ELSEVIER

Journal of Hazardous Materials 58 (1998) 15–31

JOURNAL OF HAZARDOUS MATERIALS

A client/server computer framework for solid waste management decision analysis in Taiwan

Ni-Bin Chang *, Y.T. Lin, Y.H. Chang

Department of Environmental Engineering, National Cheng-Kung University, Tainan, Taiwan

Abstract

Due to the complexities of real-world systems, solid waste management programs have to be quickly reorganized for handling various types of issues. These issues are intimately related to solid waste generation, collection, recycling, treatment and disposal. It appears that management personnel usually suffer from the technical burdens of large amount of obsolete data, requirements of spatial analysis, limitations of computational capability and lacking analytical procedures. Building a computerized decision support system through the integration of computer network and client/server databases is crucial to ease many solid waste management practices. This paper is the culmination of 2 years of experience in information technology for nationwide solid waste management decision analysis. The computer framework is designed for handling enormous amount of information flows for solid waste management among local, regional, and central environmental protection agencies. With such a client/server computer network system, the time and the steps needed to find a satisfying solution to those solid waste management issues should be dramatically shortened in the future. © 1998 Elsevier Science B.V.

Keywords: Computer network; Client/server databases; Information technology; Solid waste management

1. Introduction

Solid waste management represents a set of interdependent problems that require intensive data management and coordination among organizations and jurisdictions. Recent investigations have demonstrated that the frequency of communications within and between organizations and jurisdictions increases enormously in response to rapid growth of solid waste generation, the depletion of landfill, the promotion of recycling activities, and the continuous delay of incineration projects. The national need to

* Corresponding author.

PII S0304-3894(97)00117-9

increase the efficiency of operations for solid waste management has inevitably required the application of information technology that may significantly increases the working capacity to handle various types of crises. Such a computer-aided system is designed to provide a user-friendly interface, to handle large amount of updated data properly, to establish many statistical and optimization analyses, and to communicate with the decision makers or planners, who might not be necessary to memorize all the message, to integrate all the technical and management factors, and to learn how to write a complicated computer program.

Various applications using computer databases or computer-aided systems for environmental management have been established for many years [1,2]. However, the use of geographical information system (GIS) as a tool for spatial analysis has received wide attention in recent research programs. Such a technology designed for problem-oriented spatial analysis has been used for the management of swine manure disposal [3], siting low-level radioactive waste disposal facility [4], simulation analysis for ground water pollution control [5], generation of hydrograph in a GIS environment [6], improving solid waste management and recycling programs [7], development of soil conservation strategies [8], handling water distribution networks [9], and planning a computerized master plan of drainage system [10]. The integration with external database and model base in a GIS environment was also emphasized in applications [11]. Several environmental decision support systems (EDSSs) were therefore developed for solving various types of environmental management issues [12,13].

Furthermore, expert systems (ESs) are a branch of computer science known as artificial intelligence that attempt to simulate the situation in a computer system through a set of rules generated by human experts while tackling the real-world problems. Such a computer program specifically applies existing knowledge and inference procedures to solve problems which require significant human expertise for their solution. While ES technology exists for more than 25 years, environmental expert systems (EESs) are only about 10 years old. Hushon [14] classified the previous ESSs by four areas, consisting of interpretation, planning, prediction, and diagnosis and repair. He further provided a thorough survey of 68 such systems in 1992. At the same period, Ortolano and Steinemann [15] distinguished the 24 existing and developing ESSs based on the functional areas of hazardous waste management, water supply and wastewater management, and the calibration and use of mathematical models. Most of them focus on the field of soil remediation and hazardous waste treatment. Robinson and Frank [16] presented a thorough review regarding to how ESs have recently been applied to problems in GIS, including map design, terrain/feature extraction, geographic database management, and geographic decision support. Besides, a real world application has been established by Recknagel et al. [17], which employed artificial intelligent and simulation techniques as tools in an ES—DELAQUA (Deep Expert system LAke water QUAlity)—for decision making in water quality control of lakes and reservoirs.

It is the aim of this paper to show how management information systems (MISs) were integrated with GIS and professional models in a client/server computer network environment through a three-stage and top-down design approach for decision analysis of solid waste management. Such a computer-aided system will be responsible for proper management of enormous amount of information flows for solid waste management among local, regional, and central environmental protection agencies. The principles of integrated database structure and the relevant computer network analysis are presented in relation to the real world solid waste management issues in this paper. Such an application of both high-tech software and hardware functionality may symbolize the continuous progress in systems analysis for solid waste management in Taiwan.

2. Background information

For those complex solid waste management problems encountered nowadays, different levels of functional areas of decision making, consisting of strategic planning, management control and operational control, frequently are considered as integrated issues which required more thorough and instantaneous information. However, information and analytical technologies for solid waste management today have passed from rather narrow sense of statistical applications to the wide area of information processing and communication. It is also to be hoped that the time and the steps needed to find a satisfying solution to a solid waste management problem should be essentially shortened, and different levels of functional areas of decision making, consisting of strategic planning, management control and operational control, at various levels of environmental protection agencies, should be integrated and supported by efficient computer-aided systems.

The importance of computer network technology for future environmental management has been fully recognized by the management authority in the past few years in Taiwan. The scope for building an essential infrastructure of computer network for environmental management was proposed in 1994, as illustrated in Fig. 1. Such a network configuration was originally designed to be consistent with a four-level management framework from the central government to the local waste collection teams. However, due to the budget limitation, only the full network linkage between Environmental Protection Administration (EPA) in central government and the Environmental Protection Department (EPD) in Taiwan provincial government has been established until the end of 1995. The transmission of data in the network can be established through various type of patterns, such as microwave links, fiber-optic runs, or leased telephone lines, whereas the multiplexing, routing, and switching are performed. The HINET, which is an independent public service of network communication through a leased telephone line, is used at the current stage to link the servers between EPB and EPD for the transmission of limited amount of data for administrative uses. Part of the Environmental Protection Bureaus (EPBs) in local government have successfully connected their servers with the host computers in EPD through the use of HINET. But none of those waste collection teams owns the network communication capability.

Yet a future network management is required to provide highly reliable and efficient networking for a wide variety of voice, data, graphics, and video transmission applications at different levels of environmental protection agencies. A specific FDDI network with 100 Mbps or ATM with 155 Mbps transmission speed is suggested for building the internetworking capacity through the connection of bridge/router associated with each local area networks (LAN). Bridge/router should handle various types of communica-

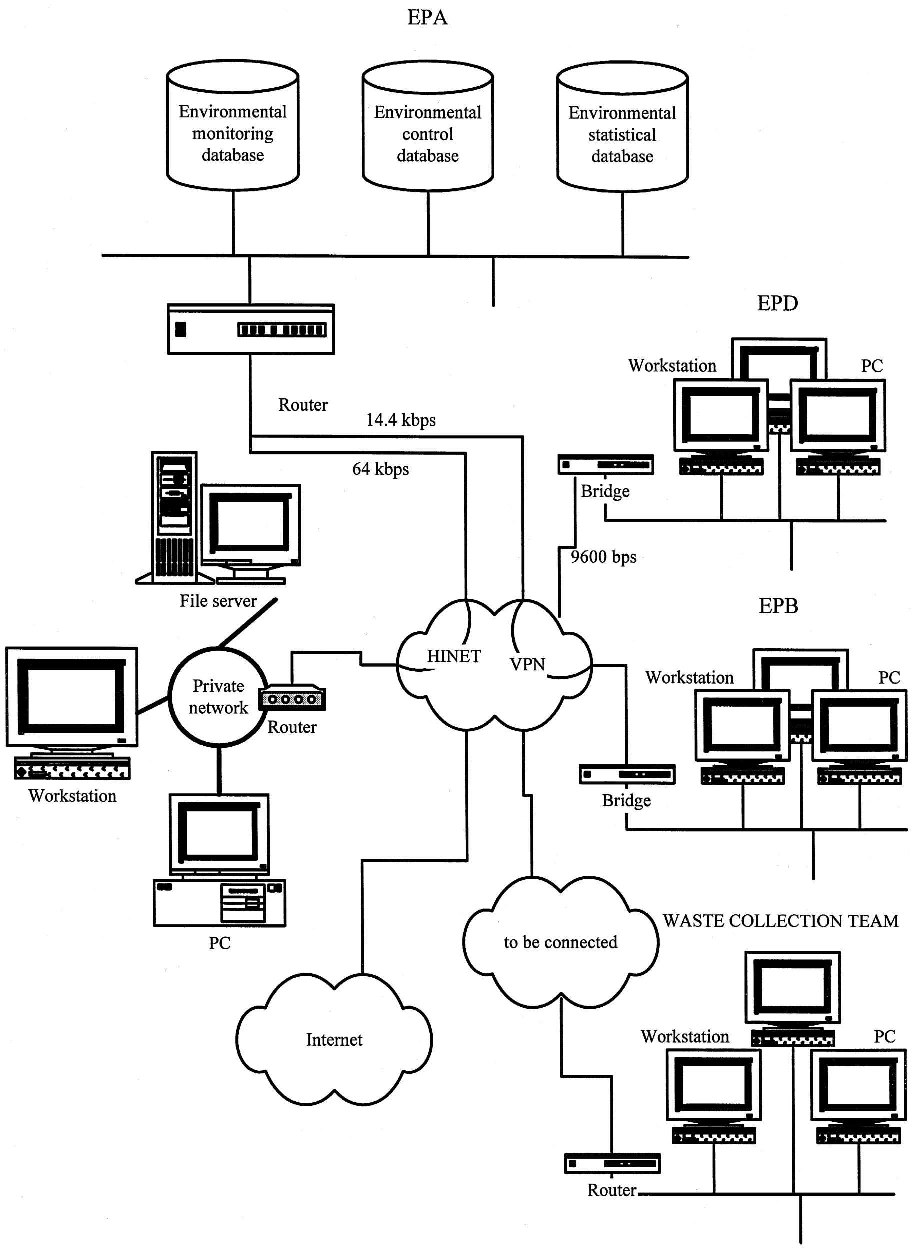

Fig. 1. The computer network environment in current environmental protection agencies in Taiwan.

tion protocols, such as TCP/IP, DECnet, Novell IPX/SPX, XNS, and Apple Talk and owns the network management capability for Telnet, tftp, FDDI MIB, MIB II, and SNMP. In the office of EPA and EPD, each LAN adopts either thick or thin Ethernet based on 10 Base T hub arrangement to connect with local computer system by 10 Mbps data transmission speed. The local computer system can be personal computers, workstations or servers storing environmental data bank.

This research program, sponsored by both EPA and EPD, therefore addresses a three-stage and top-down design approach regarding high performance information management and communication for solid waste management. A client/server, intelligent and spatial information system that will assist practising managers in solving the communication problems of solid waste management at provincial or central level of jurisdiction was proposed in the first stage. But the information sources are actually collected from those 309 waste collection teams which are separately administrated by 21 EPBs through a documentary system. The essential communication between EPD and EPBs was therefore configured within a computer network environment for handling various types of aggregate information at the second stage. Finally, a professional database was designed to assist in those waste collection teams to computerize the daily operational practice and help improve data transmission efficiency within the entire computer network system in the third stage.

2.1. First stage analysis

The type of computer system that databases run on can be broken down into four broad categories or platform: centralized, personal computer (PC), client/server, and distributed. The client/server computer network system, that was selected in this stage, chooses a distributed files system which allows computers to use data on disks attached to other data centers. The physical location of data is flexible, subject to the needs of the applications. Departmental data can be maintained at nodes on the network, while the data center can maintain a large database shared by several departments. Vital support functions, such as data backup and network monitoring can be performed by each independent data center to maintain service capability for network data access from remote request. Data centers may support many concurrent users at remote locations and batch processes with high-speed access to very large shared databases. A centralized unit, such as a mainframe system, can be one of such data centers. Fig. 2 depicts the current hardware system configuration in EPA. Data centers, located in EPD, can be networked to other data centers, located in EPA, and can communicate with various remote desktop workstations, standards-based nonproprietary server computers and peripheral devices, located in EPBs. Such an open system uses standards-based communication interface that allows professionals to share the computing and management resources from other agencies and centers and work together to proceed a collective group decision making.

Several PC-based databases, written in Visual Foxpro® (VFP), have already been developed for handling the information flows of waste characteristics, engineering projects, and waste recycling practice in the waste management department in EPD. To provide a broader management perspective, three more databases were planned to be considered for handling the information of waste collection teams, tipping fees, and spatial data. The proposed six databases, as indicated in Fig. 3, will be linked with a user-friendly interface that can be designed using Visual Basic®, C^{++}®, or GIS

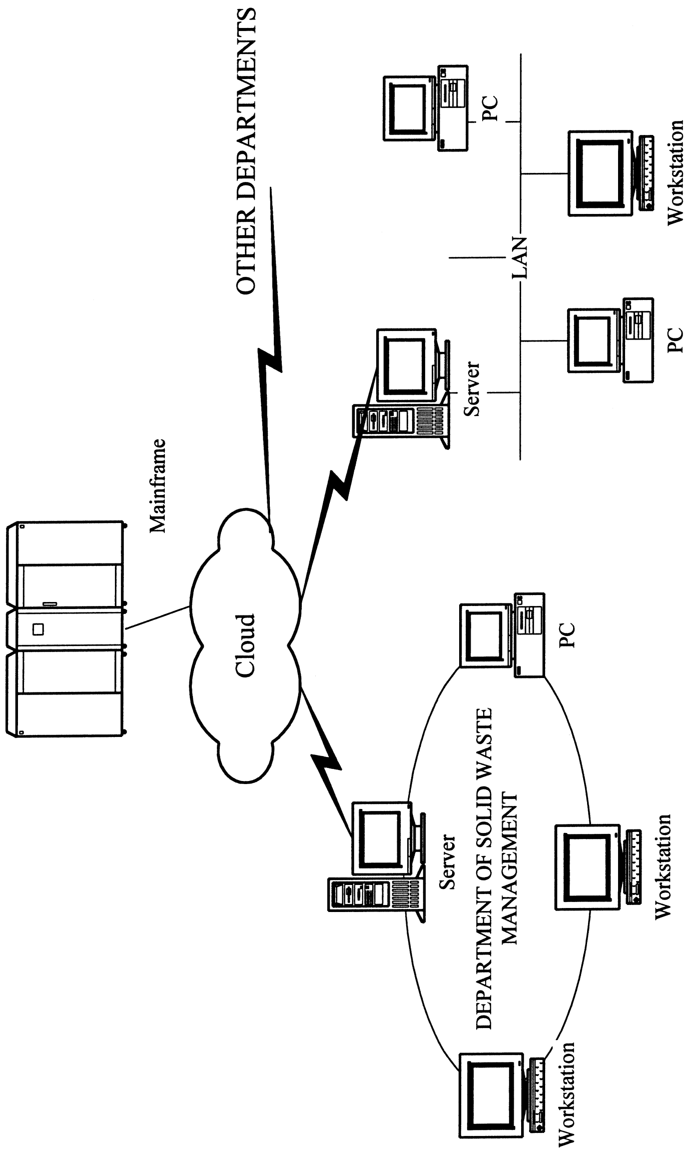

Fig. 2. The hardware system configuration in Central EPA.

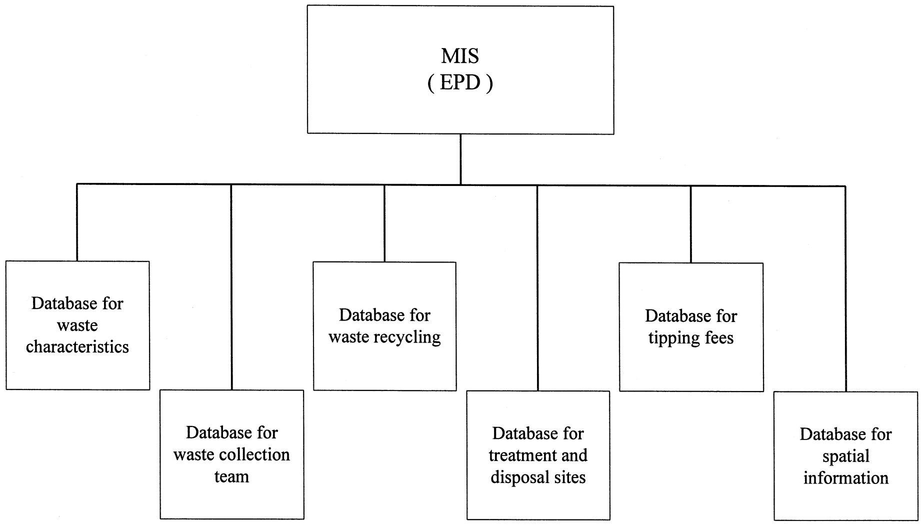

Fig. 3. The framework of MIS in EPD in Taiwan.

programming language. Various types of statistical, simulation, and optimization models can be included within such database management system as data queries and data manipulation are organized to aid in different purposes of applications. These applications range from simple statistical analysis to call up the warning message of landfill space exhaustion, forecasting of solid waste generation, system analysis for waste collection/treatment/disposal, optimal routing for shipping solid waste, and cost/benefit analysis for recycling programs. It then becomes capable for a real-time management control or operational control in central environmental protection agencies. A framework to design and implement a client/server computer-aided system was also required in the first stage analysis for the integration of spatial data in relation to those six independent databases. Through the use of a unique user-friendly interface, not having to rebuild the entire database structure to make changes corresponding to GIS analysis also represents an increase in the preservation of data integrity. User-created rules can also be added to the database to provide further data integrity and application potential.

Such a client/server computer framework can be further illustrated by both hardware and software aspects, respectively. The hardware facilities should be linked as a network and functioned as a client/server system. The network communication can be achieved through local, regional, and even international scales. The essential hardware components in the proposed system contain a DEC minicomputer and a server in the data center, as well as several PCs in the managerial departments in EPD. Auxiliary devices may include optical disk drive boxes, drawing boards, scanners, output devices, etc. Servers support not only access to shared hardware resources so that disks, laser printers, digitizers, scanners, electrostatic plotters, and other peripheral devices can be shared through the high throughput communication network but also can provide the distributed processing power required by X terminals or PCs with X terminal emulation.

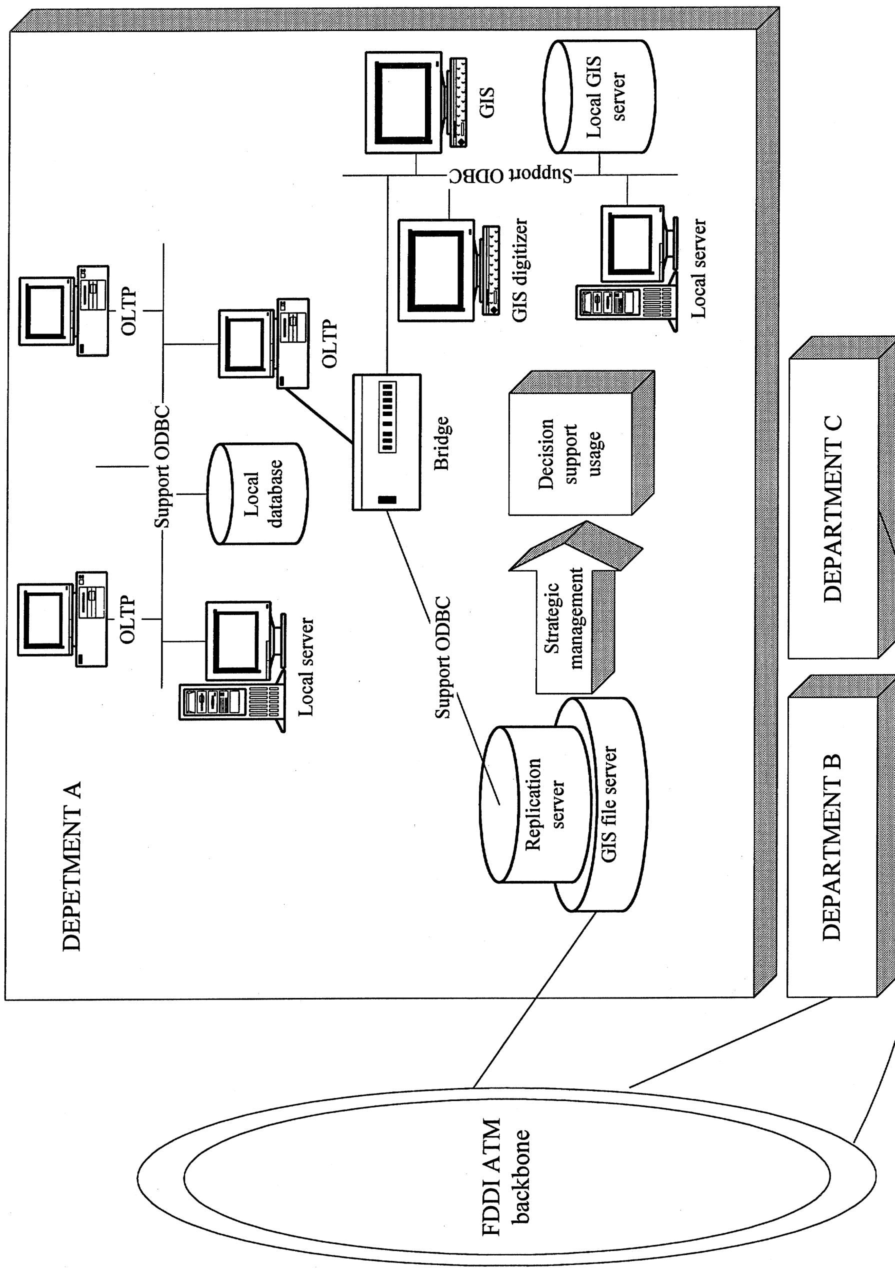

Fig. 4. The hardware system configuration in EPD.

Table 1
The investigation of client/server capability of GIS software

	ArcInfo®	Mge®	Genmap®	Mapinfo®
Client/server framework	• Unix to Unix • Windows (Win 3.1 NT) to Unix	• DOS to Unix • Unix to Unix • NT to NT	• Unix to Unix • Windows (PC Genius) to Unix	• Win to NT • Win to Unix
NFS support	third party vendor	third party vendor	included in PC Genius	third party vendor
RPC system call	Nobelnet RPC	third party vendor	included in PC Genius	third party vendor
ODBC support	yes	no (support Oracle SQL NET)	*	yes
OS of client	NT, Win 3.1, Unix	DOS, Win, NT	Win 3.1, Unix	Unix, Mac, NT
OS of server	Unix	Unix	Unix	Unix, NT
DDE for Win	yes	no	*	yes
OLE for Win	no	no	*	yes
Tool	Avenue AML	MDL	Genius PC Genius	MapBasic

* DDE: dynamic data exchange; OLE: object linking embedding.

Various input, storage, and output devices could be shared through such network servers. Fig. 4 illustrates the proposed hardware system configuration.

Besides, many GIS software packages have developed the analytical capability in a client/server environment, as summarized in Table 1. As indicated in Fig. 5, GIS is applied as an effective tool for spatial analysis. Software packages, such as database management systems and environmental modelling systems, can be integrated into a GIS. For example, the ArcView® object-oriented architecture allows multiple modules of a geographical MIS to be developed by sharing tools common to each client, such as Excell® and Statistica®. Complex map manipulation and analyses can be performed by ArcInfo® in a workstation or server, located in a data center. The communication between ArcView® in a Windows NT or Windows 95 platform and ArcInfo® in a Unix platform can be fulfilled through the use of remote procedure call (RPC), Microsoft Open Windows DataBase Communication (ODBC), and network file system (NFS). Such an integration provides a customized solution for those distributed GIS to make full use of the network capability built into servers that is ideally suited to various levels of client/server applications. Overall, VFP still serves as a fundamental tool to store the background information for solid waste management, including the distribution and generation of solid waste, location and capacity of treatment and disposal facilities, recycling programs, clean-up areas, as well as the information of crew size and equipment. Various types of statistical analyses will be performed by software package Excell® and Statistica® to constitute the essential function of decision support and management. Some data manipulation languages should also allow an invocation of simple statistics and summary. The communication between PCs in Windows 95 platform and server in Windows NT platform can be fulfilled through the use of standard query language (SQL) and Microsoft ODBC.

2.2. Second stage analysis

The remote users, located in EPBs, may access the databases in EPD through either locally connected or dial-up (remote) terminals. The terminals consist of only a screen, a keyboard, and hardware to communicate with host. Further, it was considered that the

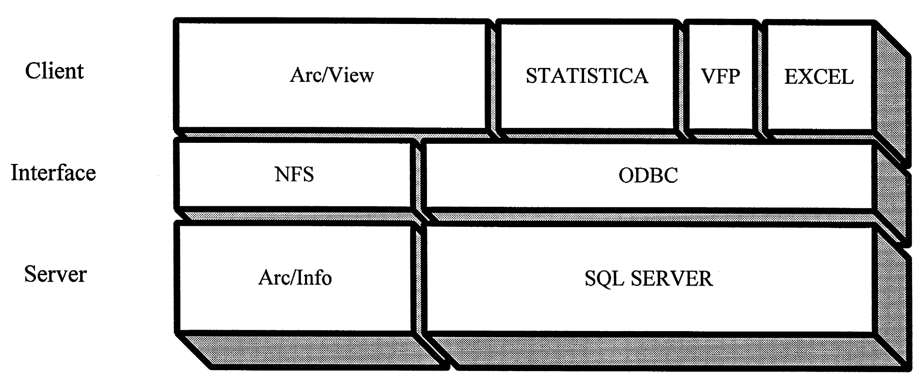

Fig. 5. The software system configuration in EPD.

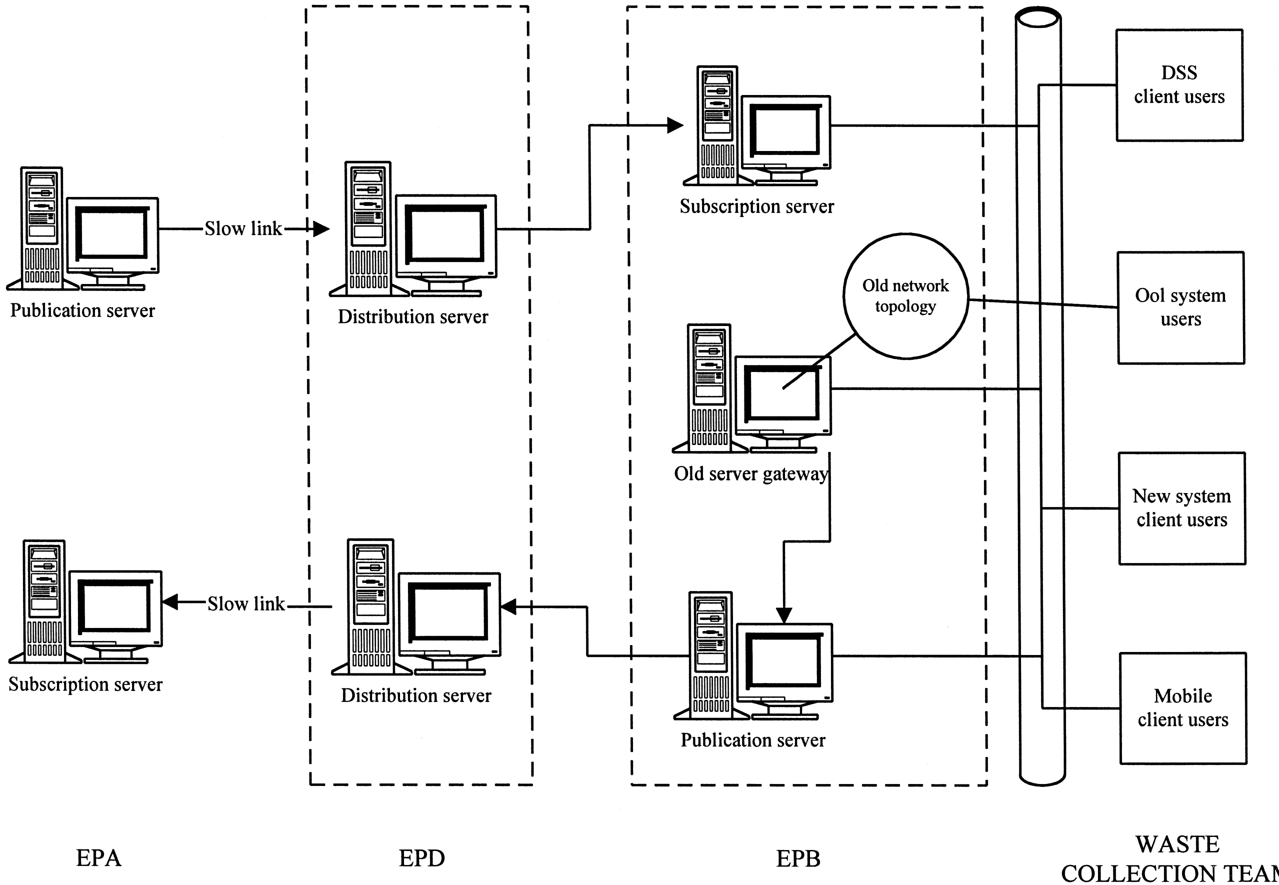

Fig. 6. The hardware network topology in the future.

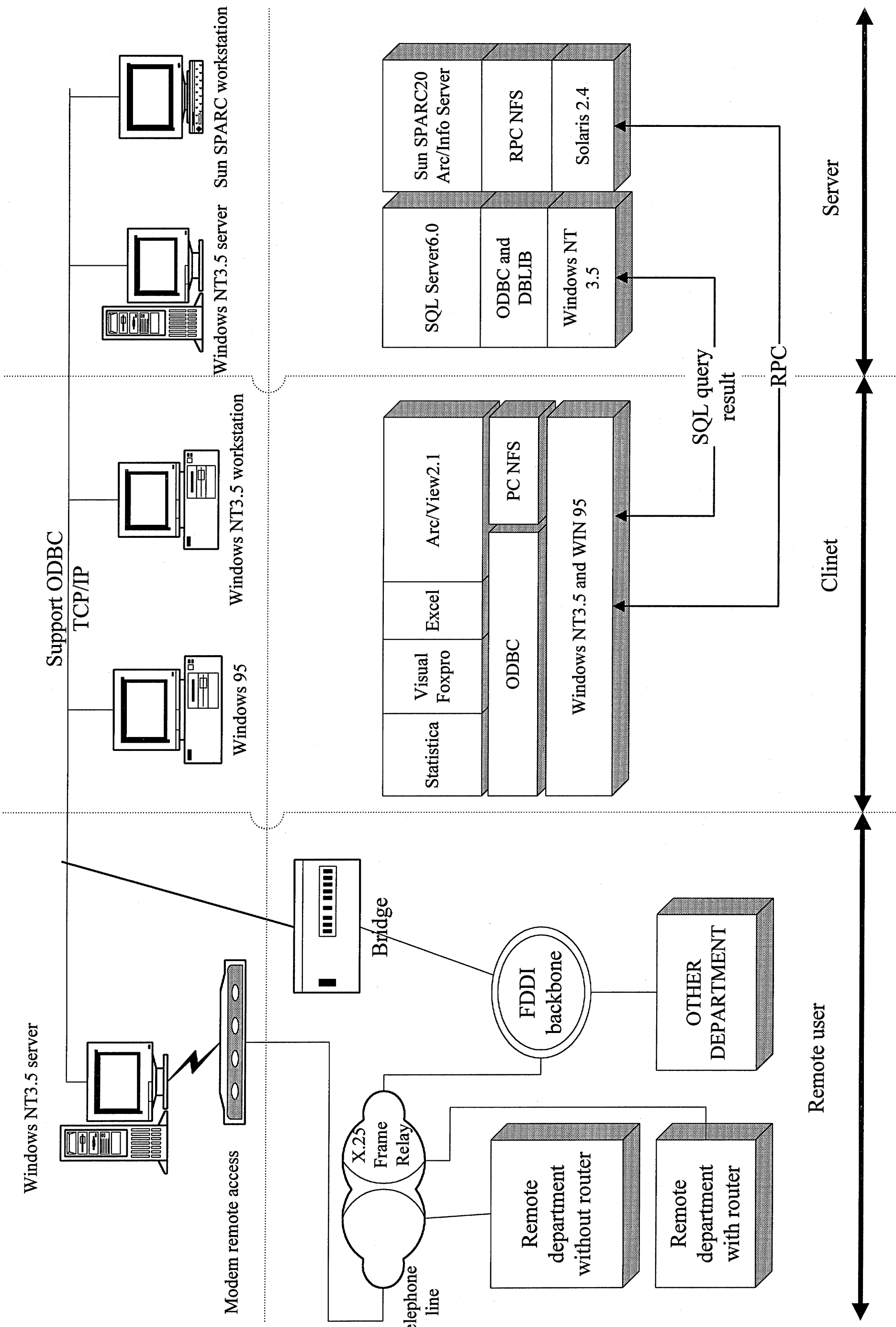

Fig. 7. The software network topology in the future.

integration of remote servers in EPD or EPA can be achieved by T-1 trunk for the purpose of remote data acquisition and videoconference in the future decision making process. Fig. 6 presents the hardware network topology of such a communication system, and Fig. 7 delineates the software network topology for future solid waste management at various levels of jurisdiction. The system operation focuses on easy implementation for less experienced personnel. The user interface should be designed by a friendly way for the user to ascertain how the system proceeds a data transmission. A menu format, coded with specific programming language, could be prepared in which the user can perform database queries, cartographic display, and request a data transmission. But the information sources are actually collected from those 309 waste collection teams through a server in each EPB. Hence, through the connections of various LANs and wide area networks (WANs), it can distribute computer software resources among dispersed multiple users who may enter the system by terminals in those waste collection teams. As part of the user interface, the GIS is used for performing data entry, integration and display, for receiving data from waste collection teams or other database management system, and for depicting analytical results by generating cartographic products.

Overall, the proposed computer-aided system in each EPB selects a distributed processing solution for new, existing, and mission-critical solid waste management applications. Distributed computing offers many advantages, including the powerful operating system (OS), support for graphical user interface tools, and flexible networking. Such a system is composed of networking hardware and software, the computers attached to the network, and the peripheral devices attached to either the computers or directly to the network. While PC is dedicated to a specific suite of tasks at local levels of waste collection teams, servers support compute-intensive processing needs and the special graphic applications at regional offices. The network can grow and shrink as network administrators modify the network configuration to match changing usage patterns in various size of solid waste management problems in each county.

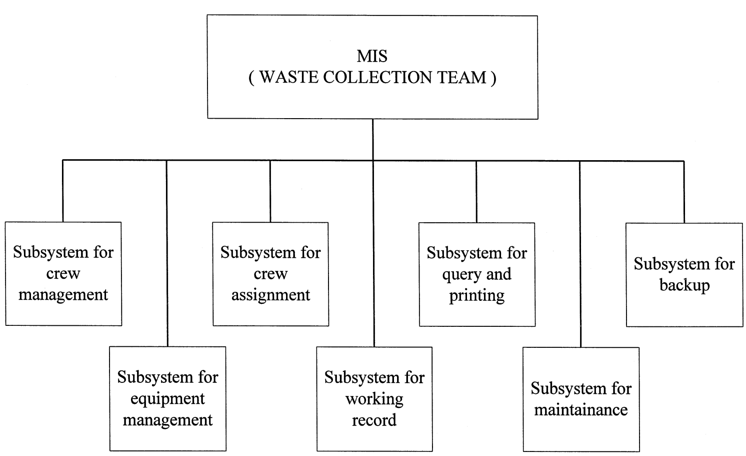

Fig. 8. The MIS structure in local waste collection teams.

2.3. Third stage analysis

It is noticed that a vast disparity of the level of computerized effort exists between all of the local waste collection teams and the EPA or EPD. Due to the lack of budget and skillful personnel, almost none of those 309 waste collection teams uses computer database to record daily operational procedure. All of the documents for collection statistics were recorded by a manual way and sent to the upper level of management authority by regular mails. The demand for rapid processing of information from the local levels of those waste collection teams was recognized as an important step toward a full integration of all network information flows in 1995. A research program was independently sponsored by the EPA for the creation of a stressful and dynamic operating database environment for local practising personnel who are responsible for various types of daily clean-up work in those 309 townships in Taiwan. This prototype

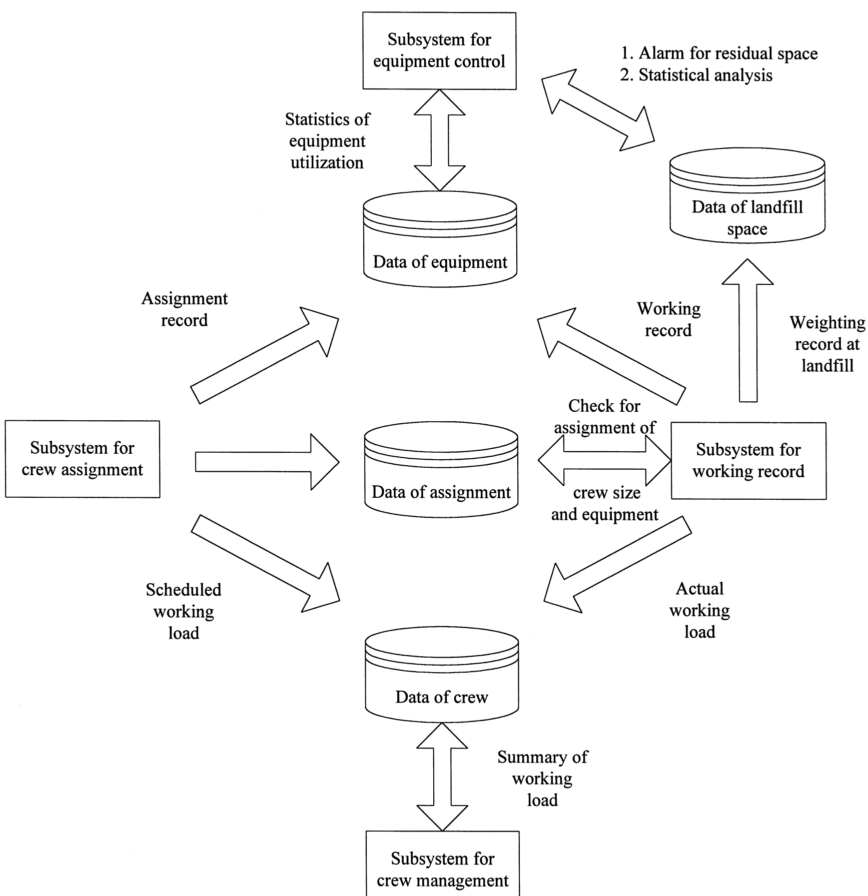

Fig. 9. The design features for MIS in local waste collection teams.

database was particularly designed for at least two selected waste collection teams as a demonstration program in 1996.

But a series of investigations show that some of the management personnel in those local agencies are not skillful for the use of complicated computer programs and not even willing to collaborate with research staffs due to the inherent reluctance to the required changes of the original operational procedure. The prototype computer program, using the software package Visual Foxpro®, was specifically designed based on the user-friendly principles such that managers may use the computer-aided system with respect to their original daily, routine operations, and report what quantities of solid waste, recyclables, and ditch sludge are collected, shipped, and disposed within their service areas by a easier way. Overall, the prototype of such a MIS integrates seven types of information flows, as shown in Fig. 8. But the computer-aided system would inherently activate a system-wide check point corresponding to reported workload assignment vs. reported achievement of waste collection to avoid any artificial mistake in the entire operational procedure. Such a software mechanism can be illustrated by Fig. 9.

3. Further remarks

The fundamental analytical requirements of such a computer-aided system should be placed on the operational capabilities to accommodate various types of information flows among system components. The proposed interactive, graphical-based computer-aided system may handle huge amount of background information, need to be collected, rearranged, and analyzed before the decision making is performed for a solid waste management issue. The software in the proposed system configuration is basically comprised of three parts of an organization: database management software (DBMS), model base management software (MBMS), and the software for managing the interface between the decision makers and the system, which might be called the dialogue generation and management software (DGMS) [18]. Data management may own several varieties of logical patterns, including relational DBMS, hierarchical DBMS, network DBMS, and file management system. MBMS could cover a library of different models, such as optimization or regression models to support different modelling analysis. Multiple dialogue styles, including the use of common language, menu-driven, question/answer arrangements, and object-oriented framework, can be screened and selected for different purpose of decision support.

Furthermore, rule-based or knowledge-based ES may simulate the means by which a human expert tackles real-word solid waste management problems using a set of inferences programmed into the computer system. Through the communication interface, the special power actually lies in its capacity to perform data retrieval functions together with complex model building and execution, generation of standard reports, evaluation of consequences, proposal preparation and decision making. The complex of solid waste management problems, such as the siting of landfills and incinerators, has prompted greater use of expert's assessment procedures to predict the potential impacts. These approaches of assessment have been the applications of knowledge-based, rule-based, or model-based expert or decision support systems that could be integrated into the proposed computer-aided system in the future.

Overall, the focus of design features of such EPs can be placed upon: Intelligence user interface—to guide an inexperienced user through the most efficient use of the system; problem classification—to recognize the analytical problem and the requirements of input data; database search—to make the search of essential numerical and geographic databases by using heuristic search methods; learning capability—to allow results of computational expensive queries to be added to the knowledge-based system to proceed subsequent decision making; cartographic output—to produce high quality maps and graphs and present the impacts of new development proposal or elevated emission of existing sources in the designated windows.

4. Conclusion

Effective environmental management is a substantial challenge in current solid waste management systems in Taiwan. This paper presents an enriched computer framework to design and implement a nationwide computer-aided system for handling enormous amount of information flows for solid waste management among various environmental protection agencies. The decision-making phases of intelligence, design, and choice of solid waste management alternatives can be considered for various types of decision analysis. It is expected that the use of such a computer framework would greatly help analysts and decision makers evaluate many management scenarios in regional and local solid waste management programs and process large amount of annual, seasonal, and monthly information flows within a very short period of time.

Acknowledgements

The authors deeply acknowledge the financial support from the Environmental Protection Department in Taiwan Provincial Government and the Environmental Protection Administration, People's Republic of China.

References

[1] A.M. Heinecke, Experiences with PC databases in maritime environmental protection, Proceedings of the Third International Conference on Development and Application of Computer Techniques to Environmental Studies, Montreal, 1990, pp. 311–321.

[2] M.H.S. Wang, L.K. Wang, T. Simmons, Computer-aided air quality management, J. Environ. Manage. 9 (1979) 61–87.

[3] M.E. Quentin, D. Cluis, A management application of geographic information system (GIS) to an acute environmental problem: swine manure disposal, Proceedings of the Third International Conference on Development and Application of Computer Techniques to Environmental Studies, Montreal, 1990, pp. 503–511.

[4] J. Cargin, J. Dwyer, Pennsylvania's low-level radioactive waste disposal facility siting project: special GIS operations, 1995 ESRI User Conference, CA, USA, 1995, 162.

[5] W. Hass, D. Schewig, M.M. Resch, Numerical simulation of ground water flow and ground water pollution in a graphical software environment, in: P. Zannetti (Ed.), Computer Techniques in Environmental Studies IV, 1992, pp. 827–841.
[6] I. Muzik, HYDROGGISS—hydrograph generating GIS software, in: P. Zannetti (Ed.), Environmental Systems, Vol. II, 1994, pp. 311–318.
[7] K. Massie, Using GIS to improve solid waste management and recycling programs, 1995 ESRI User Conference, CA, USA, 1995, 18.
[8] W. Summer, GIS and soil erosion models as tools for the development of soil conservation strategies, in: P. Zannetti (Ed.), Environmental Systems, Vol. II, 1994, pp. 303–310.
[9] G. Tsakiris, M. Salahoris, GIS technology for management of water distribution networks, in: E. Cabrera, Martinez (Eds.), Water Supply Systems, Computational Mechanics Publications, 1993, pp. 361–378.
[10] T.V. Hromadka, R.J. Whitley, R.R. Harryman, M.J. Braksator, Application of a graphics data base management system: computerized master plan of drainage, in: P. Zannetti (Ed.), Computer Techniques in Environmental Studies IV, 1992, pp. 805–817.
[11] J. Zhang, Y. Parks, Dynamic linking between GIS and surface water database, in: P. Zannetti (Ed.), Environmental Systems, Vol. II, 1994, pp. 319–327.
[12] N.B. Chang, S.F. Wang, The development of an environmental decision support system for municipal solid waste management, Comput. Environ. Urban Syst. 20 (3) (1996) 201–212.
[13] N.B. Chang, Y.L. Wei, C.C. Tseng, C.Y. Kao, The design of a GIS-based decision support system for chemical emergency preparedness and response in an urban environment, Comput. Environ. Urban Syst., accepted, May 1997.
[14] J.M. Hushon, Expert system for environmental problems, Environ. Sci. Technol. 21 (9) (1987) 838–841.
[15] L. Ortolano, A.C. Steinemann, New expert system in environmental engineering, J. Comput. Civil Eng., ASCE 1 (4) (1987) 298–312.
[16] V.B. Robinson, A.U. Frank, Expert systems for geographic information systems, Photogrammetric Eng. Remote Sensing 53 (10) (1987) 1435–1441.
[17] F. Recknagel, E. Beuschold, U. Petersohn, Delaqua—a prototype expert system for operational control and management of lake water quality, Water Sci. Technol. 24 (6) (1991) 283–290.
[18] R.H. Sprague Jr., H.J. Watson (Eds.) Decision Support Systems: Putting Theory into Practice, 3rd edn., Prentice-Hall, Englewood Cliffs, NJ, USA, 1993.