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Development of Computer Supported Information System Shell for Measuring Pollution Prevention Progress

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DEVELOPMENT OF COMPUTER SUPPORTED INFORMATION SYSTEM SHELL FOR MEASURING POLLUTION PREVENTION PROGRESS

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

Basic elements and concepts of information systems are presented: definition of the term "information", main elements of data and database structure. The report also deals with the information system and its underlying theory and design. Examples of the application of information systems for solving primarily environmental problems are presented.

Aspects of measuring pollution prevention progress are discussed. The application of system analysis and the definitions of system inputs and outputs are analyzed. Information system applications are considered as tools for measuring pollution prevention. Types of pollution prevention measurement and the usage of normalization as well as financial and management issues are briefly addressed.

A framework for an industrial production and waste generation tracking system is outlined. A model of the system is presented and parameters are precisely defined. A cost analysis of the system is carried out and examples of cost analyses suggested for selection of industrial technologies are discussed.

Based on the tracking model, an information system shell has been developed and its application for waste minimization and for measuring pollution prevention progress at an industrial facility is discussed.

Finally, the computer programming of the information system shell using commercially available database management systems is presented.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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INTRODUCTION

The growing importance of pollution prevention (P2) as an environmental strategy has increased pressure to develop systems for measuring P2 achievements. The U.S. Environmental Protection Agency defines P2 as the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or waste at the source. It includes practices that reduce the use of hazardous materials, energy, water, or other resources and practices that protect natural resources through conservation or more efficient use. The idea underlying the promotion of P2 is that it makes far more sense not to generate waste than to develop extensive processing/treatment schemes to insure that the waste poses no threat to the quality of the environment[1]. The Pollution Prevention Act[2] charges the U.S. EPA with responsibility for developing national P2 goals, and for devising a scheme for measuring national P2 progress. Industrial firms are under pressure, in part from the public disclosure of toxic release information required under Susperfund Amendment and Reauthorization Act Title III, to practice P2 and to communicate successes to the public. All of these activities must occur within a recognized frame of reference or measurement scheme to be meaningful[3]. In the Report to Congress, Pollution Prevention Strategy[4], the EPA states that establishing clear and measurable indicators of progress in P2 serves a number a purposes, such as helping to focus the efforts of each sector of society, and making it easier for the public and Congress to understand and track progress in reducing pollution. The EPA seeks continually to improve the quality of the data gathered under the Resource Conservation and Recovery Act and the Toxic Release Inventory, to improve the effectiveness of both programs in tracking progress in preventing pollution at industrial facilities. In addition, work is being carried out to:

(i) develop a more comprehensive database to measure pollution prevention in sectors other than manufacturing;

(ii) identify the most useful indicators and units for measuring pollution prevention at the source;

(iii) determine whether the same indicators and units can be used across different sectors; and

(iv) identify relationships between plant-level measurements of pollution prevention and combined effects of prevention by multiple sectors at regional and national levels.

The Chemical Manufacturers Association's Pollution Prevention Code of Management Practices[5] states that each company should strive for annual reductions, recognizing that changes in production rates, new operations, and other factors might result in increases. The goal is to establish a long-term, substantial downward trend in the amount of waste generated and contaminants and pollutants released. Quantitative reduction goals will be established that give priority to those pollutants, contaminants and waste of greatest health and environmental concern. The Code asks each member company to establish a P2 program that includes the following tasks:

- developing a quantitative inventory at each facility of waste generated and releases to the air, water, and land, measured or estimated at the point of generation or release.

- measuring progress at each facility in reducing the generation of waste and in reducing releases to the air, water, and land, by updating the quantitative inventory.

To implement P2 programs, industrial facilities must first measure the environmental impacts of their facilities. The industrial facility should set up boundaries of the observed system (unit operation, process, facility, etc.); identify and quantify system parameters (inputs and outputs toxicity and quantities) and their relationships; then collect, process and evaluate data, and make cost analyses. Finally, facility managers will encourage the implementation of P2 programs that will improve efficiency and reduce impacts on the environment; and reduce costs of facility operation and maintenance.

CONCLUSIONS

The analysis of available literature shows that the number of information system applications for solving environmental problems has significantly increased in the last three years. However, these applications are still concentrating on "end-of-the-pipe treatment" technologies rather than on the improvement of industrial operations responsible for generating environmental pollution in the first place. Furthermore, these applications proved to be very complex and site specific, and most of them incorporate graphic presentation of environmental impacts resulting in so called geographic information systems (GIS) which require teams of experts in different fields, as well as sophisticated software and hardware. Data collection, processing and evaluation remain the biggest challenge in widespread use of information systems.

The main aspects in dealing with pollution prevention measurement are applications of system analyses (including system inputs and outputs definition), databases, computer simulation and information systems, pollution prevention measurement types and normalization, financing and management practice. However, to introduce pollution prevention and to be able to measure its progress in any industrial process that generates waste, the quantity of waste at the point of its generation and the costs of generating waste have to be identified.

Tracking system for quantification of parameters in industrial production and waste generation system is presented based on the basic theoretical approach for the system understanding. Cost analysis of such a system is carried out. A scheme of an information system shell for measuring pollution prevention progress in an industrial facility is developed. Cost analysis is a part of the information tracking system. It is intended to help facility managers to measure and track quantities of waste generated, managed, released, processed, recycled and disposed. Knowing the cost of their operations, facility managers could recognize the opportunity to introduce pollution prevention measures and improve efficiency of their facility.

The information system shell has been programmed based on the idea of generality. It has been designed incorporating the common Windows interface. It consists of three main sections: data entry, data storage and manipulation, and display functions. The display functions are created and enabled based on the input of the user. In addition, the same system can be used to study more than one process; the design of the system is not based on the characteristics of the first data sets entered.

SECTION 1

IDENTIFICATION OF BASIC CONCEPTS OF INFORMATION SYSTEMS

DEFINITION OF THE TERM INFORMATION

The term "information" is defined by two main theories[6] -- semiotic (information theory of symbols and characters which further includes syntactic, semantic and pragmatic theories) and statistic (information theory of signals transmission). Figure 1 shows schematic presentation of the relationship among information theories and the definition of term information.

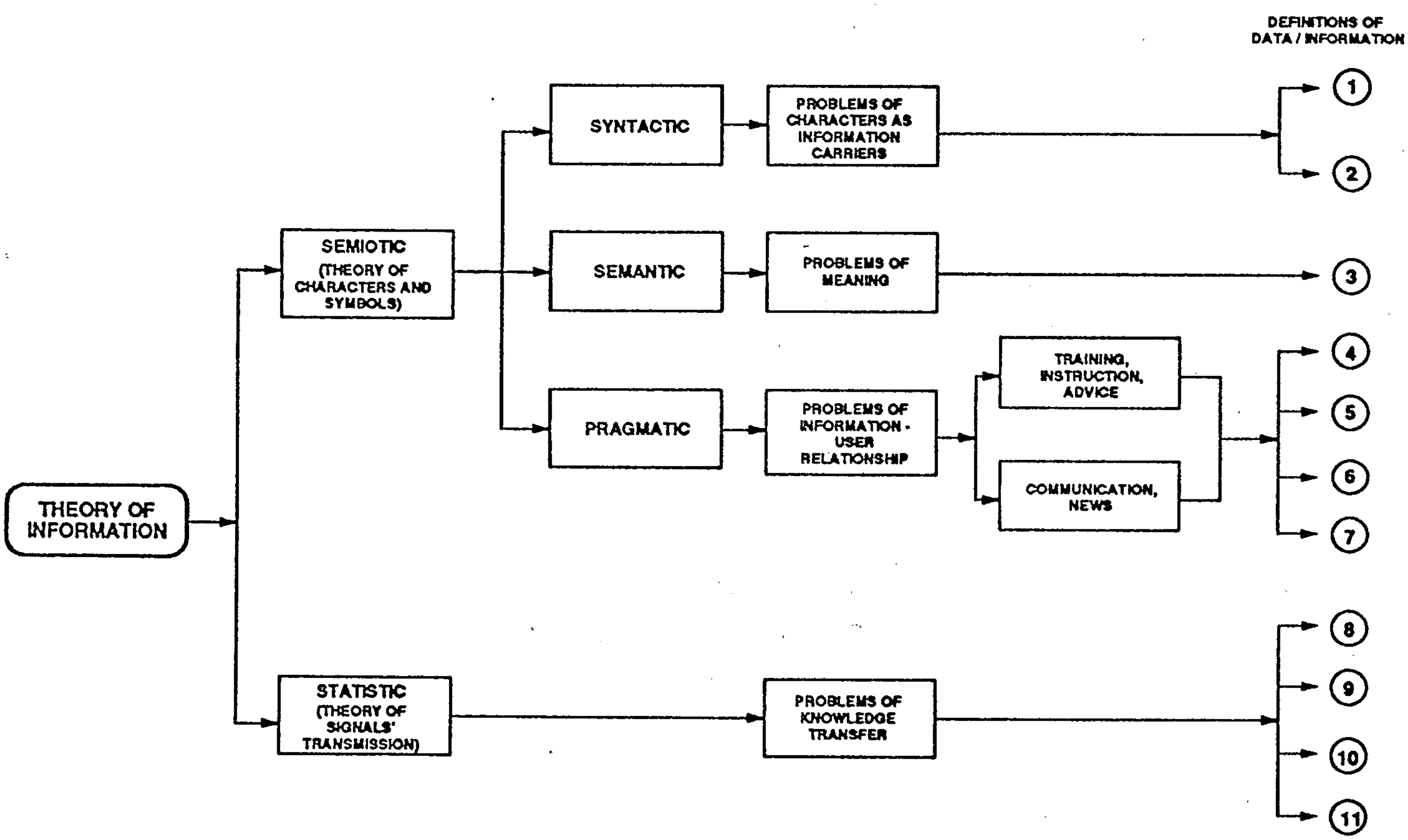

Figure 1. Concepts of information theory and definitions of the term "data/information"

The terms data and information are not always separately defined with different meanings; usually they are used as synonyms. However, in this report, the following definitions are adopted: data are sets of messages which have a certain meaning, while information is a set of data which receivers use for removal or reduction of uncertainty, as well as the basis for undertaking definite actions[6].

Data consist of a collection of symbols or characters arranged in some orderly way to serve as a vehicle for information. Information is the meaning derived from data and represents the semantics - the relationship between a symbol and the actual object or condition that is symbolized. The impact of the objects or conditions on the receiver represents the pragmatic level of information. It deals with the relationship of information and the user. Introducing parameters such as value and usefulness of information, this theory increases the capability for prediction and/or anticipation of future events. According to these theories, data/information is defined as follows:

(1) relationships among characters which respond to certain rules in order to provide meaningful information[7];

(2) collections of symbols or characters arranged in some orderly way to serve as the vehicle for information[8];

(3) data which have been recorded, classified, organized, related or interpreted within the framework so that meaning emerges[9];

(4) the enlargement of knowledge[10]

(5) the extent to which one's knowledge is enhanced upon receiving the information[11];

(6) communication of facts or instructions[11];

(7) the part of a sentence or news, which has news value for the receiver and which enables problem solving[7];

(8) event that reduces the amount of uncertainty of the system[10];

(9) numerical quantity that measures uncertainty in the outcome of an experiment to be performed[12];

(10) the amount, in the simplest cases, to be measured by the logarithm of the number of available choices[12];

(11) the quantity that is transported between two or more objects or systems when the objective is not to transport energy, mass, momentum, or charge (or any other conserved quantity of physics)[13].

Data and Potential Information Storage

In the process of applying information, all relevant information is not used simultaneously. For example, a decision-maker usually does not gather all the information necessary to make a decision. Potential information is gathered which requires that some form of intermediate storage be used. Data covering long periods of time may be necessary to undertake some manipulations and decisions. Therefore, data must be stored until needed[14].

Specification of the Information Application

The specification of application is necessary because information has meaning only when associated with any kind of action to be taken, such as[15]:

- decision making,
- planning,
- monitoring (as performance or quality control indicator),
- problem solving,
- knowledge creation.

These elements also implicitly include the specification of events to be observed, and the time and place of observation[14].

Main Elements of Database Structure

A database, according to Birolla et al.[6] is a selected set of data relevant to a specific field of application, stored in some common computer memory and organized in a such a way that its elements (data) may be accessed by users with simple user-friendly dialogues (Figure 2).

According to the Mcmillan Dictionary of Information Technology[16], the database structure is independent of programs that use the data and a common control approach is employed in adding, deleting or modifying the data.

Data models specify how separate pieces of information are related in a database. Information is broken down into data structures. The most basic of these structures are records and fields. A record can be simply defined as a collection of fields or attributes. At the logical (file) level, records are the basic units of data storage. Fields are the elementary data items. A field can be defined both in terms of its:

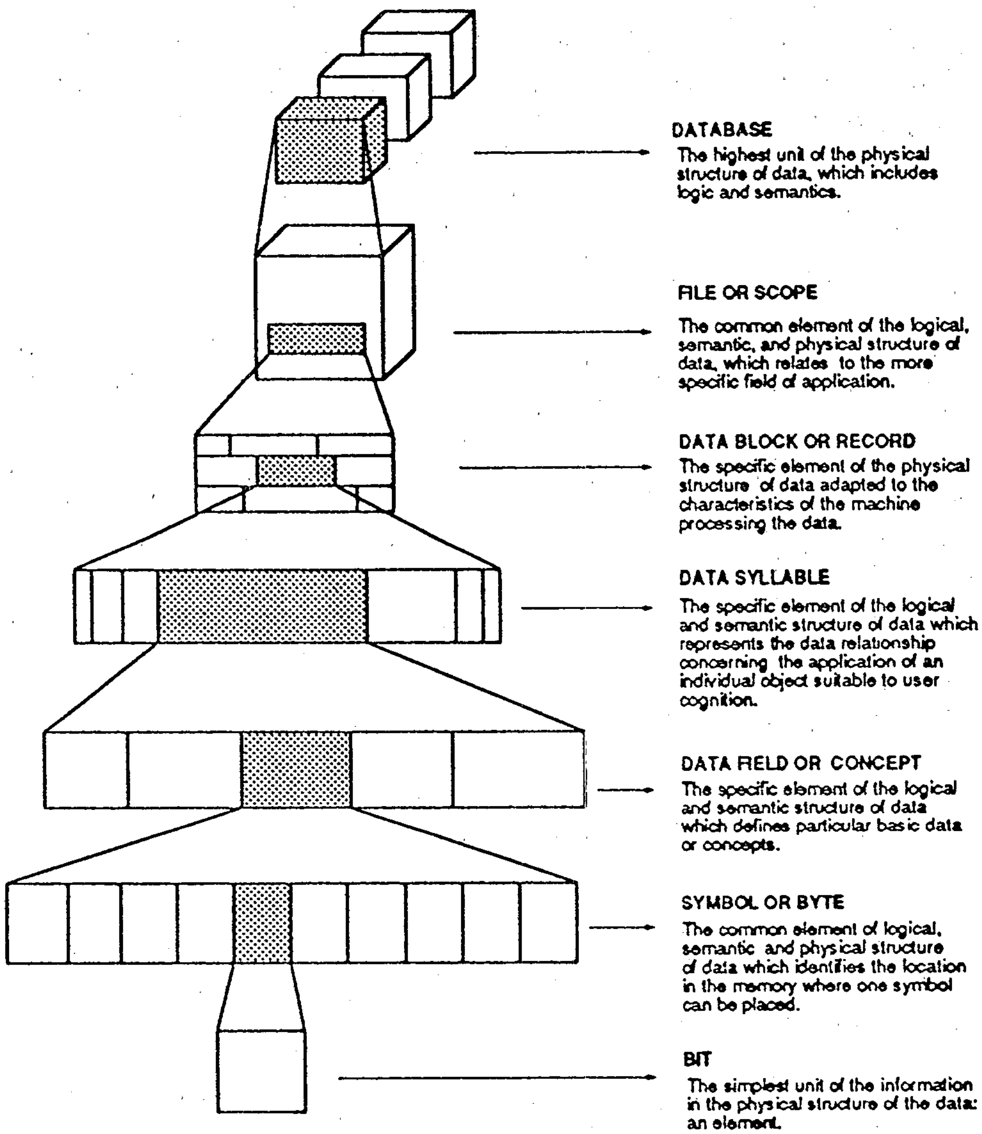

Figure 2. Physical structure of a database
in term of logics and semantics

- syntax -- the information that a field contains which conforms to a certain type, such as real number, an integer, a character or a string;

- semantics -- the meaning of information within a fields which corresponds to the concept represented by the field. Thus, if the field refers to a quantity of some measurement, the number in that field should be a realistic representation of that quantity.

Although complex data models can be defined simply, in the essence of every data model lie structures that are equivalent to records and fields, whether or not they are referred to by those names[11].

The approach in the organization and structuring of formatted databases needs to encompass two contradictory requirements:

- user needs or the way users define and use data,

- machine (computer) requirements or the way data are memorized in order to optimize machine processing.

On the basis of these requirements, two different structures of the same database may be distinguished:

- logical-semantic structure (user aspect) which completely ignores the way in which data are physically stored in the computer memory, giving attention only to the meaning and the logic connection dictated by user need;

- physical structure (machine aspect) which ignores the meaning of the data and takes into consideration only the formal characteristics such as data length, type of symbols or codes, etc.

Data Classification--

In order to reduce the large amount of different types of data to a manageable order, the classification of data, and formation of general ideas about groups of facts (or concepts) is applied.

Data generation[17] requires four steps to be useful beyond the moment of observation. The steps involve:

- classification of data - the basic problem of relating observation to anticipated situations;

- establishment of procedures for recording data in a manner that will allow retrieval, yet be sufficiently simple to enable the operation to be repeated;

- summarization of classified and recorded data;

- specification of the collection procedure of the system.

Classification reduces the complexity of the available materials, provides the basis for identification by grouping similar facts together, provides a record of experience, and relates classes of events[14].

Three major characteristics of any classification system[17] are:

- classes must not overlap - i.e., they must be mutually exclusive;

- the classification system must be exhaustive - requiring that each item be classified and placed in some distinct category;

- the basis for classification must be significant (oriented towards specific goals) and in accordance with some previously determined pattern.

Data Handling--

Since data are past-oriented, manipulation is necessary to adapt them into information relevant to the present and future. Based on the works of Johnson, Kast and Rosenzweig[18], it can be stated that the system connecting the information and its application must be designed to gather relevant facts and screen out unwanted or unusual data. Selected data may become information for decision making. However, it is more likely that additional processing is necessary before meaningful information emerges.

Numerical Data Handling--

Numerical data, as usually understood in physical sciences such as physics and chemistry, are numerical representations of the magnitudes of various quantities[19].

Data in science and technology are usually the result of experiments or observations carried out by researchers. In some instances the primary objective of the research is to obtain the data, but more frequently the data are generated for some other purpose (e.g., as a base for the establishment of legislation and regulations of a specific field of human activity). As a result, some potentially valuable data are not published at all. It is, however, desirable that such data be submitted to, and stored in, appropriate databases to facilitate later utilization[20].

Data handling is taken to include all of the steps of intellectual and physical manipulation involved in:

- recording the results of observation (in the laboratory, pilot-scale level, industrial production or field),

- interpreting and refining those results,

- publishing and disseminating the report, and improving accessibility of that report,

- re-analyzing and evaluating the results where necessary, and compiling them,

- delivering the data to a user for final application in solving some problems, or in decision making, planning, and in creation of new knowledge[19].

<u>Numerical Data Recording and Processing</u>--

The trend today is to obtain data in digital form, thereby facilitating the extensive capabilities of modern computers and telecommunication systems. As computer technology advances, there is a growing tendency toward the automation and computerization of data, including the handling, collection, storage, editing, retrieval, and dissemination of data.

The analysis and interpretation of data is becoming diffused throughout every part of science and technology. It includes the need to:

- assign a correctly assessed error to a single datum derived by measurement,

- determine the best function and parameters to represent a relationship between variables,

- detect and eliminate bias and false effects introduced by the instrumentation or the method of performing an experiment,

- test hypotheses and statistical inference.

An important function of the analysis of data is to provide a good estimate of quantities on which the observed data depend. Powerful statistical methods have been developed to perform this task. Periodically it becomes necessary to evaluate all the new data available and to ensure that any adjustments made to data sets are consistent with the operational characteristics of the system which is subjected to errors of measurement. Statistics is used to represent the interdependence of the measurement and to connect the previous data set with new measurements, in order to derive a new data set of new characteristics.

Evaluation of Numerical Data--

The critical evaluation of data refers to those processes involved in assuring that retrieved data meet certain standards for accuracy and dependability. Kieffer[21] states that a short definition of reliable data would be data which are presented with error bars which were chosen so that the probability of the 'true' value lying outside of these limits of error is extremely small. Branscomb[22] suggests that in carrying out a critical evaluation, a meaningful quantitative statement can be made about the probable presence of systematic errors in the data. This statement must be based on a set of objective criteria for assessing the likely presence and effect of systematic errors.

The processes of data evaluation procedures can be summarized[23] as: (1) examination and appraisal of the data, and assessment of experimental techniques with associated errors, (2) re-analysis and recalculation of derived results, and (3) selection of 'best' values.

The proper assessment of experimental techniques is a fundamental factor in the evaluation process, involving: (1) a study of the experimental design, (2) the way in which instruments have been used, and (3) the problem of systematic errors.

The end result of any evaluation process should be the presentation of 'best' or recommended values together with quantitative estimates of the uncertainties in these values. The 'best' values derived by the critical evaluation process are only the best values at the time reviewed. Any selection of recommended values is subject to change in the light of improved measurement or evaluation[24].

DEFINITIONS OF INFORMATION SYSTEMS

There are many definitions of the term information system. The following refer to the definitions of a computer-supported information system:

- a set of hardware, software, and informational facilities that permit the accumulation, classification, storage and retrieval of a large amount of information. An information system not only stores data, but also provides facilities for assigning meaning to it, and hence, provides information. The information system consists of three major components:

  - a large repository for data called a database,
  - a means of accessing the data,
  - a means of processing the data for analysis and reports[25];

- any means for communicating knowledge from one person to another, such as by simple verbal communication, or by completely computerized methods of storing, searching, and retrieving information[9];

- systems concerned with collection, storage, processing, transmission, distribution, retrieval and utilization of information[26];

- a system whose goal is to provide information and information services for its environment. This definition implies that an information system must encompass at least two subsystems, one consisting of the system's collection of information, the other providing the information services[27];

- an application of the computer that provides for the routine processing of data. It is made of databases, application programs and manuals, and machine procedures. The databases store files (subject of the system). The application programs provide the data entry, updating, query and report processing of the system. The manual procedures document how to obtain the necessary data for input into the system and how to distribute the system's reports and forms. The machine procedures instruct the computer how to perform the system's processing activities in which the output of one program is fed as input to the next program[28];

- a system designed to solve a variety of data, information, and knowledge-based problems. Information systems provide analytical support to users. They help allocate and evaluate resources, plan and simulate large events and processes. This extremely important distinction defines the range of application of modern information systems. Recently their applications have been expanded from data-oriented to analytical computing (search, identification, classification, categorization, planning, evaluation, prioritization and decision-making)[29].

According to Nichols[14], the general function of information systems is to determine user needs, to select pertinent data from the infinite variety available in an organization's environment (internal and external), to create information by applying the appropriate tools to the data selected, and to communicate the generated information to the user.

A special type of information system is the geographic information system (GIS) which can be defined as an electronic data storage system or database connected to graphic tools for mapping and illustrating data that they contain[30]. According to Bruckman et al.[31] a GIS is a specialized data management system designed for the entry, analysis, management, and display of data commonly found on maps. The GIS is an effective tool for determining the relationships among demographic, natural resource, land use, and air and water quality objectives. For example, a GIS can overlay spatial data of various types and compute populations affected by air quality, or it can map emission estimates and land cover for a visual relationship, analyze them spatially, and report the resulting statistical relationships. A GIS can provide maps and tabular summaries of results (e.g. areas of implementation, results, ratio of cost to effectiveness) or maps of progress to date compared to environmental goals.

Information Paradigm

A possible way to look at information systems is through the so-called information paradigm[27]. In the information paradigm real systems are distinguish as parts or aspects of reality to be investigated as a whole, in order to know or eventually control them; information systems describe the real systems in the past, present or future for the purpose of knowing and controlling. Information system functions then include collection, storage, processing, retrieval, transmission and distribution of data by people and machines. An important aspect of the information paradigm is the so-called recusion principle, which specifies that the information paradigm also holds for the sub-systems, i.e., for all real systems and information systems within the system considered, and that it does so at all levels. This view has important consequences for modelling information systems, and designing models of information systems or real systems. The information system in this view must always be considered in combination with the real system of which it is a representation, and special attention is to be paid to the dynamic behavior of this combination.

The system under manipulation becomes more and more complex. Therefore, the behavior of information systems, and their interaction with the real systems, becomes harder and harder to predict. Nevertheless, that is exactly the intention: the task is to achieve certain goals in a real system (e.g., just-in-time delivery in a transportation chain, or 100% of the airplane-seats sold without having to reject any customers), to try to develop information systems, modify the real systems, to define the interfaces between these two, and to achieve these goals. In order to understand the objectives, and subgoals derived from them, and comprehend the dynamic behavior of both the current and alternative systems, the discipline of information systems is to offer new approaches and new techniques.

Systems Theory

Systems theory as an approach to studying organizations and their behavior has its roots in physics and biology[27]. Its application to the study and development of computer-based systems gained particular importance and attention with the development of cybernetics, defined as a science of communication and control concerned especially with comparative study of automatic control systems. Many papers have been published describing systems and their fundamental properties, characteristics, environments, components, relationships, and regulatory capabilities.

According to Nordbotten[27], the most basic concept is that of a system, which can be initially defined as "a group of units so combined as to form a whole and to operate in unison". A system is composed of a group of units. These units can be considered as subsystems. The system is also a component of some supersystem. In addition to the system under consideration, the supersystem is composed of one of more units (subsystems) that form the environment for the system.

When analyzing a particular system, it is necessary to fix attention on that system and then to identify[27]:

1. its supersystem, i.e., that system of which it is a component unit,
2. the environment with which the system interacts, and

3. its component subsystems.

Subsystems 'so combine as to form a whole'. There must be a system structure that relates the component subsystems into an organized whole: the system. The system structure is defined by the relationships that exist among the subsystems. The relationships among the system components define order, sequence, interdependency, and time relationships. The relationships define the sequence of actions and activities within the system. An important task of a systems analysis is to identify and evaluate the performance of these actions.

The primary goal for the system defines its reason for existence, that end toward which the system strives. Further, when the subsystems are goal-fulfilling at their subgoal level, the system's goals can be greater than the sum of the subgoals. This axiom is central to the interest in determining the primary goal(s) for the system before considering the subsystems goals. Consequently, the system can be defined as a structured, interrelated set of components (subsystems) whose combined goals act to achieve the primary goal.

Systems are of two types: closed and open. A closed system is one that is entirely self-sufficient, with no necessary interaction with its environment. However, information systems exist to provide information services for their environment and thus can not be considered closed system. On the contrary, an open system is one that is dependent on its interaction and relationships, with its environment. The primary goals of the system are defined in relation to this interaction. These environmental interactions or relationships fall into three classes (Figure 3):

1) input, consisting of stimuli, which can be taken from resources, directives, queries and/or information directed toward the system, and which can be used in some fashion by the system;

2) output, consisting of the system's reactions to the input stimuli, which may take the form of results, products, and/or system state information available to the environment. Outputs are released to the environment, possibly initiating some feedback.

3) feedback, consisting of messages and reactions to the outputs from the system. The feedback commonly generates new or modified input to the system, and as such is a special type of input relation.

In analyzing an open system, defining the primary system goal(s), the system may be considered as a 'black box' or undefined entity, and the attention can be concentrated on the environment's interactions with the system.

The topic of this text is concentrated on the following:

1) open systems,
2) goal-directed systems,
3) the interaction of systems with their environment, and
4) a structured set of interrelated subsystems which systems are composed of.

The lowest-level subsystems are considered to be the atomic elements if the system. The atomic elements of a system are either elementary processes or system objects. Elementary processes perform some action on the system objects and can be combined to form the action(s) or task of the subsystem.

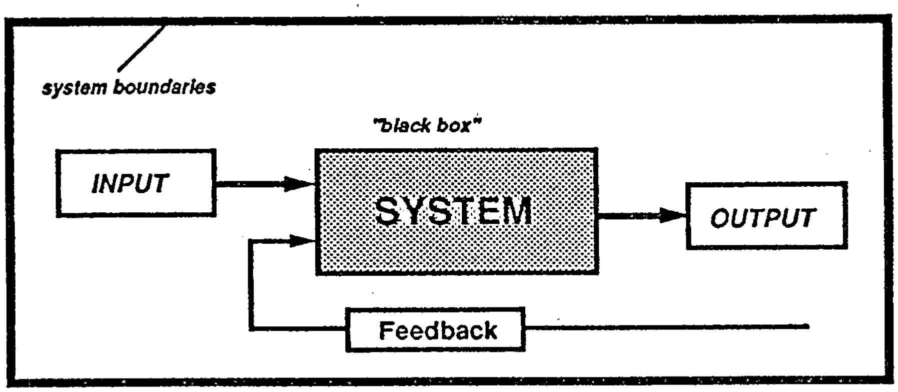

Figure 3. Open system concept

The three basic system components important for understanding of information system concepts are:

1) processes, or actions performed on objects as required by the system goals,

2) objects, or things of interest to the system (synonym for the system object is entity), and

3) relationships, which exist between objects and processes.

System processes are the actions of the system. Systems objects or entities are of interest to the system, as defined by the system goals. They are described by characteristics or attributes. There are two types of attributes:

1) descriptive attributes, whose values give descriptive or identifying properties of an individual object, and

2) associative attributes, whose values identify a relationship between two separate objects.

System objects can be grouped into classes, where a class is defined as a group of individuals having some common attribute(s) of interest to the system.

The third basic system component is the relationship set. Relationships exist between system processes, between system objects, and between processes and objects. Nordbotten[27] recognizes that there are two kinds of relationship relevant to information system concept:

1) structural relationships, which define the organization or structure of the system processes and objects, giving groupings and sequences, and establishing the place, within the whole system, of each of the subsystems, and

2) communicative relationships, which define the interactions between the system and its environment and among the system's subsystems.

The structural relationships commonly coincide with the movement of objects, such as material resource flow through the system and in this way, representing the system's external relationships. Communicative relationships exist between the system and its environment and between the system's subsystems. They define the system's paths for exchange of information in terms of the inputs to each unit and the expected or required outputs. It is among the communicative relationships that the system goals can be found. Further, the set of communicative relationships defines the information transfer of the system. This information flow can be changed over time in response to the changes in the external system goals. Consequently, the major task of system analysis is to identify these relationships and evaluate them with respect to the current or anticipated goal set.

Information System Design as Problem Solving

Designing and building of information systems can be regarded as a process of solving an ill-structured problem. In most cases the information system is developed to learn about or control the real system. According to Nordbotten[27], to solve a problem of information system design, the process of creating an information system is divided into the subprocesses of problem perception, conceptualization, specification, development of proposed solutions, solution choice and implementation.

Developing information systems and problem solving are closely related activities. In problem solving and, therefore, in information systems design, conceptualization plays an important role. When a problem solving case is looked at, the structure of the decision making process can be used as a framework. This process consists of the following steps: (1) intelligence, and the analysis of possible courses of action, (2) choice, (3) selection of an alternative course of action from those available, and (4) implementation, efficiency and effectiveness of the choice.

An information systems designer tries to solve problems in the real system that is being controlled. A problem can be thought of as a state in which the problem owner is in doubt how to identify one or more desired outcomes. A problem is defined as a situation meeting the following conditions:

(i) there is a decision maker;

(ii) the decision maker has a desired result (a goal);

(iii) there are two or more alternatives to achieve that goal. The alternatives have differing efficiencies;

(iv) the decision maker is in doubt as to choose from the alternatives; and

(v) the environment that cannot be controlled by the decision maker has an influence on the result of the decision.

Problems may be considered as well-structured or ill-structured. A problem is defined as well-structured when it meets the following requirements, and as ill-structured if it fails to meet one of the requirements:

1. the set of action alternatives is finite and identifiable;

2. the solution is consistently derived from a model that shows a good correspondence; and

3. the effectiveness or the efficiency of the action alternatives can be numerically evaluated.

In problem solving two more types of models, known as models as-is and models to-be can be identified. Analysis of the existing situation results in a model as-is. The construction of the model as-is is achieved by going through the sub-cycle problem as perceived - (conceptual model-empirical model), as often as needed to reach a degree of correspondence that will suffice. The construction of models to-be is achieved by going through the sub-cycle conceptual model-empirical model solution as often as needed to reach a satisfactory degree of validity.

Available Information System Building Tools

In order to structure the ideas about what an information system should do, diagraming techniques were introduced[27]. Data-flow diagrams, entity-relationship diagrams, activity graphs, and precedence diagrams are some of the multitude of techniques that were advocated. Essential in most of these diagramming techniques is the idea of decomposition: the aim is to cut up an information system into manageable and understandable pieces. These pieces, or components, may be of a very high level of abstraction.

One major problem of these diagramming techniques is the need of different techniques in order to get a somewhat complete view on a particular system. An additional problem is that the different techniques harmonize badly, which makes consistency-checks extremely difficult. A weakness is that they mostly give only a static representation of the information system under consideration.

In the growing interest in information systems design, a great number of automated tools have appeared on the market to support the design process, although the first attempts in this field originate from the 1950s. New tools usually support a particular design methodology. A tool that is able to create and maintain a dynamic representation of systems is simulation. A number of available simulation computer languages have a powerful animation (picture) function. In that way they are capable of giving insight in the dynamic aspect of the empirical model that is being studied.

Information System Objectives and Design

Holloway[32] stated that the objectives of an information system can be summarized as follows:

- clear communication with the user concerning the objectives and role of the information system in the field of application, and commitment to apply the appropriate resource once priorities have been set;

- a clear sense of direction based on the above objectives and information system role;

- information system functions organized so as to support growing needs such as user computing, data resource control and application architecture; and

- appropriate levels of skills and resources, as well as adequate planning, to meet demands.

Figure 4 shows a methodological approach to information system design[32]:

- first level (Level 1) assists in "application/construction" and database implementation. If a methodology has only these two components, it can be said that it facilitates the efficient translation of an application design into the software program having capabilities to integrate application design and database design. This suggests another level is needed to aid design;

- second level (Level 2) suggests that there is an application design and database design, and it can be said that it facilitates the efficient translation of user requirements into a high-capability software program connected with powerful database management system. This suggests that before a design is started, it is necessary to understand user requirements;

- third level (Level 3) helps identify and clarify user requirements; and

- fourth level (Level 4) determines user requirements which consist of information systems analysis and conceptual data modelling. Information system analysis considers the processes and the data used by the processes, by prototyping the requirements with the user.

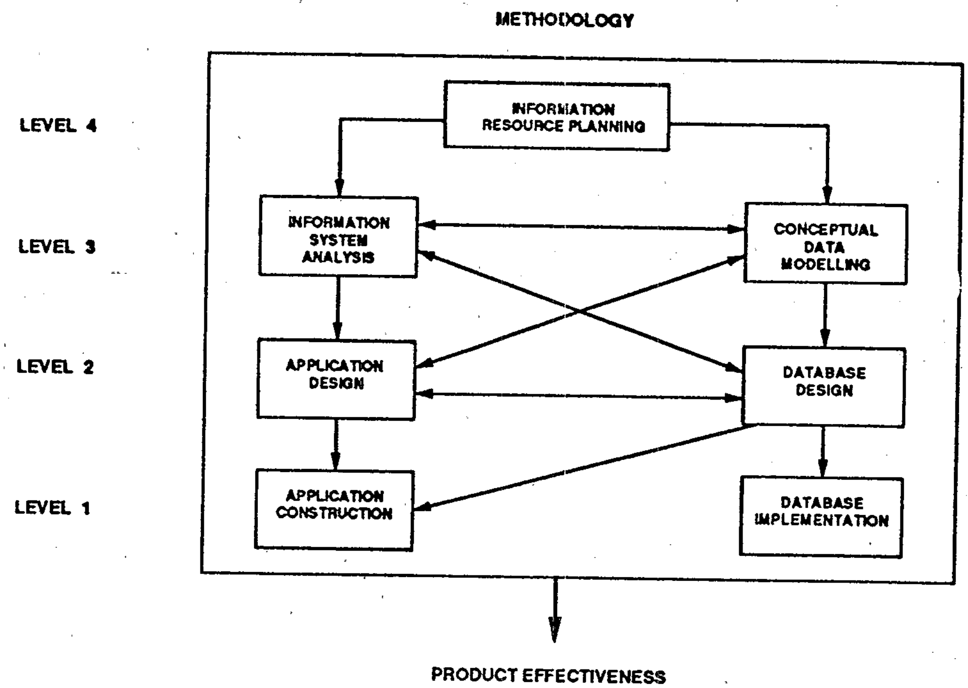

Figure 4. A methodological approach to information system design

When a methodology has all four levels, it can be said that it fosters product effectiveness in supporting interrelated applications which share common data. In modeling a system, its dynamic composition needs to be described by the way it accomplishes work, not just its static structure. The dynamic composition of a system can be described in terms of activities, processes and events. This applies to virtually all systems, especially information systems, whose accomplishment of work depends on the interaction of computer, software and human activities. These interactions are analyzed, designed, implemented and maintained. The following analysis and design approaches can provide advantages to the system during information system development[33]:

1. more realistic representation of real world behavior leading to improved information system analysis and design;

2. inclusion of important system evaluation measures such as cost, productivity and reliability as components of the modeling tool;

3. more rapid development of information system projects by identification of feasible alternatives through simulation;

4. improved maintenance of current operating information systems through

simulation of proposed changes; and

5. personnel and hardware/software productivity improvements achieved by extensive sensitivity analysis of important variables.

The construction of a dynamic model of a real-world information system includes the specification of the operational parameters and behavioral relations of the information system, the assignment of probability or other distributions to necessary input variables, and the simulation of the alternative system design.

The performance-related variables might include the following:

- Costs
  - Development
  - Implementation
  - Operations
    - Personnel
    - Hardware
    - Software
    - Supplies, etc.

- Physical Productivity
  - Total capacity
  - Per unit processing time
  - Personnel utilization time
  - Hardware utilization time
  - Database activity rate

- Reliability
  - Error rates of hardware, software and personnel
  - System downtime rate

Organizations confronted with building an information system usually have a staggering amount of information for planning, implementation and development of this technology.

According to Flagg[34], in general, the form of an information system follows an understanding of the organization's functional objectives. The following seven steps are recognized as important to the success of any complex information system building. According to the author, the steps follow a logical progression, but the distinction becomes less clear as the information system building process matures.

1) Orientation of Decision-Makers and Staff. This step involves a formal orientation and introduction to an information system, and includes:

- discussion of various information system uses and functions;
- implications to an agency's organizational structure;
- operation, staffing, cost and personnel requirements;
- performance expectations and general implementation time frames;
- questions raised by the technology (legal, political, economic, scientific);
- relational and object-oriented data model information; and
- a hardware/software demonstration.

2) Organizational Assessment. This step involves identifying existing operations, funding mechanisms, functions and missions, and includes:

- determining the types of graphic-based applications conducted and documenting how the graphic information is used;
- identifying existing graphics data support personnel;
- understanding what, how and how well information flows between sections, departments and other agencies;
- determining data formats, scales and media;
- identifying how an information system could assist specific projects and programs;
- identifying various automation solutions (both software and hardware) that may be appropriate;
- identifying and considering various organizational scenarios for information system placement, including possible system designs, service levels and staffing; and
- analyzing information system costs and benefits.

3) Functional Objectives and Implementation Plan. This step involves creating and documenting specific information system objectives and functions, and includes:

- establishing automation priorities and time frames related to programs and projects;
- developing a plan to establish and further information system processes both internally and externally;
- designing the general process for information system decision-making and production;
- establishing a training plan;
- formalizing data development and maintenance agreements with outside organizations; and

- providing answers to questions such as how the agency will handle data requests, how the agency will work with other agencies, whether the agency will seek to collect revenue, how legal issues will be resolved, who will have access to the data and how data integrity will be maintained;

4) System Design. This step involves designing the system specifications that will support an organization's program and project goals, and includes:

- designing hardware and software environments and schematics;
- describing required interfaces;
- developing benchmarks for hardware and software purchases;
- establishing a plan and chronology for procuring necessary hardware and software;
- describing the user interface;
- designing information access levels and security; and
- describing the databases.

5) Project Requirements. This step involves selecting a pilot project and evaluating the data and funding required to complete it, and includes:

- identifying project goals and the primary project impetus, e.g., scientific, political, etc.;
- determining data quality objectives, constraints and critical decision pathways;
- identifying the information and base themes needed to complete the project;
- assessing existing data formats;
- determining who will be responsible for the information;
- assessing whether the information exists or developing additional information;
- procuring necessary funding;
- identifying a project team;
- defining the roles and duties of each team member;
- determining if extra training or outside help is needed;
- deciding if additional hardware or software is needed;
- establishing quality assurance/quality control procedures; and
- setting checkpoints and target dates for completion.

6) Detailed Database Design. This step involves the design, development and output of the application information, and includes:

- evaluating program/project needs;
- reviewing available software;
- designing data layers;
- designing and defining coding schemes, global variables and conventions for object names;
- creating data tables and related tables, as well as data and project directory structures and documentation for all project-related work;
- defining data characteristics and relationships;
- designing processes for data input and conversion, updates, maintenance and archival; and
- adding to data documentation.

7) Application and Development. This step involves the design, development and output of the application information, and includes:

- assessing specific user needs;
- designing and testing macro programs and user-interface menus to most efficiently meet project goals;
- developing a user-friendly interface;
- establishing hierarchical structure charts;
- creating logical data query and analysis screens;
- reconciliating spatial and data inconsistencies for all data layers;
- eliminating redundancy;
- fixing problems;
- reviewing problem solutions;
- re-evaluating project goals and accepting feedback form project manager(s);
- automating and outputting all data sets, including digitizing, entering and importing files;
- creating and outputting graphic files;
- developing a prototype;
- creating test plots and a trial run of the acceptance test;
- checking, adjusting and cleaning outputs using quality assurance/quality control procedures;
- running the acceptance test;
- documenting and reviewing all procedures;
- maintaining all data;
- procuring additional funding; and
- obtaining, finally, bliss.

According to Essnik[35], an information system is a system that is created to support a larger system of which it is a component. That larger system is to be studied, as seen from a set of specific perspectives, in order to delineate and structure a variety of informatory and decision making support to a number of user groups. The development of information system is, in essence, the transformation of a model of a part of reality into a model of the target information system. For this reason the abstract model is the representation ('what is relevant to be depicted within the information system') and embedding specification ('who will use the system for what') of the target information system. Most of the methods do not make it clear how they perceive these relationships, although such a treatment is essential to understand the way of modeling and the perspectives that are encompassed (or rather that are disclosed).

As an effect, three basic 'axioms' are to be incorporated in the information system development strategy:

1. the information system is part of the observed system ('the component paradigm'), an abstract model of the reality ('the model paradigm'), and support system for the observed system ('the controlled system paradigm');

2. the information system can be seen as a simulation instrument of the observed system in order to contribute to the steering of the behavior within the observed system. Because the observed system itself is a dynamic system, the information system model should reflect the dynamic properties of the observed system;

3. the problem of information system development is to be seen as the evolving generation of a specific and partial real-world model, and the transformation of that model into an information system model. The generation of the evolving model of information system is a cyclic process in which the information system is seen at different levels of abstraction.

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SECTION 2

EXAMPLES OF INFORMATION SYSTEM APPLICATIONS

INTRODUCTION

The application of elements of information science (databases, simulation, expert systems and information systems) as a tool for planning, decision-making, monitoring and problem solving has steadily grown as more capable and user-friendly computer software programs become available on the market.

Below are summaries of available published literature explaining the application of information systems for solving of environmental and industrial production problems. As can be seen, the majority of information systems use geographical mapping system as an integral part, so that geographical information systems (GIS) are predominant in this review.

In order to discuss the application of information systems, environmental protection and industrial process areas are divided in the following categories:

- water management,
- wastewater management,
- waste management,
- environmental impact assessment,
- environmental management, and
- industrial process control and total quality management.

WATER MANAGEMENT

Strategies for Managing Water Quality

Nonpoint source load data generated for a recent project funded by the Galveston Bay National Estuary Program (GBNEP) was used to develop strategies for managing Galveston Bay's water quality[1].

The project involved defining the drainage areas contributing runoff to the bay and developing a current land use map for those areas. A GIS hydrological model was developed to calculate runoff from the drainage areas, and a water quality model was designed to calculate the total load of a given water quality constituent entering the bay. Nonpoint sources include a wide array of diffused pollutant types and sources from land drainage, human activity and major storm water outfalls. Pollutants include sediments, nutrients (total phosphorous and total nitrogen), BOD, oil and grease, heavy metals, synthetic organics and fecal coliforms.

ARC/INFO, a GIS software developed by Environmental Systems Research Institute, Inc., served as the fundamental tool for the entire Galveston Bay nonpoint source assessment. The GIS allowed researchers to store, manipulate and process several hundred megabytes of electronic data required for the nonpoint source calculation. Hydrologic and nonpoint source load models were incorporated into the system so flow and water quality calculations could be attributed to different geographic regions.

Three main GIS mapping types were developed:

1) GIS watershed/subwatershed mapping; 2) GIS soils mapping; and 3) GIS land use mapping.

The first dealt with mapping of two drainage delineations: watershed and subwatershed. For this study the area was divided into watershed boundaries which were digitized into a GIS database from maps. The second mapping concerned soil types within the project area and these were mapped using the county soil surveys published by the Soil Conservation Service (SCS). The third mapping is the product of a land use database which was developed from interpreted Landsat satellite imagery.

For GIS nonpoint source modeling purposes, each pixel in the land use database was associated with a subwatershed and a soil map. A soil type/watershed composite polygon map was obtained by overlaying the soils maps and the subwatershed map layers in the GIS. The soil type/subwatershed composited polygons were transformed to pixels through an ARC/INFO transformation process. A software utility was developed to overlay the soil type/subwatershed pixels and the land use pixels, and to output data aggregated by the land use category, subwatershed and soil type attributes of each pixel in the study area.

A GIS runoff and water quality modeling was tested based on raingage data. A GIS model for calculating runoff from the study area was developed using the

Soil Conservation Service's method. The runoff calculation model was used to calculate the runoff from the whole basin. For each land use class, typical concentrations - Event Mean Concentrations (EMCs) - of each constituent were estimated from available nonpoint source data. A nonpoint source load calculation model also was developed. The load model requires calculated runoff volumes and EMC values for each pollution parameter based on land use.

The project's GIS mapping are expected to be the foundation for future bay projects that require intensive mapping effort.

Management of Water Resources in the Changing Economic System in Russia

Belyaeva et al.[2] describes the cooperation between the Water Problem Institute of the Russian Academy of Science and the Tennessee Valley Authority to develop a joint project demonstrating the use of GIS in managing water resources under the changing economic system in Russia. The purpose of the project is to improve decisions by better organizing, analyzing and presenting water resource data and management options. Results to date include development of a conceptual approach and review of existing data. The project area includes the Upper Volga River Basin which encompasses the Moscow metropolitan area. Data are being managed at three levels. Initial conclusions indicate a great potential for this technology application, but many social and economic obstacles due to the current political situation are also apparent.

Groundwater Management

Hall and Zidar[3] explain the cost-effective microcomputer technology for groundwater data management, data analysis and the delineation of wellhead protection zone. The data was designed to be transported to a UNIX platform and integrated in the GIS.

Wellhead Protection Areas and Management of Environmental Resources

According to Rifai et al.[4], the article exemplifies one of many potential links between ground-water models and GIS. An example demonstrates through a GIS user interface for delineating wellhead protection areas (WHPAs) the tremendous opportunities presented by GIS for management of environmental resources.

The project developed a GIS database and modeling interface to implement ground-water protection strategies by state and local government and regulatory agencies. The specific objectives were to:

- collect and incorporate the data relevant to developing a wellhead protection program from the various federal, state and local agencies into the GIS database;

- develop an automated linkage between the GIS database and a ground-water model to delineate WHPAs around public water-supply wells for the City of Houston;

- evaluate the various WHPA model parameters to address the effects of parameter input on the size and shape of delineated WHPAs;

- show how GIS helps delineate WHPAs; and

- develop a prototype ground-water management system (using the interactive GIS/modeling capabilities). This management system allows areal enlargement, incorporation of more data, or use in other areas which are developing a similar ground-water protection program.

A geographic information system promotes efficient and effective management of ground-water resources. The GIS database combines data from numerous sources into one system and spatially relates the data to enhance the decision-making process of wellhead protection programs.

The main advantages of this type of system are:

(1) the data are contained in one database and accessed from one system and are therefore easily transferable;

(2) the system can be used by several governmental or regulatory agencies, promoting data sharing and interaction between the different agencies;

(3) any change in the public water-supply wells or the sources of contamination and land-use patterns can be assessed quickly; and

(4) decision-makers are able to spatially conceptualize and easily relate all the available data. All these factors allow for more informed decisions regarding ground-water protection and management strategies.

Irrigation and Drainage Systems Rehabilitation

Allen[5] presented the application of GIS for solving of water irrigation and drainage problems. Topics include the planning and rehabilitation of irrigation and drainage systems, managing conflicts between irrigation and drainage systems and urban development, urban-agricultural transfers and exchanges, and economic and regulatory influences on conservation. Other uses include: managing conflicts between wetland resources and irrigation projects, developments in surface irrigation, groundwater management, hydrology and management of intermountain groundwater basins, aquifers, evaporation ponds, watershed hydrology, and the potential effects of climate change on water resources.

Water Quality Implications of Nonpoint Source Pollution

Heidtke and Auer[6] explain the magnitude and water quality implications of non-point source phosphorus loadings to Owasco Lake in New York, and they use data supplied by GIS to establish the specific land use, soil texture and surface slope attributes within each of the hydrologic sub-basins comprising the overall watershed. Data are evaluated through the application of a methodology which links geographic characteristics, long-term average runoff loads and a set of critical lakewide water quality response parameters. The GIS-generated attribute matrices provide a much more accurate depiction of critical geographic characteristics known to impact nonpoint source runoff loadings, thereby improving the reliability of current and projected phosphorus loads to Owasco Lake.

WASTEWATER MANAGEMENT

Storm Sewer System Management

The City and County of Denver's Wastewater Management Division (WMD) realized that an adequate funding base was needed to maintain its deteriorating storm sewer system[7]. A revenue system existed for the sanitary sewer system but not for the storm sewer system. City Council approved a revenue system that required property owners to pay an equitable share for maintaining the storm sewer system. A method was needed that reasonably predicted the amount of water runoff from any given property. A billing system was devised that determined a charge by taking the percentage (or ratio) of impervious area to the total parcel area. Initially, a group of field inspectors measured impervious areas on properties using a hand-held wheel. However, it was estimated that it would take approximately 80 years to measure the entire city. In 1986 WMD solicited information from technical contractors on the development of a computerized information system that uses aerial photography.

A system was designed and developed that requires individuals to collect data on a workstation that provide on-screen digitizing capabilities. The workstation uses specialized hardware and software that combines the technologies of photogrammetry, image processing and GIS. The system initially used the Kork Geographic Information System (KGIS) and an ORACLE relational database management system. Later the system was converted to ARC/INFO, a GIS software developed by Environmental Systems Research Institute, Inc., Redlands, CA, and the workstation was upgraded to Microvax 3800.

The collection system operates by converting a portion of a black-and-white aerial photography to an image that appears on a high-resolution color monitor as a 256-level gray-tone image. The GIS calculates the area of the features instantaneously, providing a basis for determining the ratio of a particular land parcel bill. The calculations are converted into a transportable ASCII file and moved across the ETHERNET network for billing.

WMD is correcting the GIS databases for future billing. The process includes registering photographs, modifying line and annotation information, and verifying data in the billing database.

Wastewater Treatment Process Control

Arnold[8] presents process control with consideration of environmental aspects or so-called "phase model of production". It is introduced as a semantic tool for a structured visualization of complex processes and exemplified in wastewater treatment. Based on the elaborated information model, various engineering applications that determine the plant's instrumentation or requirements of field communication are illustrated. Prospects for process control in relation to the environment are presented.

Sewer Flows Forecast

Shamsi and Scheinder[9] discuss the applicability of GIS to help forecast sewer flows and determine whether a watershed has the ability to meet the county needs (Allegheny County, PA, USA). The watershed is expected to undergo significant development in the future. The main issue appears to be the concern about the watershed hydraulic capacity to convey future flows.

An analysis of the terrain, hydrography, soil associations, land use, census properties, and locations for major trunk and interceptor sewers was conducted to develop the watershed GIS. The software programs used in the project were primarily ARC/INFO, and ERDAS, an image processing and raster-based GIS from ERDAS, Inc., Atlanta, GA, USA. Additional programs were written whenever needed for data format changes or for creation of a product for which the methodology was not available in either of the commercial packages.

The final GIS analyses were performed on raster information layers. The color, raster maps were produced: (1) existing service areas, (2) present land use, (3) census tracts and (4) soil associations.

The present land use map shows that despite the existing developments, a substantial watershed area is still undeveloped. Future subareas outlined are based on the assumption that each parcel of land ultimately will be developed. The U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) simulates dry weather (sanitary) flow and wet weather (storm water) flow on the basis of land use, demographic conditions, the hydraulic conditions in the watershed, meteorological inputs and conveyance/treatment characterizations. Based on these, SWMM can be used to predict combined sewage flow quantity and quality values. SWMM is well suited to this study and is the model of choice for most combined sewer overflow feasibility studies. The capacity analysis was performed by comparing the maximum simulated flows in various sewer segments on the interceptor to their full flow capacities, defined as the maximum flows that can be conveyed by sewers without surcharging, estimated from sewer size, slope and roughness.

WASTE MANAGEMENT

Waste Recycling, Source Reduction and Disposal

Portland's Metro is a regional government agency that serves three Oregon counties. The agency is charged with responding to a population of 1.4 million on a variety of regional and environmental issues. In recent years, the public's interest and participation in recycling has grown to challenge Metro's staff[10]. One area directly impacted is the agency's Recycling

Information Program. A GIS-based call response system is one way the district is managing its response.

Metro's Recycling Information Program is a regional clearing house for recycling, waste reduction and disposal information. The program offers a telephone hotline, which receives more than 80,000 calls annually, and provides information to businesses, governmental agencies, schools and the public. The typical information requested is the name, location and hours of a recycling or solid waste disposal facility that handles a specific material; directions to a facility; or instructions for preparing recyclable materials.

Thus, the information has to be retrieved quickly to respond to caller questions. Often this involves locating the appropriate facility nearest the caller from among the area's more than 280 recycling facilities. This is done by the help of fully integrated computer system.

In order to improve the efficiency of its operations, Metro has incorporated a call response system. The system developed is based on ARC/INFO GIS software and is compatible with the Regional Land Information System (RLIS) used by Metro's Transportation Department.

Basically, the system links Topologically Integrated Geographic Encoding and Referencing (TIGER) files and the base maps of Metro's RLIS with a series of databases containing recycling information. The various databases store information about individual recyclers and haulers, curbside recycling, business recycling, yard debris recycling and processing, household hazardous waste disposal, and general recycling data.

The system supplies information for referrals to other government agencies and community resources, records complaints and referrals, and provides maps of ZIP code areas and main streets. The system allows Metro staff to compile a variety of reports: monthly reports can be generated by ZIP code, by county, and by type of request to help review and monitor the program's activities.

<u>Waste Management - Cleanup Activities</u>

Salzmann[11] reported on GIS applications in the environmental field particularly in waste management. According to the author there has never been such a wide-scale effort in subsurface investigations, from a corner gas station underground storage tank (UST) removal (tank yank), to Superfund cleanup efforts across the country. The environmental industry also is changing its purpose, shifting away from Remediation Investigation (RI) and moving into actual clean-up operations.

The role of GIS technology is proportional to the scale of the clean-up efforts. For example, a UST job by itself does not call for a GIS application. However, a GIS is essential if many of these operations occur within a municipality and the local government needs to monitor cleanup activities. Increasingly, the technology is employed to detail where a responsible party's contamination is located, and how much contamination can be defined legally on that property.

Geological software alone could be directly applied to the hazardous waste business. A true GIS solution would manage the automated mapping/facilities management (AM/FM) infrastructure needs of the site's residents; store, display and model the contaminant; and forecast the contaminant's transportation.

Site Characterization and Remediation Activities

Ganter and Cole[12] discuss the establishment of a Facility for Information Management Analysis and Display (FIMAD) to support site characterization and remediation activities of the Department of Energy's Environmental Restoration Programs (ER). An important first step for these programs is establishment of necessary infrastructure to support the massive clean-up efforts that will be required. FIMAD is designed to support management, research and documentation of all ER activities, through a series of workstations available to task leaders. Within the workstation environment, GIS and Relational Database Management System (RDBMS) tools are currently provided.

ENVIRONMENTAL IMPACT ASSESSMENT

Nonpoint Pollution from Agriculture

According to Mertz[13], each year more than 1 billion tons of sediment wash from agricultural lands into U.S. waterways. With the runoffs and sediment come pesticide residues and nitrogen and phosphorus from fertilizers, further deteriorating water quality. Actually, agriculture is one of the biggest contributors to nonpoint pollution.

Advances in combining GIS with modeling capabilities offer a powerful, efficient opportunity to target regions creating the most nonpoint pollution.

This technology is being used in Pennsylvania and the Chesapeake Bay drainage basin. Farms located in Pennsylvania's Susquehanna River Basin contribute nearly one-third of the nitrogen and one-quarter of the phosphorus pouring into the Bay. States participating in the federal Chesapeake Bay program are committed to reducing nitrogen and phosphorus input 40 percent by the year 2000.

Researchers working in this program spent a year defining watersheds in Pennsylvania and identifying the processes and parameters that contribute to nonpoint pollution. Ultimately, their GIS-based model ranked the nonpoint pollution potential of 104 watersheds in Pennsylvania, providing a map for targeting funds.

The project's one-year time frame forced the researchers to use existing data. Seven data layers were scaled and subdivided into 1 hectare grid-cells. These layers were adapted from a number of existing data sets:

1. Watershed boundaries
2. Land use data
3. Animal densities (N and P were calculated by developing nutrient loadings)
4. Topography (latitude/longitude)
5. Soils data (types and percentages of individual soils)
6. Precipitation layers (daily precipitation)
7. Rainfall-runoff (22-year average)

An Agricultural Pollution Potential Index (APPI) was developed from the data layers to rank the 104 relative nonpoint pollution potential. Runoff Index, Chemical Use Index, Sediment Production Index, and Animal Loading Index were developed also.

The 104 watersheds were ranked according to their potential for nonpoint pollution. Only the pollution potential of agricultural lands were assessed. Results showed that watersheds with the greatest agricultural pollution potential were located in the southwestern and northeastern sections of Pennsylvania, despite the fact that agricultural production was conducted on less than 40 percent of the land within those watersheds.

The GIS-based computer model is accurate on a statewide basis but it is not reliable if the attention is focused on the small, individual watershed. Further, the watersheds were divided with the highest nonpoint pollution potential into subwatersheds. Extra details provided a clearer picture of watershed nonpoint pollution potential. The GIS-based model may widely affect management of nonpoint pollution in the entire Chesapeake Bay drainage basin. The model was also used to evaluate agricultural nonpoint pollution potential in the Chesapeake Bay drainage region.

GIS will remain an essential tool for decision makers. More and more local people are starting to realize that GIS is an indispensable tool for setting priorities and concentrating programs. GIS-based computer models provide scientists with pictures, an important communication tool. According to the researchers, one of the real values of GIS is the visual mapping so that people can easily see problems.

An additional layer is already in the works. Groundwater information is being prepared for Pennsylvania. Other layers that would be incorporated into the system include detailed pesticide/chemical use information, urban pollution potential, and mining effects.

Development of Emissions Inventories and Emission Modeling

Many studies have been performed to address the ozone nonattainment problem in the United States[31]. More recently, many of these investigations have relied upon the use of advanced photochemical models. Pollutant emission rates are a key input to these models. Four different types of emissions estimates are required:

- base year emission estimates,
- periodic annual updates to the base year emissions estimates,
- reasonable further progress projected emission estimates, and
- emission estimates for input to photochemical and other models.

The emission database needed for photochemical modeling involves the preparation of spatially and temporally resolved emission estimates. The development of an emissions modeling database requires the spatial management of large quantities of emissions data and emissions estimates. GIS have been used to develop a more flexible, user-friendly emissions modeling system.

An emission model is an integrated collection of equations and other computational procedures that are encoded for computer-based calculation of emission estimates. Emissions data refer to the information, typically stored in a database and commonly referred to as an emission inventory, that is input to an emissions model to produce emission estimates, by source category or source within given classification.

An emission modeling system (a group of emissions models executed in specified sequence) further processes the emission estimates and generates speciated, spatially and temporally resolved values for input to photochemical and other regional air quality models.

GIS can be used to facilitate the development of modeling of emissions data, emission estimates and the quality assurance of these emissions-related information. This paper presents several different techniques that illustrate how GIS can be used to help:

- develop emission data,
- process emission data to produce emission estimates, and
- perform quality assurance functions on emissions data and estimates.

Environmental Impact Assessment for Gold Mining

One of the largest gold mining companies in the USA, Independence Mining Co. (IMC), is looking to expand its exploration and development operations on 3,000 additional acres in Jerritt Canyon, Elko County, Nevada[14]. To develop an environmental impact statement to substantiate its expansion plans for rigorous federal requirements, IMC is merging global positioning system (GPS) and GIS technologies, and hiring numerous experts in mapping, air and water quality, soils, vegetation and wildlife biology.

According to the author, the IMC is trying to extract minerals in an environmentally sound manner. Mill, roads and disposal site were designed to minimize the mine's impact on designated threatened species. The IMC has been accumulating more data about the impact of its operations. In cooperation with U.S. Forest Service, the IMC is working to create a detailed Cumulative Effects Analysis (CEA) as a tool to try to quantify cumulative effects and to move away from qualitative assessments. As a part of EPA's EIS requirements, CEA will provide a baseline for environmental norms before the mine expansion and carefully monitor changes in the total environment during mine operations. The refined information in IMC's CEA will be entered into a GIS for storage, analysis and cartographic display. The transfer of survey data into the GIS also would be time-consuming, requiring manual digitizing and separate entry. Meanwhile, the GIS would be only as useful as the field data supporting it.

After surveying the options, IMC chose GeoLink, a computerized GPS/GIS mapping system, to provide the missing link between field data collection and GIS map creation. The system basically quantifies ecological and other mine information and puts it into a GIS.

Oil Spills Accidents

The applicability of GIS to deal with oil spills in general and particularly in Florida's most ecologically sensitive habitats and popular beaches near St. Petersburg is discussed[15].

Florida Department of Environmental Protection (DEP) has been designing a GIS application to help manage spills; the accident occurring in August 1993 near the mouth of Tampa Bay provided the test of the application's design.

The U.S. Geological Survey (USGS) topographic maps are annotated with Environmental Sensitivity Index (ESI) for shoreline types, wildlife-resources areas and strategies. The ESI ranking of shorelines is critical because it cartographically indicates the vulnerability of specific shorelines to an oil spill.

The existing ESI are updated and the information integrated into a GIS to facilitate more frequent updates and real-time analyses. One of the tasks also was to provide the DEP Office of Coastal Protection with the capability and technical support to facilitate oil-spill contingency planning, response and damage-assessment responsibilities.

A Florida Marine Spill Analysis System (FMSAS) was initiated. The principal goal of the project is to design an application that integrates a variety of information (digital maps, images and tabular data) with targeted analytical routines needed to implement an oil-spill response strategy focused on resource protection. Additional requirements are to implement a selected set of these conditions for pilot study area and in Florida Keys to develop a strategy for expanding the prototype to a state-wide, operational system.

The functional requirements of and basic format for the FMSAS database design were tested. In addition, the needs assessment and database and application designs determine data requirements and guide a thorough inventory and evaluation of coastal data available in Florida. The FMSAS prototype is used with 10 different databases (including data on marinas, habitats, and threatened and endangered species) to generate a resource-at-risk report. Experience gained from this and other exercises are used to further refine the evolving FMSAS design and prototype.

Many data resources were combined to provide maps for simultaneous evaluation and monitoring aspects of the response efforts. To meet those requirements, additional data have to be acquired and integrated in GIS. GPS receivers are used to record locations of the vessels and the changing perimeter of the spill. The GPS files are imported immediately into GIS and incorporated into maps. The maps includes information such as road networks, navigational aids and the locations of temporary rescue headquarters. Scanned USGS quadrangle images are rectified and used as base maps to provide maximum annotation quickly. The various databases and images are combined to create different maps: those showing the changing locations of spill boundaries and resources at risk are used by command center and media and field workers, while those showing information for determining environmental sampling strategies are used to create response and damage assessment.

The question of whether GIS can contribute to oil spill management was answered in the Tampa Bay accident. The conceptual design and physical characteristics of the system are further refined. The plan for further incremental development prioritizes key databases. The challenge is to assemble and automate the data for each region of the state before a spill occurs there. DEP is exploring the possibility of cooperative agreements with other agencies and organizations to foster a collective investment so FMSAS can be shared and improved without redundant expenditures. The long term goal is to continue FMSAS development to provide greater protection for Florida's natural resources.

ENVIRONMENTAL MANAGEMENT

UNEP Global Environment Monitoring Systems

UNEP (United Nations Environmental Programme) has established GEMS (Global Environment Monitoring Systems) to assess the state, trends and problems of the environment. This task requires a well-coordinated, high-quality data collection program. The task of assembling, storing and disseminating data in geographic form was given to the GRID (Global Resource Information Database). Both GEMS and GRID are elements of Earthwatch, the environmental assessment side of UNEP and UN. According to Hebin and Witt[16], conventional methods of data collection, distribution and analysis are not suitable for large-scale multi/interdisciplinary studies. So GRID initially undertook a pilot study during which a variety of activities were performed. The most prominent were global data set collection and a series of case studies in the developing world, as well as the development of a comprehensive environmental database in digital form for the African continent.

GRID's task-oriented activities and objectives include database management, GIS/IP (Geographical Information System/Image Processing) technology transfer and GRID system development in response to the requirements of the UN Conference on Environment and Development's "Agenda 21," which called for strengthened GRID to promote decision-making information.

UNEP/GRID's long-term goals are to facilitate access to all major existing global and regional environmental databases; to make available to all UN agencies and intergovernmental organizations compatible GISs; and to promote the use of databases and GIS/IP technology in national environmental assessment and management.

There are two UNEP-funded GRID centers: GRID-Nairobi and GRID-Geneva. There are several nationally funded GRID centers (Arendal for Norway, Tsukuba for Japan, Warsaw for Poland, then in Nepal, Fiji, and in Brazil) and some are in process of being established (Denmark, Germany, Russia and Ukraine). The idea is for the whole to form an interconnected network for data exchange and data management. The intention is to connect all GRID centers with communication links to be able to transmit data to and from them.

To fulfill GRID's task, data are collected from a wide variety of sources such as statistical tables, satellite images, and digital data. The data are stored in the computer systems after being ingested, reformatted and georeferenced to a standard coordinate system and projection. Data processing includes use of GIS and IP analysis systems from many public and private sources.

GRID also uses a wide variety of software packages including ARC/INFO, which is used primarily for digitizing and GIS functionality; NASA's Earth Resources Laboratory Applications Software (ELAS) and Land Analysis System (LAS); IBM's Image Analysis Executive (IAX); ERDAS' image processing software ERDAS; Clark University's IDRISI program for both GIS and IP capability; TYDAC's SPANS for modeling purposes; and various database management, graphics and word processing systems.

Decision-Making for Environmental and Natural Resources

Gracia and Hecht[17] report on a program prepared to develop an effective decision-support tool for the Naval Undersea Warfare Center (NUWC) at Keyport, Washington and its Environmental and Natural Resources Division. The program goals are twofold: (1) to improve the data assimilation or data fusion function that must be performed by the Center's environmental managers through use of graphic GIS-based site characterization; and (2) to improve the overall environmental data management process.

Common to all hazardous waste reclamation programs is a requirement to follow the CERCLA (Comprehensive Environmental Response, Compensation and Liability Act) which requires sites to be screened by applying a Preliminary Assessment and Site Inspection evaluation. Sites meeting predefined criteria are subject to a detailed Remedial Investigation/Feasibility Study (RI/FS) to gather information to support a selection of clean-up alternatives and cost-effective remedial actions. Authors of NUWC believe GIS offers a marked improvement in the way restoration is typically conducted and managed.

Initial project results indicate that GIS will provide solutions to the complex data management problems associated with environmental restoration programs. The early results indicate that the spatial analysis and display capabilities of GIS can improve the ability of environmental restoration managers to visualize and evaluate site conditions and the scope of their sampling plans and programs. The research will continue to address site characterization, data fusion and data management functions. Near-term project emphasis is being focused on two areas: (1) applying predictive modeling techniques to support the risk assessment process and subsequent decision-making activity, and (2) integrating GIS with other data systems and analytical tools to enhance decision-support use.

Environmental Protection and Energy Conservation

Cassitto[18] describes the use of information and communication technology as being increasingly applied to enhance environmental protection and energy conservation. Automation and control systems allow energy recovery schemes to be used in the most effective manner, while intelligent buildings use computerized information systems to regulate energy use and the internal environment. The use of telemanagement systems to monitor and optimize natural gas supply in cities and water supplies and wastewater treatment is also described. Information systems are being applied to air quality monitoring networks, to improve environmental pollution control, and to manage traffic problems worldwide. Efforts to apply communication technology to improve energy and environmental services in Europe (Italy, Norway, Germany), Asia (Turkey) and New Zealand are highlighted.

Environmental Quality and Land Use

An unidentified source from Israel[19] describes the implementation of policies concerning environmental quality in land use and the application of information science. In the past 15 years, environmental protection has been achieved through policies the have been incorporated into the land-use planning system by environmental advisors to national, district, and local planning authorities, by environmental impact statements (EIS), and through the use of computer technology. The EIS system is the formal means by which environmental considerations are incorporated into planning decisions. The EIS is a statutory system which deals with a restricted number of major development schemes such as airports, industrial plants, and solid waste disposal sites.

The development of the GIS allows the analysis of geographic data for environmental purposes. GIS can be used to identify areas of environmental impact and to choose alternative sites.

Environmental Protection in Germany

Page[20] presents the review of the state of data processing and applied informatics in environmental protection in West Germany (FRG). The main results of an empirical study of environmental computing by the FRG's Environmental Federal Office are cited. Subject and technically oriented aspects are discussed, and a final evaluation of the development state of environmental software is presented. The informatics approaches discussed are mainly non-standard database applications, interactive ecological simulators, and expert system approaches.

Environmental Information Systems Inventory

Kokoszka[21] discusses an attempt to automate environmental information in order to develop an extensive network of databases. The U.S. EPA for example has established an Information Systems Inventory (ISI) that consists of more than 600 EPA (regional and headquarters) systems, databases and models. A brief description of the basic application of each database is included. The databases are arranged for discussion according to the following categories:

* Air
* Contractors
* Emergency Response
* Facilities
* Hazardous Waste/Solid Waste
* Laboratory QA/QC

* Physical/Chemical Properties
* Superfund/CERCLA
* Toxic Substances/TSCA
* Toxicity
* Treatment
* Water

INDUSTRIAL PROCESS CONTROL AND TOTAL QUALITY MANAGEMENT

Utility Industry Application

Epner and Parmenter[22] describe the application of GIS in the utility industry. This industry has embarked on management and structural transformations aimed at providing higher quality service at a competitive price to keep old customers and win new ones. Under these conditions, quality management programs are fast becoming the norm in the utility industry. These programs come under a variety of names, but total quality management (TQM) is best known.

For utilities, accurate, up-to-date and easily accessible information provide the foundation for delivering quality service to the customer. As the amount and the complexity of information grows, more and more utilities are converting their information sources to integrated AM/FM/GIS (Automated Mapping/Facilities Management/Geographic Information System) databases. However, the critical need for database accuracy and the high cost of data conversion present enormous hurdles to overcome before the benefits of AM/FM/GIS can be realized.

The philosophy behind TQM is the following: by improving the process of production or service delivery using well-defined tools, long-term improvements in quality and productivity can go hand-in-hand. TQM transforms the approach to quality by focusing on process. According to the authors, 80 percent of quality problems are designed into the process and thus are management issues, while only 20 percent are due to individual job performance. Thus, 80 percent of quality problems can be eliminated by developing a better process, which at the same time eliminates the inspection and rework required to correct the problems.

Without good, detailed and objective data, one cannot assess process performance. With good data, facts replace options, conflicts can be minimized, real problems can be identified and solutions can be monitored.

Process data may come from a variety of sources. Computers can provide data by measuring time or automatically tallying errors found in automated inspections. Whatever the data source, management must make the source's use clear to everyone involved. First, there must be a well-defined purpose for collecting data. More data are not necessarily better; they may not show anything new and they will take time and effort to collect. Second, management must reassure team members that the data are for process analysis, not individual performance evaluation. To ensure the optimal use of data for process analysis, data should be kept in computer spreadsheet programs. An efficient, accurate database must be in place and operational. TQM, applied from the beginning of AM/FM/GIS development, brings users and conversion specialists together to create a smarter conversion process. Using TQM analysis tools and sharing data and brainpower, this process can be made even more efficient as it proceeds.

Development and Implementation of an Information System for Process Control at Inco's Copper Cliff Smelter Complex

In recent years, Inco has implemented major productivity programs with the purpose of decreasing unit costs. Key activities at the Smelter Complex have dealt with improvements in operating and maintenance practices, energy conservation, redefinition of administrative structures and employee involvement. Metallurgical process control has played an important role in the development of more efficient operating practices with high specific throughput. This has permitted a reduction in the number of operating units, allowed the removal of redundant pieces of equipment and has led to a reduction of maintenance and operating costs. Landolt et al.[23] discuss the strategy and approach followed in the development and implementation of information systems for process control. It includes descriptions of process assessment work in the plant, modelling, implementation of improved practices, and development of information system for operators and supervisors.

Offsites Management Systems in Oil Refineries

Computerized offsites management systems in oil refineries offer a unique opportunity to integrate advanced technology into a coherent refinery information system that contributes to benefits-driven optimal operations[24]. According to Valleur, the information system can improve oil refineries by improving business opportunities, oil movement and advanced technology, and project scoping and sizing.

The following business opportunities have been recognized by applying information systems:

- increased complexity of day-to-day refinery operations with more products and more complex commercial specifications;
- recognition that offsites must not deoptimize what advanced process control has generally achieved on process units;
- efficient short-term scheduling requiring flexibility on the offsites; and
- availability of new equipment such as low cost, reliable on-line analyzers and emergence of commercial software packages to monitor, control, and schedule oil movement operations.

Advanced instrumentation and computing technology is used in conjunction with information systems to improve:

- mixing techniques and tank status,
- accuracy and reliability of on-line analyzers, and
- expert systems to help operators in selecting options and diagnosing incidents.

Project scoping and sizing the system's engineering effort are difficult because of their combinational nature and integration requirements with other systems such as laboratory, oil accounting and scheduling. Applying cost/benefit analysis and thorough economic evaluation based on information system relationships would select the optimal investment.

TABLE 1. Summary of information system applications

No.	Area of Application	Research Objective	IS Type	Year of Development	Author(s)
1	Water Management	Water quality monitoring	GIS hydrogeological model	1993	Rifai et al.
2	Water Management	Decision-making improvement	GIS managing water resources	1993	Belyaeva et al.

No.	Area of Application	Research Objective	IS Type	Year of Development	Author(s)
3	Water Management	Cost-effective groundwater data management	GIS	1993	Hall & Zidar
4	Water Management	Water quality monitoring	GIS	1993	Rifai et al.
5	Water Management	Irrigation/ drainage system management	GIS	1993	Allen
6	Water Management	Water quality monitoring	GIS	1993	Heidtke & Auer
7	Wastewater Management	Cost-effective storm sewer system maintenance	GIS	1993	Smith
8	Wastewater Management	Wastewater treatment process control	IS	1993	Arnold et al.
9	Wastewater Management	Wastewater flow forecast	GIS	1993	Shamsi & Scheinder
10	Waste Management	Recycling information program	GIS-based call responsive system	1993	Himes
11	Waste Management	Superfund cleanup	GIS	1994	Salzmann
12	Waste Management	Superfund cleanup	GIS	1991	Ganter & Cole
13	Environmental Impact Assessment	Nonpoint pollution potential ranking	GIS	1993	Mertz
14	Environmental Impact Assessment	Ozone no-attainment problem	GIS emission model	1991	Bruckman
15	Environmental Impact Assessment	Gold mining environmental impact	GIS	1993	Rodbell
16	Environmental Impact Assessment	Oil spill management	GIS	1993	Friel et al.
17	Environmental Management	Global environmental monitoring system	GIS	1993	Hebin & Witt
18	Environmental Management	Decision-making for environmental and natural resources	GIS	1993	Gracia & Hecht
19	Environmental Management	Environmental protection and energy conservation	IS energy consumption	1990	Cassito
20	Environmental Management	Environmental quality and land use	GIS	1989	Unv., Israel

No.	Area of Application	Research Objective	IS Type	Year of Development	Author(s)
21	Environmental Management	Environmental protection	IS	1988	Page
22	Environmental Management	Environmental protection	IS	1992	Kokoszka
23	Industrial Process Control and Total Quality Management	Total quality management (TQM)	GIS	1993	Epner & Parmenter
24	Industrial Process Control and Total Quality Management	Process control	GIS	1988	Landolt et al.
25	Industrial Process Control and Total Quality Management	Oil refineries off-sites management systems - benefits driven optimal operations	IS	1993	Valleur

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SECTION 3

ASPECTS OF MEASURING POLLUTION PREVENTION PROGRESS

INTRODUCTION

Measuring pollution prevention (P2) is a significant challenge. The difficulties are conceptual--how do you measure waste that has not yet been created and practical--what units to use, and whether to track money saved or waste avoided? Another question involves the use of measurement data: is it desirable or even possible to compare P2 results of different companies and different industries[1]?

Further, why should P2 be measured? How should accomplishments be measured? How can pollution prevention measures be incorporated into the larger environmental data reporting scene? Are we trying to measure overall national progress in reducing waste or merely local progress in reducing discharges to local air, water, and landfills; to measure the physical amount of waste reduced or reductions in toxicity and other adverse environmental effects; to measure the efficiency of a single industrial plant or to be able to compare across plants, products, or economic sectors[2]?

An analysis of available literature[2,3,4,5,6,7,8,9,10] shows that the main aspects in dealing with P2 measurement as summarized by researchers from industry, academia and R&D institutions are:

(1) application of system analysis;
(2) system inputs and outputs definition,
(3) database, simulation and information system application;
(4) pollution prevention measurement types and normalization application;
(5) financing; and
(6) management practice.

(1) Application of System Analysis

Research carried out in industry has shown that efforts are concentrated on measuring releases before and after some waste and/or wastewater minimization actions have been applied. Thus, system analysis is a commonly recognized technique in dealing with industrial production systems (Figure 5). Detailed process diagrams[10], a simple block flow diagram[11] or process flow diagrams[12,13] are applied to analyze the system under consideration. Boundaries (unit operation[10], product unit definition[12] or facility boundaries[14]) of this dynamic system[14] are determined ("black box"[8] approach). Furthermore, time of system observation is considered. Mass balance[12,13,15,16] appears to be the usual approach in quantifying system parameter relationships.

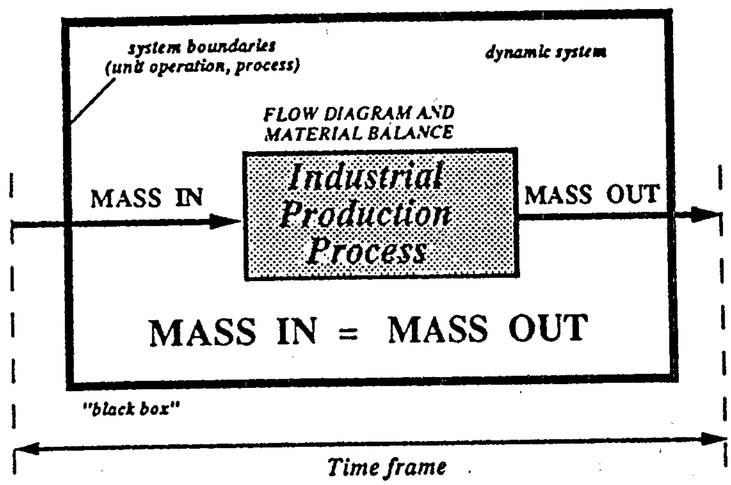

Figure 5. Schematic presentation of system analysis application to industrial production process

(2) System Inputs and Outputs Definition

System inputs[17] (raw and other materials) entering into the industrial production processes as well as system outputs[17] (products, by-products[12], process losses[10], waste[16], emissions[7], discharges[8], nonproduct outputs[13], releases[18]) are in most cases precisely identified and quantified[15]. The terms describing products and by-products are commonly used and their meaning widely understood. However, it seems there are many different definitions concerning the amount that is generated, lost, emitted, and/or released into the environment, as shown in Figure 6. It appears that considerable work on standardization of these terms is needed to clarify precise meanings.

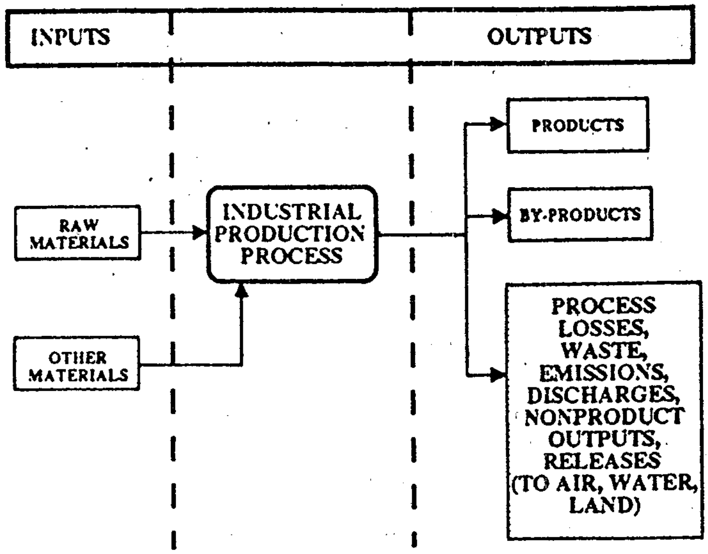

Figure 6. Industrial production system's inputs and outputs

(3) Database, Simulation and Information System Application

Computer-supported databases[15,16,19,20] are used to organize and process data on inputs and outputs that characterize any industrial production system. These databases allow establishment of tracking matrix[19] and/or loss tracking system[21] for bill of materials, shop production, and product routing[15]. A computerized information system is applied to provide material accounting[22], inventory control (for purchasing minimal quantities of raw materials[23]) as well as computerized integrated manufacturing (CIM)[21]. Computer-supported simulation[16] is used for direct observation of system behavior under a variety of conditions, while optimization[24] has proven to be a powerful tool for the scheduling of resources such that the overall efficiency of the system is achieved.

(4) P2 Measurement Types and Normalization

According to some theoretical research[12,13,15,16] a material balance is the most commonly used approach for measuring P2 progress in industry. Terms such as material accounting system[10,13], inventory of production and emissions[6], purchase records, material inventory, product records and specifications[22] are also being used. Some companies have developed tracking matrices[19], while others use input, by-product and emission reduction indexes[12], as well as so called point loss measurement. Normalization of data to present more meaningful P2 measurement has been used in many different ways. Some practical application showed industries compare data on system inputs and outputs with previous year data and adjust for production[5], while others use material use efficiency expressed in percentage or economic efficiency[21]. Absolute and normalized pollution levels[25], as well as absolute and normalized pollution reduction[25] are also being used in practice. Independent variables[12], regression theory[12], and autocorrelation[12] approaches are applied. The quantity of waste generated is presented per unit of product[22]. Production index[21] and normalization per unit of product at each step of production[15], is used.

(5) Financing

The financial aspects of P2 are considered to be very important[7,17,21,22]. Cost analysis[22] serves as a basis for P2 project selection in industry. Activity based costs (ABC)[23] and/or economic feasibility analysis[7] are applied. In industry, the placement of environmental costs are recommended to be made into separate accounts[26] to serve as a powerful tool for resource use optimization.

(6) Management Practice

Total Quality Management-- zero losses or 100% efficiency[21] --is only a different term for the introduction of P2 practice into industrial production based on material balance. So called Total Quality Management Structure[20] and/or Total Quality Management Program (TQMP) are also being introduced[27]. Measuring effectiveness[7] by the ratio of waste reduction and production is also being used. Important considerations for industrial management concerning introduction of P2 measurement are time frame[28], costs[28], priorities[28], and implementation period[29]. Material accounting could therefore be considered as a standard management procedure for P2 measurement.

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SECTION 4

DEVELOPMENT OF A MODEL OF AN INDUSTRIAL PRODUCTION AND WASTE GENERATION TRACKING SYSTEM (IPWGTS)

INTRODUCTION

Waste characteristics and quantities of waste generated, managed and/or released in the environment in a given time have to be determined to implement waste minimization and/or pollution prevention measures in any industrial production process generating waste. Cost analysis of such a system could enable one to estimate waste generation and management costs and could help production managers to evaluate the system and to introduce measures to reduce or minimize waste at the point of its generation, or to prevent release of pollutants into the environment.

Industrial Production and Waste Generation Tracking System

A framework for the determination of the main parameters of an industrial production and waste generation tracking system[1,2] was defined (Figure 7). It is based on the following main production process variables:

1) raw materials (rm),
2) other materials entering production process (v),
3) produced products (P),
4) generated waste (y).

This generated waste may be:

a) managed (g) by applying waste management,
b) released (z) into the environment, causing environmental pollution.

Managed waste (g) may be further processed to be:

c) used as secondary raw material and/or energy (s),
d) finally disposed of as processed waste (residues) in a special (or secure) landfill (d).

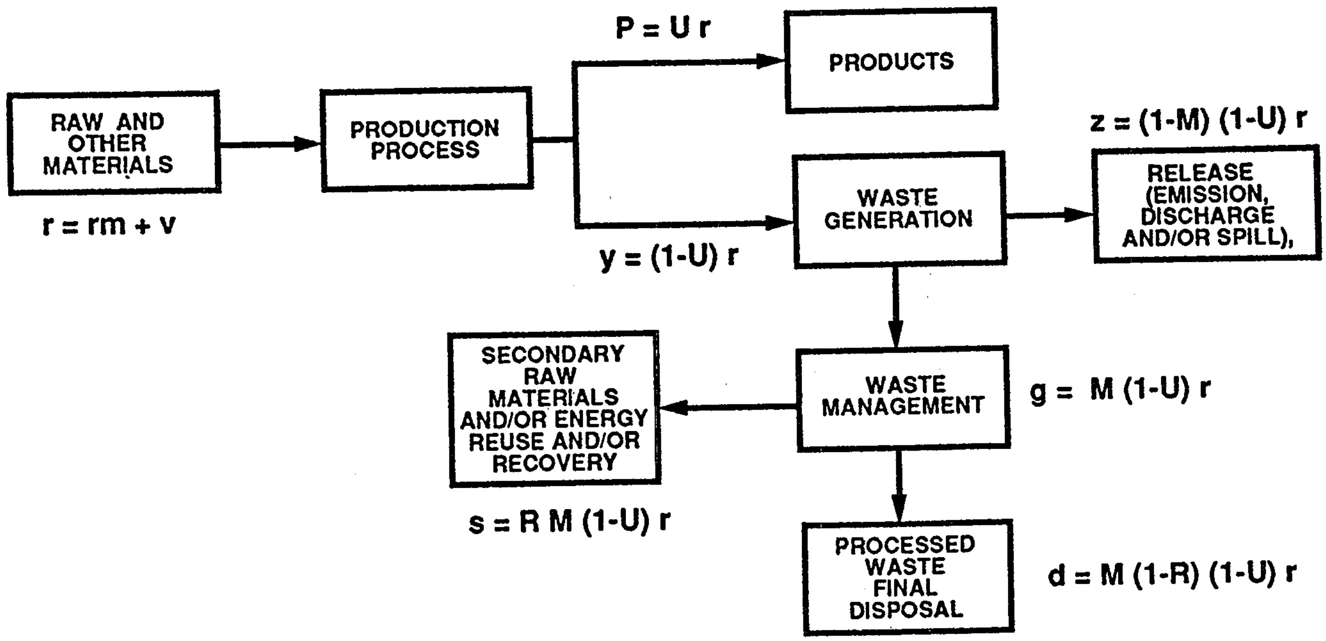

Figure 7. Industrial production and waste generation tracking system

Development of IPWGTS Model

Based on the works of Baetz et al.[3], a model, enabling calculation of quantities of waste generated in an industrial production was developed and defined in Table 2.

During an industrial process at time **t**, a production factor **U**, correlating quantity of raw materials **r** ($r = rm + v$, where v represents "other materials" not defined as raw materials entering production process. An analysis of large data set on raw materials consumed, products produced and waste generated in different industrial production sites[4] enabled recognition of additional parameters including "other materials" entering production in time **t**. For example, paints and lacquers in "white goods" and furniture production - those materials are usually not defined as raw materials) and products (**P**) has the value $0 \leq U \leq 1$ is defined as:

$$U = P/r$$

The quantity of products then may be expressed as:

$$P = U r$$

while quantity of waste generated is

$$y = (1 - U) r.$$

Managed waste is further quantified by a waste management factor M which is defined as the ratio between waste managed and waste generated:

$$M = g/y$$

and can have a value $0 \leq M \leq 1$. The quantity of waste managed by storage, collection, transportation, processing and final disposal is then

$$g = M (1 - U) r$$

while the quantity of waste released (emitted, discharged and/or spilled) into the environment is

$$z = (1 - M) (1 - U) r$$

If waste is further processed by physical, chemical, thermal and/or biological processing to recover secondary raw materials and/or energy, then processed waste is determined by the waste recycling factor R:

$$R = s/g$$

having the value $0 \leq R \leq 1$. The quantity of waste recycled into secondary raw materials and/or energy by waste processing is

$$s = M R (1 - U) r$$

while the quantity of waste to be finally disposed is

$$d = M (1 - R) (1 - U) r.$$

Knowing quantities of raw and other materials (rm + v) entering the observed system and quantities of products (P) produced, quantities of waste generated (y) could be calculated. If the quantity of waste managed (g) by the waste generator is known, it is possible to predict quantities of material lost (z) through release (emission, discharge, and/or spill). Finally, if the waste generator recycles managed waste into secondary raw materials and/or energy (s), then the quantity of waste to be disposed (d) can be determined.

TABLE 2. Definition of IPWGTS model parameters

Parameter	Definition
t	industrial production time in which system was observed;
rm	quantity of raw material entering industrial production in time t;
v	quantity of other materials (not defined as raw materials) entering industrial production in time t;
$r = rm + v$	quantity of raw and other materials entering industrial production in time t;
$U = P/r$	production factor after time t. U = 1 represents total production, while U = 0 represents zero level of production and therefore, total waste generation;
$P = U\ r$	quantity of products produced in time t;
$y = (1-U)\ r$	quantity of solid, liquid and/or gaseous waste generated in time t;
$M = g/y = g/(1-U)\ r$	waste management factor after time t. M = 1 represents total waste management while M = 0 represents zero level of waste management and therefore, total release (emission, spill and/or discharge) into environment;
$g = M\ (1-U)\ r$	quantity of solid, liquid and/or gaseous waste managed by waste management (temporary storage, collection, transportation, processing and final disposal);
$z = (1-M)\ (1-U)\ r$	quantity of solid, liquid and/or gaseous waste released to air, water and/or soil/land, causing environmental pollution;
$R = s/g = s/M\ (1-U)\ r$	waste recycling factor after time t. R = 1 represents total waste recycling by physical, chemical, thermal and/or biological process to recover secondary materials and/or energy, while R = 0 represents total waste processing by physical, chemical, thermal and/or biological process for final disposal in environment;
$s = M\ R\ (1-U)\ r$	quantity of secondary raw materials and/or energy recovered from solid, liquid and/or gaseous waste by waste recycling;
$d = M\ (1-R)\ (1-U)\ r$	quantity of processed waste for final disposal.

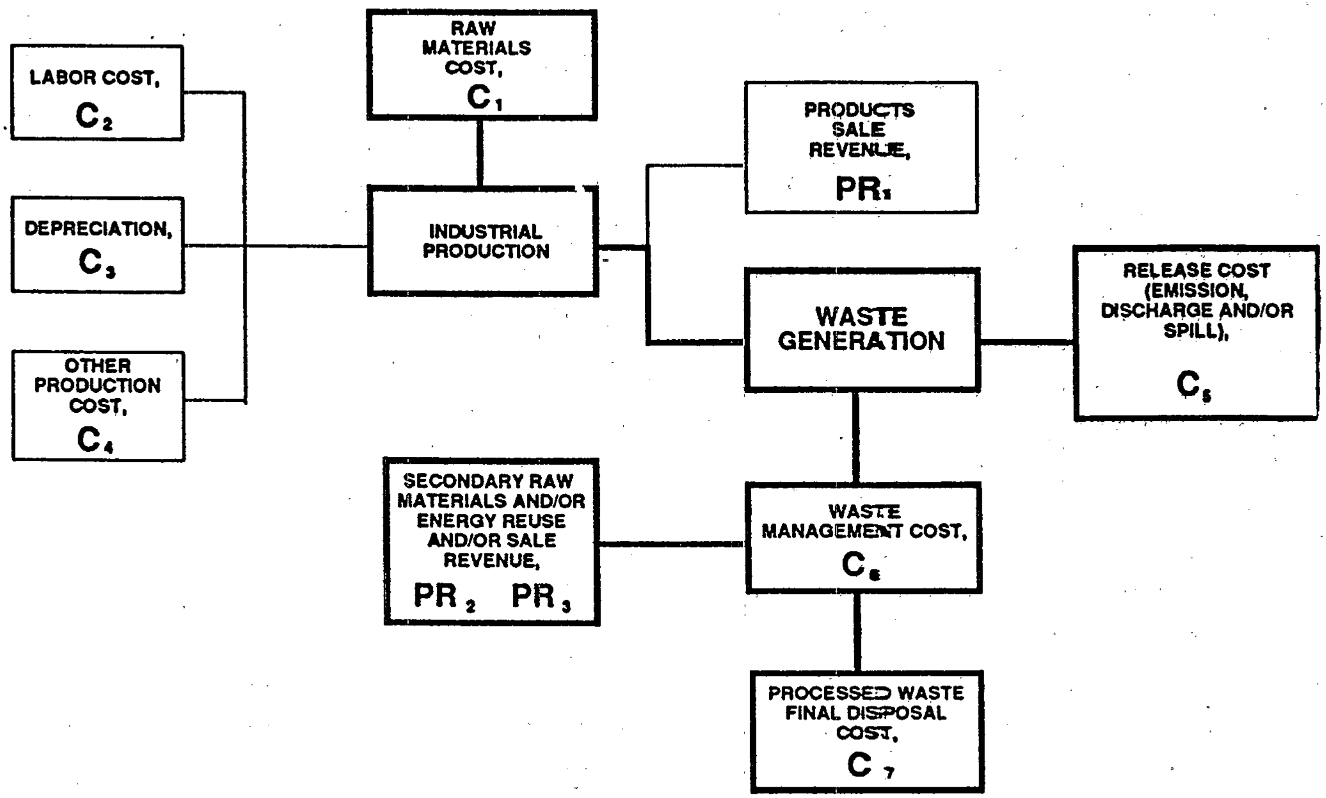

Figure 8. Cost analysis of an industrial production
and waste generation tracking system

Cost Analysis of IPWGTS

A cost analysis of an industrial production and waste generation tracking system is defined[2] in Table 3 and general scheme presented in Figure 8. The cost analysis discussed is an example but does not necessarily include all costs associated with environmental issues and/or industrial production process. However, the idea of approaching the problems of assessing costs at the facility level of industrial production is shown.

TABLE 3. Costs and revenues of industrial production and waste generation tracking system

COSTS	
$r_1, r_2, r_3, \ldots r_n$	quantity of raw materials (by type)
$p_{r1}, p_{r2}, p_{r3}, \ldots p_{rn}$	unit price of raw materials (by type)
$r_1 * p_{r1}, r_2 * p_{r2}, r_3 * p_{r3}, \ldots, r_n * p_{rn}$	cost of raw materials (by type)
C_1	**total cost of raw materials**
$l_1, l_2, l_3, \ldots l_n$	number of employees by employment classification
$w_1, w_2, w_3, \ldots, w_n$	wages per employees by employment classification
$l_1 * w_1, l_2 * w_2, l_3 * w_3, \ldots, l_n * w_n$	labor cost per employment classification
C_2	**total labor cost**
$m_1, m_2, m_3, \ldots m_n$	number of machines (by type)
$p_{m1}, p_{m2}, p_{m3}, \ldots p_{mn}$	unit price of machine (by type)
$\delta_1, \delta_2, \delta_3, \ldots \delta_n$	depreciation rate of machine (by type)
$m_1 * p_{m1} * \delta_1, m_2 * p_{m1} * \delta_2, m_3 * p_{m3} * \delta_3, \ldots m_n * p_{mn} * \delta_n$	cost of machine depreciations
C_3	**total depreciation**
$o_1, o_2, o_3, \ldots o_n$	number of miscellaneous production factors (by type) (e.g. commercial and/or financial, insurance activities, transport, energy, etc.)
$p_{o1}, p_{o2}, p_{o3}, \ldots p_{on}$	unit price of miscellaneous production factors (by type)
$o_1 * p_{o1}, o_2 * p_{o2}, o_3 * p_{o3}, \ldots, o_n * p_{on}$	cost of miscellaneous production factors (by type)
C_4	**total cost of miscellaneous production factors**

COSTS	
$z_1, z_2, z_3, \ldots z_n$	quantity of gaseous, liquid and/or solid raw materials lost by release to air, water and/or soil/land
$p_{r1}, p_{r2}, p_{r3}, \ldots p_{rn}$	unit price of raw materials (by type)
$z_1 * p_{r1}, z_2 * p_{r2}, z_3 * p_{r3}, \ldots, z_n * p_{rn}$	cost of raw materials loss (by type)
C_5	**total cost of raw materials loss**
$g_1, g_2, g_3, \ldots g_n$	quantity of gaseous, liquid, and/or solid waste managed (by type)
$p_{g1}, p_{g2}, p_{g3}, \ldots p_{gn}$	unit cost of each increment of waste management (temporary storage, collection, transportation and processing)
$g_1 * p_{g1}, g_2 * p_{g2}, g_3 * p_{g3}, \ldots, g_n * p_{gn}$	cost of each increment of waste management
C_6	**total cost of each increment of waste management**
$d_1, d_2, d_3, \ldots d_n$	quantity of processed waste for final disposal (by type)
$p_{d1}, p_{d2}, p_{d3}, \ldots p_{dn}$	unit cost for processed waste final disposal (by type)
$d_1 * p_{d1}, d_2 * p_{d2}, d_3 * p_{d3}, \ldots, d_n * p_{dn}$	cost for processed waste final disposal (by type)
C_7	**total cost for processed waste final disposal (by type)**
REVENUES	
$x_1, x_2, x_3, \ldots x_n$	quantity of products (by type)
$p_{x1}, p_{x2}, p_{x3}, \ldots p_{xn}$	sale price of products (by type)
$x_1 * p_{x1}, x_2 * p_{x2}, x_3 * p_{x3}, \ldots, x_n * p_{xn}$	revenues on sale of products (by type)
PR_1	**total revenues on sale of products**

REVENUES	
$s_1, s_2, s_3, \ldots s_n$	quantity of secondary raw materials (by type) recovered by waste processing
$p_{s1}, p_{s2}, p_{s3}, \ldots p_{sn}$	sale price of secondary raw materials (by type) recovered by waste processing
$s_1 * p_{s1}, \; s_2 * p_{s2}, \; s_3 * p_{s3}, \ldots, \; s_n * p_{sn}$	revenues realized on reuse or sale of secondary raw materials (by type) recovered by waste processing
PR_2	**total revenues realized on reuse or sale of secondary raw materials (by type) recovered by waste processing**
$e_1, e_2, e_3, \ldots e_n$	quantity of energy recovered by waste processing
$p_{e1}, p_{e2}, p_{e3}, \ldots p_{en}$	sale price of energy recovered by waste processing
$e_1 * p_{e1}, \; p_2 * p_{e2}, \; e_3 * p_{e3}, \ldots, \; e_n * p_{en}$	revenues realized on reuse or sale of energy recovered by waste processing
PR_3	**total revenues realized on reuse or sale of energy recovered by waste processing**

Note: The assumption that **n** raw material types, **n** employee classifications or **n** machine types, etc. are involved in the industrial production process is not correct. There are actually **n** raw material types, **k** employee classification types and **f** machine types, etc. This notation, however, complicates parameter identifications; consequently, **n** does not represent the same number in every case.

CASES OF INDUSTRIAL PRODUCTION AND WASTE GENERATION SYSTEM COSTS FOR DECISION-MAKING

System Costs for Decision-Making

Costs defined C_1, C_2, C_3, C_4, (Figure 8) are usual costs in any type of industrial production and they can vary, but they are inevitable. Revenue realized on production sale, PR_1, has to cover all these costs and provide a profit for successful continuation of the production.

However, the costs caused by waste generation, C_5, C_6 and C_7, are rarely precisely defined, quantified and evaluated in terms of price in the production process. Little is known or appreciated about true costs associated with generating waste in industry[5].

For example, costs C_6 depend on the level of legislation and regulations of the country where an industrial production is under consideration. However, these costs have to be added to one of the basic cost of industrial production, C_5, caused by material release (and thus material loss) to the environment. Therefore, even if legislation does not define permissible levels of waste releases to air, water and/or soil/land and does not include taxes on waste generators, a manager of an industrial production can still calculate these costs.

Roney[6] approaches the same problem from a total production quality management point of view; he stated that hazardous waste is a result of bad quality and is a significant part of manufacturing costs. He suggested that high class manufacturers have to eliminate it for these reasons alone -- they have to cut their emissions to be allowed to keep their factories open while environmental pressures close down the others.

A similar situation exists with revenues obtained on reuse or sale of secondary raw materials and/or energy recovered by waste processing. Cost analysis can identify profitability of waste processing for recovering secondary raw materials and/or energy, or for finally disposing of processed waste into landfill. This analysis did help environmental regulators to encourage waste recycling by introducing high taxes on waste to be finally disposed of in a landfill.

Finally, the industrial production and waste generation system under consideration can be generally viewed according to the following three cases:

Case I

In countries where legal sanctions against environmental pollution are absent, industrial technologies (production processes) are operated and/or typically selected maximizing profit, i.e., the difference between revenue and cost, as it is shown in the following expression (i):

$$\text{(i)} \max \{PR_1 - (C_1 + C_2 + C_3 + C_4)\}$$

Case II

In countries where sanctions against environmental pollution have been legislated, industrial technologies are operated and/or selected taking into account:

$$\text{(i)}\quad \max\ \{PR_1 - (C_1 + C_2 + C_3 + C_4)\}$$

as well as additional technologies for reduction of waste generation (by processing waste into secondary raw materials and/or energy), maximizing the difference between revenues and costs, as shown in (ii):

$$\text{(ii)}\quad \max\ \{(PR_1 + PR_2 + PR_3) - (C_5 + C_6 + C_7)\}.$$

Case III

However, an overall approach to the solution of environmental problems caused by industrial productions generating waste is suggested by operating existing and/or selecting industrial processes through:

1. industrial production technology,

2. technology for reduction of waste generation (waste processing into secondary raw materials and/or energy), and

3. improvement/optimization of industrial production by introducing pollution prevention measures,

which maximize the total profit:

$$\text{(iii)}\quad \max\ \{(PR_1 + PR_2 + PR_3) - (C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8)\}.$$

In the expression (iii) C_8 (total costs of activities related to improvement/optimization of industrial production for environmental production) is incorporated. These pollution prevention costs should enable optimal industrial production under reduction of waste generation. In this case costs of materials loss, C_5, as well as waste management and processed waste final disposal costs, C_6 and C_7, could be minimized or even eliminated.

Using this or similar cost analysis could help industrial managers/operators to evaluate their industrial production processes and to concentrate on improving/optimizing production processes, instead of concentrating on managing waste and/or wastewaters generated by these processes. In fact, one dollar spent on improvement of the processes efficiency means in a long run, one dollar more of revenue realized on sale of products. Finally, for industrial managers/operators, applying pollution prevention strategies means observing their processes from different points of view which could result in improved efficiency and reduced costs.

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SECTION 5

DEVELOPMENT OF INFORMATION SYSTEM SHELL FOR MEASURING P2 PROGRESS

INTRODUCTION

The objective of this part of the research was to build a generic computerized information system shell (ISS) for measuring pollution prevention progress in any industrial facility generating waste. It comprises a real data model of an industrial production and waste generation tracking system (IPWGTS). The IPWGTS model precisely defines the observed system parameters and their relationships (Section 4).

The essential part of the information system shell is a model of an IPWGTS. An IPWGTS model was tested in selected industrial production processes of an industrial sector, and real data were used for ISS building, model testing and improvement.

An ISS could provide industry, research organizations, and governmental institutions with a powerful tool for implementation of pollution prevention strategies and introduction of efficient waste reduction/minimization practices by calculating quantities of waste and/or wastewater generated in industrial sectors and by applying cost analysis. After introducing process optimization while minimizing waste and wastewater generation in production processes, ISS provides measurement of P2 progress.

Commercially available database management systems (DBMS) for information system shell building applicable on IBM PC are analyzed and appropriate DBMS are selected.

Structure and Function of the Information System Shell

The information system shell includes databases on the following data (Figure 9):

(i) codes, types, quantities and cost of raw and other materials entering production process;
(ii) codes, types, quantities and revenues of products;

(iii) codes, types, quantities and cost of waste and wastewater generated by the process;

(iv) codes, types, quantities and cost of waste and wastewater management system;

(v) codes, types, quantities and cost of material loss through emission, discharge and spill;

(vi) codes, types, quantities and cost/revenues of secondary raw materials/energy recovered by waste processing and/or wastewater treatment processes; and

(vii) codes, types, quantities and cost of processed waste final disposal.

Using developed parameter relationships of IPWGTS it is possible to calculate the quantities of waste and wastewaters generated by the observed industrial process in a selected time interval. Data evaluation could be carried out by using the U.S. EPA's Toxic Release Inventory data as well as direct measuring and monitoring of releases.

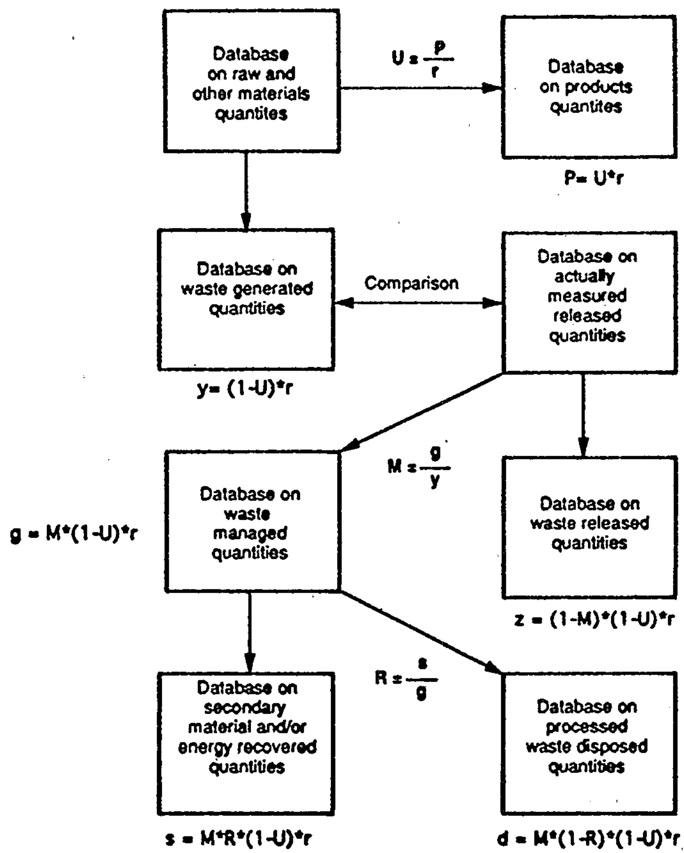

Figure 9. Scheme of an information system shell

The IPWGTS model provides among others the following data:

(1) production factor determines the overall production process efficiency;
(2) waste management factor determines the level of waste and wastewaters management and estimates the waste and wastewater management system efficiency;
(3) waste recycling factor determines the level of recyclability and estimates the secondary material and/or energy recovery efficiency;

Use of Information System Shell

ISS is programmed in a way that allows the use of existing data in any industrial facility. A facility manager can select a unit operation, several unit operations, a part of facility and/or a whole facility as the IPWGTS for testing. A manual for the use of ISS is available describing data preparation and import into the system, as well as the steps of using the ISS. Once data are collected and imported, all calculations are provided by the ISS. Further, quantitative and cost analyses and the determination of the efficiency of the observed system can be done quickly and precisely. The ISS provides daily, weekly, monthly, quarterly and yearly time frames (Figure 10).

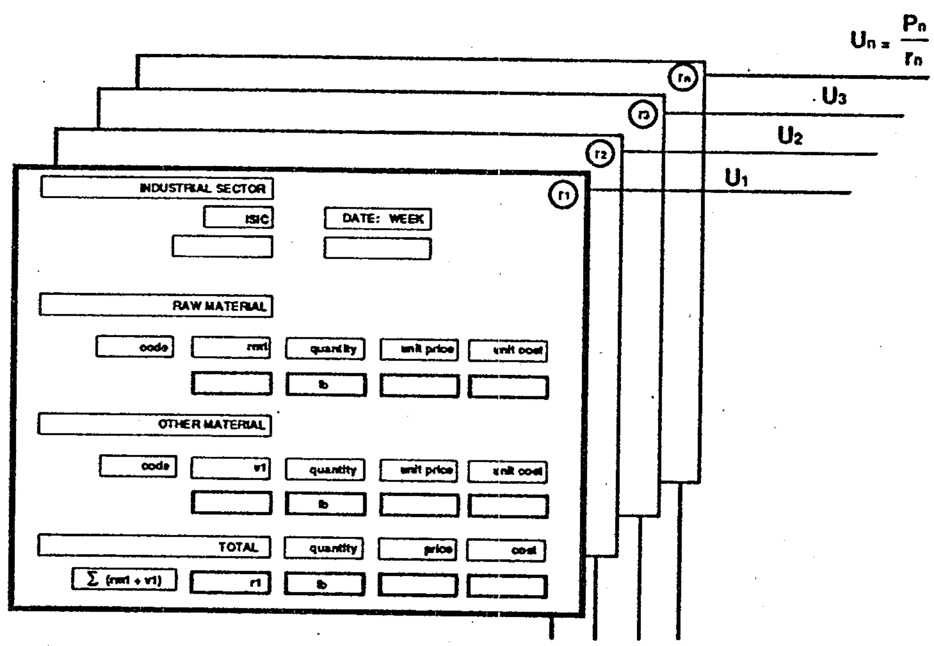

Figure 10. Schematic presentation of the ISS databases

Finally, ISS allows schematic, tabular and graphic presentation of the system parameter relationships. After the estimation of the facility efficiency, the management team could decide which waste minimization and/or pollution prevention measures should be applied, if any. If improvements have been selected and implemented, the ISS can be used again and measure pollution prevention achieved.

SECTION 6

COMPUTER PROGRAMMING OF THE INFORMATION SYSTEM SHELL

SYSTEM OVERVIEW

The structure of the ISS is based on the parameters and relationships of an IPWGTS discussed in Section 4. The ISS has been developed using Microsoft windows and requires MS Access 2.0 and MS Excel to run. For fast performance, it is recommended that ISS be used on a 486DX computer with around 66 MHz. However, a 386 computer with Windows will also work.

Quantitative Analysis

The information used within the ISS can be broken into seven categories: raw materials input, other materials input, products, waste generated, measured releases, and managed waste (Figure 7). Each of these categories contains measurements of a specific parameter quantity taken on a daily basis. The ISS is based on the relationships that exist among these seven categories through the model.

There are three factors used to correlate quantities within this system: the production factor, the waste management factor, and the recycling factor (Section 4). Each of these can be computed within the ISS on the basis of available data.

By implementing these formulas, the ISS is able to calculate parameters quantities. For example, in an industrial production process where only the inputs and the product are closely measured, the total amount of waste generated can be predicted but the management and recycling factors cannot. In addition, these formulas could aid in determining if the methods of parameter calculations are producing correct results.

Cost Analysis

In addition to calculations of the quantities of input and output of materials in a process, this ISS also provides the capability to make a cost analysis. The cost analysis incorporated in the ISS is based on the model of IPWGTS and its parameter relationships and their unit prices. There are eight cost types recognized within the ISS (Section 4):

C1: Total cost of raw materials: $\Sigma(r_i\ p_i)$, where r = quantity of raw materials by type and p = unit price of raw materials by type;

C2: Total labor cost: $\Sigma(l_i\ w_i)$, where l = number of employees by employment classification and w = wages per employee by employment classification;

C3: Total depreciation: $\Sigma(m_i\ \delta_i\ p_i)$, where m = number of machines (by type), p = unit price of machine (by type), δ = depreciation rate of machine (by type);

C4: Total cost of miscellaneous factors: $\Sigma(o_i\ p_i)$, where o = number of miscellaneous production factors (by type) (e.g., commercial and/or financial, insurance activities, transport, etc.) and p = unit price of miscellaneous production factors (by type);

C5: Total cost of activities related to improvement/optimization of production: $\Sigma(i_i\ p_i)$, where i = number of activities related to improvement/optimization of production for environmental protection and p = cost of activity related to improvement/optimization of production for environmental protection;

C6: Total cost of raw materials loss: $\Sigma(z_i\ p_i)$, where z = quantity of gaseous, liquid, and/or solid raw materials lost by releases to environment and p = unit price of raw materials;

C7: Total cost of waste management: $\Sigma(g_i\ p_i)$, where g = quantity of gaseous, liquid and/or solid waste managed (by type) and p = unit price of each increment of waste management;

C8 Total cost of processed waste final disposal: $\Sigma(d_i\ p_i)$, where d = quantity of processed waste for final disposal (by type) and p = unit cost for processed waste final disposal (by type).

As data are collected, the user will be able to input new data as it arrives. At all times, the ISS will determine, from the available data, if any other types of quantities can be predicted, thereby offering the user an improved view into the industrial production process under study.

INFORMATION SYSTEM SHELL

The structure of the ISS can be divided into three sections: **data entry, data storage/manipulation**, and data display. These sections are bound together through the user interface.

Goals and Requirements

One of the requirements the ISS must fulfill is to be user friendly. By being user friendly, the ISS is responsible for the following:

- organization of data in a format that allows easy comprehension by user;
- the display of correct values throughout system;
- quick and timely responses; and
- a system that is easy for the users to learn.

In addition to being user friendly, the ISS is expected to be applied to a wide range of industrial processes and domains. In order to meet this requirement, the system has been designed in a shell-like fashion. The core of the system consists of table definitions and functions that are used for data input, storage, manipulation, and display. Depending on the data entered, the core system will produce different storage and displays specific to the process being studied at that time.

Another requirement of this ISS is that it functions successfully not only for the ideal situation, (having all data at hand from the beginning), but also for the bare minimum, which in this case means only data on the raw materials, and other materials, and products to the system. The next requirement is that the system should be able to handle not only new data, but also new data of different types. This will not only lead to more storage types, but also to new areas within the user interface.

Implementation

The ISS is being developed on a PC machine and it entails two software packages: Excel 5.0 (A Microsoft spreadsheet package) and Access 2.0 (Microsoft DBMS). In order to form a more coherent system, Visual Basic 3.0 (Microsoft) has been used to connect these packages.

The data entry section of this system has been set up as an Excel application. The design has taken the liberty of assuming that the majority of users by this time have implemented storage of data on industrial processes within spreadsheet packages. Excel has been used because of its conversion capabilities, its general user friendliness, and its compatibility with other software packages. In addition to data entry, the majority of calculations needed by this system are done within Excel due to its speed. The calculations are usually made up of multiplications and division operators. The cost calculations used within this system are not calculated within Excel.

Access 2.0 is a database management system (DBMS) package produced by Microsoft. In the ISS system, it is used for data storage and manipulation. This ISS has been based on two databases: Archive and DM databases. The Archive database is used strictly for data storage. The DM database is used for data manipulation and is dependent on the Archive database. The system has been split into two databases in order to conserve storage space and to allow, in future implementations, the choice of different Archives as the basis for the DM database (i.e., allow the user to choose the production process archive to use at a given time). The Archive has been set up as the primary storage facility of the system, therefore, each unique process studied will have its own Archive database. The DM database references the data in the Archive database. The ISS will contain only one DM database that is independent of the type of process studied. The DM database is made up of pieces of code (SQL) that create information by organizing data relationships in different ways. This new information is stored as tables known as queries. These queries, rather than the original tables, are used by the user interface.

The user interface has been designed and implementation has begun using Visual Basic. This has been done to enable an easier transition between the software packages and a more coherent display. In addition, Visual Basic offers more control than interfaces designed and implemented in either Excel or Access. Visual Basic blends well with these application packages because all use similar data structures and objects within the programming language.

Data Entry

The data entry for the ISS can be divided according to the amount of data that they accept. The bulk of the information needed for the system to operate is entered using an Excel application. This application accepts and formats the daily measurements of all materials that course through the system. In addition, the Excel macro is responsible for calculating the predictive values used within the system. However, in addition to this bulk information, the system also requires specific information about each parameter and outside source that may affect the parameter relationships inside the process. The amount of this type of data is usually not as large as the primary data and can therefore be entered into the ISS by the user through the user interface.

Data Entry - Bulk Information--

Bulk information is used to refer to the daily data collected throughout the system. These data contain information on quantities of material flowing through the industrial production process. Because the structures of the ISS are dependent on the user input, the data entry section of the system is made up of macros and functions written in Excel Basic (similar to Visual Basic) to accept formatted input and perform the needed calculations, and extra formatting procedures to allow easy transition of data between Excel and Access.

Data Format---In order for the system to be successful, data entry must follow certain formatting guidelines. It has been assumed that each type of data is stored in a separate file which conforms to the following guidelines:

1. all data on parameters quantities will be given on a daily basis;

2. all data conversions will been performed before data enter into the system;

3. the first row in each column in a table will contain a unique title for that column. The title can be a parameter name or some type of representation symbolizing that parameter, and

4. the incoming spreadsheets will be formatted in the following ways:
   - the first column in every sheet contains the date;
   - no overall daily totals are given on any sheet;
   - for parameters named (managed waste, measured releases, managed releases, and secondary raw materials) the sheets will contain four columns: date, waste, wastewater contamination, and air emission. If these titles are not supplied, the system will automatically assign them in that order.

As the user is entering the needed files, the application will be performing calculations and additional formatting based on the type of data being entered. For example, when the sheet containing the amounts of raw materials is entered, the application will compute the daily totals and assign variables needed for transfer into the archive database.

Calculation with Data Entry--When the user has completed entering data, the application will develop additional worksheets based on the types of entered data. Based on the user inputs, the system will determine what extra types of calculations can be made. The minimum required types of data for the ISS to function are: raw and other materials (inputs), and products. The user will not be allowed to continue the system until these three types of data are entered into the system. If a system is given only these three types of data, the application will create a worksheet containing the predicted amounts of waste generated based on the production factor computed from the inputs and the products quantities.

As for the rest of the data types, the user is responsible for entering as much information as possible. It is hoped that through the use of this system, in addition to improving the efficiency of the observed production process, the user will take the initiative to improve techniques needed to measure, collect and handle these types of data. Based on this second goal, in future sessions with the information system, the user will have the ability to incorporate new types of data that may not have existed at the beginning of the ISS application. In adding new types of data to the system, the data entry will be able to perform different calculations used within the system. For example, given the quantities of waste generated and waste managed, it will be able to predict the quantities of waste released using the previously calculated managed waste quantity.

Automatic Data Entry--The user is sent directly into the Excel application from the Setup window in Visual Basic. The user is given a choice between manual and automatic data entry. Manual data entry allows the user to enter data directly from the keyboard. This option will probably not be viable due to the size of data files. Therefore, the data entry application will not begin until the user presses the "Automatic" button on the top screen. Automatic data entry will prompt the user through the process by asking for the type of data and the file where that data is stored.

Once data entry begins, the automatic window, known as a dialog frame in Excel, will remain on top of spreadsheets throughout the data entry stage. It contains a set of click buttons which represent different data types. As the user loads these different data types, the dialog frame will disable the data type click buttons that have already been used. In this way, the dialog frame facilitates the ease and correctness of data entry by keeping track of what type of data has already been entered, and keeping track of what types of data are yet needed. Since certain types of data require different computations, calculation errors made by the application can be limited by specifying the type of data entered. In addition to highlighting a click button, the user is prompted for the full path name of the file containing the data. After these two inputs are given, the user can load the file by pressing the "load" button on the dialog box. Once this button is pressed, the background of the screen will display the file being loaded into Excel and the resulting calculations that the application will perform on the given sheet.

The following steps represent the summary of data entry procedure:

1. press "Automatic" Button on Top Form. (Dialog Frame will appear);

2. click on type of data to be entered;

3. enter full path name of file containing that type of data;

4. press the "Load" button: the file will be loaded and required calculations will be performed (e.g., total columns for raw material input, other material input, products, and releases);

5. repeat steps two through four until all available data or at least the minimum required data are entered;

6. press "Complete" button signaling completion of data entry. Application will perform predictive calculations based on the data given; and

7. press "Back to main" button on the tool bar within Excel to return to user interface.

After entering data spreadsheets, the user continues the Excel application by pressing the "complete" button on the dialog frame (step 6). This button will signal to the application that data entry has been completed and based on the types of data that have been entered, additional spreadsheets are created by the application (Table 4). At the conclusion of these calculations, a message box stating that the data entry has been concluded will appear. At this point, the user is ready to exit the data entry application.

TABLE 4. Summary of calculation requirements and results of data entry.

Given:	Output:
Raw material inputs, other material inputs, products	Waste calculation
Raw material inputs, other material inputs, products [releases], managed waste	Waste calculation, production factors, managed releases, management factors
Raw material inputs, other material inputs, products [releases], managed releases	Waste calculation, production factors, managed waste, management factors.
Raw material inputs, other material inputs, products [releases], {managed waste/releases}, secondary raw materials	Waste calculation, production factors, managed waste/releases, management factors, final disposal and recycling factors.

Exiting Data Entry--After completion of extra calculations performed and entering the available data types, control will return to the user, and the user will be responsible for exiting the application by pressing a toolbar button. The toolbar button will perform the data transfer between Excel and the Archive database in the background. Exiting the data entry application in this manner allows the user who may be familiar with the capabilities of Excel to "play" with the data, i.e., explore different tabular and graphical functions within Excel using the data created by the application. To get a full understanding of this data however, the user is referred to the discussion on the formulas used in the calculations section.

Module Design--The following are the basic divisions of the modules used within the data entry section. Only the major procedures and functions have been included in this listing:

Data Entry: controls the user screen in general cases;

AUTO BUTTON CLICK(): sets up "Automatic" dialog box and displays it to user, called from "Top" sheet;

MAN BUTTON CLICK(): sets up "Manual" dialog box and displays it for user. Also called from "Top" sheet;

CANCEL_BUTTON(): cancels the Excel application;

BACKTO_ MAIN(): assigned to a box on a tool bar. It is used for the exiting data entry section after data entry is completed by user. BACKTO_MAIN will saved the entered data, and then call and Access function based in the Archive database to transfer the data into the database.

Automatic Input: controls the automatic data entry;

LOAD BUTTON_CLICK(): loads the user defined file into the workbook. It also calls functions to perform calculations based on the type of data that the new worksheet contains. Finally, it keeps track of what types of data have been entered and adjusts the dialog box accordingly;

DETERMINE_ ADATA(): determines what, if any, types of additional data have been entered into the system. Waste managed, releases, and managed releases are considered as additional data;

COMPLETE_BUTTON_CLICK(): signals completion of data entry. It first checks for the three minimum data types required; if all three are not present, it issues a warning to the user and does not allow the user to exit the data entry section. It then transfers control over to the control_calc procedure;

Manual Input: controls the manual data entry and dialog box. Similar to the automatic input module described above;

Total Calculation: computes the daily totals for all sheets;

COMPUTE TOTALS(): computes daily totals for all sheets and adds information needed for data transfer. Waste Calculation: used to compute the various predictive calculations;

WASTE_CALCULATIONS(): creates a new worksheet containing calculated waste values. These include the production factor, total inputs, and total waste using data from raw materials, other inputs, and products worksheets. It is called every time new data is entered into the system;

CONTROL_CALC(): using the information from the automatic entry and the additional data determination function, it controls the calculation of further predictive calculations dealing with waste management;

Managed Waste and Releases: computes the predicted values of waste managed and released. It will create at least two new tables depending on given input. Only called when either managed releases or managed waste values are given;

CALC_MFACTORS()/CALC_MFACTORS2(): calculates management factors. One is used for calculations when managed waste values are given and the other is used when managed releases are given;

CALC_MRELEASES(): calculates managed release amounts when managed waste is given;

CALC_MWASTE(): calculates managed waste amounts when managed releases are given;

CALC_MANAGED_RELEASES(): controls the calculation and creation of two new sheets: managed releases and the management factors used;

CALC_MANAGED_WASTE(): controls the calculation and creation of two new sheets: managed waste and the management factors used;

Calculate secondary material and final disposal: computes all of the needed information for secondary raw materials and final disposal amounts. It will create two new tables: one containing final disposal amounts according to types of waste, and one containing recycling factors used in this calculation. Can only be called when either managed wastes or managed releases are input to the system;

RECYCLING_FACTORS(): enters the formulas needed for computing recycling factors;

DISPOSAL_FORMULAS(): enters the formulas needed for computing final disposal amounts;

RFACTOR_TABLE(): takes computed values and moves them into a separate table;

DVALUE_TABLE(): takes completed disposal values and moves them into a separate table; and

CREATE_NEW_VALUES(): controls the creation of two new worksheets: d_rfactors and d_final_disposal.

Data Entry - Specific Information--The data entry implemented through the user interface is responsible for accepting a relatively small amount of needed data. The specific information collected by this system includes: information on individual materials input used within the process, costs associated with labor, machinery, miscellaneous factors, and measurements of different waste streams (Section 4). Within the system, only the material input information must be entered before the analysis screens can be viewed. The other information can be entered into the system either at the beginning or during the ISS testing. Like the bulk information, the ISS system can successfully be used without entering all types of available data.

Input Material Information--The specific information on the input materials within the process include the following:

* **name** - filled in by system according to bulk data entry;
* **inventory code** - code used by company or organization for the given raw or other input materials;
* **unit of measurement** - unit from daily measurement;
* **section of process where material occurs** - the section of the process where the material was measured and filled in by the system; and
* **unit price** - unit price of the material for a single unit.

In order to enter the analysis display section of ISS, the information must be entered into system. The data entry screen is found through the setup screen. For a new process, this data can only be entered after the bulk data entry is completed. However, if a previous process is being tested, this information can be updated once the user enters the setup screen. However, there is a warning: only one unit cost can be used for calculations. That is, if the unit cost of a certain parameter goes up or down over time, the ISS cannot accept more than one cost per parameter. The cost analysis cannot take into account parameter price changes over time.

Cost Analysis Information--In order to form a complete cost analysis study, extra information about the process must be taken into account. This extra information includes data on labor, machinery, and miscellaneous factors Section 4). This information is not required for the ISS to successfully run; however, it will offer the user a more complete view of the process under study. These data entry screens follow basically the same format: the user is allowed to update the information contained within the tables if desired, but is then required to specifically tell the system that a new piece of information is going to be entered. The following is a listing of the information collected for each of these types of data:

Labor/Employee: Description of job type.
Job type number.
Number of individuals employed at this type of job.
Salary for this type of job.

Machinery Depreciation: Description of machine type.
Machine type number.
Number of machines of this type used in process.
Cost for one machine of this type.
Depreciation rate of machine.

Miscellaneous Factors: Description of activity.
Type of activity.
Number of activities of this type.
Unit cost of the activity.

The format of the data entry windows for this type of information is prepared. The buttons on the bottom of the screen include arrows to view and update all records within the table. An update button, when pressed will clear the text boxes on the screen allowing for new information to be entered. The update button must be pressed only after the new information is entered into the system to record the new pieces of data. The cancel button is used to close the window and return to the system.

Waste Streams--Finally, the last type of information that can be entered into the system deals with measured quantities of specific waste streams. This type of information has been separated from the other data entry because in many systems this type of information may not be available at such a specific level. If this type of information is available, it can be used to form a more complete cost analysis of the process and potentially offer more opportunities to apply pollution prevention strategies.

ISS accepts waste streams into three main groups (names are chosen to be easily distinguished): vent flow, liquid waste stream, and waste stream. The data entry for specific information pertaining to the contents of these three waste streams expects the measurements for each type of waste stream to be stored in its own Excel spreadsheet file maintaining the same format as the data types entered through data entry for bulk information. The data entry screen for this type of information is also prepared. The user is asked to type the full path name of the data file and the type of waste stream that the file contains. When the ok button is pressed, the ISS will automatically find these files and enter them into the archive database and perform the needed data manipulation.

DATA STORAGE AND MANIPULATION

Data storage and manipulation in ISS is accomplished using two separate database files: the Archive and the Data Manipulation (DM) database. The Archive database is only used for storage of the information needed to study the process. No manipulation is done within this database. The DM database contains the necessary functions and queries to allow the user to study the observed process. The DM is a read-only file; it uses attached tables from the Archive database as its source of data. This has been done to limit the possibilities of data corruption.

Data Storage - Archive Database

The data storage function in ISS is accomplished using a single database file. This file is referred to as the Archive database. It is the foundation of the Information System Shell. The Archive database contains only the data tables and the macros used to control the acceptance of data from the data entry sections of the system. The user will never directly access this database. Once information is entered into the system, it is saved by the Archive database. This information can then not be changed or deleted by the user. This limitation has been implemented to ensure data integrity and eliminate potential errors by users. The Archive database is the only data file saved at the end of a testing session in order to be used in another testing session of the ISS.

An empty Archive database contains 13 tables. These tables are empty in the beginning; only their data dictionary is defined. Depending on the number of different types of data entered into the system, the tables corresponding to these types of data will be filled. The system, based on the user input, will determine which tables are to filled. In addition to filling the pre-defined tables the Archive database creates three new tables each time a new process is to be studied. These three tables, containing raw material inputs, other material inputs, and products quantities are defined dynamically, since they are created at run time. The following is a list of the tables defined and created by the Archive database:

1. Daily raw material inputs - created dynamically
2. Daily other material inputs - created dynamically
3. Daily amounts of products - created dynamically
4. Daily amounts of measured releases
5. Daily amounts of calculated wastes
6. Daily amounts of managed waste
7. Daily amounts of managed releases
8. Daily amounts of secondary raw materials
9. Daily amounts of final disposal
10. Daily values of management factors according to type of waste
11. Daily values of recycling factors according to type of waste
12. Material Information
13. Current name of industrial process and company using this system
14. Labor/Employee information
15. Machine Depreciation information
16. Applied Pollution Prevention Techniques
17. Miscellaneous Production factors
18. Waste Stream information: Vent Flow
19. Waste Stream information: Waste Stream
20. Waste Stream information: Liquid waste stream

For the data types numbered 1 through 10, the user will enter data into this database indirectly through Excel. By pressing the "back to main" button, the Excel application has been programmed to open the Archive database and then transfer the data into the Archive. This process has been automated to eliminate potential user errors and increase the system's user friendliness. For data formats that remain constant throughout different processes (e.g. waste, managed waste, managed releases, management factors, etc), the Archive database simply appends the information into the existing table. If however, the data is of type numbered 1, 2, or 3, that may change or be dynamic among different processes. The Archive will first check to determine if a table already exists. If a table does not exist, the application will create a new table and transfer this data into the table. If the table does exist, the application will append the data into the table.

For the data types numbered 11 through 20, data will be entered into these tables through the user interface using the methods for specific information (described in section Data entry). Data table number 12, material information is a special case. The contents of this table are based on the information entered in the Excel macro as well as the information collected from the user directly. The Archive database is responsible for taking the bulk information and extracting chemical names and data types to enter into the material information table. The rest of the required data is entered by the user through the interface of the system. The material information table has been designed in this way to improve the quality of data by enforcing consistency throughout the data and reducing the data entry performed by the user, thereby reducing the possibilities of error and data corruption.

The following describes the actions that the Archive database takes to develop a file for a given process:

1. Open Archive database.
2. Determine if all needed tables exist.
3. If all needed tables do not exist:
   - Create needed tables;
   - Transfer data from Excel into Archive;
   - Fill chemical information table;
4. If the tables do exist:
   - Transfer data from Excel into Archive;
5. Close Archive.

Module Design

Control: contains the driver program for the Archive database;

CONTROL_ARCHIVE(): determines if tables exist and takes the necessary actions depending on the result of determination.

Get Names: fills the input table with chemical information;

FILL_CHEMICAL(): contains the code to fill the input table successfully;.

GET_NAMES(): inputs the field names of the imported tables containing raw material inputs, other material inputs, and products, and enters them as records in the input table under the chem-name field. In addition, this procedure will also enter the original table name where the given material is originally located;

Input Archive: enters the user data into the appropriate tables either by creating new tables or appending the information into the already existing tables;

AMT_TABLES(): returns the number of tables within the Archive database at a given moment. Used to determine if all tables have been created;

APPEND_ARCHIVE(): used when tables already exist within the database and data must be appended into the tables;

APPEND_CALC(): enters data into the tables containing "calculated" values as well as tables with consistent format among processes. It appends the data into the existing tables.

CREATE_TABLES(): creates the needed tables for loaded data. These tables will not remain constant between different types of processes and are therefore considered to be dynamic.

DM Database Design

The DM database is responsible for the manipulation of the parameter tables in order to emphasize informative relationships occurring within the data. The DM is dependent on the Archive database for its data only. It is not dependent on a given process and the specific contents of the data represented by the Archive. Different Archive databases can be "plugged into" the DM and still provide a successful system operation.

In order to maintain data integrity, the user never directly views this database. All creation requirements have been automated so that the user may simply press a button and wait for the system to complete.
The following is a summary of DM database creation:

1. attach tables from Archive database;
2. create Queries using attached tables;
3. close Database and return control to user.

The informative tables, known as queries, that are created within this database are based on data referenced in the Archive database. These references are read-only, thus reducing the chance of data corruption. Information is created through these tables in DM rather than within the user interface in order to take advantage of the speed of the DBMS package. By creating these queries within DM, while there may be a lag time at the beginning of execution while the queries are formed, the remaining system will run smoothly and at a higher speed.

Data Queries

Data queries are only developed once during a testing session with ISS. These queries must be recreated every time ISS is run in order to maintain a DM that matches the Archive database used. The user is able to change the Archive used at the beginning of the system, but is not given such an option for the DM database. Recreating the queries in the DM does not take long and reduces the amount of memory needed for the system.

The DM database maintains 59 queries. The DM contains queries that organize the data into tables according to time frame requirements: there is a separate table for each type of data according to time frames: daily, weekly, monthly, and quarterly. While this may seem to take up much space, it allows a speedup in the interface by having the data in a format ready to be displayed rather than forcing the interface to both prepare and display the data, slowing the system down. In addition to time requirements, these queries are used to organize data for the display functions. For example, in displays containing all input material information, a join on the raw input material and other input material must be created.

Not all of these queries are created dynamically because certain data types have been carefully laid out and formatted so the contents are always constant, regardless of the data type. Measured quantities of release is one example of this type of data. All tables containing release data will be made up of five attributes: date, air emission, wastewater, solid waste, and total waste. However, certain data types are not constant throughout uses, i.e., for given processes, the contents of the data types vary. The dynamic data types that force queries to be created dynamically are raw input material, other input material, and product material. These tables can consist of a varied number of attributes because each attribute represents a material. Table 5 gives a listing of all queries created dynamically at start-up.

TABLE 5. Queries created dynamically by DM database at start-up

Basic Table	Daily Query	Weekly Query	Monthly Query	Quarterly Query
daily raw material input	daily_raw	w_raw	m_raw	q_raw
daily other material input	daily_other	w_other	m_other	q_other
daily product	daily_product	w_products	m_products	q_products
daily raw input material and daily other input material	daily_inputs	w-inputs	m_inputs	q_inputs

In addition to these queries if the user enters specific information on materials within one of the three waste streams, the DM data base will create twelve queries in order to allow the user to view information according to time frame requirements (Table 6). This is based on the same reasoning used in the creation of the queries for input and products materials, that each process may contain a different amount of materials within each of these waste streams.

TABLE 6. Queries created dynamically by DM database for cost analysis

Basic Table	Daily Query	Weekly Query	Monthly Query	Quarterly Query
daily vent waste flow	daily_ventflow	w_ventflow	m_ventflow	q_ventflow
daily liquid waste flow	daily_liquidwaste	w_liquidwaste	m_liquidwaste	q_liquidwaste
daily solid waste flow	daily_solidwaste	w_solidwaste	m_solidwaste	q_solidwaste

Module Design

Attach Tables: determines what tables are to be referenced from Archive database;

ATTACH_TABLES(): checks if Archive database is referenced for correct data. If not, it will create the reference from DM to the Archive database;

TABLE_ATTACHED(): determines whether a specified table is already attached by trying to select it in the database window. It is called from Attach Table;

Starting runs all needed query creation procedures during start-up;

DYNAMIC_QUERIES(): functions as the driving program for creating the needed queries.

Time frame provides the individual functions that are used to create the dynamic queries;

DAILY_QUERY(): creates the SQL code for queries containing daily information. These new tables contain an updated format to be compatible with the other time based queries for the same data material;

INPUT_QUERY(): creates the SQL code for queries containing input information, which combines data from raw material input tables and other material input tables;

MONTH_QUERY(): creates the SQL code for queries containing monthly sums for the materials used within the process;

QUARTER_QUERY(): creates the SQL code for queries containing quarterly sums for the materials used within the process;

WEEK_QUERY(): creates the SQL code for queries containing weekly sums for the materials used within the process.

Cost Analysis2 creates the queries containing specific information about materials within the specified waste stream. Queries then used as a basis for the time frame queries and cost analysis display.

COST_SQL(): creates the SQL for queries containing cost information for materials lost during production;

FIND_PRICE(): determines the price of a given material;

DAILY_LOST AMTS(): creates the SQL code for queries containing the daily sums for the materials measured within the waste streams. It is created to improve compatibility.

WEEK_LOST(): creates the SQL code for queries containing the weekly sums for the materials measured within the waste streams;

MONTH_LOST(): creates the SQL code for queries containing the monthly sums for the materials measured within the waste streams;

QUARTER_LOST(): creates the SQL code for queries containing the quarterly sums for the materials measured within the waste streams.

User Interface Design

ISS is a windows program created using Visual Basic for its user interface. Visual Basic has been used because of its compatibility with Access and Excel and ease of use. The interface serves as a unifying front end for the two applications being used.

Forms and Controls--

A form is an individual window used to either display system output or accept user input. Controls are text boxes, buttons, click boxes, etc., that appear on forms. These items accept user input. Each time the system is used, it is called a session.

In order to develop an overall idea for the entire system, Figure 11 is given. This diagram is a control flow graph of the ISS system. By following the transfer of control, users can determine where they are within the system. The dotted boxes around the Access modules represent hidden systems programming used to create information system. The user will never directly see these modules. Finally, display functions represent the hierarchical structure of the screen transition diagrams shown in Figures 12 and 13.

Overall System--The system is based on user input. Therefore, the development of the user interface has been based on the fact that some of the forms used for display will be dynamic. The only forms that are dynamic correspond to the dynamic queries; all forms dealing with the display of raw input materials, other input materials, products, or any combination of these three must be created dynamically. To accomplish this dynamic property within the user interface, grid controls have been implemented in all forms. These grid controls are similar to spreadsheet pages. By using grid controls, multiple columns and rows of data can be developed based on the user input. In addition to these grid controls, code modules have been developed to extract the needed data from the database and fill these grids.

Data entry in this system, as discussed above, is split between an Excel spreadsheet application and the forms within the user interface. These data entry functions have been placed within the system at the beginning of the flow of control. It is hoped that the user will enter in all relevant data at one time, at the beginning of the session.

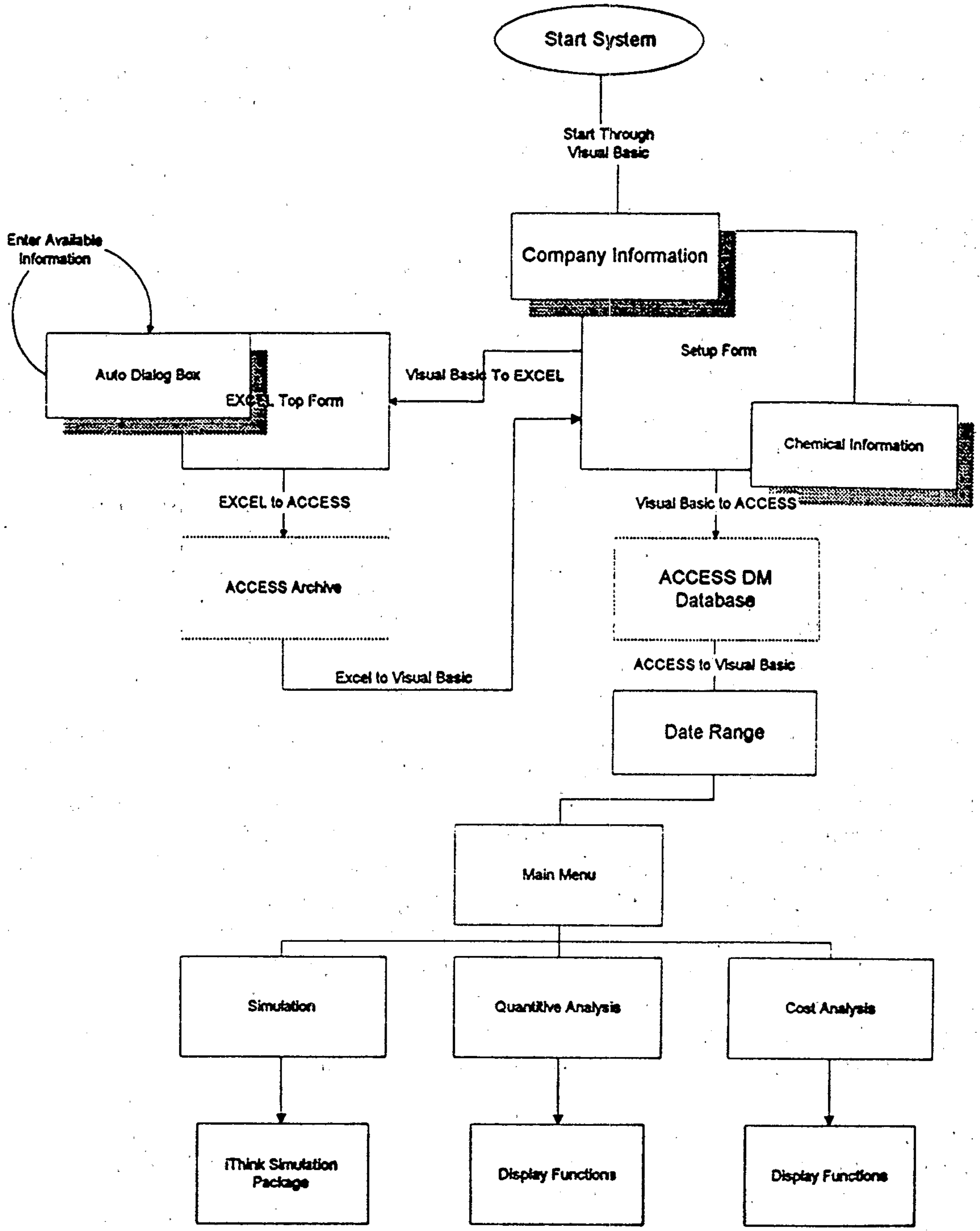

Figure 11. Control flow graph of the ISS system

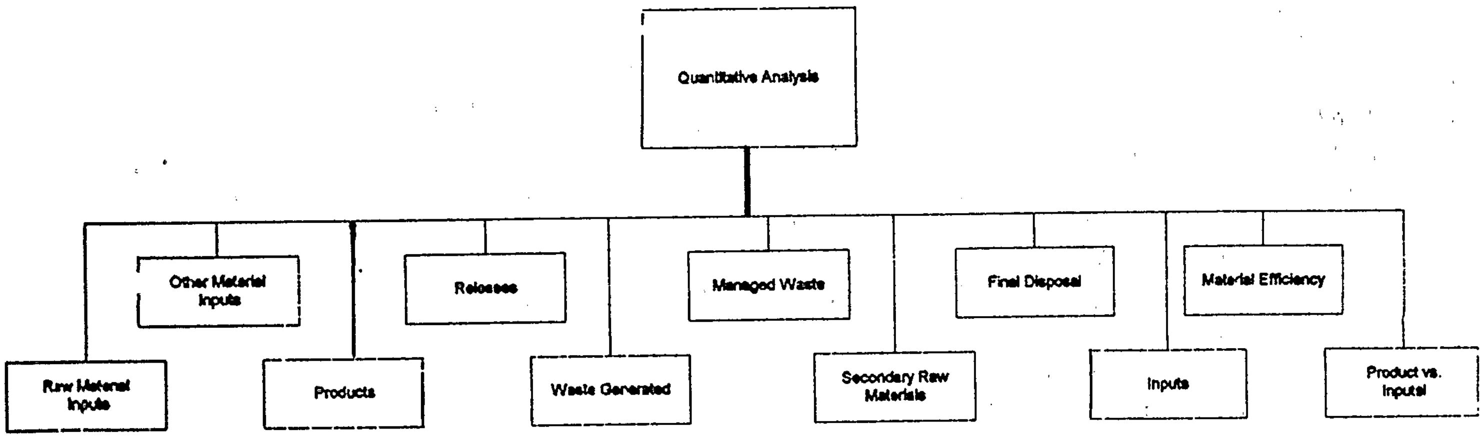

Figure 12. Screen transition graph - quantitative analysis display functions

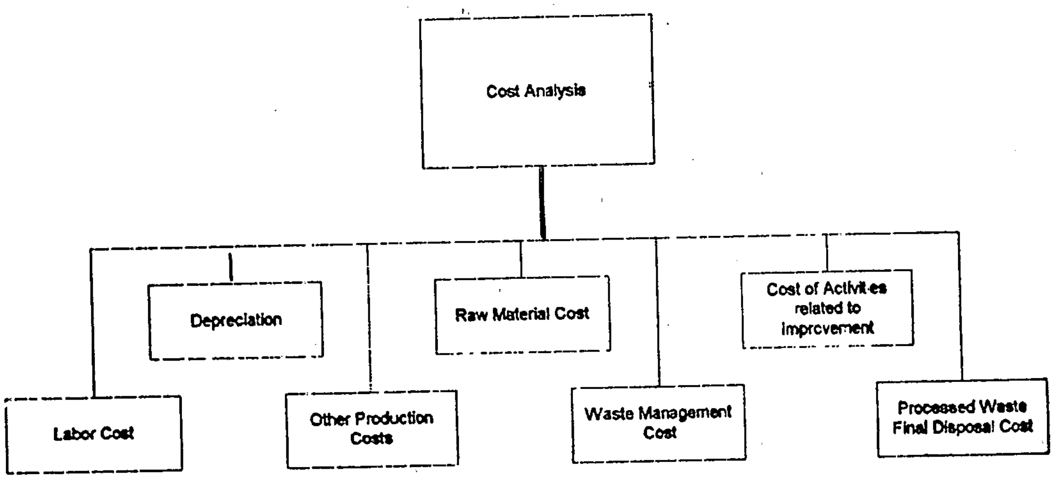

Figure 13. Screen transition graph - cost analysis display funcions

The user interface has been designed to allow as much freedom as possible in determining what to study while maintaining some control over the flow of events. The following lists some events that must be controlled and ordered in a particular way:

1. Data entry of bulk information must be done before the archive database can be created, as well as the creation of the DM database.

2. Material information can only be entered after the bulk information has been stored within the archive database.

3. DM database can only be accessed after the bulk information has been stored.

4. Time frame requirements can only be set after the queries within the DM database have been created.

5. Analysis display functions cannot be accessed until all costs within material information have been completed.

This control has been enforced by enabling and disabling certain control buttons at given points within the execution. This type of enforcement is also used within the display functions to limit the user to the displays containing information to be viewed.

<u>Common User Activities</u>--Throughout this ISS system, a set of activities exists that the user will expect to be able to complete. These activities relate to studying the available data and forming some conclusion based on the apparent trends. When attempting to study trends, it is sometimes beneficial for the user to be able to summarize or break the data into different sets according to elapsed time (i.e. a trend may become clearer when data is viewed monthly rather than simply daily). Therefore, within this system, these activities have been implemented using common controls and menu bars on each form.

Moving through the System: in order to move through the system, from whatever form has the current focus, the user can specify the next display by clicking on hot spots or control buttons located on the form itself. Another way to move from form to form within the system is to use the menu bars located on each form. Within the pull down menus, the user is offered the data type to view, and based on what type the user chooses, the display for that data type is brought up.

Grouping Data According to Time: when the user is faced with attempting to determine trends within the data, it may be easier to view the data according to a different time frame. The time frames within this system include: daily, weekly, monthly, and quarterly. This option has been implemented on these forms in a control button known as the time period button, and the View pull down menu. The time period button located on the form will always display the current time frame (the default is Daily). If the user decides to change the time frame, if using the time period button, the system will change the time frame according to the order daily, weekly, monthly, and quarterly. If the user is interested in viewing quarterly information, and does not want to spend the time going through the other time frames, the user may go directly to the quarterly time frame by using the View pull down menu. When using the pull down menu, the current time frame will appear with a check beside its listing. When either the time period button or View menu is used, both are updated to display the current time frame in use.

In addition to these common activities, the menu bars implemented on these forms allow the users to perform additional activities. The File pull down menu offers the user two additional choices other than Close: Print to print the current form, and Exit to quit the system entirely. The Graph pull down menu enables the user to go to a common graphing form where the user is given the choice of what types of materials to graph, based on the form that opened the graphing capability. Each menu contains a Help pull down menu.

Closing Forms: when moving around the system, the user will be forced to close certain forms when the screen becomes too cluttered. The cancel button and Close menu option under the File pull down menu can be used in this case. The cancel button on a form, when pressed, will close the form and open the form that appears above it in the tree structure of the transition diagram (Figures 12 and 13). The Close option on the other hand, will only close the current form and not open another form.

Studying Individual Pieces of Data: while the display forms will show only one data set at a time, it becomes obvious that in order to make any type of decision based on these data collections, all of the data must be able to be viewed by the user. Because this system is based on databases, two arrow buttons have been implemented on these forms to be used in traversing the data. When each button is pressed, the form will display either the next data set or the previous data set to the user. These buttons have been programmed to sound a beep if the user attempts to move to a data set that does not exist either because the user has reached the last data set in the table, or has reached the first data set in the table.

Using the ISS system--

Starting ISS: in order to begin a session with ISS, double click the ISS icon. The first form that will appear deals with the Archive database. This window offers the choice to either use a Previously developed Archive file, or create a new Archive. Assuming that this is the first time the user is running ISS, a new Archive is chosen. If a previous Archive database were chosen, the summary found below would still be followed, but rather than offering the user the ability to add new data in step 2, the button will appear with a label "Add Data". This button, as well as the "Material Information" and "Work System" button will be enabled, allowing the user the choice of either continuing with the current Archive as is, or adding new data to it.

The following is a summary of the actions that must be taken by the user in order to set up a study for a new process:

1. From Setup menu form, click on grey factory button. This will lead to the setup form.
2. Enter bulk information through Excel application by pressing the "New Data" button.
3. User will be in Excel application. Complete data entry within Excel application and return to interface.
4. Wait until computer has stopped working.
5. At this point, the "Material Information" button and the "Work System" button will be enabled (i.e., the user will be allowed to click on these buttons and receive a response). Enter material information by clicking on respective button.
6. Once the material information has been entered, click on the "Work System" button to create the DM database. Wait until computer has stopped working.
7. At this point, the Date Range box will appear on screen. The user is to choose the date range for the current session.
8. The setup form has now been completed, to continue on to display functions or specific information data entry press the "OK" button.

At Step 7, the user is asked to determine a date range for use within this session. This date range will serve as a filter for the rest of the system; only data falling within that date range will be displayed for the user. The user is allowed only to set the date range at this time. The date range form is prepared. It is made up of two list boxes: the first one, the start list box will contain a listing of dates within the system. When the user highlights and clicks on a given date, the end list box will contain all dates following the start date. This has been done to eliminate the possibility of the user entering an ending date that may come before the start date. If the user chooses to do so, all data can be viewed by highlighting the check box located on the form. This form will not disappear until the user enters either a starting and ending date or checks the all data box. At this point, the system will continue on to the display functions.

Concluding a session with ISS: the system can be terminated only through one form, the Exit form. This form is reached through the setup menu. The Exit form will ask the user for a full path name to save the current Archive database. The current Archive must be saved under a new name in order to run the system again. Once the Archive database is stored under a new name it can be used in future sessions of ISS.

Development of Dynamic Forms--

In this system, most of the forms can be designed and created before run time. However, as in the DM database, those forms which are based on raw material inputs, other material inputs, and products must be created at run time. This has been implemented in order to make the system able to accommodate a variety of processes. The user interface creates these screens based on usage. If the user does not reference forms, the forms are not created. The forms display the chemical name, the amount of the chemical, the unit of measurement, the unit cost, and then the total price of the amount of specific chemical. The number of rows displayed is determined at run time.

Constant Forms--

All other forms not based on raw material input, other material input, and products data can be developed during design time. These forms deal with waste and release amounts. Appendix ISS - Visual Basic Interface gives a diagram of each form and the modules that control it.

Quantitative Analysis--

The quantitative analysis section is based on the diagram in Figure 7. This figure represents the relationships among all types of data involved within the process. This diagram has been implemented with "hot spots" that allow a user to position the cursor on top of an area and when the mouse is clicked, a new form will open for the user. "Hot spots" are located on top of each box describing a type of data material. By clicking on one of these boxes, the user will be sent to the corresponding display form. In addition to these "hot spots", there is a listing of common comparisons made with this type of data. The user is free to view those display forms by double clicking on the desired description. The appearance of this form will change according to the amount of different types of material entered into the system. The "hot spots" corresponding to material data that has not been supplied or calculated for the current session will be disable-appearing grey to the user and performing no action when clicked upon. This has been implemented in order to aid user in testing and limit the possible choices that could be made by the user. The hierarchical structure of the system is shown in Figure 7. This type of structure has been implemented in order to facilitate ease of learning and high retention rate for the user.

Cost Analysis--

The cost analysis of this system will follow the same pattern found in the quantitative analysis. The basis for this section is shown in Figure 8. It is similar to the form used by the quantitative analysis in its use of "hot spots" and the limitation of user choices according to available data, but cost analysis contains different types of information. However, it does not offer the user the ability to view common relationships among the different types of data. Within the cost analysis however, data entry screens can be brought up to update information dealing with labor and employees, machinery, miscellaneous factors, and applied pollution prevention techniques.

Future Work

With the completion of this ISS, the true test of any software package is its acceptance by the users. The system will be distributed to interested users in order to get feedback. It is hoped that this system will be valuable to the user. The following is a listing of subject areas and potential extensions of this work.

Data Entry - A major concern throughout this project has dealt with the measurements of materials within different parts of the system. Because this system has been designed to deal with many data types, not all of which are required by the system to successfully execute, formatting requirements have been enforced. Future work in this area can include:

* A better way of formatting data coming into the system. This method should be developed and improved upon based on user feedback.

* A better way of determining and defining the types of data coming into the system. A prime example is in the waste streams: for some processes, all three types of waste may be measured, allowing the system to simply create a total for these three wastes. Other organizations will measure only the total amount of waste coming out of the process rather than separating it into the three types of waste. Not only does this affect the methods of accepting this data into the system, it also plays a role in calculating the predictive formulas based on these measurements.

Output of System - At this time, the only output that ISS produces is seen in its display functions. In the future, a report capability could be added to this system. At this time, the report function could be implemented as a call to the DM database. This would involve creating dynamic reports within the DM database. It is not clear how much time the creation of these reports may require.

Display Function - Through actual use of this system, it can be improved by adding display forms for relationships among the data that may not have been included in the system. These relationships may be specific to a process or organization, but can be included within this system if needed.

Updating the System - As mentioned above, display functions could be added to the system if appropriate. However, as an extension to this system, a "create your own relation" could be added. This would allow the user to create a useful relationship within the system. This would allow the system to grow according to the needs and requirements of the organization.

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