The Design and Implementation of a Cadastral Database with a Spatiotemporal Modeling Approach in Turkey

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Abstract

The cadastral data in Turkey form a large spatial dataset and require efficient data management tools. A fruitful and effective database should be designed and developed therefore to manage cadastral data. The database to be developed should be modeled using a spatial and temporal modeling technique. This study describes the design and implementation of a cadastral database with a spatiotemporal modeling approach in Turkey. The objectives are to propose a design of a spatiotemporal database that fulfills the requirements for spatial, temporal, and spatiotemporal queries for cadastral data, to implement the proposed design in a study area, and to enforce the development of multipurpose-motivated cadastral data. In order to meet the study objectives, the required characteristics of a cadastral database were taken into consideration while performing the design. The phases followed during database design process include the requirements collection and analysis, the conceptual design, the choice of a database, the logical design, the physical design, and the implementation of the database system. The proposed design was implemented in Cayyolu quarter of Ankara. Oracle 8i Spatial was chosen as the Database Management System since it provides the storage and the management of spatial data in an object-relational structure. MapInfo 6.0 GIS software was used to display, manipulate, and query the cadastral data.

1. Introduction

The common understanding of cadastre is that it is a form of land information system. A land information system (LIS) gives support to land management by providing information about the land, the resources upon it and the improvements made to it. The cadastre is a subset of LIS that has been defined as a record of interest in land, encompassing both the nature and the extent of these interests. An interest in land (or property right) may be narrowly construed as a legal right capable of ownership or more broadly interpreted to include any uniquely recognized relationship among people with regard to the acquisition and management of land (NRC 1980). The basic spatial unit of cadastre is a *land parcel*, on which all land tenure and land use records are compiled. Data that may appear in a cadastre include geometric data (coordinates, maps), property addresses, land use, real property information, the nature and duration of the tenure, details about the construction of buildings and apartments, population, and land taxation values (CERCO 1995).

The diversity of data brings the complexity in data management and requires to be managed by using an advanced database management system (DBMS). A database may have special characteristics according to the structures of the data managed by, such as spatial databases which manage the geographical data. When the time constructs are considered in a spatial database, it is called *spatiotemporal database.* Database definition and modeling has an important role on database administration and optimizing data storage and processing.

The complexity of spatial data structures and the advances in geographic data management together with a wide application of GIS have made spatial database modeling an interesting and challenging research area. In recent years, several models have been proposed that are based on either an entity-relationship (ER) approach or an object-oriented (OO) approach. MODUL-R, GeO2 and GeoER models were developed based on an ER model. GeOm, POLLEN and CONGOO are the examples for OO approaches in conceptual modeling. As can be seen from the previous studies that a cadastral database should be modeled using a spatial and temporal modeling technique because of its spatial and temporal data characteristics. Basic cadastral queries require information about the changes on objects, their attributes, and the relationships between these objects. Thus, storing historical information on cadastral objects and the relationships between them is an important necessity.

Land registry and cadastral works in Turkey are carried out by the General Directorate of Land Registry and Cadastre (TKGM). While the cadastral surveys are performed by TKGM, the land rights are guaranteed by the state. Since 1925 Turkey's cadastral system has been formed by the state with several legal and organizational modifications. These modifications have resulted in a lack of standardization and the inconsistency in the geometric aspects of the cadastral data, such as the cadastral maps without a coordinate system or in different coordinate systems. The problems regarding data standardization, data quality, inconsistency, digital archiving, and the slowness in cadastral services forced to make a reform in Turkey's cadastral system tending towards a computer-based cadastral information system. Several past studies focused on designing a cadastral system in Turkey. Yalin (1986) and Erdi (1990) studied on an overall system design but a detailed spatial database design was not conducted. Ercan (1997) studied the design and the development of a cadastral information system for Turkey. However, he did not use a spatiotemporal database modeling approach. The modernization and the automation of the cadastral system started in 1986 with a reform project on mapping and cadastral works (HAKAR 1986) conducted by TKGM and the Turkish Scientific and Technical Research Organization (TUBITAK). However, the project was stopped after the system analysis phase. In 1990, the first project for developing a Land Registry and Cadastre Information System was planned and accepted as one of the national projects of the State Planning Organization (DPT). Unfortunately, no developments were achieved on this project either. Recently, in 2000, a new project (TAKBIS) started for developing a Land Registry and Cadastre Information System. The goal of TAKBIS is to establish a countrywide cadastral information system by making use of DBMS and GIS software and to develop several application software required by the end users. This project is currently under development and it is anticipated that it will be successfully finished.

In this study, the requirements of a cadastral database were analyzed for Turkey and a spatiotemporal database was designed and developed to fulfill the requirements for spatial, temporal, and spatiotemporal queries for cadastral data. The study was implemented in Cayyolu Quarter of Cankaya District in Ankara, the capital city of Turkey. The cadastral data and the basic cadastral queries have certain spatial and temporal characteristics, such as querying the changes on the location and the shape of a land parcel, querying the ownership changes on a land parcel, etc. Therefore, a spatiotemporal database modeling technique was used to model the cadastral database. The system requirements were defined based on the land laws in Turkey and by interviewing the technical staff of TKGM. After collecting the system requirements, a conceptual database design was performed using the Spatiotemporal Entity-Relationship (STER) Model in combination with the Enhanced Entity Relationship (EER) model. The proposed conceptual schema was then mapped onto a logical data model in a relational design approach. Oracle 8i Spatial was chosen as DBMS because it provides spatial data handling capability. The physical design and database system implementation phases were treated together. The database tables defined in logical schema were created using Oracle 8i Spatial. The cadastre and land registry data of the study area were loaded into the database tables created. Since Oracle 8i does not provide graphic edit and display functions for spatial data MapInfo 6.0 GIS software was used to retrieve, display, manipulate, and analyze the cadastral data.

2. Cadastral Data

The cadastre is an information system consisting of two parts: (i) a series of maps or plans showing the size and location of all land parcels, and (ii) the text records that describe the attributes of the land. The basic spatial unit of cadastre is a land parcel on which land tenure and land use records are compiled (figure 1).

Figure 1: A part of a cadastral map.

In Turkey, TKGM is responsible for land registration and cadastre works. The main tasks of TKGM are to make cadastral survey, to make all registration operations and contracts on land rights, and to determine land tenure method. All cadastral data are produced by TKGM. Only a few types of data auxiliary to cadastral surveys, such as accurate geodetic control points, 1:25000-scale maps, forest maps, etc., are obtained from other government organizations. Basic categories of cadastral data produced by TKGM include the geodetic reference network, cadastral maps, land use information, and land tenure records.

To efficiently design a cadastral database, the user needs were determined. The intended users of the database were identified and analyzed. To do that the technical staff of Cankaya Cadastre Office, Photogrammetry and Geodesy Department, and Cadastre Department of TKGM were interviewed. The Cadastre Law coded 3402, the regulations of TKGM, the regulations for large scale mapping, a few cadastre books, and other documentation, such as cadastral maps, parcel modification forms, title deed books, etc., were examined. Some of the examples for spatial, temporal, and spatiotemporal queries that can be invoked are as follows;

- Which parcels have the land use type of 'plot' with a minimum area of 500 m2 and are located in a specified quarter of Cankaya district in Ankara?
- Who were the owners of parcel 4 in block 13633 in the last 25 years in Cayyolu quarter?
- Which parcels were owned by 'Mrs. Tuna Sevim' in the last 15 years in Cankaya district?
- What geometrical changes occurred on parcel 1 of block 13055 in Cayyolu in the last 15 years?
- What is the last parcel added to block 13064 in Cayyolu quarter?

The main cadastral objects defined are as follows: (i) land parcel, (ii) parcel block, (iii) country, (iv) province, (v) district, (vi) quarter, (vii) village, (viii) person (real and juridical), (ix) buildings, (x) cadastral map, (xi) ground control points (GCPs), and (xii) other land related data linked to cadastral data (such as transportation and vegetation data).

3. Conceptual Modeling

A spatiotemporal conceptual model that expresses both spatial and temporal characteristics can meet the main requirements for modeling a cadastral database. Such a model should give an opportunity to model spatiotemporal objects, the attributes, and the relationships between these objects. A number of studies have been carried out on spatiotemporal conceptual modeling.

In this study, the Spatiotemporal Entity-Relationship (STER) model (Tryfona and Jensen 1998a, Tryfona and Jensen 1998b) was used to model the cadastral data. The STER model was chosen because it provides advantages for graphical notation. It provides the representation of both temporal and spatial characteristics of the objects, the attributes, and the relationships between the objects. It also provides a means to represent non-spatial and non-temporal database elements by traditional ER notations. The relationships are represented using the ER notations and the spatial semantics of the relationships are explained by the relationship name.

STER model has two levels of conceptual modeling diagrams (figure 2). The first level, the abstract level, uses components that are easier for the user to follow, free of details, and is not complicated. The second level is a detailed level and allows the designer to explain all the information needed to describe an application. At this level, the new modeling constructs are extended into an ER model. Several EER constructs were added to both STER and ER models to improve the power for representing superclass-subclass and specialization-generalization relationships between the object classes. The EER model includes all the modeling concepts of the ER model. In addition, it includes the specialization-generalization, the superclass-subclass relationship, and the category concepts.

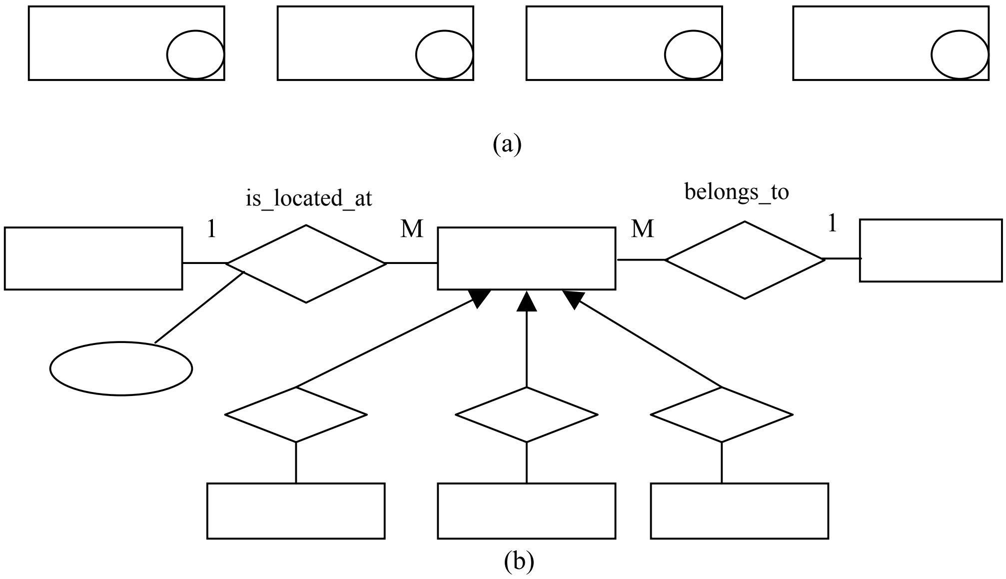

Figure 2: Representation of a spatiotemporal entity set in (a) STER model and (b) ER model.

In STER model, three types of time aspects can be defined: (i) valid time, (ii) transaction time, and (iii) existence time. The valid time of a fact is the time when the fact is true in the modeled reality. In other words, the time interval that a value is valid for a land parcel represents the valid time for the value attribute of the land parcel. The transaction time of a database is the time when the element is the part of the current state of the database. For example, a land parcel may exist between 1951 and 1999 years. However, it may be recorded in a database by 1995. The transaction time of this land parcel is then defined between 1995 and 1999. The transaction time is applied not only to facts but to any element that may be stored in a database. The existence time refers to the time when the object exists. For example, the existence time of above mentioned land parcel is between 1951 and 1999.

In STER model, the entity sets include the (i) temporal, (ii) spatial, and (iii) spatiotemporal aspects of the entities. Temporal entity sets can be assigned either the existence or transaction time or both (then called bitemporal). In figure 3, a part of the proposed abstract conceptual schema of cadastral data is given. The person, parcel, and the building are examples for bitemporal entity types. Spatial entities, such as parcel and building have a position in space that is necessary to capture in the database. The spatial entity sets of SPACE, GEOMETRY, POINT (P), LINE (L), and REGION (R) are defined to represent the space. To capture the temporal aspects of the positions of an object in an entity set, a code of “svt” and “stt” or both are placed in a circle in the lower-right corner of the entity set’s rectangle. The entity sets have two types of attributes: (i) descriptive attributes, such as the “id” of a parcel, and (ii) spatial attributes, such as the “soil type” of a parcel. The values of descriptive attributes for an entity or a relationship often change over time. Therefore, it is necessary to capture this change in the database. Since the spatial attributes may have a temporal dimension they are termed spatiotemporal attributes.

The entity sets have three types of relationships that are (i) the temporal relationship sets, (ii) the spatial relationship sets, and (iii) the spatiotemporal relationship sets. If at least one entity set participating to the relationship has temporal dimension, then the relationship becomes temporal. The relationship between a person and a parcel is temporal. Spatial relationship sets are the associations between the geometries of the spatial entities. The spatiality of a relationship is annotated by using an "s" in a circle (e.g. parcel-building relationship in figure 3). A spatiotemporal relationship is a spatial relationship set with time support. By annotating a spatial relationship set with a temporal aspect, the changes of the spatial relationship over time can be captured.

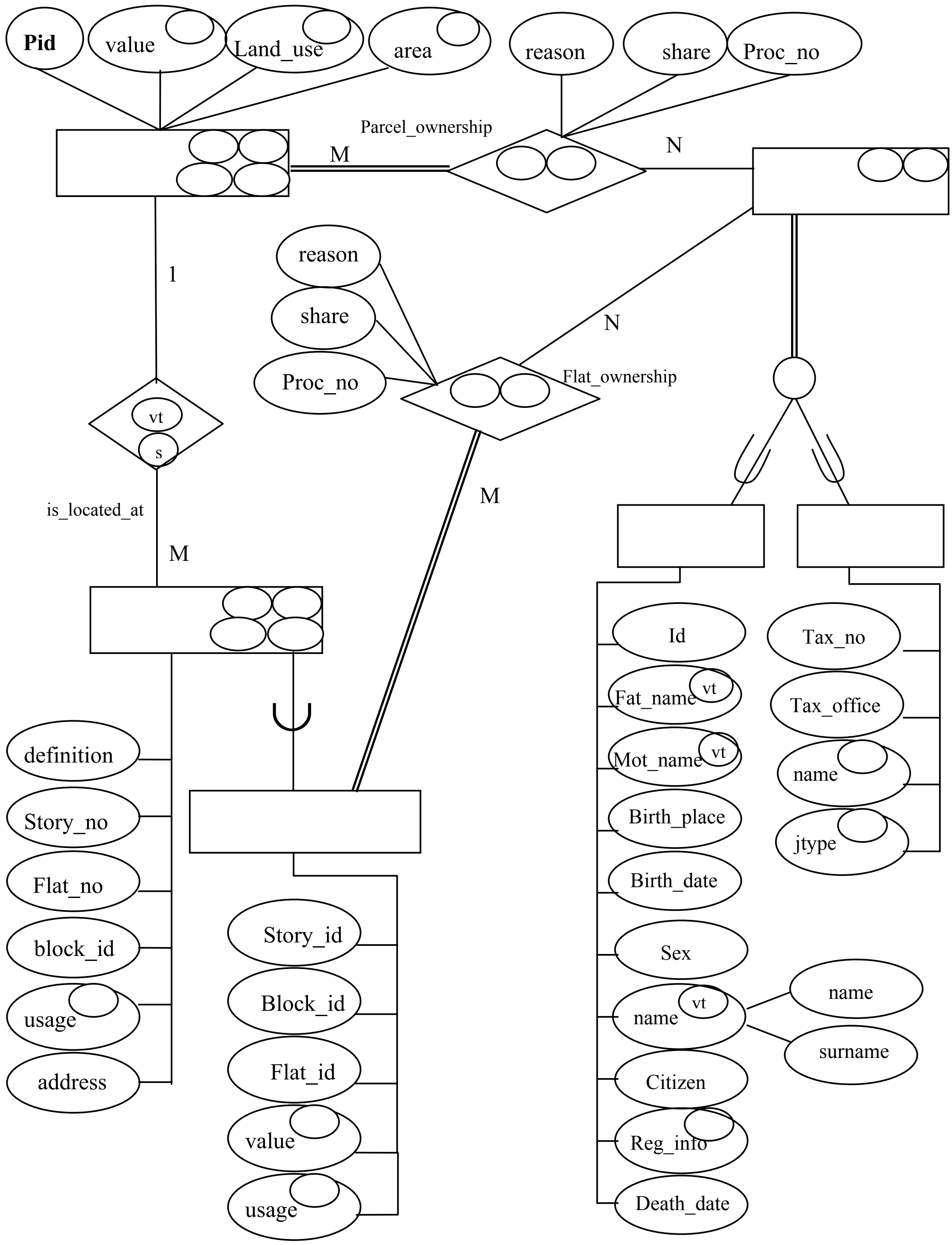

Figure 3: A part of abstract conceptual schema designed for a cadastral database.

A few EER constructs were added to both STER and ER models to improve the power for representing superclass-subclass and specialization-generalization relationships between the object classes. The EER model includes all the modeling constructs of the ER model. In ER model, all types of superclass-subclass relationships are expressed by an ISA (IS-A) relationship which is denoted by a triangle. EER model provides additional specialization-generalization relationship notations for defining the superclasses and subclasses. Adding EER constructs to STER model has improved its power to express the nature of relationships between object classes in a conceptual model. Due to the orthogonal characteristics of spatial and temporal constructs of STER model, the representation of spatial and temporal characteristics has not been affected. The relationship between real-juridical person and person is an example of denoting specialization with EER and STER model (figure 3).

4. Logical Modeling

In the first stage of logical modeling, the conceptual schema was mapped onto a logical schema. Each entity type and the relationship type have become database relations. The attribute types have become the attributes of the relations. The functional dependencies were exposed for each relation. According to the functional dependencies, the candidate key(s) of the relations were determined. Considering the functional dependencies and candidate keys, 1NF, 2NF, 3NF, and BCNF were applied onto these relations whenever necessary. The database relations, the attributes, and the primary keys were determined at the end of this operation. The parcel relation is illustrated in figure 4 on which the first functional dependency (fd1) represents that obj_id attribute determines all other PARCEL attributes. According to fd2, the geo attribute determines the area attribute. The third functional dependency (fd3) expresses that the existence time and pid attributes determine the obj_id attribute.

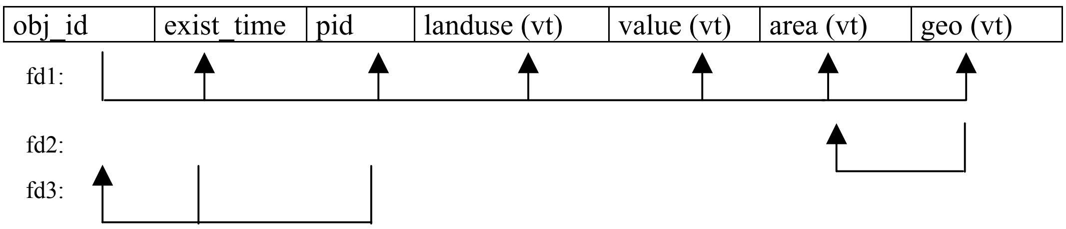

Figure 4. The PARCEL relation.

In the second stage of the logical modeling, the specific characteristics of the selected DBMS were considered and the database table structures were defined. In the present case Oracle 8i with Spatial Option was chosen as DBMS because it provides storage and manipulation capabilities for spatial data. Due to object-relational structure of Oracle 8i Spatial, first normal form rules were not applied to the geometry attributes. An object-relational structure provides both the object-oriented and the relational data model properties. It has predefined spatial object types for spatial data and also it allows users to create their own objects. In addition, all relational data model properties can be integrated to this object-relational structure. In other words, the spatial data can be handled in a relational model. Another important property assigned to Oracle 8i Spatial is the spatial indexing mechanisms that provides efficient retrieval and querying operations on spatial data. The Quadtree and R-tree indexing methods are the options that can be selected for a spatial table.

5. The System Implementation

The system was implemented in Cayyolu quarter of Cankaya District in Ankara. Cayyolu quarter is located in eastern part of Ankara approximately 20 km from the city centre. Until 1980, the majority of the area was rural. A rapid urbanization occurred between 1980 and 1990. In the study are, there were a total of 1234 land parcels covered by two 1:5000-scale cadastral maps (figure 5). The data were received from the Land Registry and Cadastre Offices of Cankaya District. Some of the cadastral maps were in hardcopy form. Some of the cadastral data were stored in a CAD format. On the other hand, some of the land registry data were stored in digital form as DBase files. There were anomalies in land registry and cadastral data, such as the duplicated data, missing data in the database tables and in cadastral data, overlapping parcels that are not allowed legally, etc.. In addition, the land registry data were not always consistent with the cadastral data. For example, several parcels that exist in a cadastral map did not exist in the corresponding land registry records, and vice versa. To correct these anomalies, fictitious data were inserted into the system. Unfortunately, the time attributes were not available. To invoke sample queries that include time, the fictitious data were inserted into the corresponding columns of the temporal tables. After the conversion and editing operations, the data were loaded into the database and a number of queries were invoked to test the system.

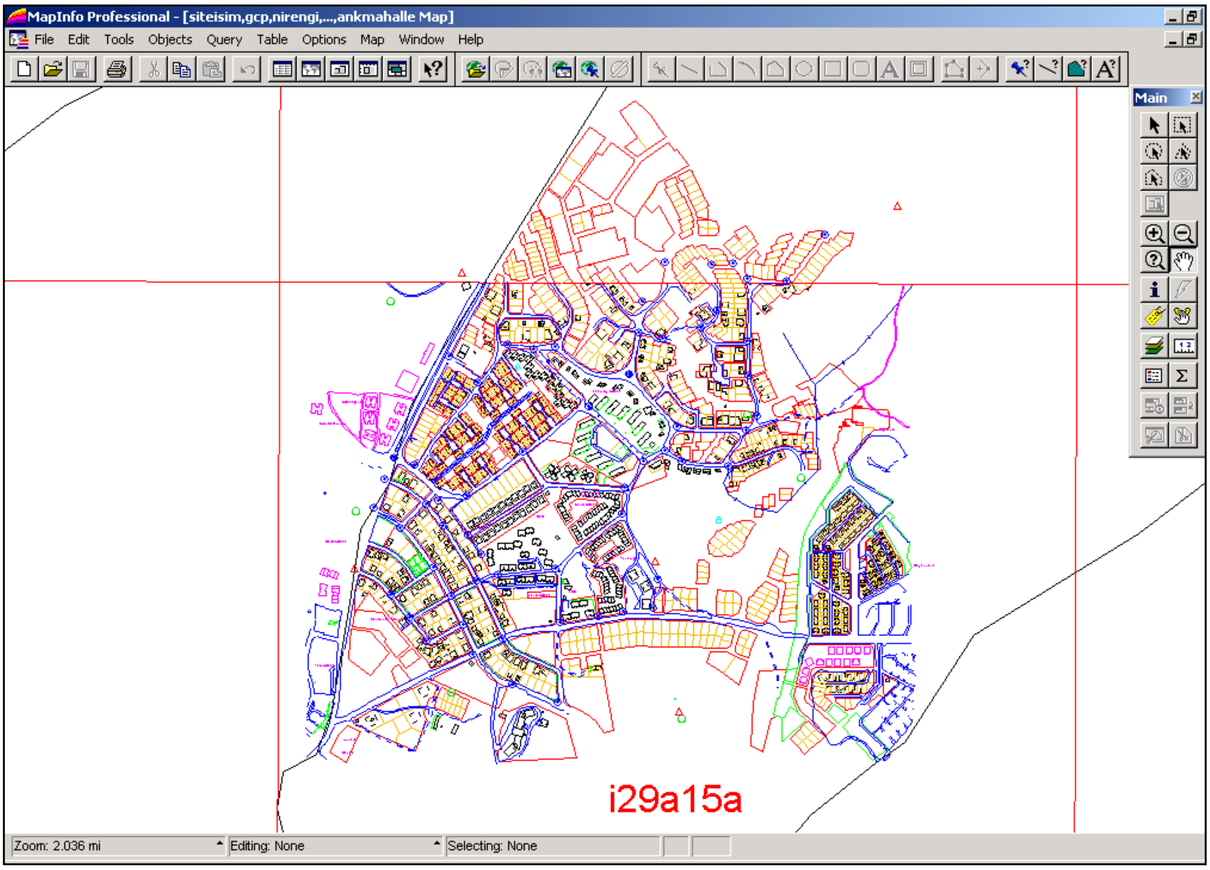

Figure 5. The representation of the cadastral maps of a part of the study area using MapInfo 6.0 GIS software.

The components of the systems used in the implementation are provided in figure 6. The spatial and non-spatial data were stored in a single database that can be accessed by Oracle 8i Spatial. A special DBMS user named MDSYS is allowed to arrange spatial functions by default. Any database user can have internal access and manipulation rights to both types of data. MapInfo 6.0 application creates a MapInfo user and accesses the database by this user. While the non-spatial data are accessed over the data dictionary of the database, the spatial data are accessed over the spatial data dictionary created by the Spatial.

After completing the database design and the implementation process, several queries were invoked to test the design. One example query is that "*What changes have occurred in the geometry of parcel 1 of block 13055 located in Cayyolu in the last 15 years*?" This query is of a spatiotemporal type. The query results are illustrated in figure 7. Each geometry was colored and labeled separately according to their start date.

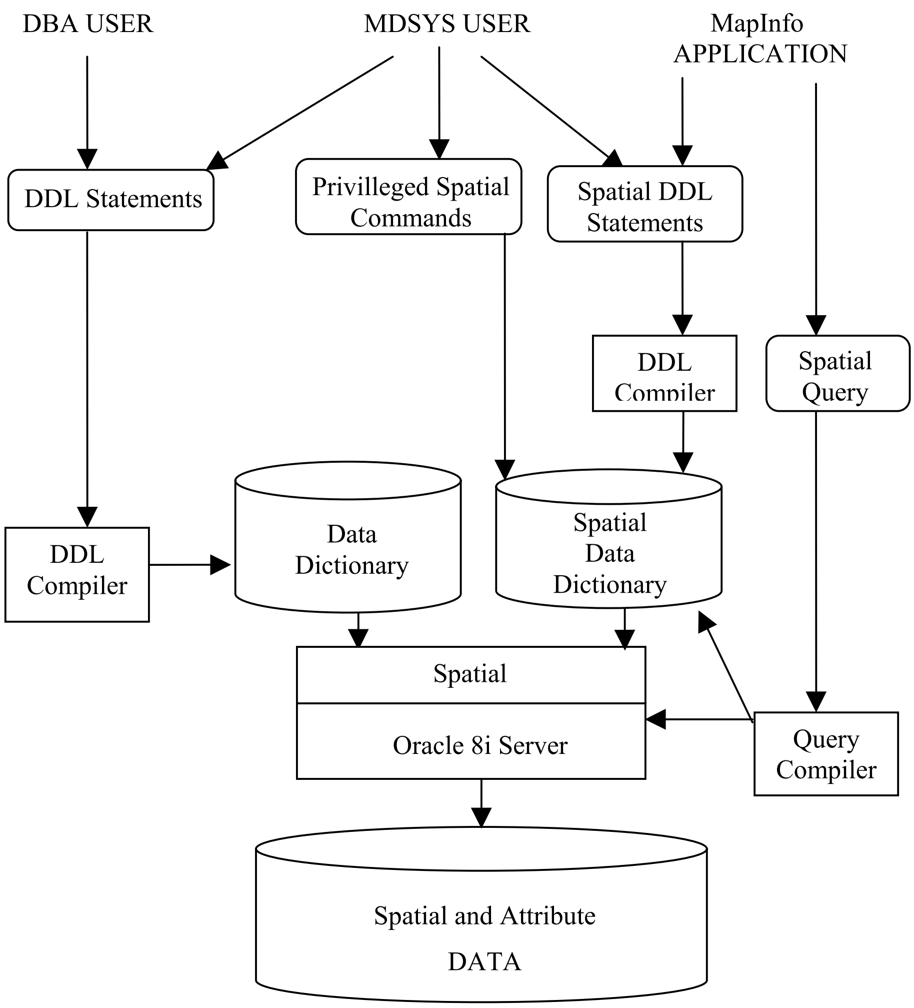

Figure 6: Components of the designed cadastral database.

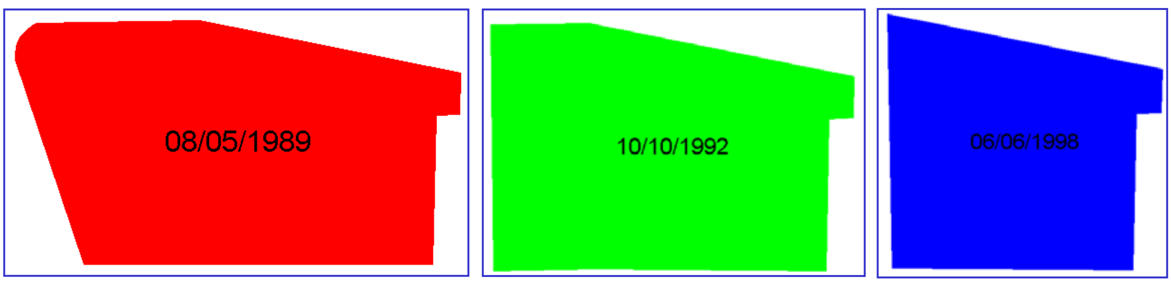

Figure 7. The changes occurred in the geometry of parcel 1 of block 13055 located in Çayyolu in the last 15 years.

6. Conclusions

In this study, the design and implementation of a cadastral database with a spatiotemporal modeling approach was described. The system requirements analysis for a cadastral database was carried out in Turkey's context. The system requirements were analyzed according to data types collected in the existing cadastral system. The restrictions on land rights such as, mortgage, usage rights, etc., were not considered during the system requirements analysis phase. The basic cadastral queries showed that a cadastral database should store historical information on land parcels and related objects. A spatial and temporal database modeling approach is inevitable to design and implement a cadastral database. The integrated analysis of land registry and cadastral data, which are stored separately, is another important feature required from a cadastral database.

The STER model has met the requirements for a spatiotemporal conceptual model. It does not require an intensive effort for learning and using. It is orthogonal to Entity-Relationship (ER) model and can be added to or removed from traditional ER model constructs when needed. Adding EER model constructs to STER model has improved the expression power of the STER model. Oracle 8i Spatial was adequate as a spatial DBMS. However, it does not provide graphical data display and analysis capabilities. Therefore, additional application software was needed for graphical display, interactive editing on maps, and graphical analysis of spatial data. MapInfo 6.0 was used therefore to solve the deficiencies of Oracle 8i Spatial. There were a few integration problems between Oracle 8i Spatial and MapInfo 6.0. When retrieving the graphical data using MapInfo 6.0, the data were also stored as MapInfo table requiring additional space from the hard disc. In addition, all spatial object types of MapInfo 6.0 were not defined in Oracle 8i Spatial, such as the ellipse objects, text objects, etc. These cause data loss problems. Another limitation of using MapInfo 6.0 was that it allows only one nested query. This limitation raises difficulties for performing complex spatial and spatiotemporal queries on the database. A single spatial DBMS software having graphical display, editing, and analysis tools would be the best solution for a cadastral database.

During the system implementation, due to several problems, such as the lack of data, data in hardcopy format, etc., not all data required by the proposed design were loaded into the database. To perform the test queries required in the system analysis phase, the fictitious data were inserted into the database. It appears that for establishing a cadastral information system or a LIS for the whole country, the data collection, editing, and loading processes will be among the major problems.

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