General Purpose Computer-Aided Engineering Tools for Environmental Software Systems

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Abstract

Software systems to support environmental research and management can often be developed and applied within the context of general purpose computer-aided engineering tools such as spreadsheets and databases. Reliance on general purpose CAE tools reduces development time, is usually less expensive and yields software that is often more capable for a specific task than custom-designed systems with a broader range of functionality. We outline several examples of such applications in this paper, including a spreadsheet for toxic emissions weighting, database and matrix manipulation software for life cycle assessment using economic input-output models, a database system to support environmental reporting, and a Java-enabled browser for visualizing a TRI database.

Keywords

Environmental Software, Computer-Aided Engineering Tools, Spreadsheets Databases, Matrix Manipulation

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INTRODUCTION

Delivering functionality using general purpose software tools is often the best approach for the development of environmental software systems. These general purpose software tools typically incorporate sophisticated user interfaces, display options, inter-communication options, problem solving utilities, and considerable application flexibility. Their capability and flexibility has increased considerably in recent years, while costs have declined. Among these general purpose tools, we include software systems that are not specialized for environmental or even engineering applications: 1) spreadsheets such as Microsoft EXCEL™ for data manipulation; 2) databases such as Microsoft ACCESS™ for data storage and retrieval; 3) numerical and optimization tools such as MATLAB™ for matrix manipulations, GAMS™ for optimization, or SAS™ for statistical analysis; 4) geographic information systems for storage, display and manipulation of spatially distributed data; and 5) geometry-based computer aided design systems for storage, display and analysis of geometric artifacts such as new products or plants.

Emphasis on these general purpose tools for most environmental applications runs counter to an existing trend to develop large custom designed software systems. Development of smaller systems with a more focussed functionality using general purpose software tools is often not considered. There are numerous instances where formal, custom procedural programming approaches are best. These situations typically involve a broad scope of well understood and stable functionality for which a large system development effort can be justified. However, there are many situations in which applications built in general purpose tools will be preferable. These situations typically involve a smaller scope of functionality, which may or may not be well defined at the time of system development. Developing robust fast prototype systems using general purpose tools can be extremely useful, both in the results that can be generated from these prototypes and in the evaluation of the functionality. A good environmental software professional should be able to adopt a software platform that is appropriate for the scope and nature of the functional requirements.

At Carnegie Mellon University, we graduate programs in Computer-Aided Engineering and Management (CAEM) in our Department of Civil and Environmental Engineering. After completing the CAEM program, students are prepared to identify the appropriate programming paradigm (e.g., spreadsheet, database, symbolic math package, procedural programming language) for the development of their system. In the following sections of this paper, we illustrate several environmental software applications developed using such general purpose CAE tools.

TOXIC MATERIAL WEIGHTING

Environmental indices are a major part of environmental performance measurement. Calculation of various environmental indices usually involves data storage and manipulation, as well as simple arithmetic, and is appropriately done using commercial, or off-the-shelf, computer software. Environmental scores have to be evaluated by the user of the software, with the help of graphs and tables, which are standard features of spreadsheet programs. Larger sets of data, such as those for entire industrial sectors or countries, can be easily handled by database programs. Some environmental data are starting to be accessible on-line: national pollution inventories like the U.S. Toxics Release Inventory (TRI) are on the Internet.

CMU's Green Design Initiative has published a methodology that weights and compares the toxic emissions associated with processes and products (Horvath, 1995) (Horvath, 1996). The Carnegie Mellon Equivalent Toxicity (CMU-ET) methodology weights toxic content or emissions by their toxicity, using the Threshold Limit Values-Time Weighted Average (TLV-TWA). The toxicity weighting is motivated by the usual practice to use TRI data without regard to the differences in the toxicity of the emitted chemicals, as if a pound of one chemical is equal to a pound of another. Our toxicity-weighted emissions index, the CMU-ET, can be viewed as equivalent to pounds of sulfuric acid released to the environment. By summing the CMU-ETs calculated for a facility's, company's, state's, product's, etc., TRI emissions, we arrive at the CMU-ET for that entity.

The CMU-ET methodology is implemented in spreadsheet and database environments. The computer environment was chosen with the potential users (company, public, government, academia, etc.) and their resources in mind. The spreadsheet program was developed in Microsoft EXCEL and the database management program in Microsoft ACCESS, two commonly available and used pieces of software in the personal computer (PC) environment.

The CMU-ET spreadsheet template contains the names and CAS (Chemical Abstract Service) numbers of TRI chemicals, and the TLVs for the chemicals. The user types in the amount of each chemical, and the spreadsheet automatically calculates the aggregate CMU-ET score. The user can also see which chemicals contribute most (and how much) to the overall score. The tabulated format of the spreadsheet is, indeed, the best software environment for such a task.

A relational database management program, TRI-TOX, was created to calculate the CMU-ET indices when a large number of data inputs are required, such as when dealing with industry, state or entire country data. The program also provides a ranking of a particular list of chemicals by different criteria. This is a feature of the database software that is not routinely available with the spreadsheet implementation. The toxic emissions indices, the different rankings of the data, etc., are calculated after queries have been issued by the user.

ECONOMIC INPUT-OUTPUT LIFE CYCLE ASSESSMENT

Effective environmental decision making requires information about environmental consequences of alternative designs. Life Cycle Assessment (LCA) is a systematic tool to provide this information. LCA aims to trace the major stages involved over the entire life cycle of a product, from raw material extraction to ultimate disposal, quantifying the environmental burden at each stage. Most currently used LCA techniques are modifications of the approach developed by the Society of Environmental Toxicology and Chemistry (SETAC, 1991). However, practical use of the SETAC approach involves drawing a boundary that limits consideration to a few producers in the chain from raw materials to final consumers (Lave, 1995). Limiting the analysis this way leads to consideration of only a fraction of the total environmental discharges associated with a product or process.

Economic input-output analysis is a well-established modeling framework that is often used for economic planning purposes (Leontief, 1970). For example, it can be used to calculate the resources needed to support an increase in the output of automobiles. An expansion in automobile production would require increased production by the various sectors that supply directly or indirectly to automobile manufacturing, such as steel, electricity, petroleum and plastics. Using these same principles, we have developed an economy-wide LCA technique by linking economic input-output tables with environmental discharge databases (Lave, 1995).

Our economic input-output life cycle analysis (EIO-LCA) method requires several distinct calculations. First, the direct economic changes associated with a choice are estimated. Second, an economic input-output model is used to estimate both direct and indirect changes in output throughout the economy for each sector. Published input-output tables can be augmented by adding more sectors or disaggregating existing sectors, if necessary, for this purpose. Third, the environmental discharges of the changes are assessed by multiplying the economy-wide output changes by the average environmental discharges associated with the units of output of each sector. The overall environmental impact is characterized by this vector of discharges and by selected summary indices.

The EIO-LCA was first implemented using MATLAB and Microsoft. MATLAB was chosen primarily for its superior matrix manipulation capabilities; matrix manipulation forms the mathematical core of EIO-LCA. The EIO-LCA method also requires maintaining a large database of environmental impacts. The ACCESS database management system (DBMS) was chosen for its widespread availability, easy-to-use visual interface, and good report generation capabilities.

The economic input-output tables and the technical coefficient tables for the 519*519 sectors of the US economy are stored as matrices in MATLAB. In its simplest form, the MATLAB portion of the EIO-LCA software accepts the new final demand vector as an input and calculates the economy-wide output changes for each sector. However, more sophisticated product EIO-LCAs require augmentation of publicly available IO tables. Simple routines are set up for disaggregation of existing sectors or addition of completely new sectors to the input-output tables to represent new products or recycling options. These augmented matrices are then used for estimation of the economy-wide incremental output changes.

There are three primary functions of the ACCESS DBMS. The first function is managing a large database of the sector- and plant-level environmental impacts. Some typical data tables maintained in ACCESS include conventional pollutant emission factors derived from EPA's AP42 and AIRS databases, toxics emission factors derived from the Toxics Releases Inventory (TRI) reports, and fuel and electricity consumption coefficients derived from the Manufacturing Energy Consumption Surveys (MECS) conducted by the Department of Energy. The second function is accepting the incremental output vector for each sector from MATLAB as an input and calculating the environmental burden arising from these changes. The third function is generating various summary reports, such as total weighted and unweighted releases into various media and offsite transfers.

ENVIRONMENTAL REPORTING SYSTEM FOR A STEEL PLANT

Conedera (1996) developed a conceptual database for environmental management; it was tested and implemented using the Microsoft ACCESS. The environmental database was divided into ten modules. A 'mother' database contains all the environmental information as tables. Modules or 'children' are formed by attaching tables from the mother database by identifying relationships. The mother database is used for data storage and entering and modifying table structures. All other database functions, such as form design and report generation, are conducted from the child databases. The collection of Mon Valley Works Steel Plant Environmental Database (MOVE) contains 127 tables, 778 data fields, and 112 relationships. Four environmental compliance activities were addressed: Clean Air Act Title V permit compliance monitoring; sludge sampling and analysis; waste drum management; and national pollutant discharge elimination system permit compliance monitoring.

A variety of data handling procedures available with Microsoft Access were used. Customized reports for internal management uses or for submittal to regulatory agencies were generated. Implementation of the conceptual environmental data management has facilitated better communication between the Mon Valley Works staff, primarily because of easier access to environmental data through use of the relational database. In addition, immediate cost savings and reduced preparation time has been realized through programming the database to produce reports previously generated by outside environmental consultants. On the basis of the success of this exploratory project, the database will be placed on a network server for more widespread use by Mon Valley Works management.

VISUAL ENVIRONMENTAL DATABASE EXPLORATION

We describe a software tool here that allows users to explore large environmental databases over the Internet without using languages that require complex syntax and semantics. These types of tools are designed to solve the problem of using and processing large quantities of information in order to make a decision. In particular, environmental scientists have to do a number of tasks when they interact with a database to do data analysis. These tasks include getting data summaries, making comparisons between data sets, observing the time variation of variables, and observing the relationships between data sets. All of these tasks can be accomplished more efficiently and easily when the data is presented visually, as in this software.

The environmental data exploration tool was developed to provide Internet users with an easy way to access the Toxics Release Inventory (TRI) database (EPA, 1993). The system has two basic components: the client interface and the TRI data server. The client is a Graphic User Interface written in Java™. In this piece of software, the user poses queries by clicking in the user interface and he/she receives a graphic answer that can be queried again by pointing and clicking the mouse. The server is a CGI script which sends the query to a database of TRI data stored in POSTGRES95™ (a DBMS) (Chen, 1995) and sends back information to the client which displays the information to the user.

In the current prototype, a user has the following choices of graphic information: Pennsylvania Releases, Pennsylvania Transfers, U.S. Releases, U.S. Transfers, Transfers Matrix, and the Top Tens (Ranking of pollutants, facilities, etc.). For example, the quantities of toxic releases by state can be visualized. To retrieve this graphic information, the user selects the chemical name, the medium for releases (air, water, land, or underground), the year to study, and then submits the query. The user receives a colored map of the U.S., with each state color representing the quantity of toxic material released. When a user clicks on a state he/she gets a dialog box with four choices to get more detailed information. The user can ask to see the names of facilities or the sectors that release the toxic chemical (arranged in decreasing order).

CONCLUSIONS

We have illustrated several examples of how general purpose computer-aided engineering tools can be employed to efficiently create environmental software systems. Often, these tools can be developed quickly and then used to gain experience about the necessary functionality. This functionality may still be deliverable in the general purpose tools used or software may need to be custom designed and implemented. In any case, the initial tool can be efficiently and cost-effectively developed and used to test the efficacy of the proposed solution. This type of approach, known as fast prototyping, should be encouraged.

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