The design of a web-based decision support system for the sustainable management of an urban river system

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Abstract The effects of urbanization on the aquatic environment, and solutions to the deterioration of water quality and stream ecology in the Love River have long been the main focus of environmental management in southern Taiwan. Apart from choosing the regular strategies of installing an intercept and sewer system, coastal wastewater treatment plant, and ocean outfall pipe, a new opportunity for improving the overall managerial efficiency is to design and implement a web-based Decision Support System (DSS). This DSS must be capable of managing storm water impacts when overflow is inevitable, river water quality variations leading to influences on the ecosystem, and changing land use programs along river corridors and adjacent urban areas simultaneously. This paper presents a new design framework for building such a DSS. By using the advanced information technology in the "Internet" environment, the proposed DSS may perform normal queries and statistical analyses in a web-enabled database, spatial analysis via the use of a Geographic Information System (GIS) in the Internet environment, and essential data warehousing/data mining. Possible linkage with various analytical models is anticipated. Such a DSS must be helpful for achieving the rehabilitation of the estuarine ecosystem and satisfying the goals for sustainable management in a regional sense.

Keywords Database; data warehousing; decision support system; Geographic Information System; sustainable management; world wide web

Introduction

Kaohsiung is the biggest commercial harbour and the second largest city situated on the southwest coast of Taiwan. It comprises an area of 153.6 sq. km, divided into 11 administrative districts with a population of 1.46 million. The Love River is one of the main urban rivers flowing through the downtown area of the city of Kaohsiung, into which drains the storm water and sewage along the river reaches towards the Kaohsiung Harbour. This city has experienced a rapid urban development in the last three decades. The economic prosperity, however, is inevitably associated with the environmental degradation of the Love River – the deterioration of water quality, the increased flooding possibility, and the loss of ecological resources in the estuarine region. The construction of an intercept system alongside the river in 1985 to collect the sewage successfully prevents a large proportion of the discharges of contaminants reaching the receiving waters – the downstream of the Love River. After the engineering efforts in building the intercept and sewer system, coastal wastewater treatment plant, and ocean outfall pipe in the 1980s, two main environmental problems have remained unresolved until now. One is the way that the municipality handles the overflows during storms in the summer, which leads to a sudden release of a great deal of effluents from the intercept system into the Love River and causes immediate oxygen depletion in the downstream and estuarine regions near the harbour area. Another is that the growing population in the upper stream areas of the Love River generates a considerable amount of sewage that requires an extended intercept and sewer system or pollution control program to handle the regular discharge and storm water respectively. Although the sewer system has been laid down in the adjacent urban area to connect the intercept system

along downstream river corridors with a coastal wastewater treatment plant since the 1980s, an advanced land use program has been continuously updated to reflect a new concern of the quality of life and regional development. Expansion of the coastal wastewater treatment plant is in progress.

Today, the restoration of stream ecology and the environmental improvement of river corridors can make a contribution to the success of urban regeneration schemes, which can enhance economic competitiveness. New approaches to the management of the urban water environment are a response to advances in multidisciplinary knowledge and information technology. Recently, various environmental applications taking advantage of the information technology can be found in the literature. Examples include environmental impact assessment (Chang *et al*., 1996), wetland protection (Lyon and McCarthy, 1995), groundwater investigation (Camp and Brown, 1993), municipal solid waste management (Chang and Wang, 1996; Chang *et al*., 1998), chemical emergency response (Chang *et al*., 1997), scrap vehicles disposal (Chang *et al*., in press), and sustainable development (Loh *et al*., 1995) etc. Designing a web-based Decision Support System (DSS) in dealing with such a multi-faceted environmental management issue, which must be capable of managing storm water impacts when overflow is inevitable, river water quality variations leading to influences on the ecosystem, and changing land use programs along river corridors and adjacent urban areas simultaneously, is one of the main focuses of this study. To achieve sustainable management in a regional sense, it is valuable to explore the interactions between the carrying capacity in the land use program and the assimilative capacity in the water environment of the Love River by such a DSS.

Methodology

Figure 1 demonstrates a schematic diagram of the DSS. To fully accommodate the practical needs regarding decision support functions, the design framework of the DSS integrates a Geographic Information System (GIS), a Database Management System (DBMS), and various analytical models. When located at distant sites, various users may access the same databases and acquire decision support information based on spatial analyses, statistical analyses, and various model outputs. Thus, the idea of using the Internet as a communication mechanism could be one of the competent solutions from the remote assessment perspective. Among the Internet applications, World Wide Web (WWW) is evolving as a major component for information storage, sharing, and retrieval in many academic research and business development programs. This paper therefore focuses on the design of such a Web-enabled DSS that is comprised of Internet GIS, DBMS, and modelling analysis.

GIS, which facilitates map-based spatial data and analysis, offers the functionality and tools to collect, store, retrieve, analyze, and display geographical information. However, due to the high set-up cost, long learning curve and difficulty in data management, it is not likely a GIS will be installed on every remote site. The advantages and characteristics of the WWW make up for what traditional GIS lacks. GIS research has been heading towards integrating Internet technology and GIS technology and developing what is called Internet GIS (Brakel and Pienaar, 1997; Kingston *et al*., 2000). Without burdening end users with complicated and expensive software, an Internet GIS enables equivalent geographic data manipulations using just Web browsers via the Internet. There are two basic approaches to deploying GIS on the Internet: server-side or client-side applications. The major difference between the two approaches is that users read the geographic data displayed as a static image using a server-side connection, while a client-side connection takes vector data to generate real graphic objects for end-users. There are pros and cons for both applications. After carefully comparing the functionality of various products, the AutoDesk
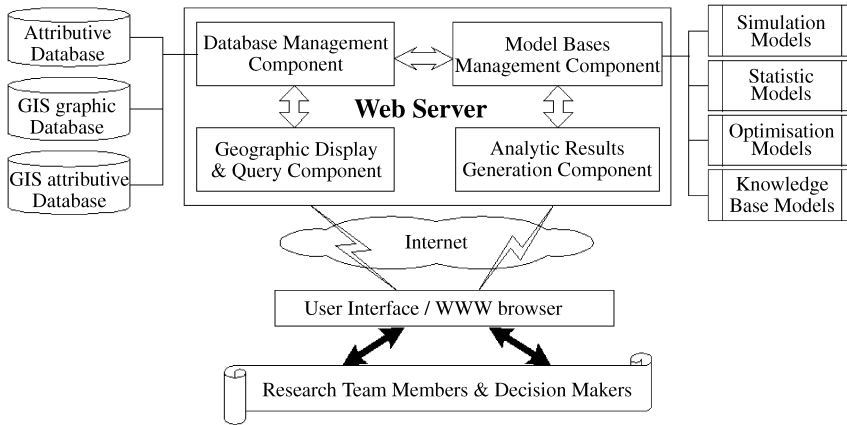
Figure 1 The schematic diagram of the DSS

MapGuide®, a client-side Internet GIS framework, has been chosen to implement the geographic information display function owing to its excellent performance, real graphic data, and database connection.

Collecting and sharing attributive data to assist decision-making are equally important in decision-making. It is therefore favorable to use a client-server DBMS over a network environment for the two-way interaction between the users and the system. In recent years, the development of Internet technology has made it possible to implement such a DBMS on the WWW, which represents a revolution in people's ability to provide information access through easy to use hypermedia computer interfaces. Nowadays many database systems are developed for public environmental information query based on the WWW platform. As Boston and Stockwell (1994) described, a WWW service provided by the Australian Environmental Resources Information Network (ERIN) may allow people to easily access key environmental information for various applications in Australia. In these cases, most Web-enabled databases operate in a four-tier architecture environment to complete data transaction and query. A user utilizes a HyperText Mark-up Language (HTML) aware Web browser to send requests through HyperText Transfer Protocol (HTTP) to a Web server. The Web server then sends these requests, using Common Gateway Interface (CGI), to a script running on the Web server. The script, such as ColdFusion®, Active Server Pages® (ASP), PHP® and Perl®, deals with Structured Query Language (SQL) generation, which embeds users' requests of data manipulation. Finally, this application server routes the request to a DBMS, which generates a result set and sends it back to the user as the HTML document.

Furthermore, advanced data queries to allow subject-oriented analysis could be a valuable addition to the DSS. The SQL used to query a relational database is suited to the normalized table construction. In decision analysis, complex questions like "how did the water quality in this time period compare with the water quality in the same time period last year around the intercept system?" can be very difficult to express using SQL. Data Warehousing (DW) and Data Mining (DM), in response to such needs, come with improved filtering and fast searching and analysis techniques. The analogy to DW is just like shopping in a huge warehouse where products are put in order such that customers won't have trouble finding what they want. This evolving approach helps users observe complex databases in an easier way to identify trends, gain insight into data and produce better explanations and decisions (Elmasri and Navathe, 2000). The design of DW is distinct from relational database systems. The most apparent difference is that a DW aggregates several two-dimensional tables into a multidimensional cube (or hypercube).

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Selected information is extracted from multiple, possibly very large, distributed, and heterogeneous databases in advance, merged and stored in a well-organized repository. When a query is issued, it is evaluated directly on this pre-built DW without accessing the original information sources to improve overall performance. Another significant advantage of DW over a relational database is that the information stored at the DW can be used by organizations for decision support. This unique function is based on the technique of On-Line Analytical Processing (OLAP) that makes heavy use of aggregate queries (Franconi and Sattler, 1999). OLAP provides users with fast, consistent, and interactive access to multidimensional views of a DW. Sometimes translated and filtered data withdrawn from the warehouse require advanced analysis for rule extraction by DM techniques. Thus decision makers without extensive mathematical and statistical training can achieve complex data inquiries. Trend analysis over long-term historical data is a typical example.

Model execution is the most critical stage for a DSS to help users solve decision-making problems. In a Web-based DSS, users are prompted with Web browsers to set up desirable scenarios that would be parsed and transferred to the Web server as model input parameters (Chen *et al*., 1999). After parameter-inquiring procedures, model-processing procedures are invoked on the server site or other remote model-base server sites to derive feasible solutions. The computation results, usually stored as numeric text files, can be reorganized in a user readable format and prepared as HTML files for Web presentation. The decision support routine mainly involves the techniques of data exchange through the Web. Currently there are several methods available ranging from the early direct file exchange, Dynamic Data Exchange (DDE®), Object Linkage Embedded (OLE®), and the recently developed Distributed Component Object Model (DCOM®) and Common Object Request Broker Architecture (CORBA®) techniques. Due to the variety of water quality management models being used in this study (Chen and Chang, 2001), applicable data exchange techniques have to be chosen to deal with the integrated modelling framework.

Results and discussion

System analysis and design is one of the key processes on the way to build any management information system. Screening design requirements from the users' view and creating a manageable framework for the project is crucial. The information technologies introduced earlier would form a viable base for designing and developing an effective DSS aiming to support the sustainable management of the aquatic environment in the Love River and Kaohsiung Harbour areas. In light of the earlier discussions, the DSS is divided into seven sub-systems to perform differing activities. They include database management, data transaction, system maintenance, database inquiry, DW/DM analysis, geographic information display, and integrated assessment. The designated users may be authorized with a preset username and password to enter the system using a browser as a tool and then to use the corresponding sub-systems stepwise. Figure 2 describes the interrelationships between the seven sub-systems. Their functionalities are elaborated in the following subsections.

Database management sub-system

This sub-system is designed as a public utility to provide easy access to the database stored for the authorized data operators. Information is organized with regard to aquatic life, environmental quality, land use, and public infrastructure systems. They include sampling data of macro-invertebrates, bio-indicators and water quality parameters, hydrologic measurements, routes of sewer pipelines, location of intercept gates, and so forth. This integrated database represents the culminated efforts of data collection in the past three years by the authors. To ease the maintenance work, the DSS grants some of the remote users the privilege to update their own database from distant sites. With a Web browser connected to the
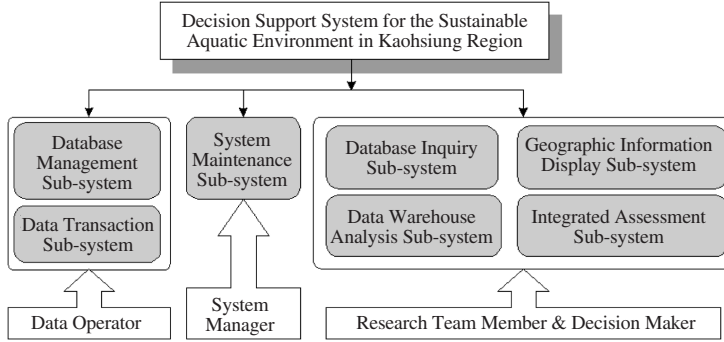
Figure 2 Functional frameworks associated with respective users

Internet, those users can easily create a new database and modify an existing one at any time. Provided that the format of tables can be well organized by the database administrators, the idea of using the Internet DSS as a common information pool to track various consistent data sources is thus achievable. Figure 3 shows the process for a remote data operator to use this sub-system for creating a new table in a designated database. At first, the user may access the DSS through the home page of the DSS system. Once a correct username and password is verified, the system would allow the classified user to manipulate this sub-system based on their granted privileges. When the user clicks on the "database management" hyperlink to create a new table, an appropriate name should be assigned to the database in advance, and then all the formatting in the fields, including field name, character type, character length, and note, should be defined sequentially and clearly. Finally when finishing the required actions, the user must click on the "Finish" button to complete the process of formatting a new database on the Web server.

Data transaction sub-system

This sub-system is primarily designed to perform the data update in any formerly created databases via the use of the database management sub-system. The data operators who are responsible for data updating must select a database in the beginning and then be prompt to update all the related fields in the database one record after the other. Similarly, the data transaction process will end up with a click on the "finish" button to commit the changes of information made from the remote side.

System maintenance sub-system

The system administrator with the highest privileges can access all databases to preserve the integrity, security, and functionality of the DSS via the use of the system maintenance sub-system. In addition, proper handling of the exceptions and publication of public news to all users on the home page of the DSS can be done via the use of this sub-system.

Database inquiry sub-system

This sub-system would enable the users to search for the information they need. The users may choose to browse the whole list of databases or key in some query criteria without referring to any complex SQL syntax. Results from database inquiries will be presented to the users as tabular HTML documents. To ease the data processing, this sub-system allows users to export the inquiry results as a spreadsheet file, such as the Microsoft Excel® file.

DW/DM analysis sub-system

This sub-system is designed to provide advanced data querying for subject-oriented analy-
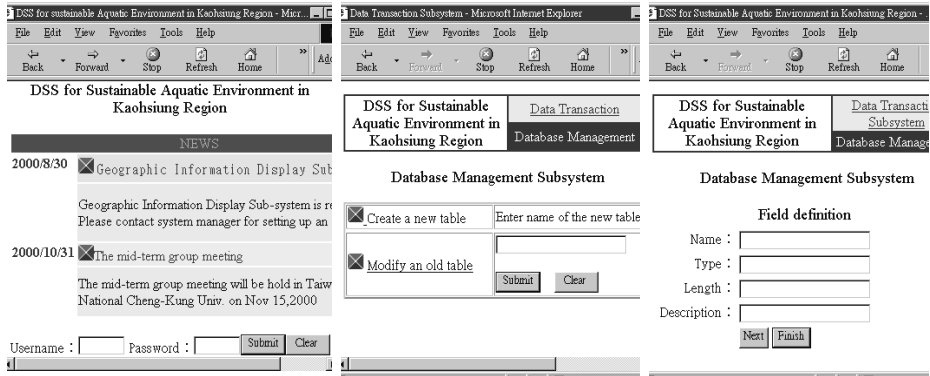
Figure 3 Create a new table using the database management sub-system

sis using the DW/DM technique. The applications would focus on water quality investigation and analysis. As the project is in progress, more potential applications using DW/DM can be identified to analyze issues with dynamic insight. The key component of advanced application is the OLAP, which provides a multidimensional presentation of DW data organized as systematic cubes for efficient analytical queries. Cubes consisting of descriptive dimensions and quantitative values can be structured as a star schema to store and aggregate relational databases. In a star schema, there is a central fact table containing numerical data that users are interested in. Dimension tables, upon which users want to base an analysis, can be treated as organized hierarchies of categories that describe the data in the fact table. For example, Figure 4 shows the star schema of the water quality data cube, where each dimension table has a single-part primary key that links to one part of the multi-part primary key in the fact table. Three descriptive categories of the cube, including time, location, and sampler, are used to further delineate the water quality data, such as Biochemical oxygen demand (BOD_5), dissolved oxygen (DO), pH, etc., in the fact table.

To implement OLAP service over the Web, Microsoft SQL® Server 7.0, which has been available for the current DSS, is used to set up the following case study for water quality analysis. In particular, Microsoft Decision Support Service® allows system developers to design, build, and manage multidimensional OLAP cubes on the server side, while Microsoft PivotTable Service® enables a client application to communicate with an OLAP server. After the water quality cube is created, the client application, which is Microsoft Internet Explorer® in this case, can use PivotTable Service to browse and analyze the data contained in it. The standard operation is shown in Figure 5. At first, the user may pick one or more desired data entries, such as BOD_5 and DO, from the field-list window and drag it to the center of the pivot table for analysis. To proceed with such analysis, the user continues to drag the dimension tables in relation to time and location data to the upper and left sides of the pivot table. Once these drag and drop actions are done, the system will automatically perform the pivot table analysis and generate the results. The outputs would display BOD_5 and DO variations over some temporal-spatial distributions. The tabular data can also be visualized using the bar chart to facilitate intuitive analysis.

Geographic information display sub-system

This sub-system is designed to provide the DSS users with an interface to explore geographic information relevant to the project. To successfully display the geographic information, the spatial data from heterogeneous sources are first transferred to the format of a Spatial Data File (SDF), as required by the MapGuide®. Then, MapGuide Author® is utilized to design the Map Window File (MWF), which defines in advance how the geo-
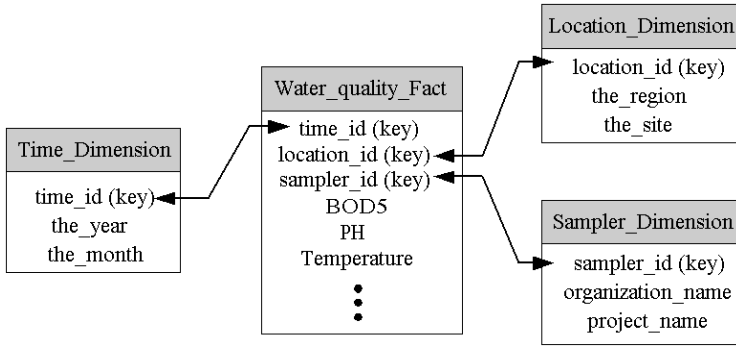
Figure 4 Star Schema of water quality cube

graphic data can be displayed. When users make a request to the MapGuide® server for sending and downloading the MWF, the MapGuide® Plug-In program for the browser may be activated to display the vector data. The graphic objects displayed on the browser are also linked to the attribute databases, which are manipulated by the Microsoft SQL® Server. Therefore, both geographic information and the associated attribute data are applicable for users when facing a spatial query. In the future, spatial analysis based on suitable models can be expected to extend the current functionalities of the sub-system.

Regular GIS operations, i.e. zoom out or in, turn a map layer on or off, and move a map layer around, are available in the sub-system to allow efficient map browsing on the client side. Once the desired graphic object is found, the users may double click on it to retrieve associated attribute data as shown on the left side of Figure 6, where the location of the sampling station and the corresponding information are presented side by side on the browser. Another convenient function offered by the sub-system is to quickly discover the graphic objects according to their attributes. By setting up the pre-built query criteria, the qualified graphic objects can be highlighted and displayed at the centre of the map window. One useful example is to find the location of the selected sewer system in the city. The sub-system would be able to prompt the user to select sewage service district, main sewer, and minor sewer from three drop-down lists in advance, and afterwards the sewer under investigation may be identified, as shown on the right side of Figure 6.

Integrated assessment sub-system

As mentioned earlier, this sub-system is capable of integrating several analytical models for improving the overall management capacity. Incorporating these simulation and
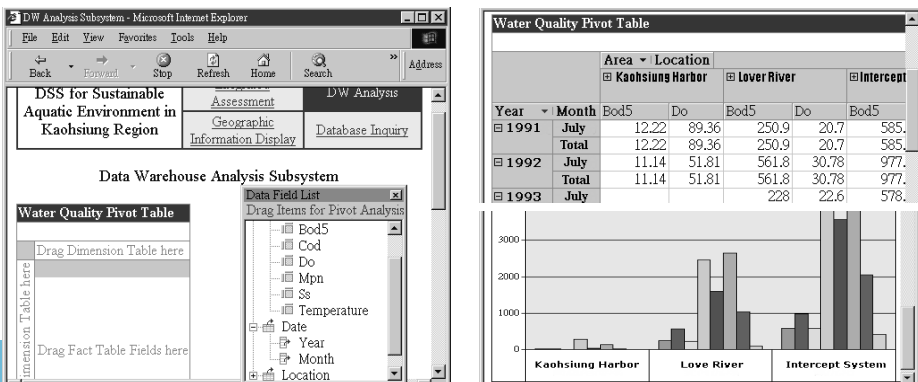
Figure 5 Advanced water quality query using DW analysis sub-system
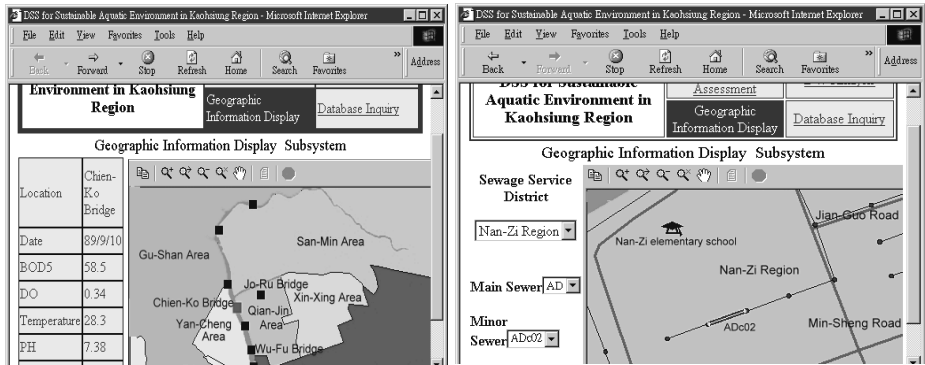
Figure 6 Geographic information display and attribute data query

optimisation models in a decision support environment is a challenging task. One water quality simulation model that has been linking with the DSS is a three-dimensional water quality simulation model that was calibrated and verified in 2001 (Chen and Chang, 2001). Simulation outputs would be helpful for determining the optimal operating policy of the intercept system in order to reduce the direct impact of storm water on the river environment. The impact of oxygen reduction on the local ecosystem is also predictable based on a company study in this project (Chen and Chang, 2001). Overall, this sub-system may enable the decision makers to improve the sustainable management strategy in the Kaohsiung region.

Conclusions
The design framework of a Web-based DSS is made up of seven sub-systems that are designed to enhance the managerial efficiency of the rehabilitated estuarine ecosystem in the Love River, South Taiwan. The Internet and its multimedia front-end, the WWW, have undergone rapid expansion and achieved worldwide acceptance that allow us to explore the Internet decision support with minute technical challenges. A variety of the state-of-the-art techniques, including a Web-based database, Internet GIS, DW/DM, and Data Exchange are incorporated together to build a workbench of information and models. With the help of such an integrated DSS, it is expected that the decision support functionalities of water quality management in the Kaohsiung region will be valuable in terms of sustainable development.

Acknowledgement

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