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Development of a decision support system using data warehousing to assist builders/developers in site selection

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Abstract

Site selection process depends on a number of spatial and business-related factors, making it a complex decision-making task. It is common for the decision makers to use their subjective judgment and gut feelings based on their experience in selecting the most appropriate site for development. The reason is that data for site selection originate from varied sources and are not organized in a format that decision makers can readily use to derive any meaningful information. One possible solution of this problem is to develop a decision support system (DSS) to help retrieve data from different databases and information sources and analyze them in order to provide useful and explicit information. Based on this concept, a DSS is presented in this paper as an aid to builders/developers in site selection for residential housing development. The prototype DSS is developed using data warehousing technology, which is a fairly recent database management technique. It is an improved approach for integrating data from multiple, often very large, distributed, heterogeneous databases and other information sources. Data warehousing is based on online analytical processing (OLAP) concept. The OLAP analyzes data using special data warehousing schemas and enables users to view data using any combination of variables. The users can also generate data trends over a period of time to make any forecasts. First reviewed in this paper are the concepts of data warehousing, OLAP and advantages of the data warehouse over traditional databases in the context of decision making. Next, a step-by-step methodology is presented to illustrate the different stages of the prototype DSS development. The DSS design is illustrated with particular emphasis on the development of data warehousing schemas and analytical processing techniques. The prototype DSS has been developed with input and refined with feedback obtained from selected local builder/developer companies. Finally, the application of the prototype DSS for selecting the most appropriate residential site for development from among a list of several available sites is presented.

Keywords: Decision support system (DSS); Data warehouse; Online analytical processing (OLAP); Site selection; Land development

1. Introduction

The selection of a suitable piece of land for development is the first and foremost challenge to builders/developers. The factors that influence the

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process of residential site selection include cost of land and appreciation trend, location of existing serviced areas, zoning and environmental regulations, physical and geological characteristics of the land, demographic characteristics, proximity to hospitals, public schools and other facilities, and possibilities of the site being of archeological significance or contaminated. Despite the availability of accurate and reliable data, top executives are found to make decisions regarding site selection on the basis of their experience and gut feelings. The reason is that they often have to make quick decisions. The data are usually very large, complex and not organized in a suitable format helpful to decision makers for extracting any meaningful information without help of database technicians. Moreover, strategic decision making requires analysis of data of several years to derive conclusive trends or patterns of land sale. Existing databases and their formats are not designed to efficiently and directly provide such information to decision makers. In situations like this, a decision support system (DSS) using data warehousing technology can be useful to decision makers, or executives in building/land-developing companies in making quick and critical decisions during crucial site selection process.

Data warehousing is a fairly recent development in the field of database and information systems (IS). Conceptually, a data warehouse is a read-only database created by combining data from multiple databases for purposes of analysis [1]. A data warehouse literally warehouses information about an organization or process in a secured computing systems environment and allow multiple users to extract meaningful, consistent and accurate data for decision making [2].

Builder/developer companies typically deal with large volumes of data containing valuable information about land characteristics, existing land development projects, land sales records, etc. These data are normally stored in operational databases that are not easily accessible to decision makers or executives in usable forms and formats. A majority of database management systems used in these organizations are based on the concept of online transaction processing (OLTP). OLTP databases are designed to handle individual records of land characteristics, lands sale, accounting and other similar operations. These databases are updated continually on a regular basis and are suitable to support day-to-day business operations. OLTP databases cannot provide a direct answer to many questions or queries asked at the executive level, such as the *what-if* and *what-next* type questions. Decision makers at this level would like to quickly analyze existing data to discover trends so that predictions and forecasts can be made with reasonable accuracy and in time to aid in the decision-making process. However, existing databases cannot provide such information quickly and efficiently. The concept of data warehousing provides a powerful mechanism to solve such information access problems. Data warehousing is based on the idea of online analytical processing (OLAP) as opposed to OLTP. Basically, this technology supports reorganization, integration and analysis of data that enable users to access information quickly and accurately [3]. Table 1 shows a comparison between OLTP and OLAP. In nutshell, OLAP is an analyst's tool used for planning and decision making.

There have been prior efforts to develop DSS for assistance in site selection. For instance, Oloufa et al. [4] developed an integrated information management system for site investigation using a Geographical Information System (GIS). Their system assists a user to rank order potential sites by visually correlating subsurface conditions to corresponding surface geographic locations. The system provides partial assistance in the site selection process as it only considers the subsurface conditions. The site selection process, however, depends on a number of other factors such as the location of existing serviced areas, zoning and environmental regulations, demographic characteristics, etc. that are not considered in this system. McIntyre and Parfitt [5] developed another DSS for selecting the most appropriate site among a set of candidate sites by using the analytical hierarchy

Table 1
Comparison of OLAP and OLTP (adapted form Ref. [6])

Characteristics	OLAP	OLTP
Operation	Analyze	Update
Level of detail	Aggregate	Detail
Time	Historical, current, projected	Current
Orientation	Attributes	Records

process (AHP). This system rank orders a set of preselected, technically feasible sites using different business and marketing factors. Both systems aid in a particular phase of the site selection process. No efforts to develop a DSS that encompass the whole site selection process, starting from the broad list of available sites for sale to the final selection of the most appropriate site, were found in the existing literature.

The main objective of the research reported here, was to develop an interactive DSS computer model that can help to select a suitable site for residential housing development. Both spatial and business-related factors were incorporated in the model. The DSS model utilizes GIS application and employs the data warehousing technique in order to narrow a vast list of available sites for sale down to a manageable short list of a few technically feasible sites. Subsequently, an analytical processing technique is used to rank order the candidate sites for selecting the most appropriate one. The DSS model can be used for both short-term and long-term decision making. Short-term decision making is referred to reviewing and analyzing available information for a particular project. While long-term decision making involves analyzing trends and discovering patterns of occurrences of certain events over several years in order to make forecasts or to predict rates of occurrences of those events.

In the following sections, the concepts of the data warehousing, OLAP and advantages of a data warehouse over traditional databases are reviewed. Then a step-by-step methodology is presented to illustrate the different stages of the DSS model development. The data warehousing schemas and their architecture is discussed with reference to the particular DSS design reported in this paper. Finally, the application of the prototype DSS for selecting a residential site in the Broward County of Florida is presented.

2. Data warehousing concept

2.1. What is a data warehouse?

Data warehousing concept is particularly useful for developing DSSs. A data warehouse is typically a read-only dedicated database system created by integrating data from multiple databases and other information sources. A data warehouse is separate from the organization's transactional databases (i.e., OLTP databases). It differs from transaction systems in that [6]:

- It covers a much longer time horizon (several years to decades) than do transaction systems.
- It includes multiple databases that have been processed so that the warehouse's data are subject oriented and defined uniformly (i.e., ‘‘clean prearranged data’’).
- It contains non-volatile data (i.e., read-only data) which are updated in planned periodic cycles, not frequently.
- It is optimized for answering complex queries from direct users (decision makers) and applications.

The transactional databases are designed to answer *who* and *what* type questions, they are not very good in answering *what-if*, *why* and *what-next* type questions. The reason is that data in transactional databases are not necessarily organized to support analytical processing [7]. For example, land sales data can provide information on the sales record of residential and commercial sites. Additionally, GIS database can provide information about the land characteristics and existing facilities. However, if an executive is interested in knowing ‘‘what is the effect of proximity of commercial areas on the sales of residential lands in Phase I?’’, OLTP databases cannot provide a direct answer. The executive asking this query must assign this task to some of his subordinates for extracting related data from sales and GIS databases. These data need to be interpreted, and then necessary computations be made, in order to get the answers. The whole process could take days to weeks depending on the size and complexity of the project. The issue is to be able to quickly analyze existing data to discover trends so that predictions and forecasts can be made with reasonable accuracy and in time to aid in the decision-making process [8].

The situation described above could have been different if the organization had implemented the concept of data warehousing. A data warehouse accesses data from several different databases, processes (denormalize, reorganize and integrate) data, develops relationships between different data according to user queries and then stores the data in special data warehousing schemas. Data warehousing evolved to support OLAP as opposed to OLTP. Thus, the focus in data warehousing is analytical processing and not transaction processing. OLAP enables users to analyze data stored in a data warehouse using different analytical models and tools, such as the AHP, the expected utility value based decision tree models or any other numerical/analytical techniques. With the appropriate user-friendly query tools, one can experiment with different views of the analyzed data, thus gaining a better insight into the situation in order to make informed decisions [9].

2.2. Generic data warehouse architecture

Typically, a data warehouse architecture has three components or tiers, as follows:

1. Data acquisition tools (back end) that extract data from transactional databases (i.e., OLTP systems) and external sources, consolidate and summarize the data, and load it into the data warehouse.
2. The data warehouse itself contains the data and associated software for managing the data.
3. The client (front end) software that enable users to access and analyze data in the warehouse.

The generic architecture of a data warehouse is illustrated in Fig. 1. It can be seen from Fig. 1 that data sources include existing operational databases and flat files (i.e., spreadsheets or text files) in combination with external databases. The data are extracted from the sources and then loaded into the data warehouse using various data loaders such as the SQL® loader. The warehouse is then used to populate the various subject (or process) oriented *data marts* and *OLAP servers*. Data marts are subsets of a data warehouse categorized according to functional areas depending on the domain (problem area being addressed) and OLAP servers are software tools that help a user to prepare data for analysis, query processing, reporting and data mining. The entire data warehouse then forms an integrated system that can support various reporting and

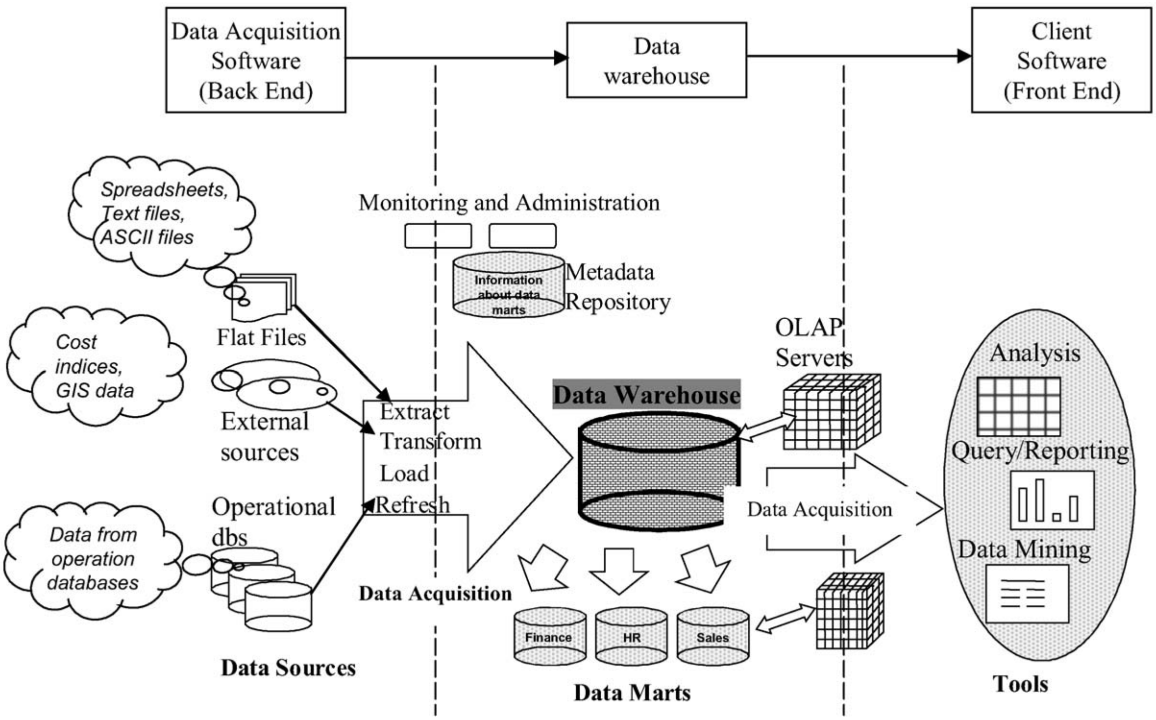


Fig. 1. A generic data warehouse architecture showing typical components (adapted from Ref. [10]).

analysis requirements of the function of decision making [10].

There are two approaches to build a data warehouse. In the first approach, stand-alone data marts assigned to individual business units or processes are developed and later integrated into an enterprise-wide data warehouse. In the second approach, a complete warehouse in the form of distributed data marts is build. These data marts are populated with data either at the time of initial development or at different stages depending on the availability of time and resources [6]. The first approach is adopted in this research as it fits with the scope of this research, and it is relatively simple.

3. Methodology

The site selection process of residential housing development is a complex undertaking and it depends on a number of factors that can be categorized as spatial (such as geographical and geotechnical characteristics of the land; proximity to schools, hospitals, archeological and contaminated sites, etc.) and business-related factors (such as cost of land and appreciation trend, inflation, mortgage rates, return on investment, etc.) [11]. In order to elicit the "most important" factors, a questionnaire survey was conducted among the executives of some selected local builder/developer firms. They were asked to rank order from a list of factors (compiled from existing literature on the topic and after initial consultation with some of the executives) based on their judgment and experience. The executives were also asked to indicate desired features they would like to have in a DSS for site selection.

The analysis of the questionnaire survey provided a list of "most important" spatial and business-related factors having significant impacts on the process of site selection for residential development. As explained earlier, spatial factors are used to select few technically feasible sites from a vast list of available sites. Then the business-related factors are used to rank order the feasible sites from which the most appropriate site is selected. The data warehouse is developed to help organize, store, retrieve and analyze data at all stages in the site selection process.

The spatial factors require geographical analysis of the available sites. Therefore, it was decided to use a commercial GIS software package. There were two reasons for choosing the commercial software package: (i) these software are developed and tested by professionals, so they are reliable, accurate and user-friendly; (ii) they provide easy interface for data transfer in different modes, thus can be integrated with any other software application. *ArcView 3.1*® was the selected GIS software package for this research. Elaborate description of GIS technique and its use through *ArcView* can be found in the referenced sources [4,15,19].

The site selection process represents a single business decision among several business functions performed by a typical builder/developer firm. Hence, and as pointed out earlier, instead of developing a full-scale data warehouse, a *data mart* is developed for the purpose of this research. As explained in Section 2.2, a data mart is a subset of a data warehouse designed for a specific business unit or process. Existing data models (e.g., the Entity–Relationship diagram) used to design traditional OLTP systems are not appropriate to design a data mart [12]. The reason is that these data models do not support analytical processing and also not efficient to answer complex queries requiring aggregation of data. Special database schemas are available for modeling data in a data mart such as the *Star schema*, *Snowflake schema*, or a hybrid of the two, the *Starflake schema*. Snowflake schema is adopted in this research. The underlying reasons for this choice and the basic architectures of these schemas along with their relative advantages/disadvantages are presented in Section 4.2 with suitable examples. Several software choices are available to build a data mart such as *MS Access*®, *Oracle*® or any other database management software. *MS Access*® is selected in this research for its user friendliness and easy availability.

A data mart prepares data for OLAP for analyzing business-related factors. OLAP queries can be performed using various analytical models such as the *AHP* or *the Expected Utility Value Theorem*, as mentioned earlier. AHP is a priority-ranking technique developed by T.L. Saaty [13]. It helps break down a complex unstructured problem into its component parts; arranging these parts or factors into a hierarchy in order to assign numerical values representing subjective judgment based on the relative importance of the factors. These values are then synthesized in order to determine or choose the factor (or the option) with the highest priority or score. The Expected Utility Value Theorem transforms the monetary value of each variable (or option) into an equivalent utility function reflecting a decision maker's risk behavior. Then using a decision tree, a technique to structure a decision problem, the best alternative could be determined. [14]. For this research, AHP was selected for its simplicity and due to the fact that it can be easily implemented using any spreadsheet software application such as the *MS Excel®*.

It is important to note that OLAP software packages such as *MS OLAP Server®* or *SQL Server® 7.0* are also available in the market. These software packages allow users to write their queries using any chosen analytical model. The advantage is that the users can use different graphical wizards to easily write their queries and display results in different graphical formats. Since our intention is not to develop a commercial software product, we utilized *MS Excel®*. Moreover, the main thrust of this research is not the techniques or tools used in the front-end of the model, but the technique of data warehousing itself.

The design of the data mart and the associated OLAP queries constitute the major portion of the DSS development effort. At the end, several interfaces are developed to link the GIS application, the data mart and the OLAP queries.

Once the DSS is developed, it is tested for selecting the most appropriate residential site for housing development from among a list of 16 available sites. The manual and system results were consistent for this test run. The area selected for testing the DSS is the city of *Miramar*, located in the Broward County of the state of Florida. This city is currently experiencing a boom period in heavy-commercial and residential development. The necessary spatial and non-spatial data for this location were obtained from the Broward County development office, the city of Miramar development office, United States Census Bureau, and the Federal Emergency Management Agency (FEMA).

The results of selected sample runs were shown to some builder/developer company executives to get their feedback. In light of their feedback, following portions of the DSS were improved.

1. Data input forms to ensure easy and consistent data input.
2. OLAP analysis (by changing some values in the criteria matrix to better reflect the real life scenario).
3. Output forms format.

After the improvement, the system was shown to the same executives. Minor adjustments were made on the basis of second feedback.

4. System development

4.1. How does the system work?

A logical model illustrating the developed DSS for site selection is shown in Fig. 2. The following steps, as highlighted in black circles in Fig. 2, explain how the DSS works:

1. The load manager uses a series of interactive forms to input the following data: land parcel records (e.g., land boundaries; location of roads, streets, schools, hospitals; flood zones; wetlands; contaminated and archeological sites, etc.), lands for sale data and geotechnical data of the available sites. This data is called the source data (i.e., the data provided by the user or by existing data files used in the OLTP systems). The source data is stored in the temporary data files.
2. The source data (typically normalized OLTP data) stored in the temporary data files is converted into target data using predefined queries. The target data is the data which will be stored in the data warehouse schemas. The purpose of this conversion is to rearrange the data, delete duplicate data and convert different data formats (e.g., .xls, .df2, .doc, etc) into one unique format (e.g., .df2) This is a basic step in building a data mart or a data warehouse. Details about this conversion process are given in the last part of Section 4.2.3.

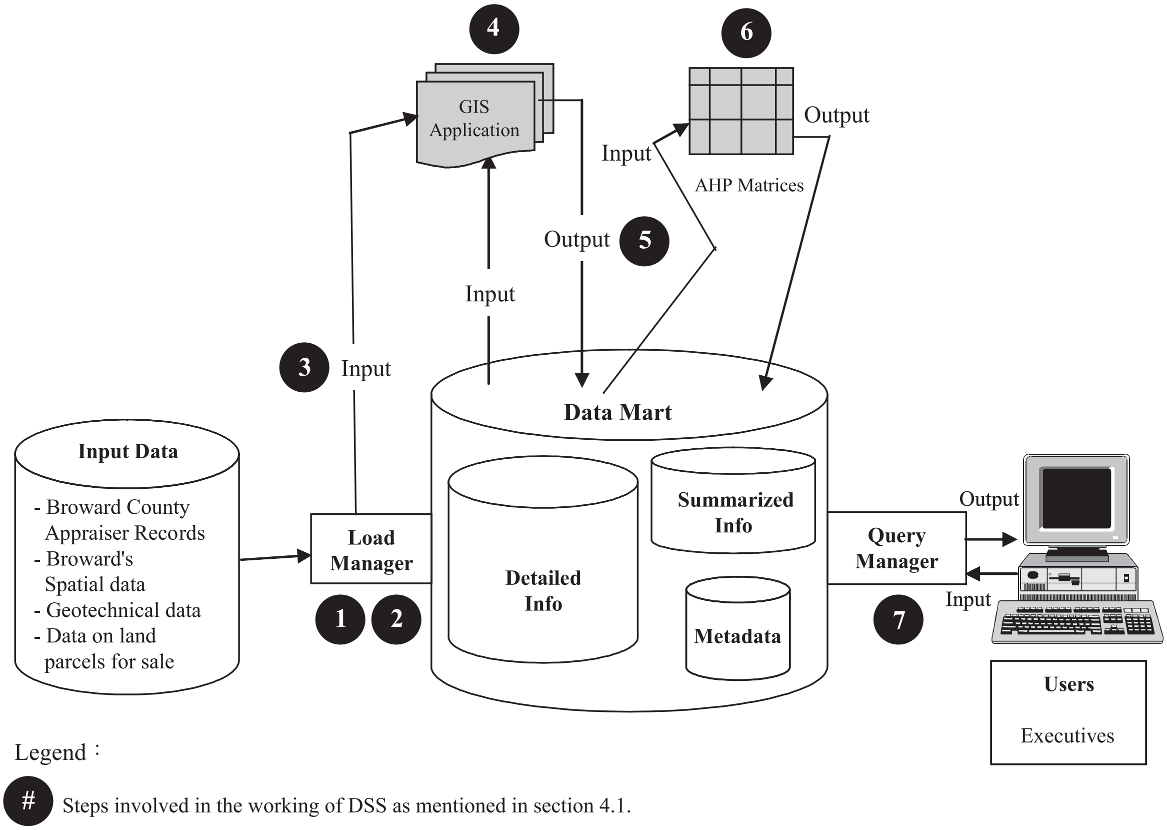
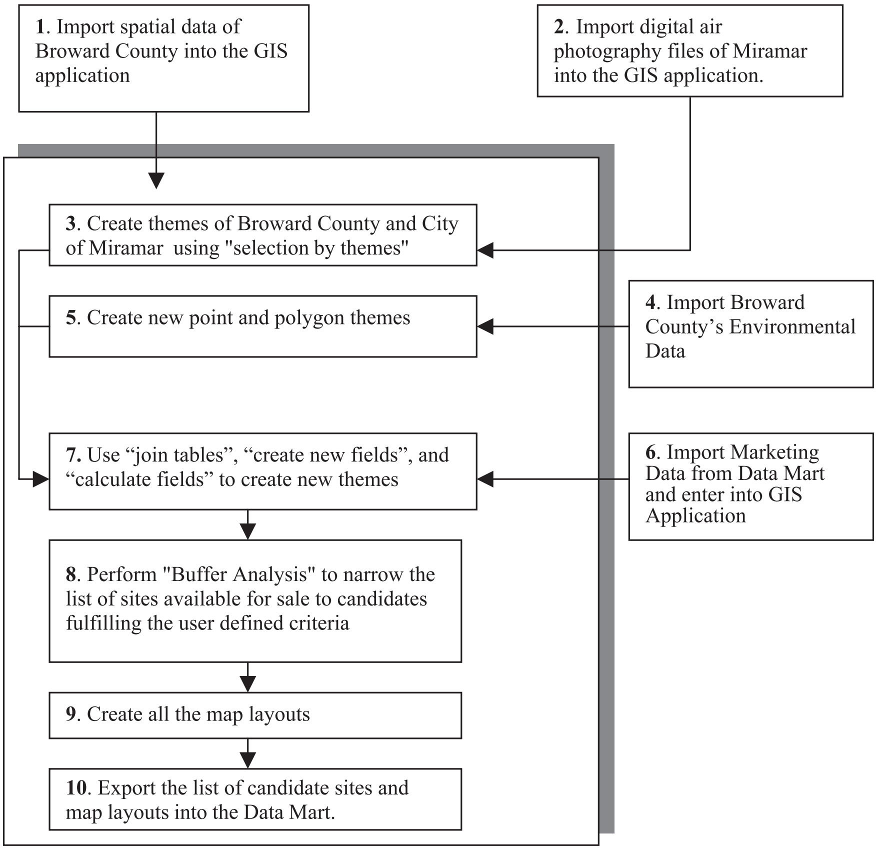


Fig. 2. Conceptual model of the proposed DSS.

3. The load manager then activates the GIS application and asks the user to input site layout plans, digital air photography files and other related spatial data into the GIS application.
4. The target data stored in the data mart is also imported into GIS application and spatial analysis is performed. The spatial analysis narrows the list of available sites for sale to a few candidate sites that fulfill a set of user-defined criteria, an example of which is given below (the criteria can be changed by users).
   Site selection criteria: Selected sites should be
   (a) within or up to 100 ft from water and sewer serviced zones.
   (b) out of wet land areas.
   (c) within 2 miles of public schools and 1.5 miles of main hospitals.
   (d) out of a 500-ft radius from contaminated sites and out of a 1500-ft radius from archeological sites.
5. The GIS application exports the list of candidate sites and their layout maps into data mart. A flow chart explaining steps 3 through 5 in detail is shown in Fig. 3.
6. The candidate sites are then rank ordered using OLAP analysis. The data is imported from the data mart into a spreadsheet application to perform OLAP analysis using the AHP. The details of this analysis are given in Section 4.3.
7. The data is then exported from spreadsheet application into data mart where query manager prepares the output forms and special layouts for managers and executives using predefined and user defined queries.

4.2. Data mart design

The data mart design constitutes the major portion of the DSS development and hence will be explained in



Explanation of GIS related terms:

1. Themes: Themes refer to separate layers of map data and descriptive information. For example, in a county's database, different themes could be hospitals, roads, schools, contaminated sites etc.
2. Buffer Analysis: A GIS based analysis to narrow the list of sites according to user defined criteria.

Fig. 3. Flow chart of the operation performed in the GIS application (steps 3–5 of Fig. 2).

detail in this section. The data mart (or data warehouse) design essentially consists of three steps as follows:

1. Identifying facts and dimensions
2. Designing fact and dimension tables
3. Designing data mart schemas

4.2.1. Identifying facts and dimensions

Facts represent quantitative (or factual) data about a business entity/transaction (an entity is an object or event for which we need to capture and store data) while dimensions contain descriptive data that reflect the dimensions of that entity. In other words, fact data contains the physical information about a factual event (e.g., if an event is *site selection* then facts could be *lands available for sale*, *price*, etc.) and the dimension data shows the description of that fact (e.g., *land owner*, *location*, etc.). Fig. 4 shows a conceptual relation between the fact data and the dimension data. For example, in the site selection process, the facts are lands available for sale, land size and price. The corresponding dimensions are land owner, land location, base price, commission and taxes. The fact data is more stable than the dimension data, meaning that the dimension data change more frequently over a period of time than the fact data.

4.2.2. Designing fact and dimension tables

Once the facts and dimensions are established they can be organized in the form of fact and dimension

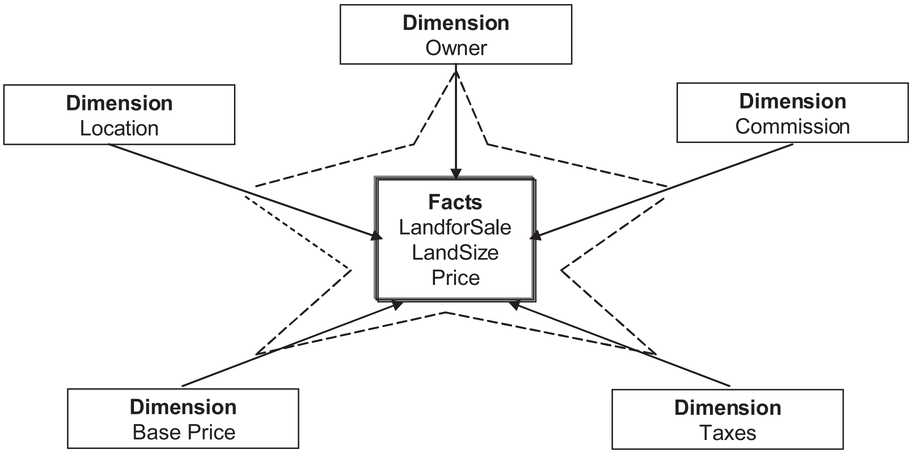


Fig. 4. Relation between fact data and dimension data (conceptual model of star schema).

tables. The dimension tables are connected with the fact table by foreign keys (FK; a foreign key is a primary key of one entity that is also an attribute in another entity. This attribute may or may not be a primary key in the other entity). As a result, a fact table contains facts and foreign keys to the dimension tables. The relationship between a fact table and dimension tables is illustrated in Fig. 6. This relationship is also called star schema, and it will be explained in the following section. The fact table is long and skinny in shape and the dimension tables tend to be short. In a query, the system first accesses one or more dimension tables, and then accesses the fact table [16].

4.2.3. Designing data mart schemas

The schema is a database design containing the logic and showing relationships between the data organized in different tables (or relations). In terms of data modeling, it is beneficial to view a data mart in terms of a *dimensional model* which is composed of a central *fact table* and a set of surrounding *dimension tables*, each corresponding to one of the components or *dimensions* of the fact table [17].

The concepts of normalization and denormalization are very important in a data mart design. Therefore, we will first discuss them briefly before moving to data mart design schemas. Normalization is the process of reorganizing data to minimize data redundancy. It usually involves dividing a database table into several tables and defining a relationship between the tables. Without normalization, redundant data in a database can create inconsistencies and update anomalies can occur during deletion and insertion processes. Database normalization is important in OLTP systems in which data modifications occur rapidly and randomly throughout a database. There are five forms of normalization often called *Normal Forms*. Most transactional databases are normalized up to the third normal form which means that: (i) there are no repeating fields in a database table; (ii) all non-key attributes are fully dependant on a primary key; and (iii) there are no dependencies between non-key attributes in a database table [16].

On the contrary, denormalization is a technique to move from higher to lower normal forms of database modeling in order to speed up the database access and thus query processing. Denormalization is suitable for static data, used in a data warehouse, to speed up query performance [16]. Fig. 5 illustrates a simple process of converting normalized data into denormal-

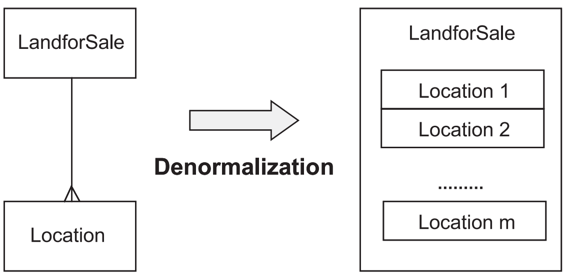


Fig. 5. Conversion of normalized data into denormalized data (conceptual model).

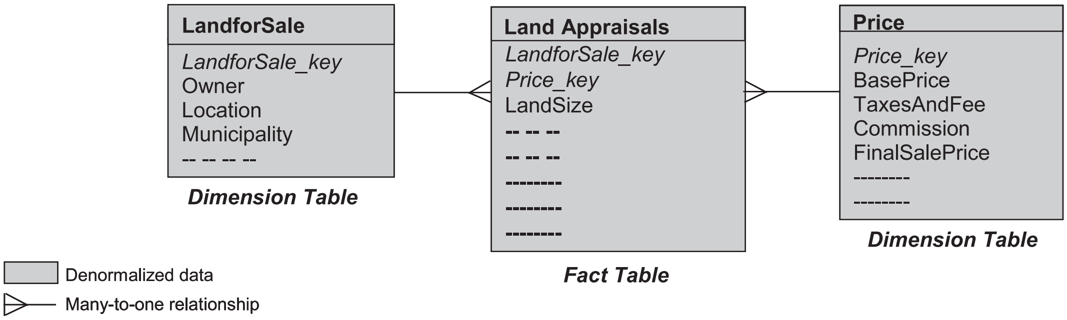


Fig. 6. Example of association between a fact table and dimension tables (data model of star schema).

ized data. Thus, while normalization is a process of dividing a database in smaller tables to effectively handle data during transaction processing, denormalization is a process of aggregating data tables into larger relations for efficient analytical processing.

There are three main types of data mart design schemas: the star schema, the snowflake schema and a hybrid of the two, the starflake schema. The star schema is the simplest database structure containing a fact table in the center which is surrounded by the dimension tables as shown in Fig. 4. The fact table must be connected with the dimension tables using many-to-one relationship to ensure their hierarchy. The star schema uses denormalized data to provide fast response times, allowing database optimizers to work with simple database structures in order to yield better execution plans. A simple star schema for site selection process is shown in Fig. 6.

The snowflake schema is a variation of the star structure, in which all dimensional information is stored in the third normal form (i.e., dimension tables have sub-dimension tables to avoid dependency of non-key attributes), while keeping fact table structure the same. To take care of hierarchy, the dimension tables are connected with sub-dimensions tables using many-to-one relationships. Fig. 7 shows an example of a snowflake schema. The starflake schema is a combination of the denormalized star schema and the

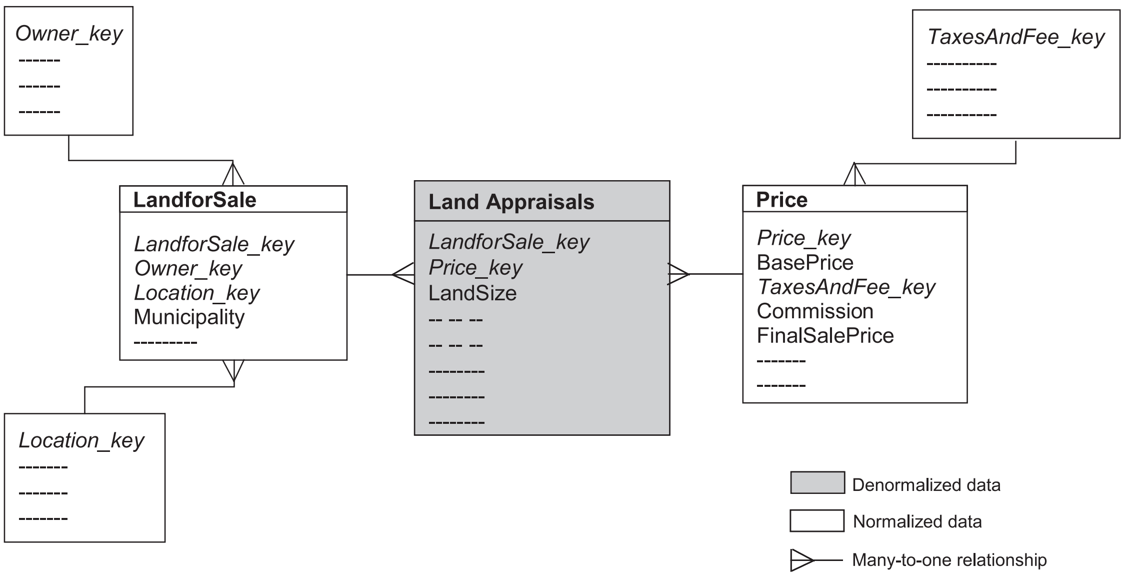


Fig. 7. Example of a snowflake schema (data model).

normalized snowflake schema as illustrated in Fig. 8. The starflake schema is used in situations where it is difficult to restructure all entities into a set of distinct dimensions. It allows a degree of crossover between dimensions to answer distinct queries as shown in Fig. 8 [7].

Due to having denormalized fact tables, these schemas can manage very large volumes of data and answer complex aggregated queries in a short time as compared to traditional normalized database structures. Hence, they are suitable for use in the design of data warehouse.

The snowflake schema is adopted in this research because it allows easy and rapid transformation of data from operational databases into the data mart. The operational databases store data in the third normal form and those data can be directly used in the dimension tables of the snowflake schema without going into any transformation process [18]. Hence, in such situations, snowflake schema is the best choice.

A part of the snowflake schema developed for the data mart design is shown in Fig. 9. The complete schema is very detailed and hence is not appropriate to be shown in this research paper. In this schema, there is one fact table, five dimension tables and six sub-dimension tables. The dimension tables are connected to the fact table through foreign keys. The same technique is used to connect sub-dimension tables with the dimension tables. An attribute with a suffix "_key" represents a foreign key. For example, "Price_key" is a FK which connects dimension table "Price" with the fact table "Land Appraisals". Similarly, "TaxesAndFee_key" is another FK which is connecting sub-dimension table "TaxesAndFee" with its dimension table "Price".

Following are the steps involved in the design of this data mart using *MS Access®*:

1. The fact table, dimension tables and sub-dimension tables are created along with their

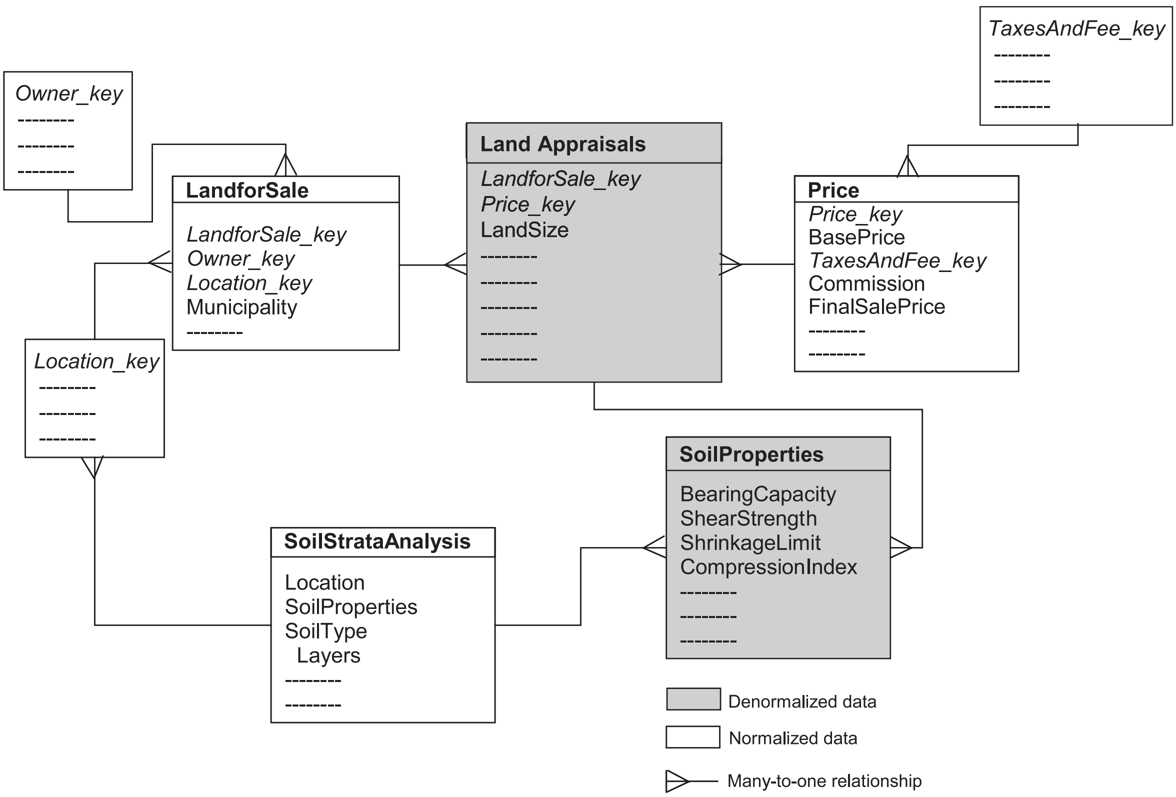


Fig. 8. Example of a starflake schema (data model).

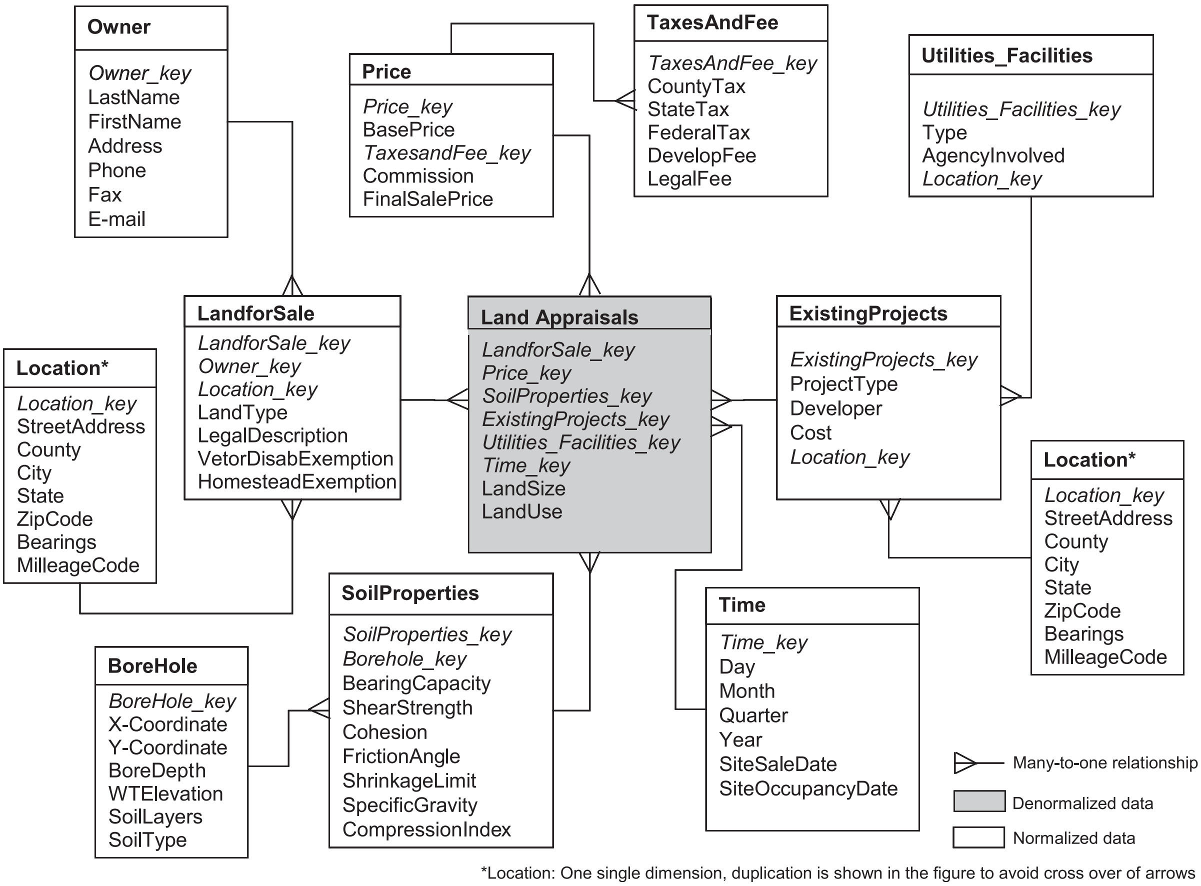


Fig. 9. Snowflake schema for site selection data mart.

metadata. Metadata is defined as data about data. It is like a card index describing how information is structured within the data mart, i.e., it defines field names, their data type, field sizes, data format, any validation rules and other such attributes. Metadata is used for a variety of purposes. As part of the data extraction and load process, it is used to map data sources to the common view of information within the data mart. As part of the query management process, metadata is used to direct a query to the most appropriate data source [16]. Fig. 10 illustrates the design of a sub-dimension table "BoreHole" and its metadata.

2. The relationships between data mart tables are established through foreign keys to form a snowflake schema as already described in Fig. 9.
3. Forms are created for each table to allow easy input and update of the data.
4. Queries are defined to convert "source data" into "target data". The conversion from source data into target data includes denormalization of the fact data and reorganization of the normalized dimension data in their respective dimension tables. The duplicate source data is deleted.
5. Interfaces are designed to import and export data for the GIS application and the OLAP analysis. For this purpose, *Macros* are written in *Visual Basic for Applications™ (VBA)*.

4.3. OLAP analysis

OLAP is the heart of a data warehouse used for decision support. OLAP is used for array-oriented

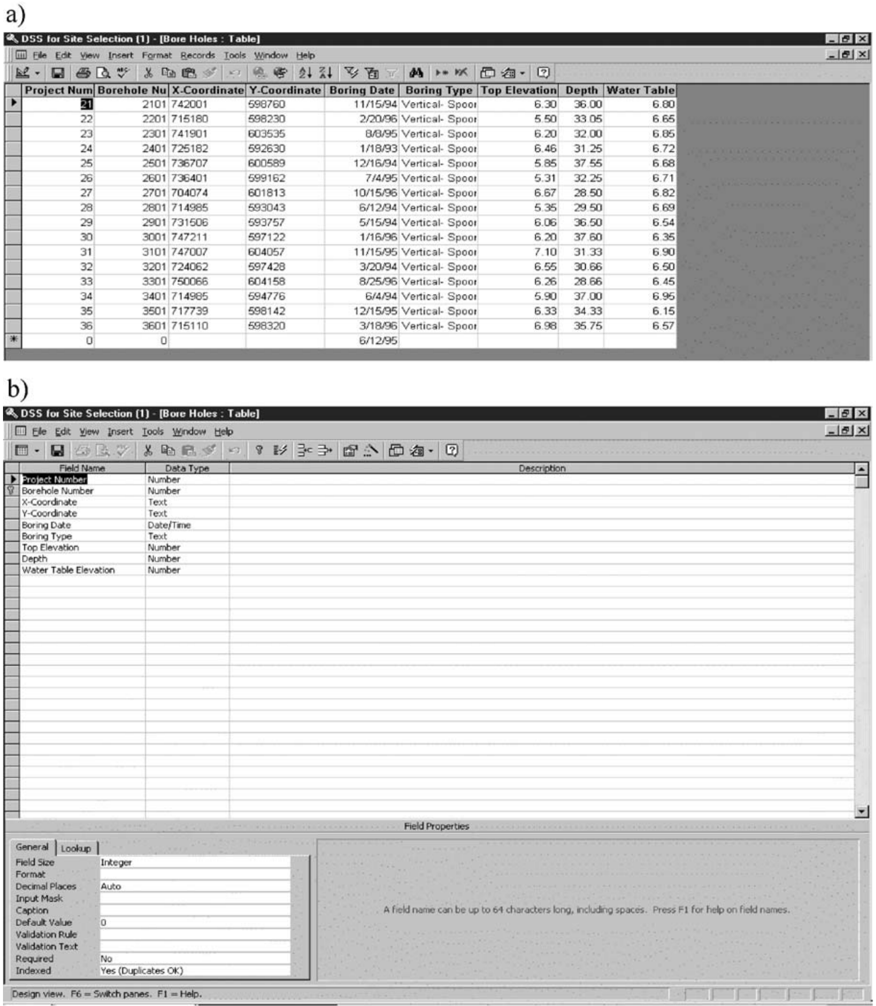


Fig. 10. Design of a sub-dimension table and its metadata. (a) Design of the sub-dimension table "BoreHole". (b) Metadata of the "BoreHole" table.

applications such as market analysis and financial forecasting. Besides these applications, OLAP should be used where [6]:

1. Requests for data are analytic, not transactional in nature.
2. Significant calculations and aggregation of transaction-level data are involved.
3. The primary type of data element being analyzed is numeric.
4. Cross-sectional views of data are often required across multiple dimensions and along multiple consolidation paths.

In this research, as mentioned in earlier sections, OLAP analysis is performed using the AHP. Elaborate description of the AHP process and its application for the site selection are available in the referenced sources [5,13]. The major steps involved are as follows:

1. Based on the results of the questionnaire survey, five factors are selected for OLAP analysis, which are Market research, Feasibility study, Physical factors, Regulatory conditions and Offsite factors.
2. Ratio scales are defined for pair-wise comparison of the factors using a scale of 1–10 as shown in Fig. 11(a).

3. The AHP criteria matrix is developed using the relative importance of one factor over the other as shown in Fig. 11(b).
4. The criteria matrix is normalized (by dividing a cell value by the sum of each column) and then checked for consistency using Eigen values.
5. For each factor (e.g., market research), a separate criteria matrix is developed to relatively compare the given candidate sites for that factor as shown in Fig. 11(c). These matrices are also normalized and checked for consistency.
6. Using the priorities determined through these matrices, the weighted overall priority of each candidate site is determined.
7. The site with the highest score became the selected candidate site as shown in Fig. 11(d).

5. Application

The prototype DSS, developed using the data warehousing technique, was used to select the most appropriate residential site for housing development in the city of Miramar, located in the Broward County of Florida. The results demonstrate the capabilities of the system in a real-life but hypothetical application scenario. In the following this process of application is described and discussed.

(a)

Ratio Scale For Pairwise Comparisons

Value (W)	Definition
1	Equal Importance of elements
3	Weak Importance of one element over the Other
5	Strong Importance of one element over the other
7	Very Strong Importance of one element over the other
9	Absolute Importance of one element over the other
2,4,6,8	Intermediate values between two adjacent judgements

(S) = Site No., (W)= Weight

(b)

Criteria Matrix

		A Market Research	B Feasibility Study	C Physical Factors	D Regulatory Conditions	E Offsite Factors
A	Market Research	1.00	0.33	0.33	2.00	0.50
B	Feasibility Study	3.00	1.00	0.67	4.00	2.00
C	Physical Factors	3.00	1.50	1.00	2.00	3.00
D	Regulatory Conditions	0.50	0.25	0.50	1.00	0.50
E	Offsite Factors	2.00	0.50	0.33	2.00	1.00
	SUM=	9.50	3.58	2.83	11.00	7.00

Fig. 11. (a) Ratio scale for pair-wise comparison of the factors. (b) AHP criteria matrix. (c) Criteria matrix of each factor to compare candidate sites. (d) Final AHP analysis indicating the most appropriate site for residential housing.

(c)

FACTOR (A)
Market Research

Property	1	2	3	4
1	1.00	0.33	0.33	2.00
2	3.00	1.00	3.00	4.00
3	3.00	0.33	1.00	2.00
4	0.50	0.25	0.50	1.00
SUM=	7.50	1.92	4.83	9.00

(d)

AHP MATRIX FOR BUILDER/DEVELOPERS

Weighted Overall Site Attribute Perception

	Sites \ Factors	Cost	Feasibility Study	Physical Factors	Regulatory Conditions	Offsite Factors	Overall Priorities
1	510000000000	0.0170	0.0489	0.0375	0.0102	0.0175	0.1311
2	510000000001	0.0565	0.1395	0.1390	0.0377	0.0649	0.4376
3	510000000002	0.0285	0.0754	0.0901	0.0245	0.0421	0.2606
4	510000000003	0.0117	0.0320	0.0730	0.0198	0.0341	0.1707

According to AHP, the most desirable Site is Property #: 510000000001

Overall Prioirity Value: 0.4376

Fig. 11 (*continued*).

• Data Input. The following data were input into the system: spatial data of Broward county (.dbf format) indicating coordinates of land boundaries, big roads, streets, schools, hospitals, census block groups and location of lands available for sale; digital air photography files (.TIF format) of the city of Miramar; Broward country's environmental data (.dbf format) showing position of archeological sites, contaminated sites, flood zones and 100-year elevation, wetlands, water table elevation, portable water supply service areas and sewer service areas; geotechnical data of typical locations in the city of Miramar (i.e., boring hole records, sieve analysis and bearing capacity of soil); and market data of the available sites for sale (e.g., cost of land/square feet, land appreciation, average income of neighborhood inhabitants, etc.). There were 16 sites available for sale, so separate data were input for each respective site.

• The DSS was run. After performing the spatial analysis, it narrowed the list of 16 residential sites for sale to four candidate sites that satisfied the following criteria:

– Be within or up to 100 ft from water and sewer serviced zones.
– Be out of wet land areas.
– Be within 2 miles of public schools and 1.5 miles of main hospitals.
– Be out of a 500-ft radius from contaminated sites and out of 1500-ft radius from archeological sites.

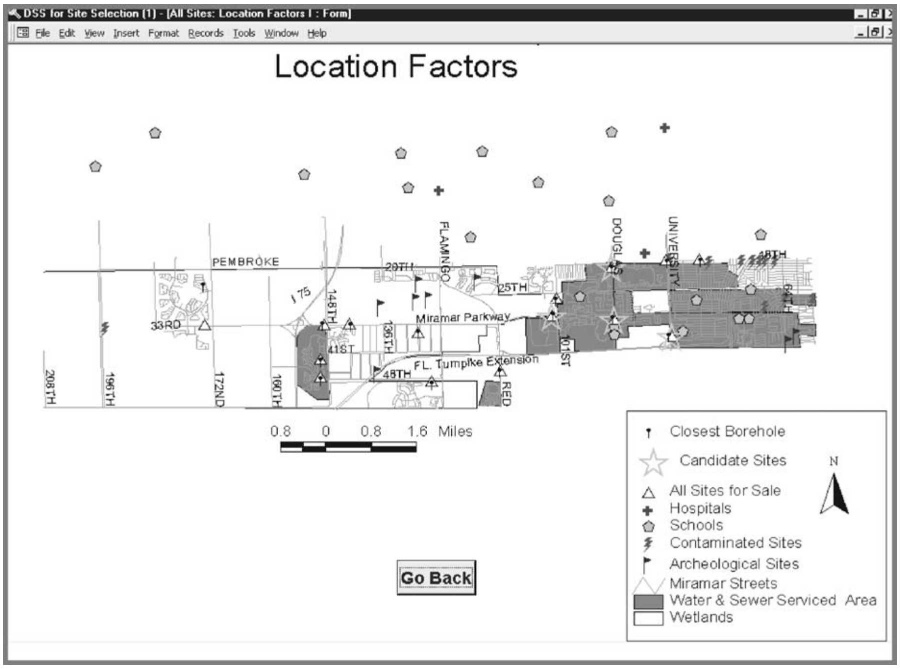


Fig. 12. Layout map showing location of four candidate sites after performing the spatial analysis.

Fig. 12 illustrates the location of these four candidate sites along with other details.

• Before performing the OLAP analysis based on AHP, a user could view the list of candidate sites for sale on the basis of the following factors:

– Cost of land per square foot
– Land appreciation
– Households per square mile
– Average income of neighborhood inhabitants (e.g., between US$50,000 and US$75,000)
– Population density (no. of persons/square mile)

This purpose of this option is to allow the user to apply his/her subjective judgment for choosing the most suitable site.

• Then the option of analytical module was chosen. The DSS performed the OLAP analysis using AHP and displayed the most suitable site for residential housing development as shown earlier in Fig. 11(d).

This demonstration clearly shows that the prototype DSS can aid decision makers in selecting the most appropriate site for residential development. The land selection criteria in the DSS can be customized according to user requirements. Thus, the system could be extended to select the land for commercial development or for any other purpose.

In this DSS, the user cannot add more attributes in the fact table and the dimension tables. However, it is possible to develop a data mart where users can add more data attributes to the appropriate tables to meet their requirements. Although not demonstrated in this system but it is also possible that the users can redesign or customize the data mart schema(s) to best fit their needs. For this purpose, suitable input forms can be generated (e.g., in *VBA*®) to allow the users to define the fact and the dimension data attributes. Then with the help of user defined queries, suitable relationship can be generated between the fact table and the dimension tables to form an appropriate data mart schema. In this way, a more customized data warehousing solution can be produced to satisfy user requirements. This is an issue of balancing between the scope of a system-developer's task and that of a user. Since the purpose of this research study was to demonstrate the concept of data warehousing, the simpler approach of developing a ready-made prototype system was used. Thus, in this prototype DSS system, schemas are already developed based on a predefined model. This is also an issue of commercial software development (not the intent of this paper) as opposed to development of an innovative concept as presented here. The above example illustrates the application of the DSS for a single project (i.e., short-term planning). However, as the system is used over a number of years for several projects, it could utilize the data of those projects to generate a trend or pattern of land sale in different types of urban and rural areas. These trends can aid the executives in making effective decisions regarding site selection. Moreover, decision makers can use these trends to further refine their land selection criteria thus improving the effectiveness and usefulness of the system.

6. Conclusions

Application of the data warehousing technique in developing a prototype DSS for use in selecting sites for residential housing development is illustrated in this paper. The objective of the prototype DSS is to help investors or builders/developers to select the most appropriate site from a list of available ones by rank ordering. The DSS is interactive and is built using data from several sources including spatial and financial ones. A GIS software has been used in the back-end of the system while an analytical modeling technique, AHP has been employed in the front-end. In between, the data warehouse is placed. It gathers data, rearranges them in schemas specially developed to support the particular decision-making process, processes user-defined queries, and finally prepares data for eventual analysis by the AHP model. A number of builder/developer companies were consulted during the development of the prototype DSS for their advice regarding the criteria for site selection. A smaller subset of the same group was contacted again once the prototype was fully developed for their feedback. To the extent possible given the scope of the study, their input were incorporated.

If populated with data from a number of projects, the data warehouse could generate site selection patterns for different areas reflecting their unique characteristics. These patterns can help users to further refine the site selection criteria. The process followed to develop the prototype DSS in this research demonstrates that, depending on the domain and scope of the problem at hand, a DSS can be built fairly quickly and can be used effectively. The process is continuous and ongoing. With continual use of the system, a data warehouse should keep growing from one or two data marts to a full-blown data warehouse. It should get enriched as well by retaining useful data in appropriate formats and by discarding data that are proved not to be very useful for decision-making. User-friendly features can be added gradually by improving flexibility in the system. As shown in this paper, a data warehouse can be used in an effective DSS if powerful software systems, such as the GIS, and analytical methods or tools, such as the AHP, are incorporated in the system.

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