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THE DEVELOPMENT OF AN ENVIRONMENTAL DECISION SUPPORT SYSTEM FOR MUNICIPAL SOLID WASTE MANAGEMENT

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ABSTRACT. *This paper presents the development of an innovative Decision Support System (DSS) as a graphical, interactive, problem-structuring tool for the management planning of solid waste collection, recycling and incineration systems. Emphasis has been placed upon integration techniques through the use of several powerful modules in the software package SAS® to constitute the essential functions in management planning. The object-oriented characteristics are specifically described in the framework of the proposed DSS. The practical implementation of this program for the city of Tainan in Taiwan shows the potential of such applications.* © 1997 Elsevier Science Ltd

INTRODUCTION

The rapidly increasing generation of solid waste and continuous landfill closing have motivated various incineration and recycling programs in many cities; but the proposed waste recycling programs prior to incineration have made a great impact on solid waste management. In addition, the inherent complexity of refuse composition and the variations of the prices of recyclables in the secondary material market have generated additional difficulties in the selection of management alternatives. The most critical question is how compatibile the recycling and incineration are in a metropolitan region. This research represents the first effort to introduce a Decision Support System (DSS) to assist the decision making of solid waste management regarding the recycling and incineration programs.

Over the last 10 years, DSSs have been developed and successfully implemented in many subjects. The proposed structure of the DSS in this analysis should include an interactive graphic display capability, the data management system for the summary of waste generation and composition and a linear programming model incorporated to generate a set of flexible solid waste management strategies for the optimal planning of recycling and incineration programs. Based on different characteristics of each city, modelling analysis, data presentation and graphic display of the analytical results can be established through the integration of several SAS® software modules, such as SAS/BASE, SAS/AF, SAS/GRAPH, SAS/OR, SAS/ETS and SAS/FSP, as a complete decision support tool. The planning practice for solid waste recycling, transportation and incineration in the city of Tainan in Taiwan shows the potential of such applications.

THE STRUCTURE OF THE DECISION SUPPORT SYSTEM

The fundamental requirements of a DSS should be placed on the operational capabilities to accommodate various types of information flows among system components, as well as the functional requirements of these components themselves. We briefly describe the nature of these information flows and their relationship with system components as follows. The DSS software system is basically comprised of three parts: 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) (Sprague & Watson, 1993). The schematic configuration of the DSS structure is shown in Figure 1. Data management may have 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

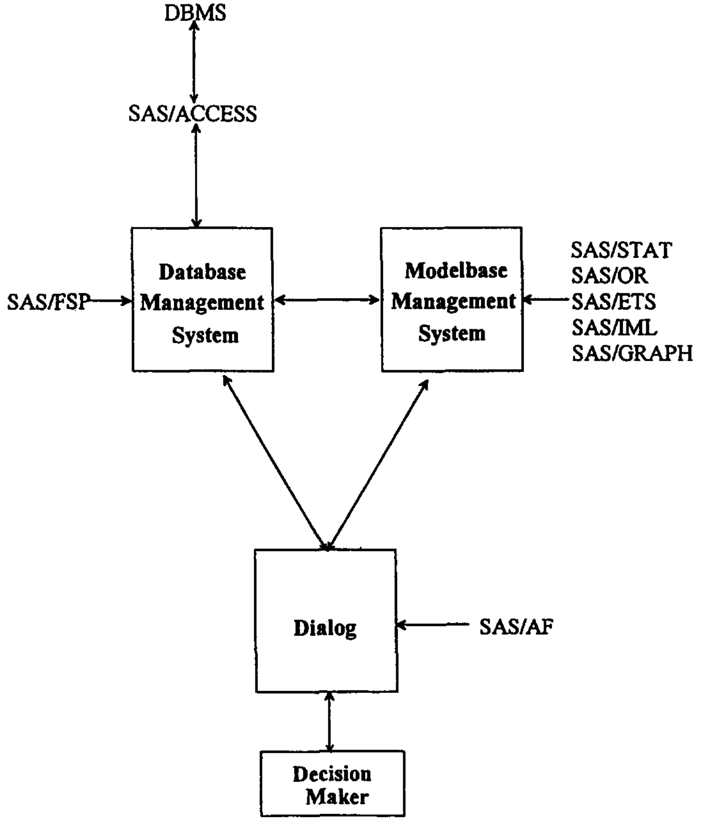

FIGURE 1. The basic structure and related SAS® software modules in this DSS.

different analyses. 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 purposes of a DSS to express various types of analytical outcome.

Thus, the technology for the DSS in this analysis must consist of three sets of capabilities in the areas of dialogue, data and modelling. The architecture of this DSS must show two-way interactions among all subsystems. This implies that the DBMS can pass any data sets or graphical files required into the modelling process as the reference base and answer general queries from the users dynamically. The numerical results and graphical outputs from the library of optimization or regression models can also be presented to the users or stored in the DBMS. It is found that the appropriate combinations of several modules in the SAS® software package exactly fit the required framework of the proposed structure of the DSS for solid waste management and can easily be operated in the environment of an IBM PC-compatible hardware system. The concepts of how to integrate the essential components in the SAS® software package and how to build a computer-based DSS system in an object-oriented environment for solid waste management will be illustrated in the following sections. The DSS developed here should help decision makers to confront uncertainty, problems of solid waste generation, prediction and optimal allocation of waste stream for recycling and incineration through direct interactions with data and analysis models.

DEVELOPMENT OF THE DSS FOR SOLID WASTE MANAGEMENT

The proposed interactive, graphical-based DSS can handle a large amount of background information which may need to be collected, rearranged and analysed before the decision making is performed for a solid waste management planning scenario. Accurate predictions of optimal solid waste distribution should rely on a good Management Information System (MIS) regarding waste collection capability, prices of recyclables, waste generation and composition, transportation cost, and construction and operating costs for these solid waste processing facilities. Furthermore, since the degree of recycling corresponding to specific physical, economic and management factors remains unclear, a special modelling analysis might be of significance in the decision making for selecting the appropriate allocation between recycling and incineration facilities. A DSS is thus needed to provide a user-friendly interface, to establish statistical and optimization analyses, and to communicate with the decision makers or planners, who may not be able to memorize all the message, to integrate all the necessary factors or to learn how to write a complicated computer program.

Several SAS® modules (SAS Institute Inc., 1994) may fully support the required functions of DSS when they are integrated appropriately. For example, SAS/FSP presents the ability to combine a variety of data sources through a data capture, entry and extraction process, while the SAS/ACCESS can communicate with other external databases, such as DBASE®, INFORMIX®, ORACLE®, etc., if needed, to accomplish a specific task of data transfer. Furthermore, different categories of optimization or regression models included in the SAS® software package, as summarized in the MBMS unit, can be flexibly assembled or independently applied according to different requirements. For example, SAS/STAT, SAS/ETS and SAS/IML have been organized for various types of statistical and regression analyses, and SAS/OR has been designed for most types of optimization analyses. SAS/GRAPH is commonly used by all the models for the presentation of model outputs, if needed. These analytical models are all embedded in the MBMS unit of this DSS. They can receive all information flows from all directions in the system, and can dispatch the outputs to any place required. Finally, the SAS/AF serves as the convenient dialogue component in this DSS, which constitutes an object-oriented framework which is icon-based and menu-driven in a touchscreen environment. Overall, the SAS/AF presents the model and data outputs to the users and collects the inputs for DSS.

Specifically, the SAS/AF software modules may provide an object-oriented framework by using the multi-level interactive graphical application in which the FRAME applications serve as user-friendly interfaces to present several important functions, such as end-user query and reporting, data access and management, data summarization and analysis, data update and display, and communication with external statistical and optimization models, or advanced graphical files. Through the use of the Screen Control Language (SCL) and the concept of object-oriented frameworks, SAS/AF can therefore link with SAS/GRAPH, SAS/STAT, SAS/ETS, SAS/IML, SAS/OR, SAS/FSP, etc. to constitute any type of project-oriented DSS. Hence, based on the convenience of such a software environment and the required structure of a DSS, as illustrated in Figure 1, the DSS can easily be created for solid waste management planning. This study is perhaps the first research that applies the techniques of SAS® object-oriented programming and the knowledge of the DSS for solid waste management.

FUNCTIONAL DESIGN AND APPLICATION OF THE DSS

It is known that Tainan City, located in the southern part of Taiwan, is divided into seven administrative districts. Only one incinerator is sited in this city and it is under construction. The task of waste shipping is handled by the Bureau of Environmental Protection of the City Government. Each district has a waste collection team. In addition to general management tasks, the major issue in this solid waste management system is what the appropriate proportion of recyclables to be recovered in the waste stream is.

The overall objective in this DSS for the solid waste management in Tainan City is then to design a set of multi-level interfaces which may provide the selective capabilities by appropriate icons. The work required for technical design of this DSS can be dramatically reduced by using object-oriented generators — SAS/AF modules. Hence, a standard objective-oriented computer code, linking with SAS/BASE, SAS/STAT, SAS/OR and SAS/ETS subroutines, has been applied for solving the related prediction and optimization analyses through a range of parameter values alternately. However, any analytical function may serve as an object in the SAS/AF framework, and can be performed whenever it is required in the system.

In this DSS, automated memory aids are achieved through the use of SAS/FSP for data input and editing. The main screen of this DSS, designed by using SAS/AF, is shown in Figure 2. Regional variations of solid waste management are emphasized along with the modelling need. Hence, Figure 3 presents a set of selective icons for database and modelling analyses. Once the user picks up the first icon, a menu listing three categories of database, including incinerator cost, manpower and equipment of collection team, and

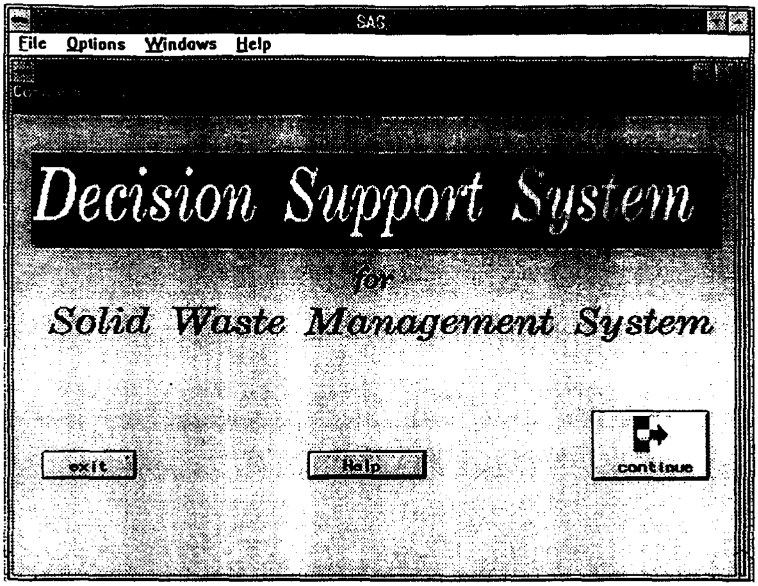

FIGURE 2. The main screen of this DSS.

waste generation and composition, can be shown for further selection (Figure 4). Any selection can generate a map outline needed when users hope to conceptualize the real world issues by diagrams and numbers on the computer screen (Figure 5). For instance, if we selected the first icon, a Taiwan map with the locations of municipal incinerators would appear on the screen. In addition, if the second icon was selected, a map illustrating the

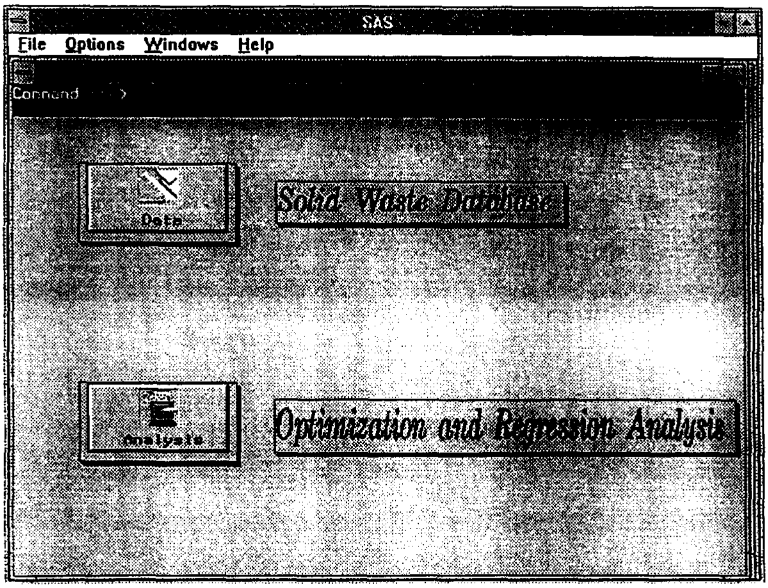

FIGURE 3. The first selective screen of this DSS.

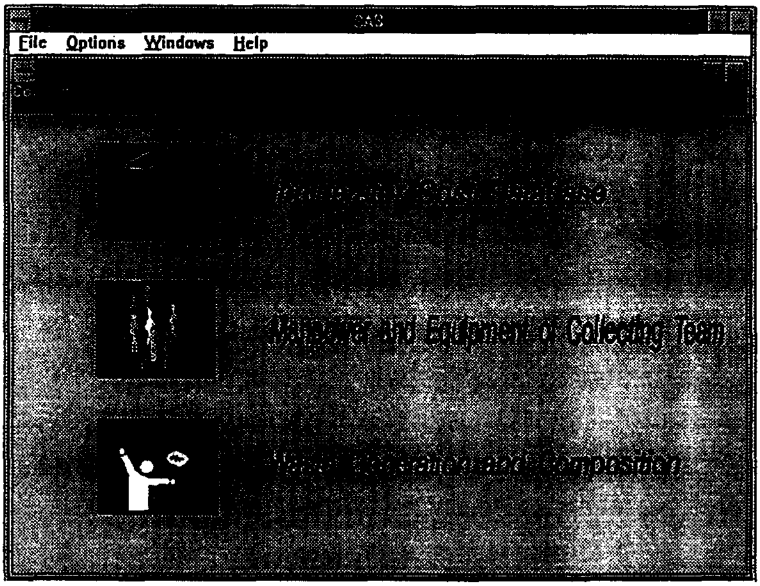

FIGURE 4. The second selective screen of the database in this DSS.

administrative boundary in the city of Tainan, as shown in Figure 6, could be used to query the user which district he or she was interested in. On the operational screen, the use of regional hotspots to obtain information on solid waste management for a specific item can thus be performed easily by clicking on hotspot areas of those SAS/GRAPH output objects. Thus, this DSS can create hotspots for the map corresponding to any administrative district in the city of Tainan and enable the user to see the areas and the

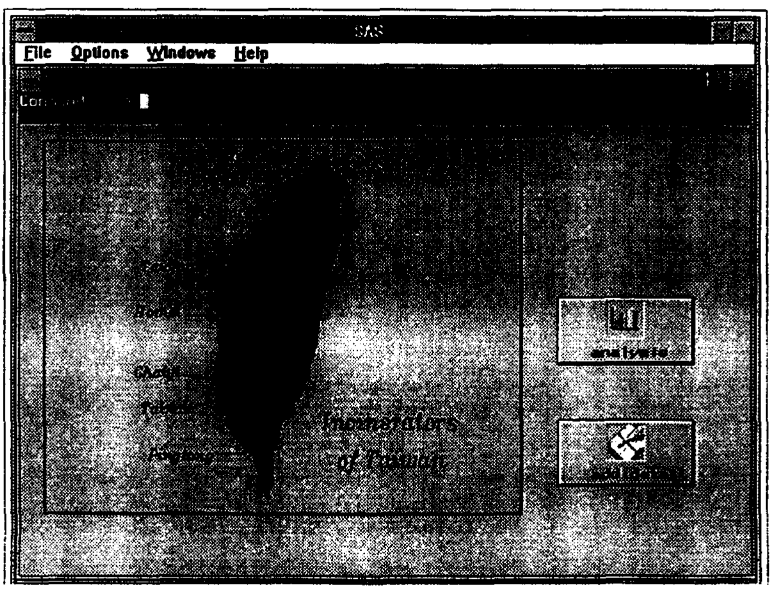

FIGURE 5. The map of Taiwan and locations of incinerators in this DSS.

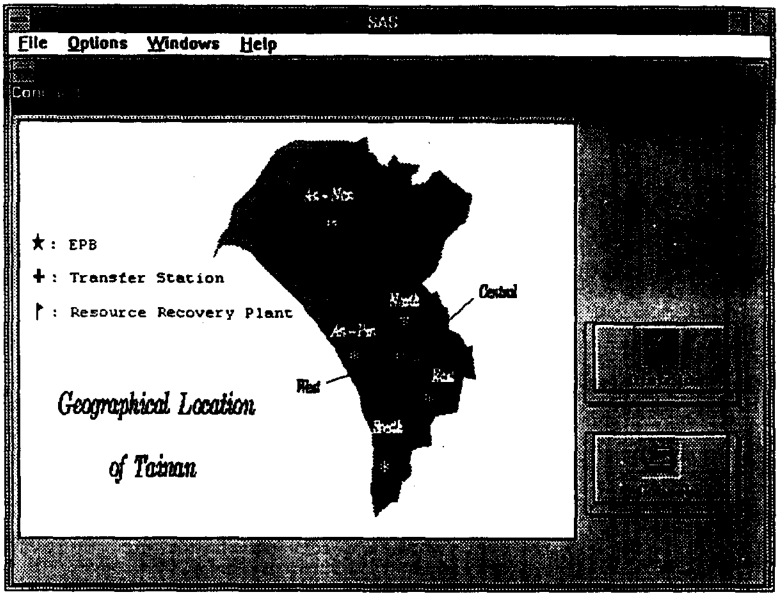

FIGURE 6. The map of Tainan City and hotspot areas in this DSS.

related data of manpower and equipment of the collection teams that are hotspotted. Figure 7 expresses the collection manpower in the north district. Options are prepared for the users to print summary statistics of the existing data. The hotspots in the output diagram are also the objects in the DSS and are designed as rectangular regions which can be overlaid on top of any widget. As a result, Figure 8 exhibits the waste composition and generation rate in the north district, in which a drill-down window appears in the upper left

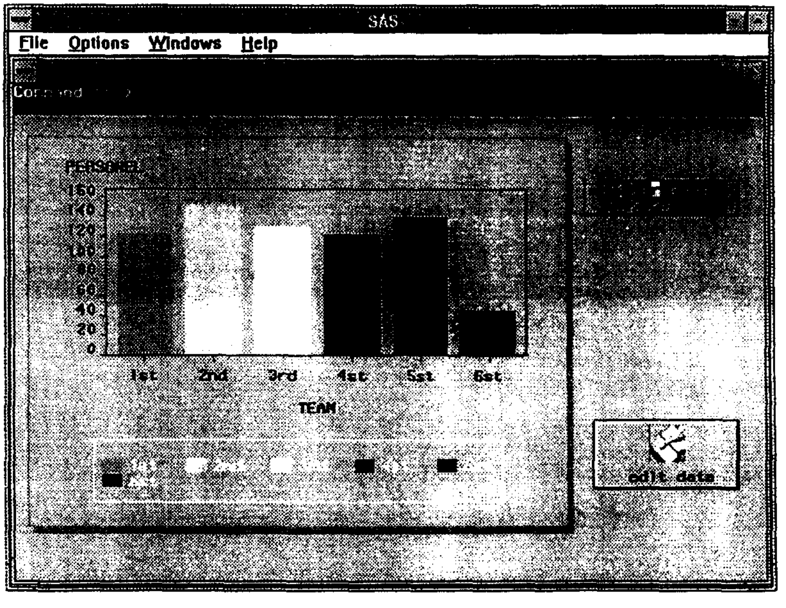

FIGURE 7. The collection manpower and equipment in the north district.

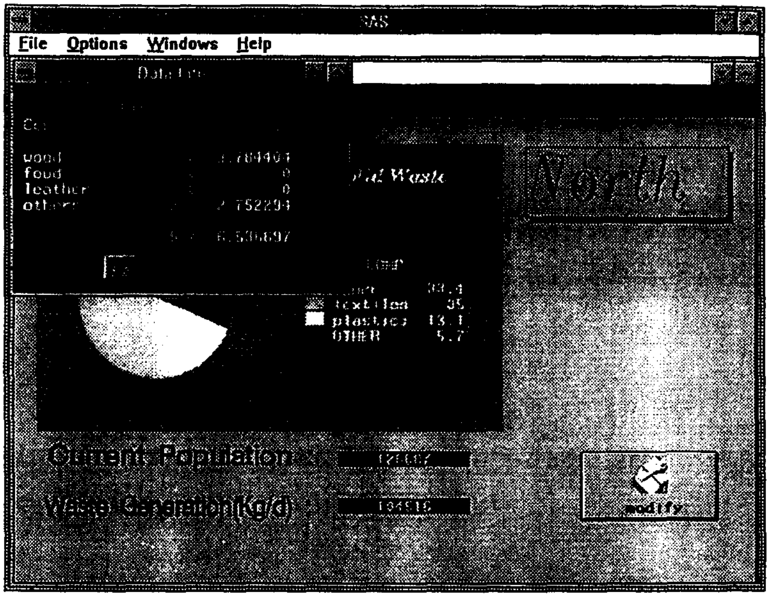

FIGURE 8. The waste generation and composition in the north district.

corner to explain the detailed information if the icon of "other" type of waste composition is a hotspot in the diagram. Such operations are prepared for the intelligence, design and choice of an appropriate waste collection planning.

If the user picks up the icon of optimization and regression analysis in Figure 3, two types of model selections are provided, as shown in Figure 9. By linking with the SAS/ETS module, Figures 10 and 11 show the regression outcome of the population trend

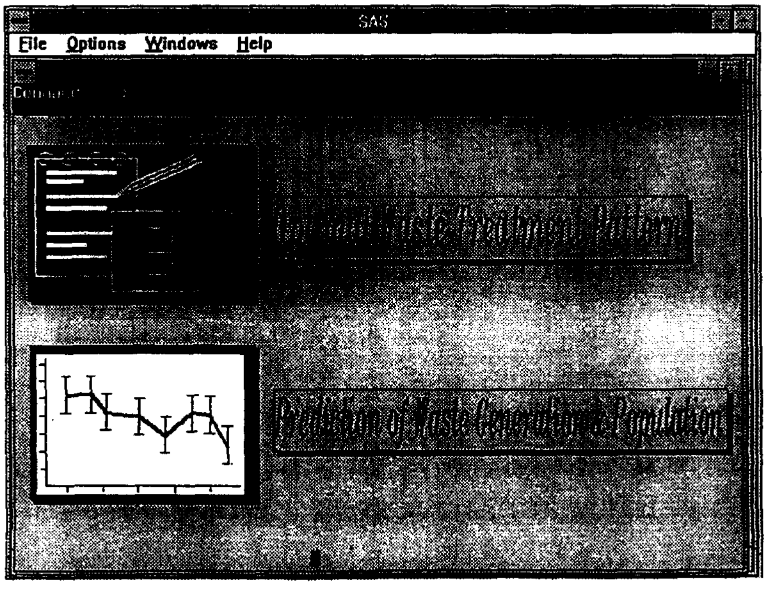

FIGURE 9. The selective screen of modelling analysis.

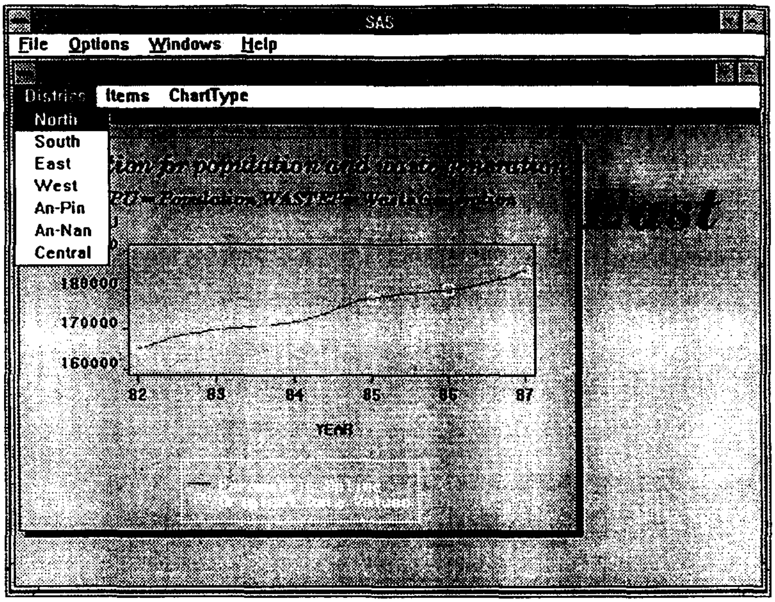

FIGURE 10. The regression results of population trend.

corresponding to the east district and the construction cost prediction of municipal incinerators, respectively. Apart from the work of general analysis and data presentation, which can be performed by SAS/STAT and SAS/GRAPH through the dialogue procedure, advanced optimization models are needed to function as knowledge sources and to provide intelligent support in decision making for waste recycling; but the

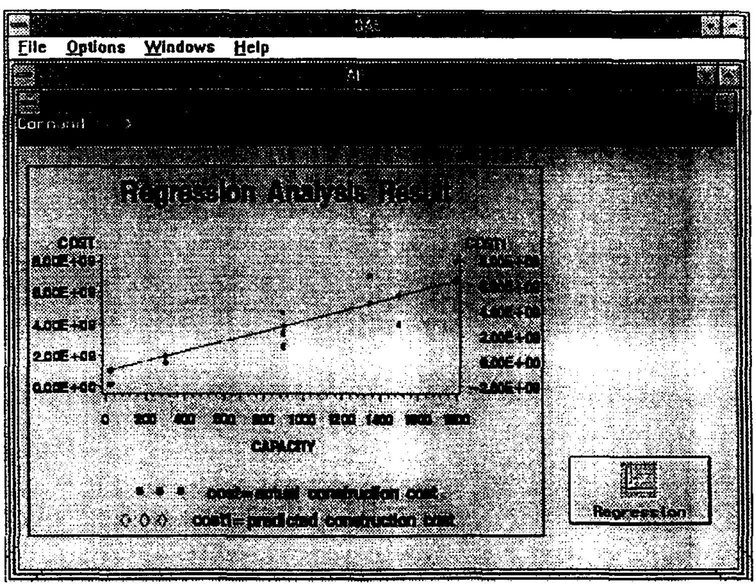

FIGURE 11. The regression result of the construction cost of incinerators.

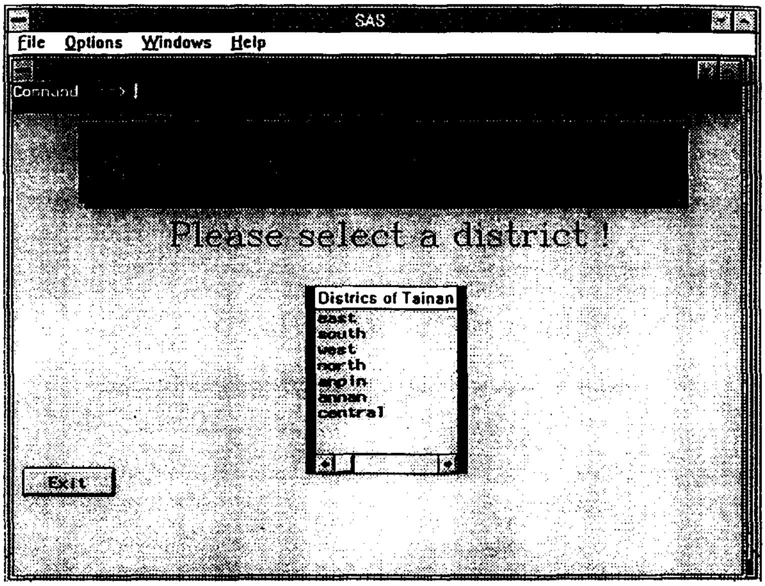

FIGURE 12. The spatial selective menu of the optimal recycling program.

interactions between incineration and recycling should be analysed. Thus, if the second icon (i.e., the optimization modelling) is chosen in Figure 9, the SAS/OR module can be initialized immediately. The interaction between the information related to waste generation, composition and prices of recyclables, and the optimization model construction, is thus conducted by the preparation of several common datasets for communication

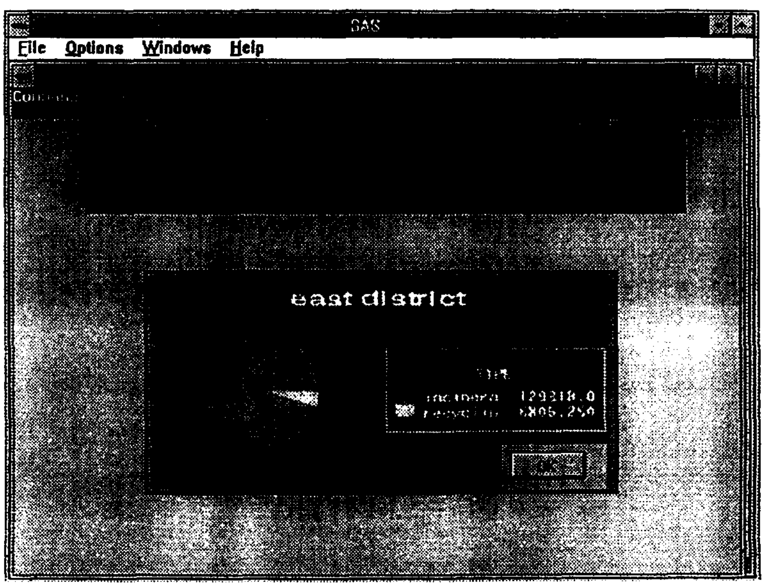

FIGURE 13. The optimal recycling pattern for the east district.

in the SAS program. The optimization model examined in this research is a linear programming model, as listed in Appendix A, to depict decision making of optimal waste distribution for both recycling and incineration programs in a metropolitan environment. The outcome of the optimization analysis is stored in another dataset waiting for subsequent analysis. Figure 12 lists the menu for further illustration of the optimal recycling pattern. For instance, if the east district is picked up, as shown in Figure 13, the optimal allocation of waste for recycling is 6806.25 kg/day, while the rest of the waste, 129,318.00 Kg/day, should be shipped to the incinerator. Similarly, many other types of applications can proceed.

CONCLUSIONS

This research presents a new area of building a DSS for handling municipal solid waste management systems. The decision-making phases of intelligence, design and choice of solid waste management alternatives can be applied to this DSS analysis. In the programming techniques, emphasis has been placed upon the integration of several modules in the software package SAS® to constitute the essential structure in the DSS. The application to the city of Tainan in Taiwan verifies that the DSS developed is a convenient tool in the decision making for regional solid waste management.

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APPENDIX A

The Linear Programming Model Formulation

$$Min \sum_i \sum_j (T_{ij} S_{ij}) + \sum_i \sum_j T_{ij} (\sum_k \sum_l R_{ikl}) \qquad \text{transportation cost}$$

$$+ \sum_i \sum_j (S_{ij} OC_j) \qquad \text{operating cost}$$

$$+ \sum_i \sum_k \sum_l (R_{ikl} RC_{kl}) \qquad \text{recycling cost}$$

$$- \sum_l (CR_l PR_l) \qquad \text{recycling income}$$

$$-\sum_i \sum_j (S_{ij} PE) \qquad \text{electricity income}$$

subject to:

(1) recycling constraint: the waste reduction by household recycling can be taken into account in terms of participation rate of residents, the recyclable ratio and the composition of waste. Hence, the recycling potential must be evaluated in advance and may encounter upper and lower bounds.

$$L_{il} \leq R_{ikl} \leq U_{il} \qquad \forall i, l$$

(2) mass balance constraint for waste generation in each district:

$$\sum_j S_{ij} + \sum_k \sum_l R_{ikl} = G_i \quad \forall i$$

(3) mass balance constraint for recyclables in each district:

$$A_i = G_i(\sum_k \sum_l R_{ikl}) \qquad \forall i$$

(4) mass balance constraint for a specific recyclable in the whole city:

$$CR_l = \sum_i G_i(\sum_k R_{ikl}) \qquad \forall l$$

in which:

G_i (tons/day)	daily waste generation in the administrative district i;
U_{il}, L_{il}	the upper and lower bounds of the recyclable l in the waste stream of district i;
OC_j (\$/ton)	annualized construction and operating cost of incineration plant i;
T_{ij} (\$/ton)	unit transportation cost from district i to incineration plant j;
S_{ij} (tons/day)	optimal waste flow shipping from district i to incineration plant j;
R_{ikl} (tons/day)	optimal recyclable flow from district i to recycling centre k corresponding to the recyclable i;
RC_{kl} (\$/ton)	recycling cost corresponding to recyclable l at recycling centre k;
PR_l (\$/ton)	prices of recyclable l in the secondary material market;
PE (\$/ton)	income from electricity sale by burning 1 ton of solid waste;
CR_l (tons/day)	the amount of recyclable l recovered in the whole city;
A_i (tons/day)	the total amount of recyclables recovered in district i.