rigorous computational method has been adopted to reason about topological relations between spatial regions and to infer consistency of topological information. The proof validates the proposed Triangular Pyramid Framework (Bahl et al., 2011) based on 4-intersection model which is considered as the basic model for representing binary topological relationships between two objects.

The research proceeds to understand how the In-Memory Data-Grid solution (Bahl et al., 2012) for storing the GIS databases is better than the conventional method of storing the database in the secondary storage.

## IMPORTANT ACHIEVEMENTS

### PROPOSED MODELS

#### Topo-Net Spatial ER Model

The Topo-Net Spatial ER model for Geographic Information Systems has been proposed at conceptual level for representing topological, network and spatial features for GIS applications Indeed, an analysis of existing models shows that topological and network features are weakly defined. The proposed Topo-Net Spatial ER model supports topological ,network and Generalization features effectively. The model is far more flexible, simple than what many other models offer. Finally, Topo-Net Spatial ER model led the application designers to discover the importance of topological , network and generalization features within their application. The usage of the same to represent Optical Fiber Cable Network is shown below:

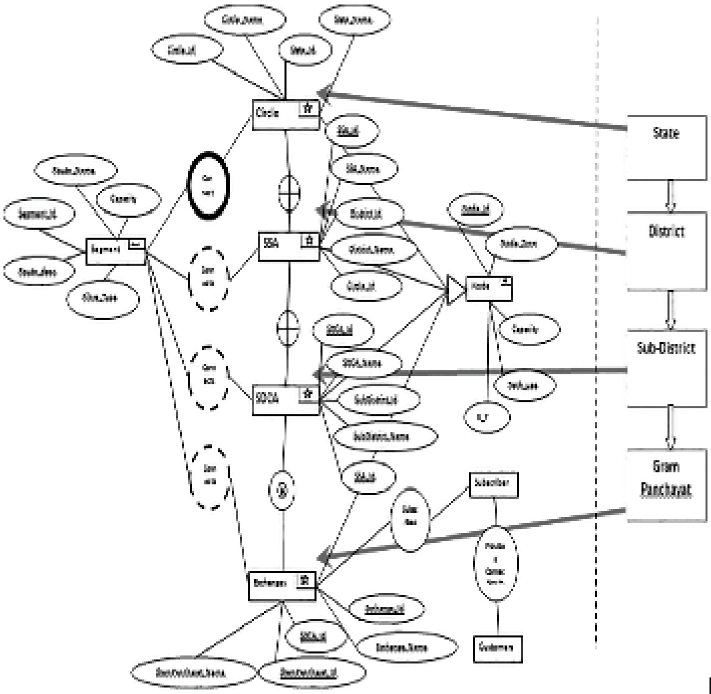



**Figure 1. Topo-Net Spatial ER Model for Optical Fiber Cable Network (From Bahl et al., 2011)**

#### Proposed Triangular Pyramid Framework for Enhanced Object Relational Dynamic Data Model for GIS

The objective of Triangular Pyramid Framework for Enhanced Object Relational Data Model (Bahl et al., 2011) is to develop a framework for enhanced object relational dynamic vector data model, for representing the complete information being required for representing the data for GIS based application.

The Data Model being developed has three levels of abstraction. They are: The Object Component (Highest Level), the Geometric Component (Middle level), and the Location Component (Lowest Level). The diagrammatic representation of the same is shown in fig 2.

#### The Object Component (Highest Level)

Map is a combination of different types of layers. These maps and layrs are called objects as they are real life entities having both attribute and behavior. Attribute corresponds to the nature of the phenomenon the data represents and behavior specifies the manipulation processes. This is the highest level of abstraction, and at this level geographic data is represented by layers representing the relative position of spatial objects.

#### The Geometric Component (Middle Level)

The Geometric component is the middle level as it is the interface between the object and its actual spatial existence on the earth. Each geographic object at the higher level has its corresponding geometric object. The information at geometric level represents the shape of the geographic object, which is categorized into three: - point, line, polygon.

The first is point data where each object is associated with a single location, Example a city, district, school, hospital etc.

The second is line data where the location is described by the string of points, Example: - road, river, drainage, national highway etc.

The third is polygon data, where the location of object is represented by a closed string of coordinates. They are thus associated with areas over defined space, Example: -blocks, villages etc.

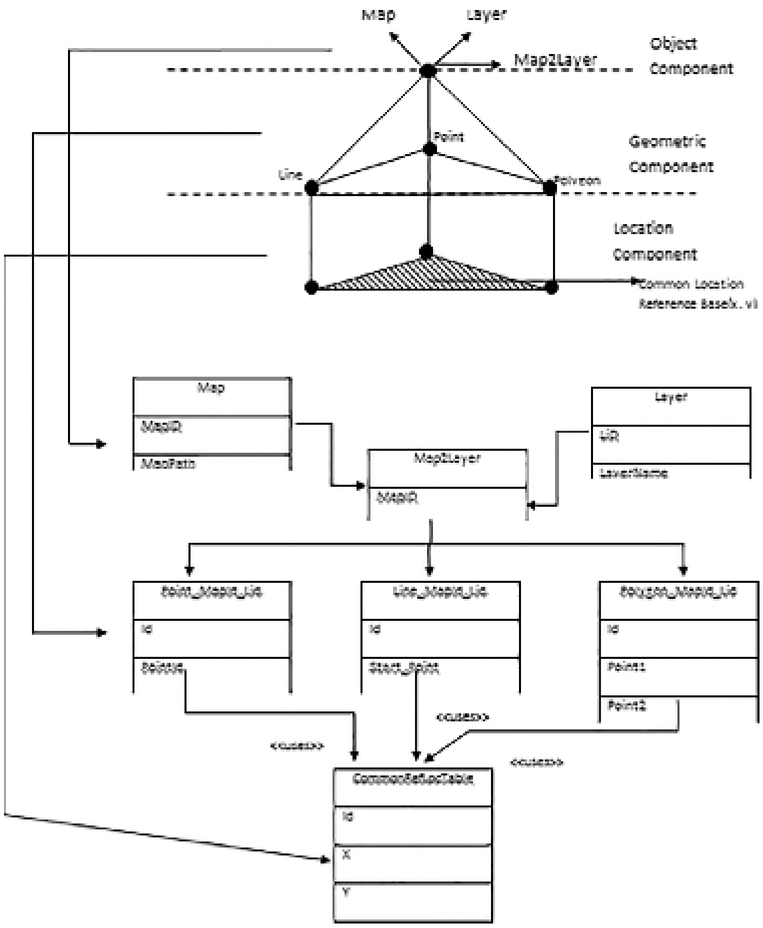



**Figure 2. Triangular Pyramid Framework**

**The Location Component (Lowest Level)**

The lowest level of proposed data model is location component which represents the actual screen coordinate values of the geometric objects at the middle level.

The proposed model has been designed in a way that it is liberated from various topological inconsistencies caused due to topological relations that arise at the time of digitization and data storage. It introduces Reusability and Dynamicity for the database. Reusability concept allows storage of distinct objects having same spatial representation onto a single storage space and dynamicity allows creation of relations on user's requirement. The third level being introduced to store the common location data in the framework is the basis for inconsistency removal of the spatial data.

**Methodology Adopted For Developing Terzatto Tool**

The tool is developed using top down approach implementing Triangular Pyramid Framework. It is developed by incorporating functionality of MapWinGIS ACTIVEX CONTROL in VB.NET which helps to Load Shape file and perform various functions like Add label, Clear Label, Zoom In, Zoom Out, Zoom to Shape, Zoom to Previous Shape, Panning and many other features. The database is being designed in Postgres SQL considering various aspects like referential integrity, unique data types, extensibility and plug-in. By using Plug-in shape files are imported, which are required to be transformed. The system thus developed is user friendly with a simple GUI which allows user to interact with system, with no or minimal help. It performs insertion and retrieval of data successfully for all the three types of geometric shapes (point, line & polygon).


**XPERIMENTAL RESULTS**

Comparative Performance graphs corresponding to retrieval time being taken when data is stored using bi-level data model and Triangular Pyramid Framework have been shown in Figure. 3 & Figure. 4 below:

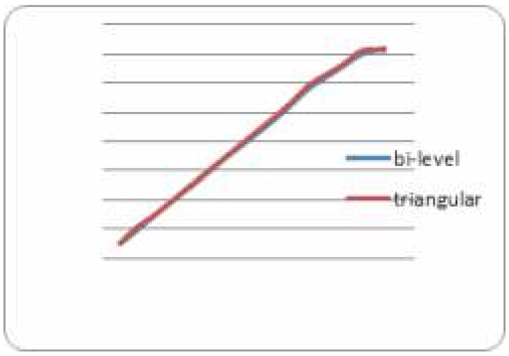



**Figure 2: Retrieval Time Graph**

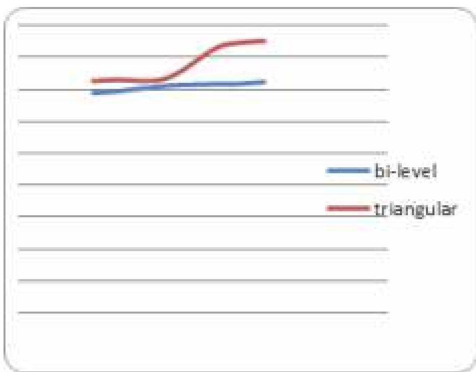



**Figure 3: Retrieval Time Graph**

**Figure. 4 shows the comparative graph with the constant number of rows and varying number of columns as per the retrieval time values being shown in table below:**

**Table :Retrieval Time (Varying No. of Col.)**

| No. of Col. | 10 | 9 | 8 | 6 | 4 | 3 |
|---|---|---|---|---|---|---|
| Bi-level (retrieval time in ms) | 14.416 | 14.314 | 14.293 | 14.203 | 13.894 | 13.795 |
| Triangular Pyramid Framework (retrieval time in ms) | 16.999 | 16.895 | 6.54 | 14.693 | 14.597 | 14.536 |

**Table : Retrieval Time (Varying No. of Rows)**

| No. of rows | 2718 | 2500 | 2300 | 2000 | 1800 | 1500 | 1200 | 1000 | 800 | 500 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| bi-level Triangular | 14.416 | 14.008 | 13.091 | 11.712 | 10.436 | 8.663 | 7.031 | 5.877 | 4.727 | 3.043 | 1.843 |

Figure 4 shows the retrieval time with the constant number of columns and varying number of rows.

The result shows that there is marginal difference in the retrieval time when the data is being stored using the bi-level data model or using the Triangular Pyramid Framework. But when the digitized data is being stored using Triangular Pyramid Framework, it resolves geometric and geographic inconsistencies dynamically. Apart from that Triangular pyramid framework has introduced enhanced object relational data model. It is known as enhanced as it has introduced dynamicity for storing digitized data and than resolving inconsistencies in the model. It has also introduced "uses" relationship type for establishing relationship between two entities.

Bi-level data model is object oriented and it uses PART-OF relationship type to represent relationship between two entities.

A bi-level object – oriented data model defines the spatial and non-spatial geographic and geometric object layer for representing GIS application's data. New OFQL query language was also defined to provide high computational power by using nested or complex functions called super-functions. Whereas, Triangular Pyramid framework has been specially designed for data representation and its focus is on the quality parameters of spatial data. Quality concern being referred to, are Geometric and geographic inconsistencies. Experimental results show that although there is marginal difference in the data retrieval time between the two models i.e., marginally less time is being taken in bi-level model as compared to triangular pyramid framework but Quality parameters being resolved while designing the database using triangular pyramid framework makes this model more suitable for spatial data storage for GIS applications. Therefore, GIS community can use this model for spatial data storage.

**Resolving Inconsistencies**

Existing vector data available in shape file format available at National Informatics Centre, GIS department, India, has been transformed to Triangular Pyramid Database Model using "Terzatto Tool". Now the tool provides a method to acquire, manage, and display information with no geometric and topological inconsistency.

Initially the sample data of Gautama Budh Nagar, Noida, Uttarpradesh, India,is loaded with MAPWINGIS active X control and the map is drawn. On click of the map, the data is transformed to Triangular Pyramid Framework resolving both the types of inconsistences dynamically.

**Resolving Geometric Inconsistency**

Geometric inconsistency refers to geometric part of geographical features (shapes and coordinates). Three kinds of geometric inconsistency errors are repeated point: two or more points in the same position of a feature (line or polygon), repeated segment: two or more segment in the same position of a feature (line or polygon), overlapping boundaries without the same coordinates: there are different vertexes of the shared boundary of features, including different number of vertexes, or different coordinates of vertexes.

A solution has been proposed for inconsistency removal which is handled dynamically keeping in mind the storage and time constraints. Geometric inconsistencies have been handled with the inclusion of common reference table in the Triangular Pyramid Framework and MapWinGIS ActiveX control. Common location table stores the screen coordinates(x,y) of the location wherever user clicks on the map. With the help of mapWin GIS ActiveX control we are able to generate a uniqueId for every object which acts as a primary key for the common location table. Once the location for a particular object on any layer has been saved, it is not saved again in the database irrespective of repetitive selection of that same object either on same (x,y) or different (x,y) location because of the uniqueId generated for the object. Repeated line and Repeated polygon inconsistenices have been discussed below and experimental results are shown with help of data available for Gautam Budh Nagar.

**"NO REPEATED LINE"**

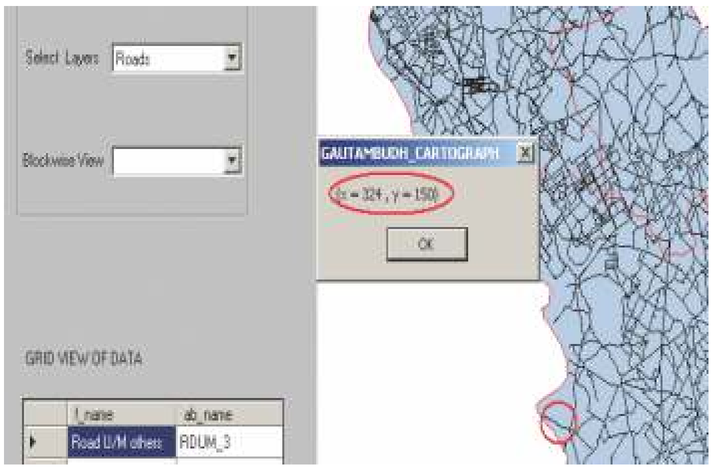



**Figure 5(a) : 1st click on the road layer.**

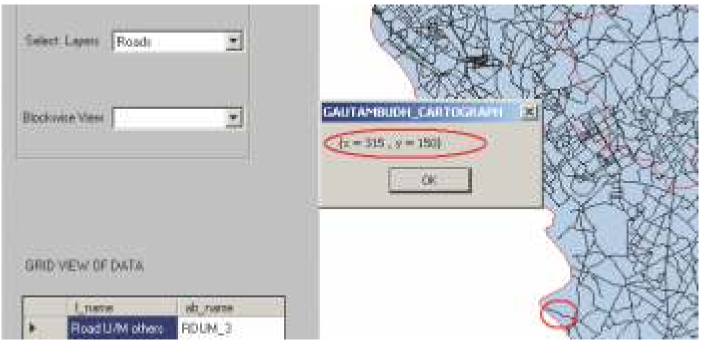



**Figure 5(b): 2nd click on the same road**

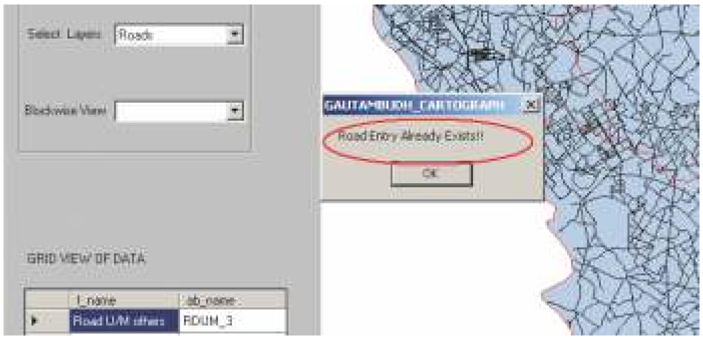



**Figure 5(c): Error Message displayed**

Cid, X, Y generated in comloc table as shown below:

| | cid [PK] integer | x double precis | y double precis |
|---|---|---|---|
| 1 | 11 | 121 | 58 |
| * | | | |

Table COMMOM LOCATION TABLE

In Layer table entries are as shown below:

| | layerid [PK] integer | layername character vai | layershape character vai |
|---|---|---|---|
| 1 | 7 | Drainage | Line |
| * | | | |

TABLE LAYER TABLE

In map 2 layer table entries are as shown below:

| | id [PK] integer | mapid integer | layerid integer |
|---|---|---|---|
| 1 | 8 | 1 | 7 |
| * | | | |

**"NO REPEATED POLYGON"**

Repeated polygon geometric inconsistency has been resolved using the proposed Triangular Pyramid Framework and is called as "No Repeated Polygon" consistency. For Gautam Budhnagar map, when user selects blocks from Select Layers option, block (polygon) layer will be loaded. On click at (x = 262 , y =323) the data for block has been extracted from the spatial file available and will appear in grid as show in Figure 6(a).At the same time a uniqueId (cid = 405 for this case) is assigned dynamically to the block with blk_name as "Dankaur" which will be saved in common location table with its (x,y) values. Now, clicking again on the same road but with different location (x = 254, y = 418), the same unique Id will be generated for the Dankaur and due to primary key constraint of the table the data will not be saved. An error message is displayed as shown in figure 6(b) and figure 6(c). Its data entries in the corresponding table are shown below.

The screen shot of block Dankaur showing no repeated polygon is represented in Figure 5.

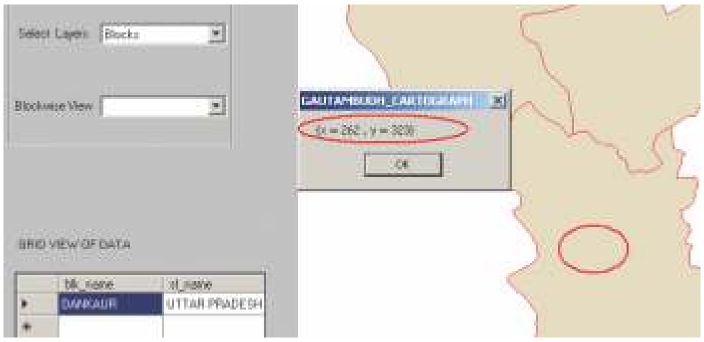



**Figure 6(a) : 1st click on the block layer.**

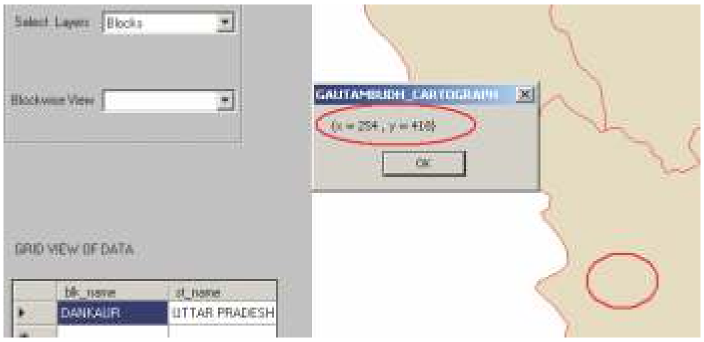



**Figure 6(b) : 2nd click on the block layer.**


**Figure 6(c) : Error Message Displayed.**

| | layerid [PK] integer | layername character vai | layershape character vai |
|---|---|---|---|
| 1 | 3 | Villages | Polygon |
| * | | | |

**Table 1: Layer Table**

| | id [PK] integer | mapid integer | layerid integer |
|---|---|---|---|
| 1 | 4 | 1 | 3 |
| * | | | |

**Table 2: Map 2 Layer**

This cid, id generated will go in row of "layer" table (block layer) where "Dankaur" information is stored. When User again clicks on block Dankaur, there will be no repeated entry in common location table as well as in row of block table in database The table in database on clicking again is shown below:

| | cid [PK] integer | x double precis | y double precis |
|---|---|---|---|
| 1 | 405 | 124 | 29 |
| * | | | |

**Table 3: Common Location Table**

This shows that there is NO REPEATED GEOMETRIC INCONSISTENCY in Database.

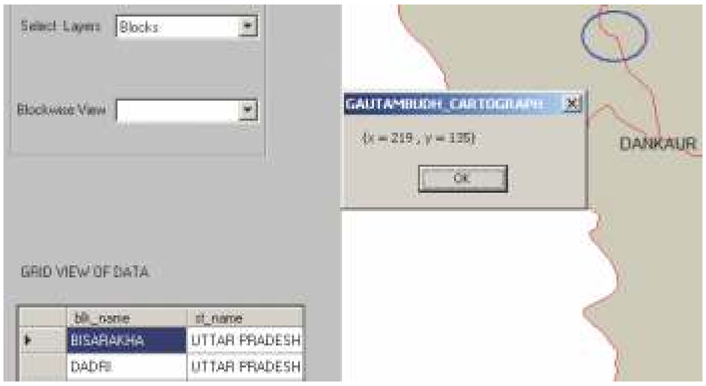
**Resolving Topological Inconsistencies**

Eight inconsistencies have been resolved.

Equals and disjoint inconsistency

In the proposed framework separate database relations have been created dynamically for each of the three layers namely point, line, and polygon; hence the disjoint inconsistency is being handled automatically. Moreover, for each object on a particular layer a unique Id has been assigned, which uniquely identifies the object. Hence the equal inconsistency is also being automatically resolved. For an example, Bisarkha has a uniqueId = 5 which is not assigned to any other object on the same layer as well as on different layer. So Bisarkha equals Bisarkha i.e. if user wants to retrieve object with Id = 5 then only Bisarkha will be shown and no other object from same layer or different layer will be shown.

Meet Inconsistency


**Evaluation of the Topological Inconsistencies**

To assess a set of binary topological relations between spatial regions a scene for Gautam Budh Nagar has been designed and using the computational table it has been evaluated. Evaluation is based on 4-intersection model (Egenhofer and Sharma, 1993). The eight topological relations being examined are disjoint, contain, inside, equal, meet, cover, overlap and covered between two spatial regions. Above mentioned five topological relations have been evaluated using the computational table. Rest of the relations have been deduced automatically using the converse property.

**Boosting GIS's Performance Using In-Memory Data Grid (Bahl et al., 2012)**

A GIS application (Samet, 2004) requires low response time, very high throughput, predictable scalability, continuous availability and information reliability which can be provided by In-Memory Data Grid.

In-Memory Data Grid is a Data Grid that stores the information in memory in order to achieve very high performance, and uses redundancy - by keeping copies of that information synchronized across multiple servers in order to ensure the resiliency of the system and the availability of the data in the event of server failure (Colmer, 2010).

Over the last few years, In-Memory Data Grids have become an increasingly popular way to solve many of the problems related to performance and scalability, while improving availability of the system at the same time. In-Memory Data Grid allows eliminating single points of failure and single points of bottleneck in the application by distributing the application's objects and related processing across multiple physical servers.

One of the easiest way to improve application's performance is to bring data closer to the application, and keep it in a format that the application can consume more easily.

Most enterprise applications are written in one of the object-oriented languages, such as Java or C#, while most data is stored in relational databases, such as Oracle, MySql or SQL Server. This means that in order to use the data, the application needs to load it from the database and convert it into objects. Because of the impedance mismatch between tabular data in the database and objects in memory, this conversion process is not always simple and introduces some overhead, even when sophisticated O-R mapping tools, such as Hibernate or Eclipse Link are used.

Caching objects in the application tier minimizes this performance overhead by avoiding un-necessary trips to the database and data conversion. This is why all production-quality O-R mapping tools cache objects internally and short-circuits object lookups by returning cached instances instead, whenever possible.

Customer expectations from GIS systems have evolved significantly over a period of time (Colmer, 2010). Today customers are expecting better and faster online experience.

Several architectures have been proposed to retrieve necessary, interested and effective information efficiently and at the same time provide scalable platform for GIS application. However, the results of these architectures generally become unsatisfactory and prone to performance loss over the period of time. As soon as the customer base increases, the performance starts retarding.

Implementation of distributed cache for a GIS application will not only boost performance of application but will also provide many more features to it.

If distributed cache is being incorporated in an GIS application the following features achieved would be - Low response time, High throughput, Eliminate bottlenecks, Predictable scalability, Continuous availability, Failover support and Information Reliability.

An effective caching mechanism is the foundation of any distributed-computing architecture. The focus of improving the performance of using in memory data grid has been finally implemented. It has been observed that retrieval time of GIS application's data saved using in memory data grid method is much less as compared to when the data is saved using the conventional database storage method. Thus, the use of distributed cache technology for spatial data storage will boost the performance of GIS application.

## CONCLUSION

The present research is focused on the GIS specific data modeling domain wherein the data models are evolved at conceptual and logical levels. The research makes two main contributions in terms of data models for geographic information systems at two different levels: Topo-Net Spatial ER model at conceptual level and Triangular Pyramid Framework at the logical level.

Data models have a significant role in any GIS product. Fundamental aspects of these models at conceptual and logical levels for vector data have been explored during the present research. A sound foundation of data model needs sufficient representation of data at conceptual level and its storage at the logical level. Vector data model triangular pyramid framework for enhanced object relational dynamic data model for GIS has been proposed. Conceptual data model topo-net spatial ER model for GIS applications has also been proposed and designed for optical fibre cable network. Tools around bi_level data model and triangular pyramid data models viz DIGITIZ and TERZATTO have been developed and compared with respect to execution time for retrieving the records from the database tables .Performance of GIS database can be improved by keeping the database in the in memory data grid has been tested .

GIS community can use the proposed conceptual Topo-Net Spatial ER data model for representing the topological and network features being required by the GIS applications. Proposed vector logical data model "Triangular Pyramid Framework" for storing the digitized data available in shape file can be adopted by GIS application's developers either by using the developed tool named "Terzatto" or otherwise by using the proposed framework for designing their database. The validation of the proposed model on the basis of 4-intersection model using compositional table further strengthens its utility for GIS databases. Performance of the GISs can be improved further by keeping the database using the in-memory data grid.

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