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Data mining OIPEA database for waste and productivity enhancements in manufacturing units

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ABSTRACT

Mining of the OIPEA Database for Waste and Productivity Enhancements

Jaison John Ipe

Small and medium-sized manufacturing plants (those with fewer than 500 employees) represent more than 98 percent of the more than 374,000 establishments in the U.S. manufacturing industry, 64 percent of employees in the total manufacturing labor force, and more than 42 percent of total manufacturing energy consumption.

In 1976 the federal government started funding industrial energy audits for small and medium sized manufacturing firms under the auspices of the Industrial Assessment Centers (IAC) that are spread throughout the U.S. The data collected from the hundreds of energy audits that are conducted each year is collected in a database maintained by the Office of Industrial Productivity and Energy Assessment (OIPEA) at Rutgers University.

This database contains a wealth of information about small and medium scale industries that are spread throughout the U.S. The objective of this research it to develop a database querying tool to analyze the database to elicit useful information about waste and productivity issues to help research any trends that may exist in the data.

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INTRODUCTION

Corporate Overview

For much of the twentieth century, US manufacturers were unchallenged in an environment in which conservative approaches to both process technology and managerial techniques produced successful results. Competition from overseas manufacturers was minimal and the domestic market encouraged product standardization and economies of scale. The companies modified strategies and processes in minor ways in response to shifting economic circumstance [23].

In the present scenario of globalization, markets across the world are becoming extremely competitive. Domestic markets, which were once upon a time, considered secure, have been beset by a growing number of foreign competitors producing high quality products at low prices. In a number of areas such as employment, capacity utilization, research and development expenditures and capital investments, trends in US manufacturing over the last decade have been unfavorable or have not kept pace with major competitors [23]. There is substantial evidence that many US manufacturers have neglected the manufacturing functional aspect have over emphasized product development at the expense of process improvements. The trend among the manufacturers was to spend dollars on product technology, neglecting the process technology aspect. Thus they did not make any adjustments that would be necessary to gain the vital competitive edge.

The United States has sustained a steady erosion of competitiveness and overall manufacturing strength over the past couple of decades which is attributed to deficiencies in standard management practices in manufacturing.

Growth in manufacturing productivity (output per man-hour) in the US during the past three decades has been among the lowest in the industrial world. Manufacturing trade surpluses show heavy deficits and the increase in manufacturing outputs could be attributed to a good extent to defense production. Employment trends have also been unfavorable in most of the manufacturing industry [23].

The general trends indicate that competition, both international and domestic, will be more intense and that factors determining competitiveness will differ substantially from past experiences. Strategies and priorities designed to enhance competitiveness in the mid-twentieth century will be far less effective in the future. It is imperative that manufacturing companies across the United States adopt new management techniques, organizational structures and operational procedures to stay afloat in the global market.

1.1 Waste Management and its Importance:

For any given manufacturing facility it is inevitable to avoid any sort of waste streams. Wastes are a part of any process and have to be appropriately dealt with. Waste generation is most often connected with air and water pollution too. The effects of waste generation are two tiered. Loss of revenue due to costs involved in waste handling and disposal and decrease in productivity due to material wastage. Consequently there is an increase in operational costs, ultimately leading to higher manufacturing cost of the product.

With rapidly changing process technology the types of wastes generated also change. It is observed that the environmental impacts of these wastes get complex. Newer solutions are required to handle these complex problems. Subsequently regulations imposed against industrial wastes are becoming increasingly stringent, mandating the use of costly equipment for effective management and treatment. The annual cost for compliance with environmental regulations, set up by the government, has increased by 300% over the last three decades, without effectively eliminating pollution [12]. This is a major concern for small and medium sized manufacturing industries since the mammoth costs associated with waste management would reduce their overall profits.

Some of the general categories of waste management opportunities that is observed in manufacturing processes and considered relevant include [22]:

1. *Operations*: Process specific opportunities, material applications, slag management, process elimination, product specifications and byproduct usage.
2. *Waste Stream Contamination*: Vapor dragout reduction and effective washing techniques.
3. *Equipment*: Fault tolerance, Process specific upgrades, Design, Automation and System Monitoring.
4. *Post Generation Treatment*: Treatment of used process solid and liquid wastes.
5. *Water Use*: Reduction in Usage, Regulate water quality and water treatment.
6. *Recycling*: Liquid and Solid Waste Streams.
7. *Waste Disposal*: Sludge maintenance and combustion of waste products.
8. *Maintenance*: Cleaning, Degreasing, Preventive Maintenance, Spillage avoidance of process material and Leak Reduction.
9. *Raw Materials*: Solvent use reduction, material substitution and recovery,

1.2 Productivity Enhancement and Its Importance

As organizations encounter increasingly competitive global market place, improving productivity remains an urgent and essential process. A company's ability to offer products or services quickly, efficiently and inexpensively is a differentiating factor that can determine its success. Increasing the output and value of products while utilizing the same or fewer resources have become an imperative for companies seeking to encounter and survive the fierce global competition.

As mentioned earlier manufacturers in the United States had over emphasized the aspect of product development at the expense of process improvements. Some of the general categories of productivity improvement opportunities that is observed in manufacturing facilities and considered relevant include [22]:

1. *Manufacturing Enhancements*: Bottleneck reduction and defect reduction.
2. *Purchasing*: Raw materials, ancillary materials and capital investments.
3. *Inventory*: Just in time, production lot size optimization and old stock elimination.
4. *Labor Optimization*: Scheduling, practices & procedures, training, automation.
5. *Space Utilization*: Floor layout and rental space.

1.3 EADC/IAC Program

In 1976 the US Department of Energy (DOE) founded the program for industrial energy assessments for small and medium sized manufacturers. The program called the Energy Analysis and Diagnostic Center / Industrial Assessment Center (EADC/IAC) is funded through the Office of Industrial Technologies' and is a major conservation initiative of the US Department of Energy [16].

EADC/IAC involves teams of college/university engineering faculty and students who perform one-day audits of industrial facilities. During the audit, pertinent information about the plant machinery, processes, energy consumption, utility charges, waste generation and other necessary details are collected. This information is then extensively analyzed to suggest suitable recommendations. Initially the EADC/IAC's concentrated only on energy consumption and conservation opportunities. But of late, the audit teams have been challenged to incorporate waste minimization and productivity enhancement opportunities also.

After the visit, a written report is prepared for the plant personnel containing the assessment recommendations (AR’s), Waste Minimization Opportunities (WMO’s) and Productivity Assessment Recommendations (PAR’s). The AR’s, WMO’s and PAR’s summarize the opportunities for energy conservation, waste minimization and productivity enhancement respectively and also provide the calculated cost savings, recommendation implementation costs and the pay back period for each. This service is provided free of cost to small and medium sized manufacturing units satisfying certain qualifying criteria with regards plant size, number of employees, annual sales turnover and total energy costs. The qualifying facilities could benefit vastly in terms of gaining improved technical knowledge and revenue savings.

Since the inception of the program in 1976, it has grown in strength from four schools to 36 universities operating the IAC’s and plans for further growth would expand the program to as many as 66 institutions by the turn of the century [16].

1.4 Office of Industrial Productivity and Energy Assessment (OIPEA)

Rutgers University established the Office of Industrial Productivity and Energy Assessment (OIPEA) in 1992 to assist industries in energy, waste & pollution and productivity issues. The aim of the OIPEA is to provide a range of engineering extension services to the community through the creation and maintenance of partnerships among government, businesses, interest groups and educational facilities. The OIPEA is a part of the Department of Mechanical and Aerospace Engineering, located in the College of Engineering on Busch Campus in Piscataway, New Jersey. [16].

As one of its primary functions, OIPEA contracts with the US DOE as a field manager of the EADC/IAC program. Rutgers University operated an EADC/IAC from 1986 to 1992 and in October 1992 started its field management duties. Currently OIPEA subcontracts with fifteen universities nationwide to operate centers. Since 1992 the OIPEA has been managing the Industrial Assessment Centers. The OIPEA has been managing and maintaining databases for the department of Energy and the Environmental Protection Agency, among many others.

1.5 Database Management Systems

Decision-making is an integral part of our lives. Some of the decisions to be carried out are simple and may be considered trivial. Other decisions are much more complex and could involve hundreds and thousands of dollars. To make an intelligent decision in a given situation, we require information or data about the situation.

Data Base Management Systems or DBMS have come into vogue in recent years. Their numbers and usage have increased tremendously in a very short time. Many organizations have looked to a DBMS as a panacea for their data processing problems.

1.5.1 DOE Industrial Assessment Database

Since its beginning, the IAC has stored such data in two comprehensive databases and it is available to the general public on the World Wide Web. Each of the hosting IAC schools contributes to these databases every time its staff performs a new energy assessment. To date, records have been kept for over 8,000 industrial site visits, including more than 60,000 recommendations to reduce the consumption of energy, minimize waste and improve productivity nationwide. Because of the large amount of available data and the diversity of places from which it comes, it is assumed that the databases are representative samples for manufacturing industries of all types (SIC 20-39). Thus, the data can theoretically be used to make correlation and predictions for similar industries.

In developing a DBMS for the data compiled by the IAC, it is first necessary to explore the contents of the two existing databases since these data determine the extent that inferences can be made. The two databases referred to, are called the Assessment Database and the Recommendation Database.

1.5.2 Assessment Database

The first of the two databases is referred to as the Assessments database. The type of data contained in this database varies. For example, there are general data collected that can be used to describe a plant. Included in these are SIC, annual sales, operation hours, number of employees, and plant area -- most of which can be found in a standard Manufacturing Directory. In addition to such general information, there are other data that deal more directly with the conservation of energy, waste minimization and productivity enhancement issues. These include annual costs and amounts of energy consumption for each type of energy resource used (i.e., electricity, natural gas, etc.), number of energy conserving opportunities that are found at each plant, types of waste generates, costs for waste management as well as information on productivity assessments. A complete listing of the contents of this database with the description is given in Table 1 [22].

The Assessment table starts with the “Id” field. This field is the unique identifying number given to all records in table based on the EADC/IAC name and the report number assigned to it. This field is unique to this table but not to the recommendation table. This allows one to many relationship between the two tables. This is discussed in the System Design section of this report. It field “EADC_IAC is the unique identifier assigned to each participating school. “Repnum” is a numeric field assigned to the report number of the plant visit. This is assigned by the school that does the visit. “Visitdate” specifies the date of the plant visit. “SIC” field denotes the standard Industrial Code that represents the principal product manufactured by the plant. The "Sales" field specifies the annual sales in dollars for the plant reported by the plant personnel. "Employees" denote the total number of employees reported by the client. As the name suggests "Plant_area" specify the total plant area in square feet used for production. "Resources" stand for the number of resources tracked at the plant. For example the plant could be using natural gas and electric power, making "Resources" = 2. "Nrgcosttot" is the total energy cost for the client from electric, natural gas, coal, oil and all other types of fuel. "Wastcosttot" is the total waste cost for the client. These include cost of water and solid waste disposal, non-hazardous liquid and solid, hazardous liquid and solids and gaseous waste in dollars. "Fy" is the fiscal year in which the assessment was made. "St" is the state of assessment.

Field	**Type**	**Description**
Id	Character	Unique identifying number given to all records based on EADC/IAC name and Report Number. This number is used when linking the two databases.
Eadc_iac	Character	The identifier assigned to each EADC/IAC.
Repnum	Numeric	The number assigned by the EADC/IAC to their visit and subsequent report.
Visitdate	Date	The date the assessment was performed.
SIC	Numeric	The standard Industrial Code that represents the principle product manufactured by the plant.
Sales	Numeric	The annual sales in dollars for the site reported by the client
Employees	Numeric	The total number of employees on the site as reported by the assessment client.
Plant_area	Numeric	The total amount in square feet area used for production.
Products	Character	Principle products of the plant (in words).
Resources	Numeric	The total number of resources tracked at the plant.
Produnits	Numeric	The units of production for the principle product.
Prodlevel	Numeric	The total number of units produced annually as reported by the assessment client.

Prodhours	Numeric	Client reported annual production hours.
Numars	Numeric	The total number of recommendations listed in this report.
Fields 15-38	Numeric	The annual usage and cost of electricity, natural gas, fuel types, coal, wood, paper and others taken from actual bills provided by the client prior to the assessment.
Nrgcosttot	Numeric	Total energy cost for this client. Figure is produced by summing the energy costs reported in columns 15-38.
Fields 40-51	Numeric	The annual production and cost of waste water disposal, non-hazardous liquid and solid, hazardous liquid & solid and gaseous waste in dollars and waste stream units.
Wstcosttot	Numeric	Total waste cost for the client. Figure is produced by summing the waste costs reported in columns 40-51.
Comments	Character	General comments about the assessment.
Fy	Numeric	The fiscal year in which the assessment was made.
St	Character	The state in which the assessment was made.

Table 1. Fields in the Assessment Database

1.5.3 Recommendation Database

The Recommendations database contains information on the outcome of the energy assessments. Thus, specific recommendations are coded and recorded in this database. The recommendations included in the database vary in complexity. A typically simple recommendation might be to either reduce lighting in an excessively lit area or to replace existing lighting with high efficiency lighting. Other recommendations are more elaborate. An example of such elaboration might be to recover waste heat from a stack to provide some alternate means of generating electricity. The Recommendations database further includes data dealing with both the cost savings and energy savings of each resource that is used to provide energy. There is also data kept on the implementation of the recommendations. This data, however, is provided six months after assessments are performed. The time delay in its data entry occurs to provide companies adequate time to implement the recommendations suggested by the IAC. The contents of the Recommendation Database are listed in Table 2 [22].

The first field in the recommendation table is the "Superid". This field is the combination of the "Id" and "Repnum" fields in the Assessment Table. This is also an unique field. "Ar_number" is the numeric recommendation number that appears sequentially in the report. The "Appcode" field represents the specific application the recommendation is going to affect like processes, raw materials or other applications. "Arctype" specifies the recommendation type. The number '2' for Energy, '3' for Waste and '4' for Productivity. "Arc" is the code that represents the specific recommendation made. "Impdate" is the client reported implementation date.

Field	**Type**	**Description**
Superid	Character	The unique identifying number given to all records based on EADC/IAC name and report number. This number is used when linking to the assessment database.
Ar_number	Numeric	The recommendation number sequentially as it appears in the report.
Appcode	Character	Application for recommendation.
Arctype	Character	Recommendation type.
Arc	Character	The code representing the specific recommendation made.
Impdate	Date	Client reported date of implementation of this recommendation.
Impstatus	Numeric	Client reported implementation status of this recommendation.
Impcost	Numeric	Client reported implementation cost.
Impconser	Numeric	Client reported amount of energy conserved upon implementation of the recommendation.

Impsaved	Numeric	Client reported amount of money saved upon the implementation of the recommendation.
Psourccode	Character	The primary resource code per 'Resource Identification Code'.
Pconserved	Numeric	The amount of primary resource conserved.
Psaved	Numeric	The primary resource's dollar savings for this recommendation.
Ssourccode	Character	The secondary resource involved in this recommendation.
Sconserved	Numeric	The amount of secondary resource conserved.
Ssaved	Numeric	The secondary resource's dollar savings for this recommendation.
Tsourccode	Character	The tertiary resource involved in this recommendation.
Tconserved	Numeric	The amount of tertiary resource involved in this recommendation.
Tsaved	Numeric	The tertiary resource's dollar savings for this recommendation.
Rebate	Logical	Indicative of whether the recommendation included a rebate for implementation.
Incremental	Logical	Indicated whether this recommendation is to be implemented on an incremental basis.
Descript	Character	Description in words of the individual recommendation.

Table 2. Fields in the Recommendation Database

"Impcost" is the client reported implementation cost. This is obtained by calling the client after a certain period of time and obtaining feedback. "Psourccode" is the primary resource code of the recommendation. "Pconserved" is the amount of primary resource conserved. For waste recommendations the units are in pounds and gallons. "Psaved" is the primary resource's dollar savings for the particular recommendation. Similarly "Ssourccode" and "Tsourccode" stand for secondary resources and tertiary resources respectively. "Descript" is the field that allows for free text entry of a brief description of the recommendation

1.6 Need For a System.

As mentioned earlier, the need for waste and productivity management by manufacturing facilities is of utmost importance. Many new initiatives are being designed to combine industrial innovations with flexibility to help small manufacturers cut operational costs. Most of these manufacturing units throughout the United States lack the much-needed information on these updates. Therefore there is an urgent need to make accessible the vast information available in this field.

Just as with many organizations, the IAC has a data warehouse where data is routinely stored and not used efficiently, or sometimes not used at all. This may occur because of a lack of awareness of what to do with the data or simply a lack of how-to knowledge necessary to do it.

With the rapid development of computing tools, the task of building a decision support system to aid manufacturers is becoming very convenient. In any event, making key decisions with useful information is always preferable to using the traditional "seat-of-the-pants" method. By developing a Database Management System, the problems normally encountered with data manipulation often become minimal as finding correlation and inferences become a much easier task. The need for a DBMS is justified by our frequent observation that several opportunities for waste minimization and productivity improvement are overlooked by the manufacturing industries.

1.7 Research Objectives

The main research objectives can be summarized as:

1. Designing and developing a Relational Database Management System (RDBMS) program to extract required data from the OIPEA database to meet the waste and productivity objectives.
2. Validate workings of the program.
3. Perform sensitivity analysis and derive knowledge from the OIPEA database using this program.

In the two databases defined, there are 80 fields and more than 65,000 records making is obvious that there is a lot of data in both databases. This stored data is nothing but information about various facilities visited and different types of recommendations, savings in terms of both dollars and energy units, suggested by the different IAC's throughout the US. The data also contains various types of energy conservation, waste minimization and productivity enhancement solutions possible for different types of manufacturing units in different states for the past decade and a half.

The main aim of this research is to convert this raw data into meaningful information. This information is important for various people such as industrialists, utility companies, IAC's, government agencies and various other decision-makers. Knowing what kinds of savings are possible in different areas will definitely help personnel from the industries. By getting meaningful information, a particular company can compare itself with similar companies throughout the nation or in a particular region. IAC's could evaluate themselves with respect to others throughout the nation. There are also many other kinds of trends, which could be retrieved from this database and made use of.

1.7.1 Waste Minimization Objectives.

Based on experience and analysis from the various industrial audits conducted by the various Industrial Assessment Centers, it is very evident that the costs due to waste generation is a serious factor that affects the bottom line of small and medium sized manufacturing units. Reduction or minimization of these costs means a subsequent increase in profitability and revenue. The increase in revenue can be related in direct proportion to reduction in waste costs.

From the standpoint of waste minimization, the overall objective of this research is to identify the different avenues that small and medium sized manufacturing units could reduce waste costs. The software that is to be developed should query the database and provide the different factors affecting waste cost generation. The different factors could be summarized as location of the plant, Standard Industrial Codes, Size of the plant, production hours, plant area and more. The decision support tool should provide data analyses with graphical outputs. These would enable the user to study comparative analyses and make useful conclusions. This would tremendously help strategize operations. The final result should be to maximize revenues and minimize waste costs.

Types of recommendations, implementation costs and savings from implementation are the other relevant data that can be used effectively.

1.7.2 Productivity Improvement Objectives

Productivity improvement is a relatively new area where the Industrial Assessment Centers are trying to help the small and medium sized industries. Similar to waste minimization objectives the increase of productivity of processes in an industrial unit translates to increased revenue generation. The objective of this research in terms of productivity improvements is to query the database for information on these issues. Like waste minimization, the factors that affect productivity are type of plant operation or SIC, annual sales, plant area, number of employees, production hours and more.

The software developed should be able to query the database and retrieve information on productivity enhancements. The tool should also provide data analyses with graphical outputs. With these analyses the user should be able to have comparative studies that would benefit the plant. Since productivity enhancement suggestions are fairly new to the IAC's compared to energy assessments, the amount of data collected is less. Also since the quantity in productivity analyses could be very varied the database does not specify enhancements by units. The relevant data that could be gathered from the fields are the savings from productivity enhancement suggestions and implementation costs.

1.7.3 System Development Objectives

A good data retrieval system is of utmost importance to get this sort of information. The aim of this particular research is to design and develop a user friendly graphical user interface which can retrieve any sort of information needed by the end user, quickly and efficiently. Another key aspect of this software to be considered during the design stage is it’s ability to provide sensitivity analysis. This can be implemented by displaying the retrieved data in the form of graphs so that the truths and trends of the data is easy to understand. A few examples of some trends that could be shown using this system are :

- Facility Location v/s Cost of Waste Management.
- Average Waste Costs v/s Plant SIC.
- Productivity Enhancement Savings v/s Plant SIC.
- Average Annual Plant Sales v/s Waste Generation Costs
- Waste Minimization Savings v/s IAC.

These are just a few examples of queries that can be generated to bring out certain trends in data available. For the proposed kind of system to work effectively, the software to be developed needs to be fast in retrieving data, should provide excellent graphical interface and be user-friendly. It should provide for sensitivity analysis of the retrieved data and provide graphical output and should also have the ability to interact effectively with the database. As a graphical user interface, it is proposed that Microsoft Visual Basic be used as it is known to provide the best front ends for database applications. A system diagram enumeration the various steps in the querying process is shown in the next section.

1.8 Systems Diagram

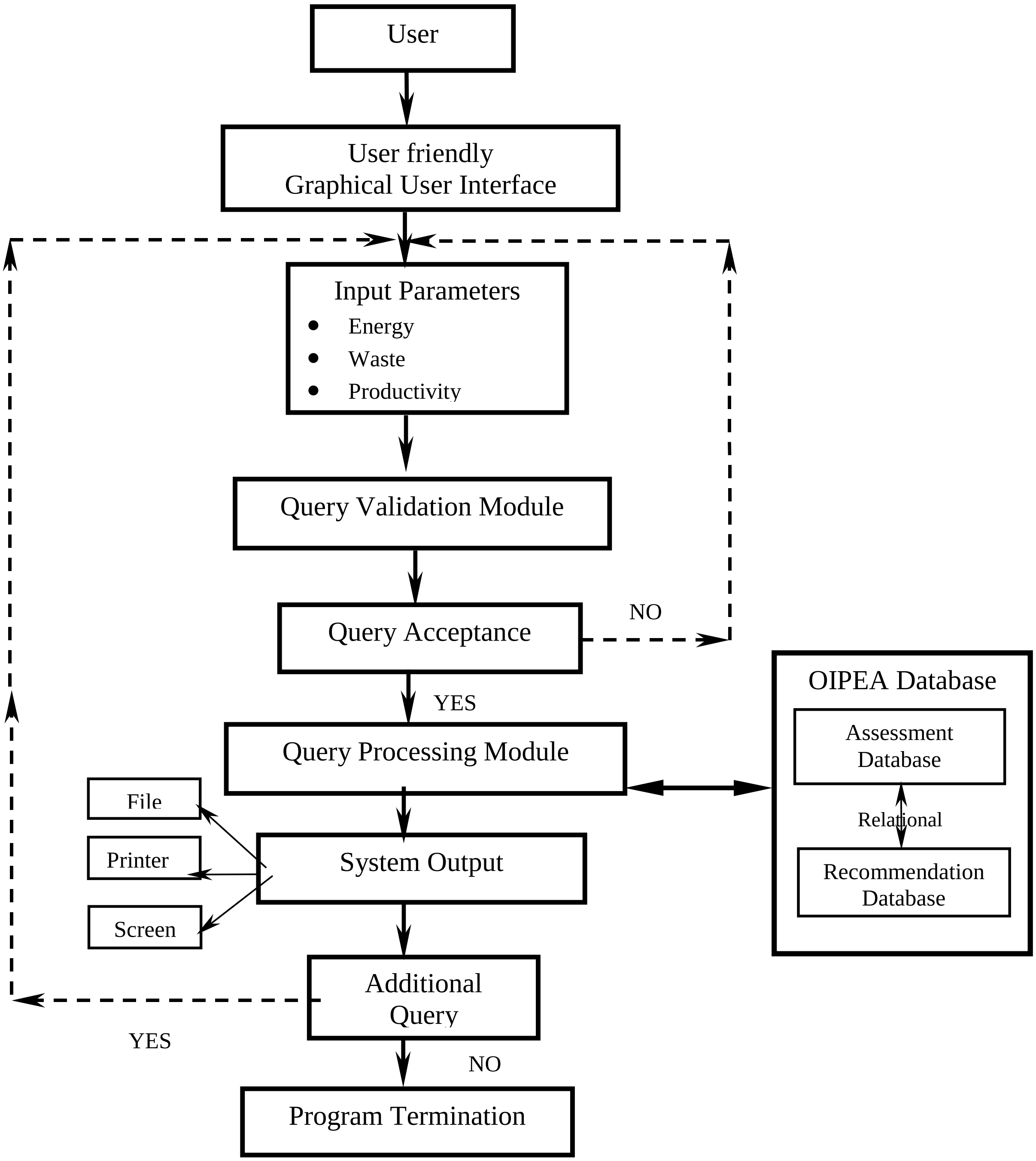


Figure 1. System Diagram

1.9 Conclusions.

This chapter has essentially highlighted the importance of waste minimization and productivity improvement to the manufacturing industries. Valuable data on the various aspects of manufacturing have been collected by the IACs over the last decade and half. A system to effectively use this data to make inferences has been suggested. The development of a relational database management system would vastly benefit a large number of small and medium sized industries across the US to curtail unnecessary expenditures and increase revenue generation.

CHAPTER 2

LITERATURE REVIEW

In the past considerable amount of research has been done on waste minimization in manufacturing industries. With respect to productivity enhancement, there has never been a collective effort to compile information except by IAC, because productivity issues are unique and vary from one manufacturing process to another. This chapter intends to explore the information on former research as a background required to substantiate the development of the proposed relational database management system.

2.1 Research on Waste and Productivity Management.

A database was created by Licis, Skovronck and Drabkin [19] that could be used as guidance by the EPA for the development of a research strategy for pollution prevention and waste minimization. Analysis of a short list of industries that were identified was carried out by gathering additional information and discussing problems. Higgins [12] studied an initial series of reports meant to evaluate the effectiveness of waste minimization projects at government owned manufacturing and maintenance facilities and prepared a pollution prevention hand book which updates the available expertise on techniques applicable to waste water, solid waste in addition to hazardous waste. He covered a broad range of industries including maintenance facilities, machining and metalworking, solvent cleaning etc. and dealt with waste streams associated with each of them.

Ottinger [24] has in his publication recommended methods of reduction, naturalization, recovery and disposal of hazardous wastes. The compilation runs up in sixteen volumes and gives extensive details of various hazardous chemicals that one could possibly encounter in any industry, their sources, storage, regulations, container requirements and operator safety precautions while handling them. Avendt [2] suggests a series of steps for conducting a waste minimization assessment and discusses means of inventory management for productivity improvement. Kirsch and Looby [18] discuss their pilot project at the University City Science Center to assist small and medium size manufacturers to minimize formation of hazardous waste but who lack the in-house expertise to do so. The results of the project were discussed and findings, recommendations, cost savings, implementation costs and payback times were reported.

The Industrial Assessment Center (IAC) located at different universities in the United States are entrusted with conducting energy, waste and productivity assessments for small and medium sized manufacturing facilities [16]. Data obtained from these assessments are stored in a database known as the Industrial Assessment Database.

Barbara Quinn's [25] article enumerates various sources of information for waste minimization and states that there is plenty of data on pollution prevention available and its retrieval and sorting takes a lot of time. This testifies the need for organization of this data to be available to the industrialists in relation to the specific situation of each facility. This corroborates the need for research in this area.

Using Envirofacts and Gateway [1], the employees at EPA were able to access the data they needed from the large databases with ease. This has helped increase employee productivity and save time lost in basic data retrieval. Barlishan and Baetz's [3] publication on the development of a decision support system for municipal solid waste suggest that even though there exists the availability of numerical models in this area, waste management engineers and planners require additional tools to assist in the development and evaluation of integrated waste management systems.

Harrington [11] in his article has discussed about automated monitoring systems designed to boost productivity of employees while Brodwin [6] has stated that suitable decision support software could help in automating the work of managerial staff and supervisors. Muhanna and Pick [21] in their article have discussed the development of operation research models and meta-modelling concepts to improve the productivity of decision makers and experts. There are many federally funded projects similar to IAC which run programs that assist manufacturers in waste minimization and productivity issues.

Production Chain Optimization (PCO) is software developed by Pavilion Technologies that helps yield profit improvements in manufacturing plants. PCO when integrated with the supply chain management system helps organizations in optimization of product manufacture. Barrington [4] states that this tool primarily helps manufacturing environments expedite new product development and also help in capacity planning and satisfy demand and responsive production planning.

A new database, UGA/CCACTI, developed by the textile science program at the University Of Georgia gives textile and apparel manufacturers access to actual waste handlers and recyclers, as well as important analysis of the types and amounts of solid waste they are generating. Available on the World Wide Web, the database lists more than 100 waste handlers and recyclers. This resource is planned to be extended to carpet manufacturers also. This Solid Waste Database was funded by the Consortium on the Competitiveness for the Apparel, Carpet and Textile Industries [30].

The ceramic industries have started providing computer-based control to older kilns. These computers continuously monitor and gather data from all data sources associated with the process. According to Paul Curtis [8] the components of a kiln database include temperatures at all burners control zones, undercar, crown and duct locations, motors, fans blowers and pumps. These databases provide continuous information and could also print out reports on the performance and profiles of the kilns being used.

Procter and Gamble’s Mason, OH, Health Care Research Center developed a real-time, Web-enabled system for access to chemical hazard and Material Safety Data Sheet (MSDS) information. The Chemical Assessment and Tracking System (CATS) was built using OPTIMA software from EMAX Solution Partners. The primary feature of the CATS system is accurate inventory and hazard information [17].

Sternberg [27] discusses how industry specific software can do most everything from capturing scale customer data to generating invoices. They can create statistical analyses that track garbage trucks. Tucson sanitation department purchased five UNIX-based stations from Solid Waste Technologies, Jamesburg, NJ helped complete automation and integration of systems and management.

Dade Behring Inc., owns and operates a warehouse with an inventory accuracy of 96% and boasts of a shipping error of less than 1%. This warehouse is improving operations by attaining new heights of productivity, real time inventory updates and the elimination of paper. Bar code scanning, outsourcing and a warehouse management system (WMS) provide the solution. The host computer is located in Delaware and the warehouse management software in Atlanta [9]

Waste Minimization Prioritization Tool (WMPT) is a windows-based software package available through the Environmental Protection Agency. This windows-based software package is intended to prioritize chemicals and assist stakeholders' efforts to meet the goals of EPA's Waste Minimization National Plan. The WMPT houses available persistence, bioaccumulation and human and ecological toxicity data and provides a relative ranking of nearly 900 chemicals based on their various rankings [5]

Maynard [20] in his article on software solutions for the construction talks about ProHome that is a software suite that allows production builders to automatically generate purchase orders from a database of their base models and options. This software also allows the builders to keep track of projects at different job sites, perform project-based financial management and keep accurate payroll accounting records.

Hollingsworth [13] reviews the different software products that help in productivity analysis. The different software products considered are IDEAS Version 6, Frontier Analyst Professional, Onfront Version 1.0 and DEAP Version 2.1.

Chemical Release Inventory (CRI) is a database developed and maintained by the British Government to track industrial pollution. This database is accessible on the World Wide Web. This database has 31,192 pages of information that is freely available to the Internet users [28]

TRW Commercial Steering Division (TRW/CSD) improved its ability to deliver high quality products to customers by reducing the time it takes to isolate and correct product quality problems. TRW used a client/server technology of Sybase Inc. for its Parts Tracking System. This system was extremely detailed, flexible and had a timely quality control. This allowed TRW/CSD to increase its product quality standards, streamline its parts tracking systems and save substantial time and money. The company uses Sybase SQL Server as the central database, along with Sybase Backup Server and OmniCONNECT [29].

2.2 Research on Database Management Systems

It is important to realize the distinction between data and information. Data are facts collected from observations or measurements. Information is the meaningful interpretation and correlation of data that allows one to make decisions. Information is only of value so long as it influences the decision-making process and results in a better decision that would have been made otherwise.

Information Management System (IMS) is a product of IBM Corporation [15] and uses the hierarchical data model. IMS was designed to handle the general problem of avoiding redundancy when storing large amount of data and provides great amount of flexibility in the definition of logical relationships between physical databases. SYSTEM 2000 is a product of MRI Systems Corporation of Austin, Texas [10]. It uses the tree structure to select data implicitly. It provides a report writer, query language with on-line batch access, procedural language interface and sequential file processing. It also allows for good security provisions. Integrated Database Management System (IDMS) is marketed by Cullinane Corporation [7] and provides excellent complex query implementation. Adaptable Data Base System (ADABAS) is a product of Software AG [26], West Germany, and provides a simple query language. This system is designed for medium to large-scale applications.

The OIPEA at Rutgers University has developed a database-querying tool on their web site [14]. The primary benefit of this tool is to retrieve information from the database based on free text character string search. On entering a string of characters into the Principal Product field the search results will be displayed. The search results would give only eight basic pieces of information. They include the IAC that conducted the audit, the visit date, the report number of the visit, the SIC of the plant visited, annual sales, number of employees and the number of recommendations. This information is not sufficient to conduct any type of analysis and does not help in any kind of decision making process.

2.3 Conclusions

As far as the development of a computer based waste minimization and productivity improvement applications are concerned, only specialized research work has been carried out for selected industries and this leaves a lot to be researched in this domain. This survey substantiates the need for a suitable DBMS application that could be developed to convert the available data on manufacturing industries to valuable inferences to support decision making by different industrialists.

CHAPTER 3

RESEARCH APPROACH

3.1 The Base

As discussed in earlier chapters, the databases maintained by the DOE contains a wealth of data on manufacturing industries. This data when interpreted in the right manner can provide useful information to a variety of people including those from the industry, government policy makers, the IACs and other small manufacturers apart from scores of individuals and economic consultants.

Presently the data is stored in the raw form and thus information cannot be interpreted easily except by the database administrators and a handful of people working for the IACs. Thus we see a need to develop a system that would make data retrieval possible for potential users. A suitable graphical user interface with the ability to process complex queries and sensitivity analyses is the need of the hour and is the proposed work that encompasses this research effort.

The proposed system functions as an essential link between the end user and the information stored in the database. The main function of this system is to simplify the data and make it available to the user in the best possible format. This could be in the form of facts, figures, charts, graphs or any other suitable output. The output should make the interpretation of the retrieved data simple and easy to understand.

3.2 Types of Queries and Query Hierarchy

Since the queries are based on the various fields in the database. The variables essentially are the field names. These variables are part of the SQL that is generated. The types of queries that can be generated are dictated by the variables involved. These queries can be a combination of resource types and dollar savings involved, the different assessment recommendation types and the different qualifiers like State, fiscal Year, SIC, Plant Area, Production hours and more. The hierarchy of the step involved is illustrated in Figure 1.1.

This hierarchical structure is based on the limiting capability of the variables or qualifiers in consideration. In the case of waste queries the resource quantities is the main limiting factor since the units is the most important point of differentiation. Pounds and Gallons being the two resource types. When either one of the resource is selected the other one has to be ignored. As an example when pounds of material is selected the user should not be given the option to choose water recycling assessments since water related recommendations are always measured in gallons. For this reason the resource quantities are on the highest priority in the hierarchy. Next on the list is the Types of Assessments. This option is restricted based on the choice selected in resource type. List of Criteria follows the Types of Assessments. List of Criteria consists of the variable qualifiers and does not require any types of restrictions. In the SQL statement these variables are connected using the Boolean methodology and is discussed in the next section.

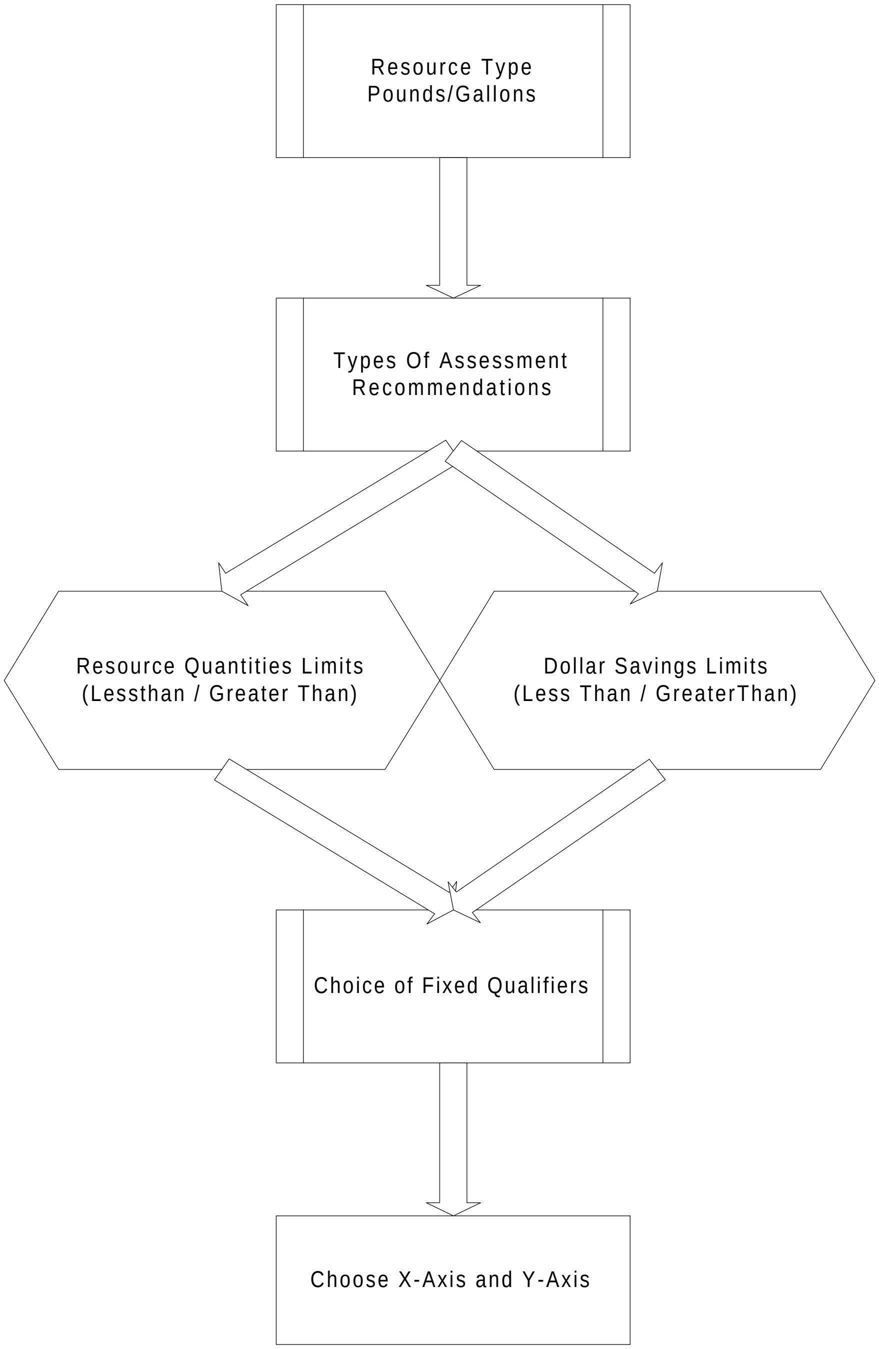


Figure 1.1: Query Hierarchy

3.3 Boolean Association of Variables for Query Generation

SQL statements use Boolean operators to connect the variables to each other and create intelligent queried. Boolean operators that could be used are explained in the following section

1. AND operator: This type of operator is used when the user requires specific information about two or more variables. This kind of operators restrict the query search to exactly the variables on both sides of the AND operator.

   Example: SELECT Ass.FY, AVG(PSAVED) AS FOUND

   FROM Ass, Rec

   WHERE (Rec.ARCTYPE = '3') ***AND*** (Ass.ID = Rec.ID) ***AND*** (Rec.PSOURCCODE ='W1'

   In the above example the AND operator specifies the condition that the Average Resource saved should be from waste recommendations (ARCTYPE = ‘3’)AND should be present in the Assessment and Recommendation Tables AND the Primary Source Code is ‘W1’ (PSOURCCODE = ‘W1’)

2. OR Operator: This type of an operator is used when the user would like to search from a set of values. These kinds of operators broaden the search to multiple values. The following example shows the OR operator.

   SELECT Ass.SIC, AVG(PSAVED) AS FOUND FROM Ass, Rec

WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID) AND (Rec.PSOURCCODE ='W1' AND (Ass.SIC LIKE '20*' ***OR*** Ass.SIC LIKE '21*'***OR*** Ass.SIC LIKE '22*')

In this example the user has requested a search of records that have SIC starting with 21, 22 OR 23. So the records retrieved would be from one of these three SICs.

3. TRUE and FALSE Operators: These Boolean operators are used primarily in Visual Basic 5.0 coding and not in the SQL statements. Used mainly in the design of Forms, Check Boxes and other components. These operators specify the enabling and disabling of the different components used.

EXAMPLE:

```
Private Sub Check1_Click()
If Check1.Value = 1 Or Check2.Value = 1 Or Check3.Value = 1
Then    Command2.Enabled = False
        Command3.Enabled = True
Else:   Command3.Enabled = False
        Command2.Enabled = True
        End If
        End Sub
```

In this example the True and False operators re used to enable and disable the Command Button depending on the Check Box selected.

4. Equality Operator (=): The equality operator is used to get specific fixed values and assigning variables to specific constant values. This operator is widely used in SQL statements and Visual Basic 5.0 coding.

   EXAMPLE: SELECT Ass.SIC, AVG(PSAVED) AS FOUND

   FROM Ass, Rec

   WHERE (***Rec.ARCTYPE = '3'***)

   In this example the value of ARCTYPE is assigned the value ‘3’, which stands for waste minimization recommendations.

5. Less Than (<) and Greater Than (>) Operators: These types of operators are primarily used to specify a range of values in a query. The user specifies the ranges of values.

   EXAMPLE: SELECT Ass.FY, AVG(PSAVED) AS FOUND

   FROM Ass, Rec

   WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID)

   AND ***Ass.PLANT_AREA > '1000'*** AND ***Ass.PLANT_AREA < '10000'***

   GROUP BY Ass.FY;

   As this example illustrates that the user is interested in getting waste cost savings from plants that had total plant area greater than 1000 square feet and less than 10000 square feet. Clearly the user has specified a range of values for the query.

3.4 Examples for the Proposed System

The proposed system will enable querying of the database by guiding the user through a series of menu driven forms. Each of the forms would allow the user input the required parameters to generate the query. If a certain form is of no importance the user is given the option of skipping to the next form. The user is also given the option of changing his inputs in the midst of a consultation and re-running the query. The forms are designed in such a manner that the user could continue using the system even if he is not aware of some of the options that are available and also that he does not have complete knowledge of the contents of the database.

The system has been bifurcated into two parts. The first part deals with all aspects of energy management like energy consumption and potential cost savings. This is discussed in length by Veena in his thesis [31]. The second part deals extensively with all aspects of waste minimization and productivity enhancement and is discussed at length in the following chapters. To display the potential of the proposed system, two examples, one each from waste and productivity management issues are discussed.

3.4.1 An Example of a Query on Waste Management.

Statement: The user is interested in finding out the total cost incurred due to waste generation and management in all the states where an industrial assessment was conducted. All types of plants should be considered which were audited in 1996 with plant area exceeding one hundred thousand square feet.

For this query the main criteria is the total waste cost and the states in which assessments were performed. The specific qualifiers that would narrow the scope of the query are the fiscal year, which is specified by the user to be 1996, and the plant area that is greater than 100,000 square feet. The various fields in the database that are of importance for this query are WSTCOSTTOT, STATE, ID, FY and PLANT_AREA.

This query could be executed manually by writing a small program in Structured Query Language (SQL). The program would pick out the required data from the tables and perform required operations before displaying it to the user. The code written for our waste management query is as shown below.

```
SELECT Ass.WSTCOSTTOT AS TOTWASTECOST, Ass.STATE
FROM Ass INNER JOIN Rec ON Ass.ID = Rec.Test
WHERE (((Ass.ID)=[Rec].[Test]) AND ((Ass.FY)=96)
AND ((Ass.PLANT_AREA)>100000))
GROUP BY Ass.STATE
HAVING (((Ass.STATE)<>"0"));
```

The program would first search for all records having the fiscal year 1996 and plant area greater than 100,000 square feet. After fixing these parameters it would group the retrieved records by the respective state provided that the record in the state field is not null and adds the total waste cost figures to give respective outputs. This output would be in the form of plain numbers, which could be interpreted graphically as shown below.

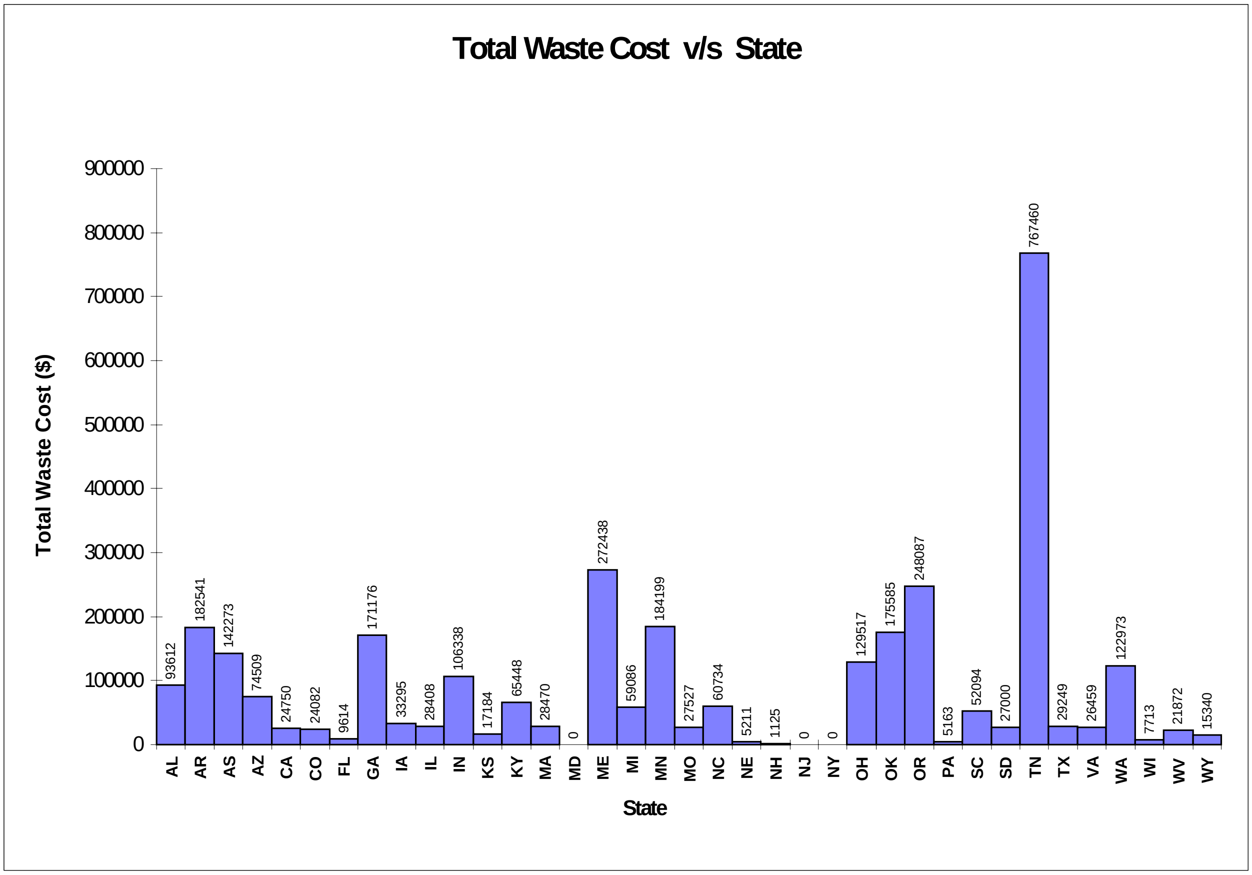


Figure2-1: Plot of Total Waste Cost v/s State where Plant Area >100000 and Year =1996

3.4.2 An Example of a Query on Productivity Enhancement.

Statement: The user would like to know the amount of savings that was achieved to date by productivity enhancement recommendations suggested by each of the participating IAC's, where the annual plant sales exceed $1,000,000.

For this query the main criteria is Dollar Savings due to productivity recommendations and the IACs. The specific qualifier being annual sales, which is greater than $ 1 million. The code written to get an output for this productivity enhancement query is as shown.

```
SELECT Ass.EADC_IAC, Avg(Rec.PSAVED) AS AVGSAVED
FROM Ass INNER JOIN Rec ON Ass.ID = Rec.Test
WHERE (((Ass.ID)=[Rec].[Test])
AND ((Rec.ARCTYPE)="4")
AND ((Rec.PSAVED) Is Not Null
And (Rec.PSAVED)<>0)
AND ((Ass.SALES)>1000000))
GROUP BY Ass.EADC_IAC;
```

The various fields in the database that are used in forming the code in SQL are EADC_IAC, PSAVED, IS, ARCTYPE, SALES. The program searches for records having ARCTYPE =4, where the number 4 denotes that the recommendation is based on a productivity enhancement assessment. Then it picks up the dollar savings for those particular recommendations where the annual sales exceed one million and finally groups by the school that performed the assessments. Again the outputs would be numerical values which could be converted into a graphical output (Figure 3) to make interpretation simple for the end user.

In the examples discussed, the queries have been manually executed to exhibit the least amount of data that could be derived from the database. More complex queries could be run to get specific data on specific industries or specific recommendations and much more. The different combinations of queries that could be run are limitless. This is where the importance of the proposed Relational Database Management System comes into play. The system would convert the queries posed by the end user and convert it to SQL codes that could be run to obtain results. As the complexity of the query increases the code size also increase. Special efforts will be made to provide the user with menus to convert numeric data to graphical outputs.

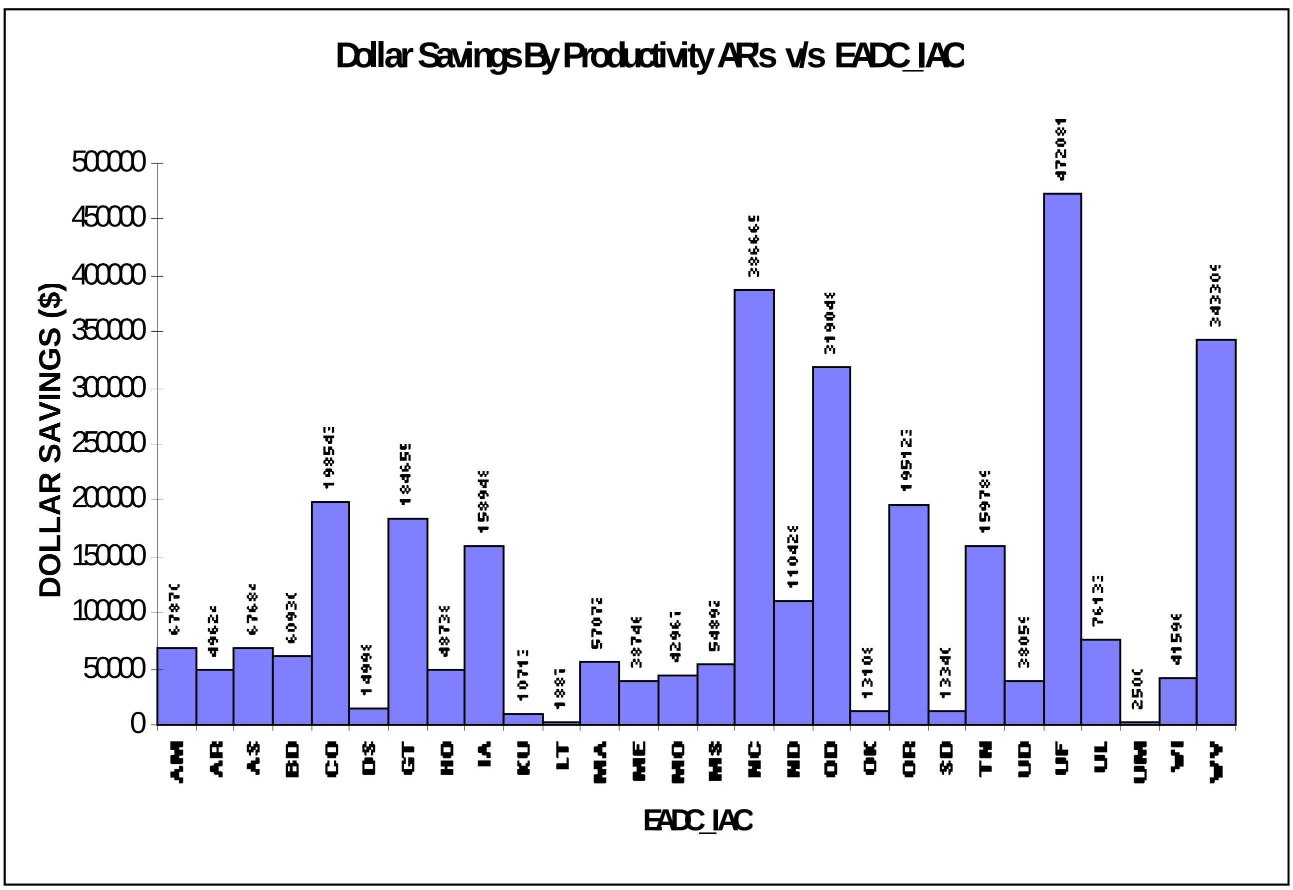


Figure2-2: Plot of Dollar Savings from Productivity v/s IACs, Annual Sales > $1,000,000

3.5 Conclusions

The simple queries in the last section clearly demonstrated that data available in such manufacturing databases contain a wealth of information that could be used effectively to solve many economic and industrial problems. Further more, the importance of the need for a suitable system to convert raw data to an interpretable form is clearly evident. Microsoft Visual Basic Version 5.0 is proposed to be the main software tool that could be used to develop the Relational Database Management System. Microsoft Access® 97 is also planned to be used as a back end to store the database as well as to generate reports. Visual Basic® 5.0 would be used to generate the necessary graphical user interface and the SQL program that could run any query.

CHAPTER 4

SYSTEM DESIGN

This chapter discusses the complete design aspects that are involved in the development of the decision support system. The main focus of the system design was the user and how the user would interact with the system. In order to effectively execute functions, the user is given different options that would generate intelligent queries in the background and search for appropriate data in the database. For effective and efficient functioning it is imperative that the system is designed optimally.

4.1 Design of System Architecture

The various components of the system are:

i. The database consisting of the Assessment and Recommendation Tables. These tables are readily available on the OIPEA web site at no cost. This database can be downloaded to any PC that has Internet connectivity.

ii. The Graphical User Interface (GUI) that has been developed in Visual Basic 5.0. This interface is the link between the user and the information

iii. The Structured Query Language that converts the information entered by the user into the Graphical User Interface to a format that can be understood by the database-querying engine.

iv. The output devices that could be in the form of screen displays or physical print outs using printers.

The various components are shown in Figure 2.

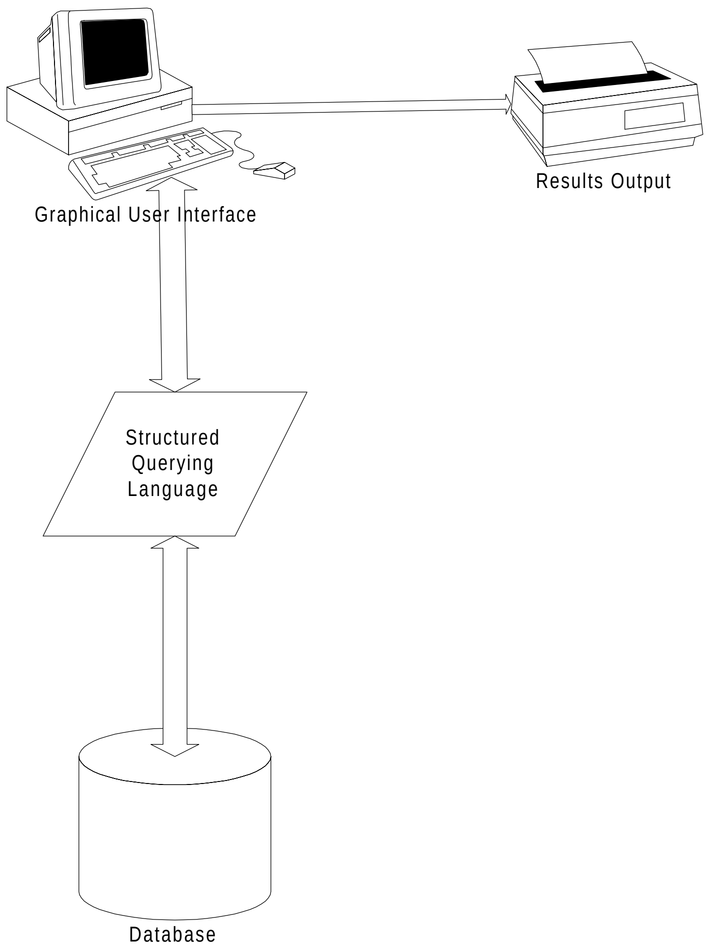


Figure 2. System Architecture

4.2 Database Design

Microsoft Access® 97 was selected as the database tool for the system. The selection was based on various factors such as compatibility with the Graphical User Interface, ability to store the required amount of data, ability to execute Structured Query Language commands, low cost and ready availability.

Database design is an important aspect of system design. The Assessment and recommendation tables contain the information that has been gathered by the various IACs. The assessment tables contain general information about the plant like the SIC, annual sales, number of employees and more. The recommendation table contains information about the various recommendations that were suggested during the plant visit. Both these tables by themselves would not be able to give any sufficient information to make useful decision information. It is therefore necessary to create a relationship between the two tables. Creating such a relationship between tables enable a relational database management system. This considerably enhances the capabilities of the system to run greater amounts of queries from the database. The database of the Assessment and Recommendation Tables provided by OIPEA is in DBASE IV format. These tables can be converted into the Microsoft Access® format by importing the tables. Import is an in-built functionality within Microsoft Access and does not require any custom development.

4.3 Graphical User Interface Design

Design of the Graphical User Interface consisted of a major contribution to this project. Since the GUI was the sole point of contact between the database and the end user it was imperative that the user perspective be given the utmost importance in design. The most effective design would be the one that enables the user to perform a query on the database with the least number of steps, getting the most in terms of information and with the least likelihood of making an error. Limitations due to the nature and type of information in the database could be an impediment in designing a perfect system and such limitations need to be accounted for while designing the flow of events in the GUI. Aesthetic importance is another consideration in the GUI design, but is not necessarily as important as other factors. Factors like cost of development software and the skill sets required for development and time required for development and testing is also taken into account.

4.3.1 Defining the Qualifiers

Before proceeding with the flow analysis and the design of queries it is important to define the various qualifiers that would be used for query generation. The two types of qualifiers identified are

1. Fixed Qualifiers

Fixed Qualifiers are the ones in which the values have a constant set of values. These values always remain the same. The different IAC/EADC schools are an example. There are thirty-six different schools that provide information for the database and this value always remains a constant. Each school is represented by a code. WV for West Virginia University. The list of fixed qualifiers can be updated if necessary. The identified fixed qualifiers are

i. Assessment Recommendation Codes

ii. Standard Industrial Code

iii. Fiscal Year of Assessment

iv. IAC/EADC Participating Schools

v. State in which the Assessment was done

2. Variable Qualifiers

Variable qualifiers are the ones in which the values usually have to be calculated. These values keep changing depending on the nature of the query that was selected. Waste Cost and Annual Plant Sales are examples of variable qualifiers. The values of these variable qualifiers change depending on the value of the other qualifiers chosen as part of the query. The identified variable qualifiers are

i. Total Waste Cost

ii. Amount of Resource Conserved

iii. Dollar Savings on Resource Conserved

iv. Annual Plant Sales

v. Recommendation Implementation Cost

vi. Number of Plant Employees

vii. Plant Area

viii. Production Volume

ix. Plant Production Hours

4.3.2 Waste Minimization Queries

Based on the different information found in the Assessment and Recommendation tables in the database and information provided in the ARC manual, the different classification levels were decided. The different levels were based on the way the data could be differentiated. We start from a broad differentiation to a narrower differentiation as the query processes. The classification levels for qualifiers are

1. Resources Conserved

   The information about waste resources in the database can be classified into two broad categories. Solid resources in pounds and liquid resources in gallons. So in the first step the user is prompted to enter one of the three choices

   - Pounds of material: for all solid related waste queries
   - Gallons of liquid: for all liquids related waste queries
   - All assessments: for a combination of all solid and liquid related waste queries

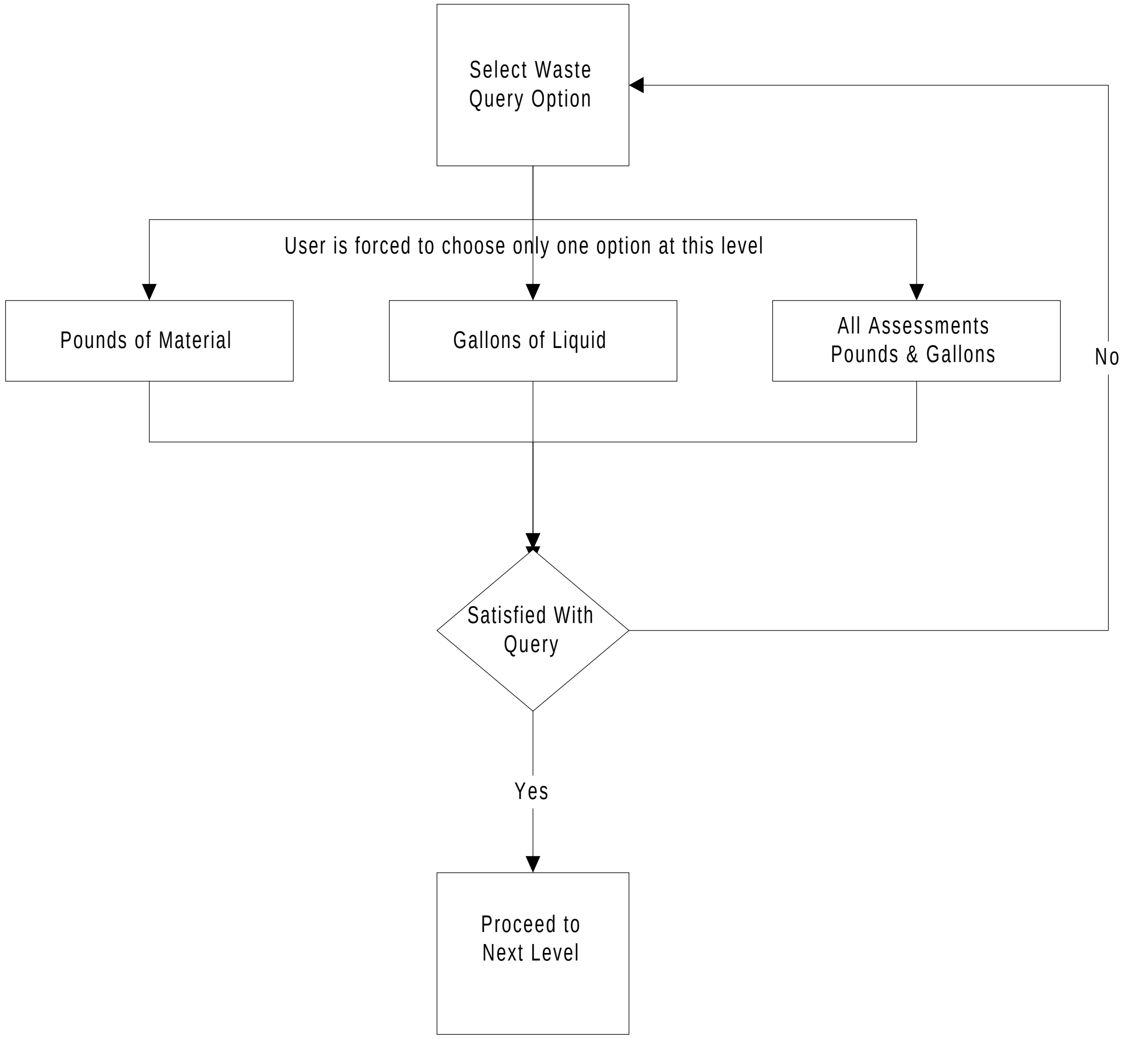


Figure 3: Design Level 1 Classification.

2. List of Assessment Recommendations

This is the second level of classification of qualifiers. This level is divided into eight broad categories. These categories are selected based on the Assessment Recommendation Codes from the manual. The eight categories are

- Operations: This includes process specific recommendations, material application, desulfurization, slag management, byproduct use and such similar recommendations
- Equipment: Fault tolerances, painting operation losses, problems with tank design, need for automation and more form a part of this type of recommendation.
- Post Generation Treatment: Neutralization for adjusting pH values, removal of contaminants, using different methods and material concentration like evaporation and reverse osmosis are included in this type of recommendation
- Water Usage: Ways to reduce and minimize water usage and treatment are included in this type of recommendations.
- Recycling Material: This includes liquid waste recycling, reuse of inks, dyes and tanning solutions, paper and cardboard recycling, metallic scrap recycling.
- Waste disposal: Sludge maintenance and combustion of waste products are examples of this type of recommendation.
- Maintenance: Cleaning, greasing, spillage and other leak reduction measures comprise this type of recommendation.
- Raw Materials: Solvents, solids and other raw material wastage form a part of this type of recommendation

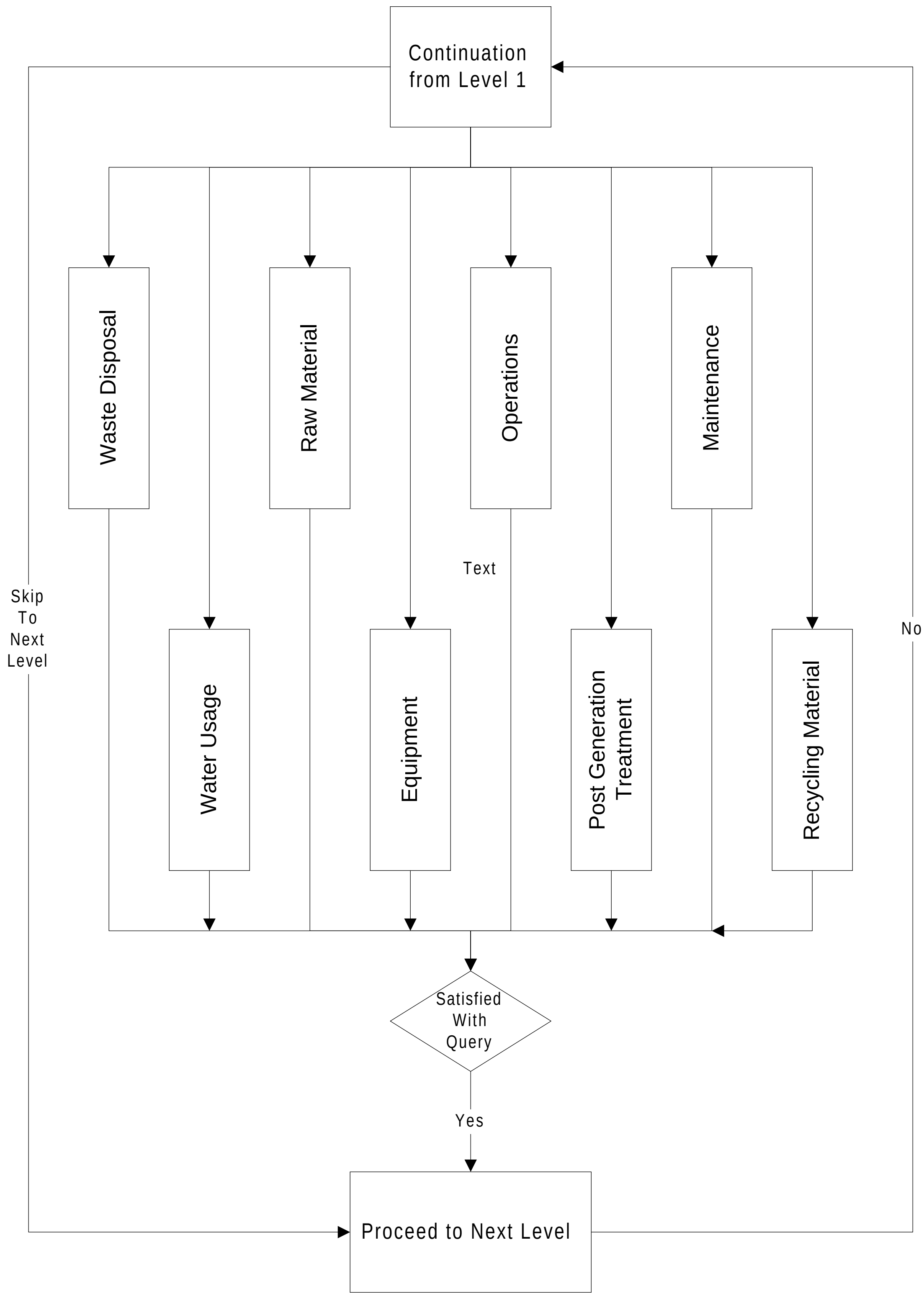


Figure 4: Design Level 2 Classification

3. Resource Quantities and Dollar Savings Values

In this third level of classification, the user has the option of limiting the resource quantities in terms of gallons or pounds of material. The user also has the option of limiting the dollar savings values to the query. Selection of options in this level is optional. The user could skip this level to the nest one without selections.

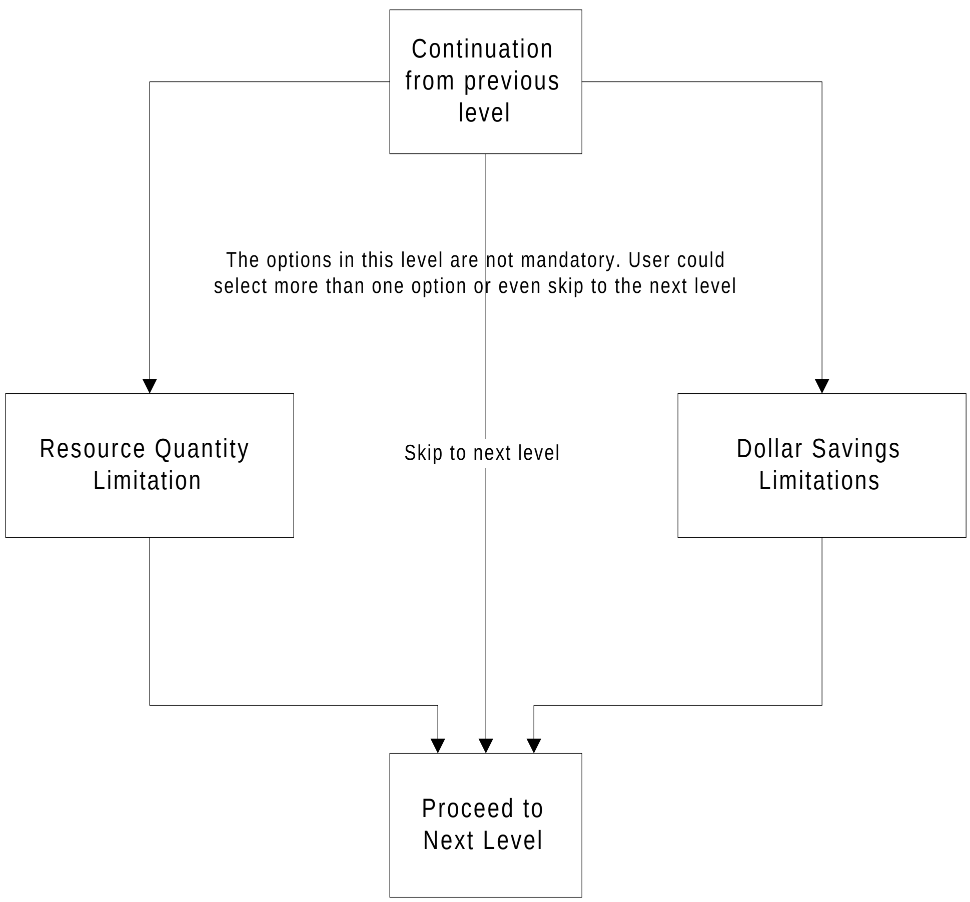


Figure 5: Design Level 3 Classification

4. List of Criteria

This fourth level of classification includes the fixed and variable qualifiers that could be potentially used to narrow down the query. Selection of options in this level is not mandatory and the user can proceed to the next level. There are nine categories in this level.

- IAC/EADC – Schools participating in the program
- State- The state where the plant information has been gathered
- Plant SIC- Standard Industrial Code of the plants visited
- Plant Area- Square footage of the plants visited
- Annual Plant Sales- Annual sales of plants visited
- Plant Production Hours- Annual hours of operation of plants visited
- Number of employees- The number of people employed at the plant
- Fiscal Year- The year of plant visit
- Implementation Status- The status of implementation of the recommendation suggested.

Each of the above nine categories has sub-categories. When a category is selected the user is given to choose from the sub-categories. These sub-categories could either be a list or be a range that the user would have to input. This primarily depends on the category selected. Figure 6 clearly illustrates the categories and its corresponding sub-categories that are available for the user to choose from.

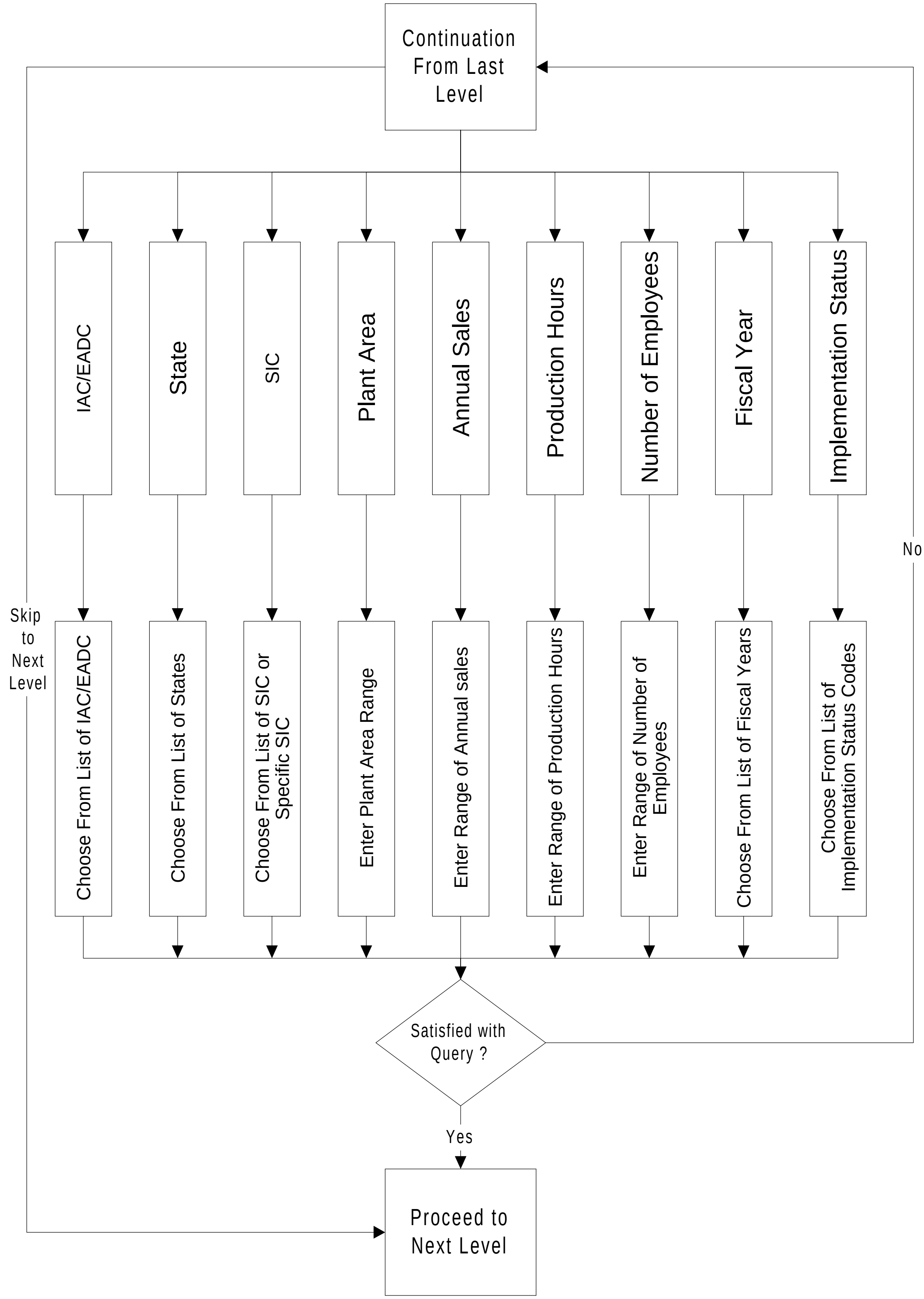
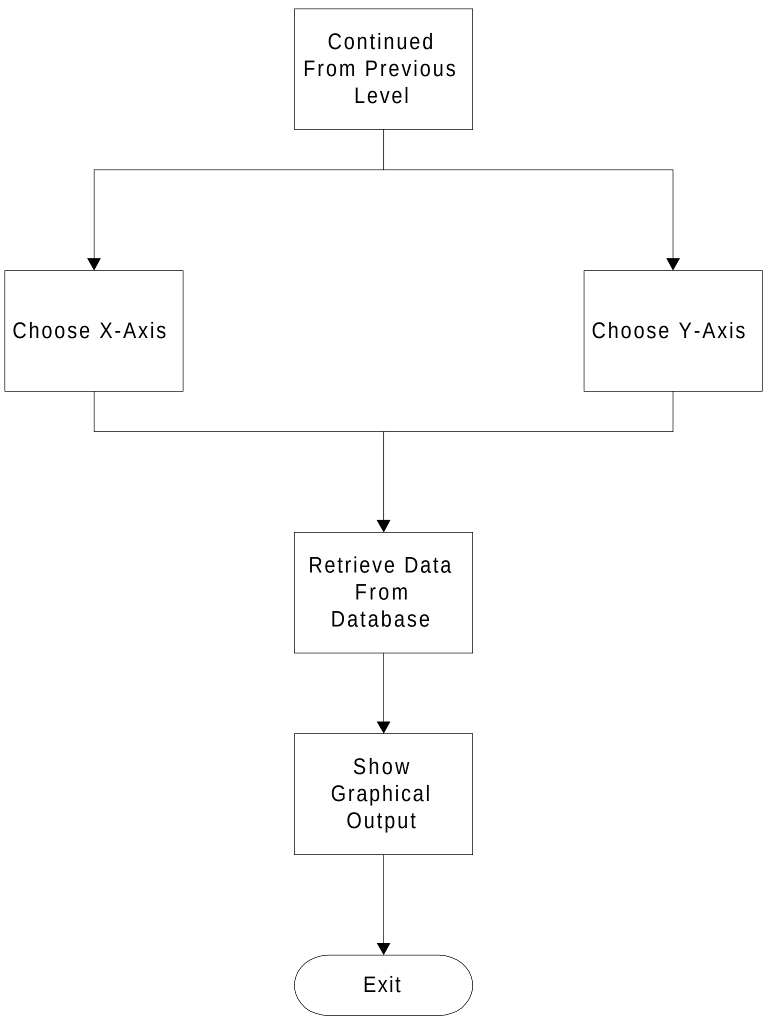


Figure 6: Design Level 4 Classification

6. Choosing the X and Y axis

This is the fifth and final level of classification before the graphical output could be generated. This gives the user the option of choosing the qualifier that they are interested in viewing against the queried qualifier from the database. The fixed qualifiers are the options that are available to be placed on the X-axis while the variable qualifiers are displayed on the Y-axis.

Figure 7: Design Level 5 Classification



4.3.3 Productivity Recommendation Querying

Information and data on plant productivity have been gathered only from the last quarter of 1997. Due to this reason the amount of data in the database is considerably small. Also the database has still not been configured completely to add specific information about productivity recommendations as like for energy and waste recommendation. Any specific resource quantities or units do not classify productivity recommendations since they can span over any different kinds of platforms. The point of differentiation between productivity and waste recommendations is the Assessment Recommendation Code. The fixed and variable qualifiers do remain the same. Due to the inherent nature of the productivity data the database the design of the productivity query flow is slightly modified as compared to waste queries. Productivity queries consist of only Level 1, Level 4 and Level 5 as discussed for the waste management queries. This would give the necessary querying capabilities considering the limitation placed by the nature of productivity recommendation data. The querying capabilities can be changed appropriately as and when the database is updated.

4.4 Graphic Server Design

The Graphic Server is the final step in the querying process and converts the retrieved data from the query generated into useful graphical outputs. The data retrieval is and consequently the graphical output is based on the values chosen on the X and Y axis in the level five of the Graphical User Interface design. The default setting for the

Graphic Server is three-dimensional bar graph. The other options on the drop down menu list include pie charts, line graphs and area graphs. The drop down file menu enables the user to perform functions like saving the graphical output to a file, copying the graph to a clipboard as a bitmap file and enabling the print option for paper print outs.

4.5 Conclusion

It is well known that system design is an important aspect of any database querying system. Efficiency, flexibility and ability to minimize errors are the key factors taken into account in this system design. The flow pattern eliminates the need for the user to scroll through all options. The user could choose exactly the parameters required, also multiple options and continue to the next level. This makes the system efficient and less time consuming. Also the user has the flexibility to complete the transaction as and when required as long as the basic parameters are entered making the system flexible. The software design enables and disables functionality based on the options that the user chooses. This greatly reduces errors due to incorrect querying. Once the querying is done the retrieved data is converted into graphical output. The output options enable the user to view graphs in different forms.

CHAPTER 5

DEVELOPMENT OF THE QUERY MANAGEMENT SYSTEM

The various components used in the development of this query management system should have excellent data storage and retrieval capabilities along with being a good interface with users. The user interface is developed using Microsoft Visual Basic. The data is stored as a Microsoft Access Database and the querying is performed using the Structured Querying Language (SQL).

5.1 Development of the User Interface

The user interface developed in Microsoft Visual Basic consisted of the four parts that are discussed. Figure 8 illustrates the various components.

1. Forms. This is the background of the application and forms the base to add and carry all other components in the application. The user interacts with the various components like buttons and check boxes on the forms. Text fields are also embedded in these forms and serve as instructions and titles for the different stages of the operation. The properties of the forms like color, size and more can be changed based on the design requirement.

2. Command Buttons. As the name suggests, Command Buttons basically drive different commands that can be executed using Visual Basic. The basic functions include beginning, interrupting or ending a process. It can be used to navigate between forms, display data, display other options, visual effects and more.

3. Check Boxes. These controls primarily perform the function of selection. The user points the mouse into the check box and clicks. This enables the selection. Another click in the same check box makes it unavailable. Check boxes are generally used when multiple selections are necessary and possible.

4. Option Buttons. These controls are used in an option group to display options from which the user selects only one. When a user selects an option button, the other option buttons in the same group are automatically unavailable. In contrast any number of check box controls can be selected.

5. Text Boxes. These are used to enter information by the user as limiting factors in the querying and are primarily input fields.

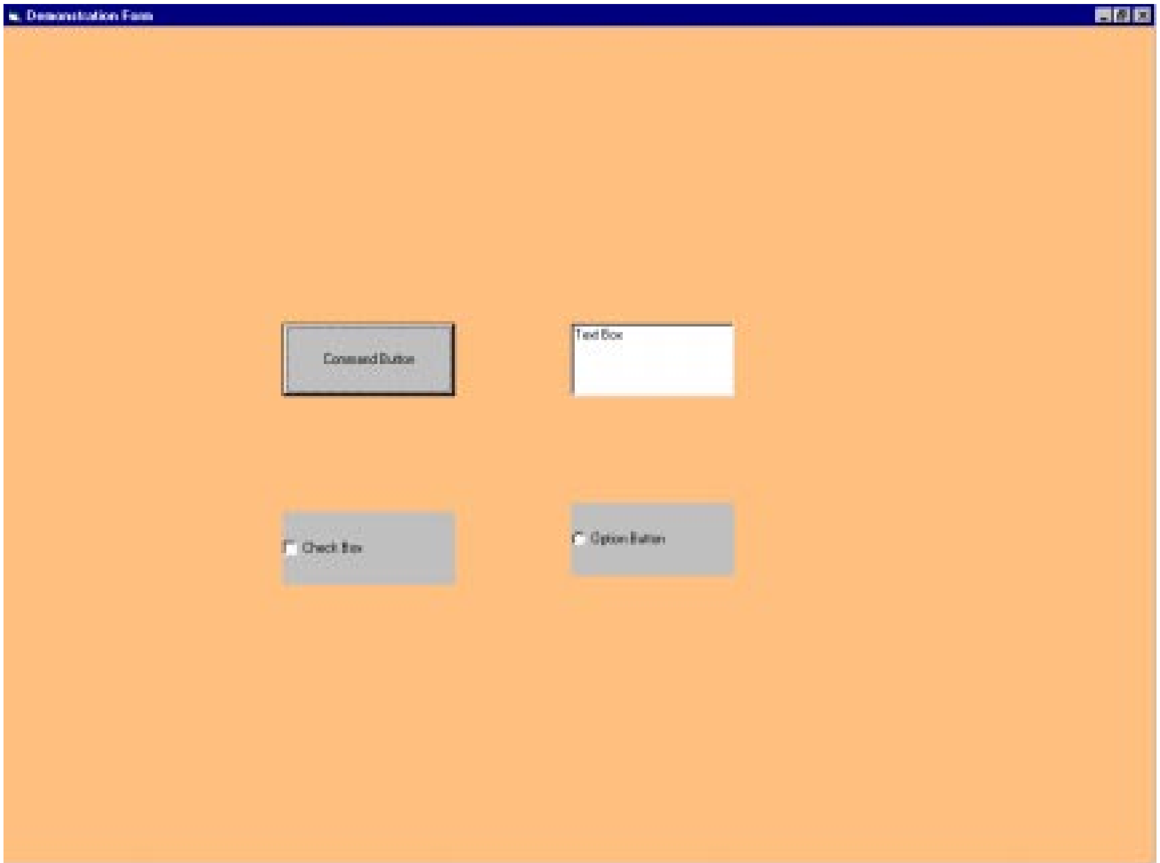


Figure 8: Components of the Graphical User Interface

5.2 Development of the Relational Database Management System

Relational Database Management Systems (RDBMS) have been the focus of data management systems for more than a decade. They provide technologically advanced storage, data retrieval and distribution function to enterprise wide data processing and information systems.

The main factor for data retrieval from a database through a relational database management system is that the tables are related by a common field. This is the basic requirement for a database management system to be relational. The relationship is achieved by linking the unique field in one table, also known as the Primary Key, to the field containing similar set of values in the second table. By such an arrangement information can be retrieved from either of the tables based on the other table.

The assessment and recommendation tables are linked together by creating a common field in both tables. The ID field in the Assessment table is copied into the Recommendation table to create a one-to-many relationship between the tables. This makes it a relational database. Figure 9 gives the illustration.

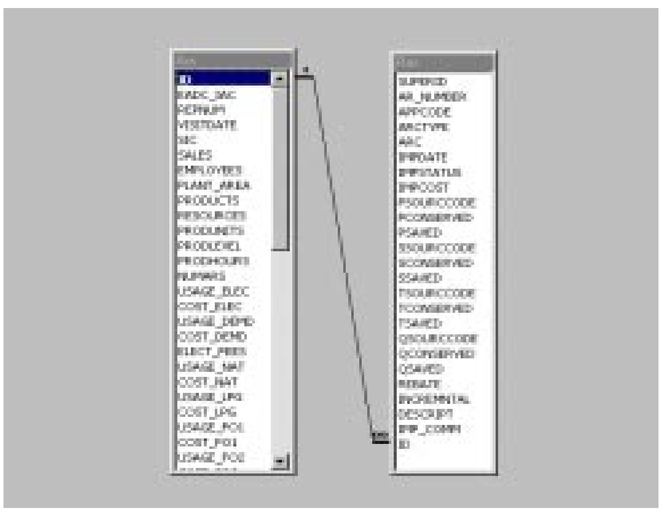


Figure 9: Assessment and Recommendation Table Relationship

5.3 Structured Query Language (SQL)

Structured Query Language is a powerful data manipulation tool compatible with Microsoft Visual Basic and Microsoft Access to access data from the database. SQL statements are categorized into two types. Data Defining Language enables the user to define data tables, indexes, primary keys and database relationships. Data Manipulating Language statements are used to select, sort, summarize and calculate information stored in data tables. For the waste and productivity querying applications the obvious choice was the data manipulating language.

The Structured Query Language in itself consists of various statements like a programming language. An example of the language is shown below and its components explained thereafter.

SELECT

Ass.FY, AVG(WSTCOSTTOT) AS FOUND

FROM Ass, Rec

WHERE

(Rec.ARCTYPE = '3') *AND* (Ass.ID = Rec.ID) *AND* (Rec.PSOURCCODE ='W1' *OR* Rec.PSOURCCODE ='W2' *OR* Rec.PSOURCCODE ='W3' *OR* Rec.PSOURCCODE = 'W4' *OR* Rec.PSOURCCODE = 'W5' OR Rec.PSOURCCODE = 'W6' *OR* Rec.PSOURCCODE = 'R1' *OR* Rec.PSOURCCODE = 'R2' *OR* Rec.PSOURCCODE = 'R3' *OR* Rec.PSOURCCODE = 'R4' *OR* Rec.PSOURCCODE = 'R5' *OR* Rec.PSOURCCODE = 'P1' *OR* Rec.PSOURCCODE = 'P2') *AND* (Ass.EADC_IAC = 'ZZ' *OR* Ass.EADC_IAC = 'WV')

GROUP BY Ass.FY;

5.3.1 SELECT Statement

This is a very commonly used SQL statement. SELECT enables the user to choose and pick records from tables. The selection could be form a single table or from a set of tables.

SELECT

Ass.FY, AVG(WSTCOSTTOT)

This statement selects Fiscal Year (FY) and Average Waste Cost from the Assessment Table.

FROM Statement

This statement specifies the exact tables to search for records that are specified in the SELECT Statement.

FROM Ass, Rec

This statement specifies the records to be selected from the Assessment and Recommendation Tables.

5.3.3 Where Clause

This is a clause that limits the query depending on the various operators that specify exact type or quantity of the records that are being queried.

WHERE

(Rec.ARCTYPE = '3')

This statement limits the records specified in the SELECT and FROM statements to records where the Assessment recommendation Type in the Recommendation Tables equals the number 3 (For Waste Recommendations).

5.3.4 AND & OR Operators

These are operators that enable Boolean operation to the query. This basically could limit the query or expand the query depending on the priority of usage**.**

5.3.5 GROUP BY Statement

This statement essentially groups all the results obtained from previous statements, clauses and operators. All common fields are grouped together based on the operation that is performed on the retrieved data

GROUP BY Ass.FY;

In this statement the retrieved data, Average Waste Cost is grouped by the Fiscal Year of Assessment.

5.4 Development of the Different Levels of the System

The design of the different levels of the database querying system was discussed in the Systems Design chapter. The development of the different levels includes the creation of forms, command buttons, option buttons and check boxes for each of the forms. The SQL statement is generated at every level and transferred progressively as each stage progresses. At the final level the SQL is sent to the database and the Graphic Server converts the returning value to a graphical output.

5.4.1 Development of Stage 1 (Waste or Productivity Criteria)

The Stage 1 gives the user the option to choose from Waste and Productivity Queries. The form created for this stage is illustrated in figure 10. The user chooses the option and proceeds by choosing the "Next" command button.

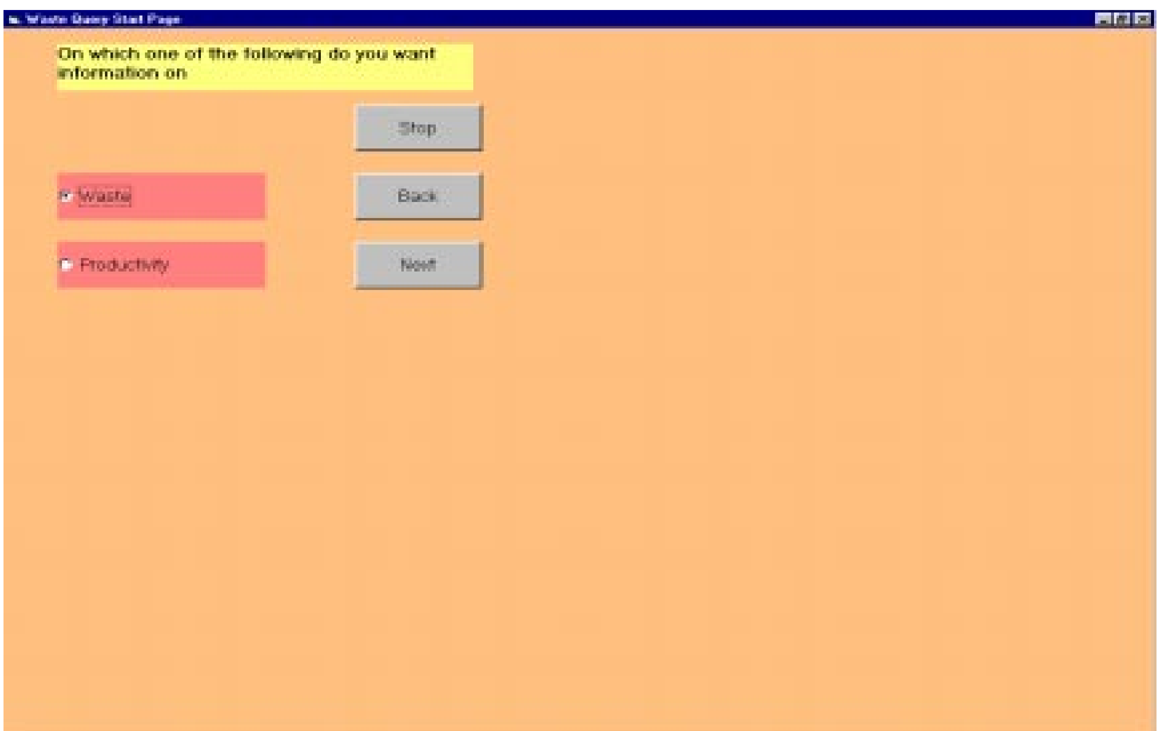


Figure 10: Stage 1 of Development

The code for this stage of development is shown and explained below.

```
Private Sub Command4_Click()
End
End Sub

Private Sub Command6_Click()
If Option2.Value = True Then
   fm2Continue.Show
   fm1Start.Visible = False
End If
```

This section of the code relates to the “Continue Button”. Once the “Continue Button” the next stage is displayed.

```
If Option3.Value = True Then
   finalqry = " WHERE (Rec.ARCTYPE = '4') AND (Ass.ID = Rec.ID)"
   fm4aCriteria.Show
   fm1Start.Visible = False
End If
End Sub
```

This section pertains to the Productivity section of the system. If the user selects the Productivity Option, he is led to that section of the query

```
Private Sub Form_Load()

Dim dtbase As Database
Dim asstab As Recordset
Dim rectab As Recordset

Dim assnam As String
assnam = "Ass"
Dim recnam As String
recnam = "Rec"

Dim pthname As String
pthname = "C:\thesis\Waste Queries\DATA.mdb"

Set dtbase = DBEngine.OpenDatabase(pthname)
Set asstab = dtbase.OpenRecordset(assnam, dbOpenDynaset)
Set rectab = dtbase.OpenRecordset(recnam, dbOpenDynaset)
```

End Sub

The first part of the code specifies the query to handle waste type or productivity type issues. The second part of the code connects to the database located in the “C:Thesis\Waste Queries\” directory.

5.4.2 Development of Stage 2 (Resource Type Criteria)

This stage prompts the user to enter the resource types. Waste queries have three options. Pounds of material, Gallons of liquids and a combination of both types to resources. The form for this stage is shown in figure 11. The Visual Basic code for this level is also enumerated below.

Figure 11: Stage 2 of Development

Visual Basic Code is explained below.

```
Option Explicit
Dim fm2q1 As String
Dim fm2q2 As String
Dim fm2q3 As String

Private Sub Check1_Click()
If Check1.Value = 1 Then
Frame1.Visible = True
Frame1.Enabled = True
Else
Frame1.Visible = False
Frame1.Enabled = False

End If
End Sub
```

The first section assigns the variables that will be used in this section of the script.

```
Private Sub Check2_Click()
If Check2.Value = 1 Then
Frame2.Visible = True
Frame2.Enabled = True
Else
Frame2.Visible = False
Frame2.Enabled = False

End If
End Sub
```

The second section deals with the user selecting the check box from the form. If the user check the box one frame is made visible and the other is made invisible.

```
Private Sub Command1_Click()
If Option1.Value = True Then
'fm2q1 = " SELECT * FROM Ass,Rec WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID)    AND (Rec.PSOURCCODE ='W4' OR Rec.PSOURCCODE ='W5' OR Rec.PSOURCCODE ='W6' OR Rec.PSOURCCODE = 'R1' OR Rec.PSOURCCODE = 'R2' OR Rec.PSOURCCODE = 'R3' OR Rec.PSOURCCODE = 'R4' OR Rec.PSOURCCODE = 'R5' OR Rec.PSOURCCODE = 'P1' OR Rec.PSOURCCODE = 'P2') "
fm2q1 = " WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID)    AND (Rec.PSOURCCODE ='W4' OR Rec.PSOURCCODE ='W5' OR Rec.PSOURCCODE ='W6' OR Rec.PSOURCCODE = 'R1' OR Rec.PSOURCCODE = 'R2' OR
```

```
Rec.PSOURCCODE = 'R3' OR Rec.PSOURCCODE = 'R4' OR Rec.PSOURCCODE = 'R5' OR Rec.PSOURCCODE = 'P1' OR Rec.PSOURCCODE = 'P2') "
finalqry = fm2q1
'Else: finalqry = ""
End If
If Option2.Value = True Then
'fm2q2 = " SELECT * FROM Ass,Rec WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID)  AND (Rec.PSOURCCODE ='W1' OR Rec.PSOURCCODE ='W2' OR Rec.PSOURCCODE ='W3'  OR Rec.PSOURCCODE = 'R1' OR Rec.PSOURCCODE = 'R2' OR Rec.PSOURCCODE = 'R3' OR Rec.PSOURCCODE = 'R4' OR Rec.PSOURCCODE = 'R5' OR Rec.PSOURCCODE = 'P1' OR Rec.PSOURCCODE = 'P2') "
fm2q2 = " WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID)  AND (Rec.PSOURCCODE ='W1' OR Rec.PSOURCCODE ='W2' OR Rec.PSOURCCODE ='W3'  OR Rec.PSOURCCODE = 'R1' OR Rec.PSOURCCODE = 'R2' OR Rec.PSOURCCODE = 'R3' OR Rec.PSOURCCODE = 'R4' OR Rec.PSOURCCODE = 'R5' OR Rec.PSOURCCODE = 'P1' OR Rec.PSOURCCODE = 'P2') "
finalqry = fm2q2
'Else: finalqry = ""
End If
```

This third section is activated when the user hits the “Continue” button. The query is generated by the user selection from previous stages. At this stage the type of assessments interested, in our case waste assessments are set.

```
If Option3.Value = True Then
'fm2q3 = " SELECT * FROM Ass,Rec WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID)  AND (Rec.PSOURCCODE ='W1' OR Rec.PSOURCCODE ='W2' OR Rec.PSOURCCODE ='W3'  OR  Rec.PSOURCCODE = 'W4' OR Rec.PSOURCCODE = 'W5' OR Rec.PSOURCCODE = 'W6' OR Rec.PSOURCCODE = 'R1' OR Rec.PSOURCCODE = 'R2' OR Rec.PSOURCCODE = 'R3' OR Rec.PSOURCCODE = 'R4' OR Rec.PSOURCCODE = 'R5' OR Rec.PSOURCCODE = 'P1' OR Rec.PSOURCCODE = 'P2') "
fm2q3 = " WHERE (Rec.ARCTYPE = '3') AND (Ass.ID = Rec.ID)  AND (Rec.PSOURCCODE ='W1' OR Rec.PSOURCCODE ='W2' OR Rec.PSOURCCODE ='W3'  OR  Rec.PSOURCCODE = 'W4' OR Rec.PSOURCCODE = 'W5' OR Rec.PSOURCCODE = 'W6' OR Rec.PSOURCCODE = 'R1' OR Rec.PSOURCCODE = 'R2' OR Rec.PSOURCCODE = 'R3' OR Rec.PSOURCCODE = 'R4' OR Rec.PSOURCCODE = 'R5' OR Rec.PSOURCCODE = 'P1' OR Rec.PSOURCCODE = 'P2') "
finalqry = fm2q3
'Else: finalqry = ""
End If
```

This section is activated if the user chooses the third option of “All Assessments” and then hits the “Continue” button. The SQL is appropriately generated at this level that includes all assessments. This is then assigned to the variable “finalqry”

```
fm3aArlist.Show
fm2Continue.Visible = False
End Sub
```

This section makes the existing form invisible and brings up the next form that is “fm3aArlist”.

```
Private Sub Command2_Click()
End
End Sub

Private Sub Command3_Click()
fm1Start.Show
fm2Continue.Visible = False
End Sub

Private Sub Option1_Click()
If Option1.Value = True Then
fm3bPostGen.Check1.Enabled = False
fm3aArlist.Check4.Enabled = False
fm3bRecycling.Check1.Enabled = False
fm3bWasteDisp.Check1.Enabled = False
fm3bRawMat.Check1.Enabled = False
fm3bRawMat.Check2.Enabled = False
Else
fm3aArlist.Check4.Enabled = True
'fm3aArlist.Check4.Value = 0
End If
```

When the user selects “Pounds of Material” the various options for specific selections of assessment recommendation is disabled. This has to be done to prevent the user from inputting any extraneous and wrong selections. This is one of the ways to prevent queries without intelligence.

```
If Option1.Value = True Or Option2.Value = True Or Option3.Value = True Then
Command1.Enabled = True
Command3.Enabled = False
Else
Command1.Enabled = False
```

```
Command3.Enabled = True
End If



End Sub

Private Sub Option2_Click()
If Option2.Value = True Then
fm3aArlist.Check1.Enabled = False
fm3aArlist.Check2.Enabled = False
fm3bPostGen.Check2.Enabled = False
fm3bPostGen.Check3.Enabled = False
fm3bRecycling.Check2.Enabled = False
fm3bRecycling.Check3.Enabled = False
fm3bWasteDisp.Check2.Enabled = False
fm3bWasteDisp.Check3.Enabled = False
fm3aArlist.Check7.Enabled = False
fm3bRawMat.Check3.Enabled = False
End If
```

When the user selects "Gallons of Material" the various options for specific selections of assessment recommendation is disabled. This has to be done to prevent the user from inputting any extraneous and wrong selections. This is one of the ways to prevent queries without intelligence

```
If Option1.Value = True Or Option2.Value = True Or Option3.Value = True Then
Command1.Enabled = True
Command3.Enabled = False
Else
Command1.Enabled = False
Command3.Enabled = True
End If

End Sub

Private Sub Option3_Click()

fm3aArlist.Check1.Enabled = False
fm3aArlist.Check2.Enabled = False
fm3aArlist.Check3.Enabled = False
fm3aArlist.Check4.Enabled = False
fm3aArlist.Check5.Enabled = False
fm3aArlist.Check6.Enabled = False
fm3aArlist.Check7.Enabled = False
```

```
fm3aArlist.Check8.Enabled = False
```

> When the user selects “All Assessments” the various options for specific selections of assessment recommendation is disabled. This has to be done to prevent the user from inputting any extraneous and wrong selections. This is one of the ways to prevent queries without intelligence

```
If Option1.Value = True Or Option2.Value = True Or Option3.Value = True Then
Command1.Enabled = True
Command3.Enabled = False

Else

Command1.Enabled = False
Command3.Enabled = True
End If

End Sub
```

5.4.3 Development of Stage 3 (Assessment Recommendations Criteria)

In this stage the user enters from the options of the different waste minimization recommendations available. The different options are taken from the Assessment Recommendation Manual. If the user chooses All Assessments from the previous stage then all the options in this stage are disabled. The form for this stage is illustrated in Figure 12.

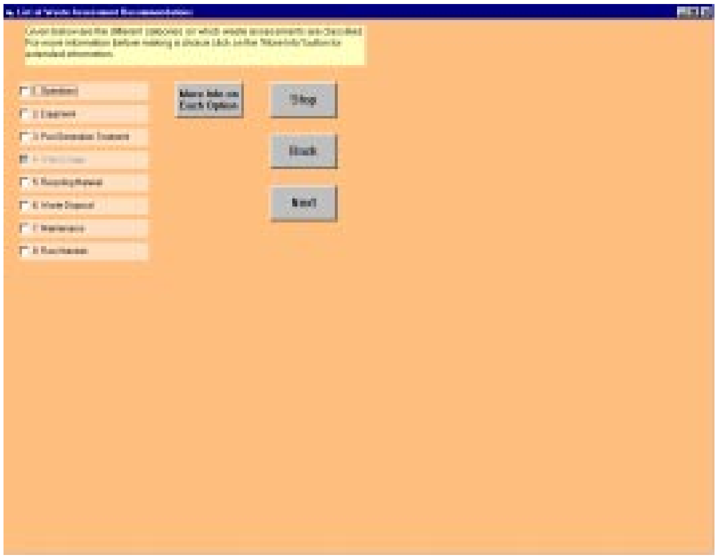


Figure 12: Stage 3 of Development

5.4.4 Development of Stage 4 (Resource Quantities or Dollar Values Criteria)

In this fourth stage the user is prompted to enter the limiting values of resource quantities or dollar savings. This level is not a mandatory level and if the user chooses to skip, he could do so by hitting the continue button. See Figure 13 for illustration.

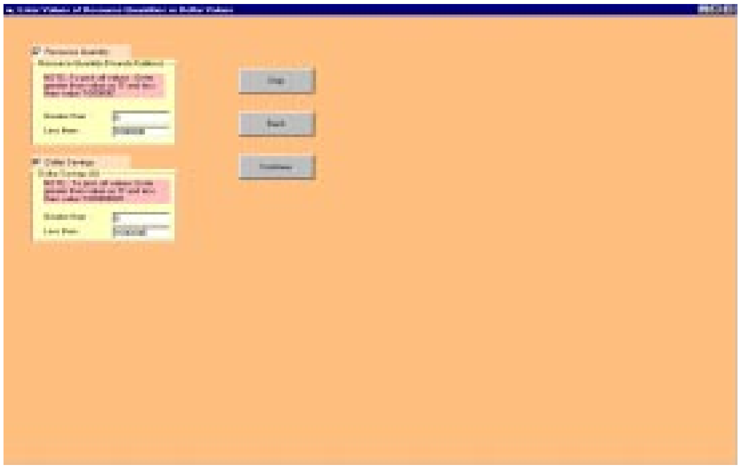


Figure 13: Stage 4 of Development

SQL statements are generated in the background with the constraints placed by the user in the text boxes and is concatenated to the existing SQL statement. All of this is carried over to the next stage.

5.4.5 Development of Stage 5 (List of Qualifiers Criteria)

In this stage the user is prompted to choose from the various qualifiers from the database. The different qualifiers are discussed in the design of the system. On choosing one of the nine options another sub-form pops up for the specific options in each of the criteria. This stage is optional too and the user can skip to the next level by hitting the continue button.

Figure 14: Stage 5 of Development

5.4.6 Development of Stage 6 (Choosing the X-axis and Y-axis)

In this stage the user chooses the value to be plotted on the x-axis and the y-axis. The values presented on the X-axis are the fixed qualifiers and the values presented on the Y-axis are the variable qualifiers. These fixed and variable qualifiers represent all possible data information that are useful in query generation. Figure 15 shows the form generated in this stage. The text box displays the SQL generated. The Graph command button takes you to the final stage where the graph is displayed.

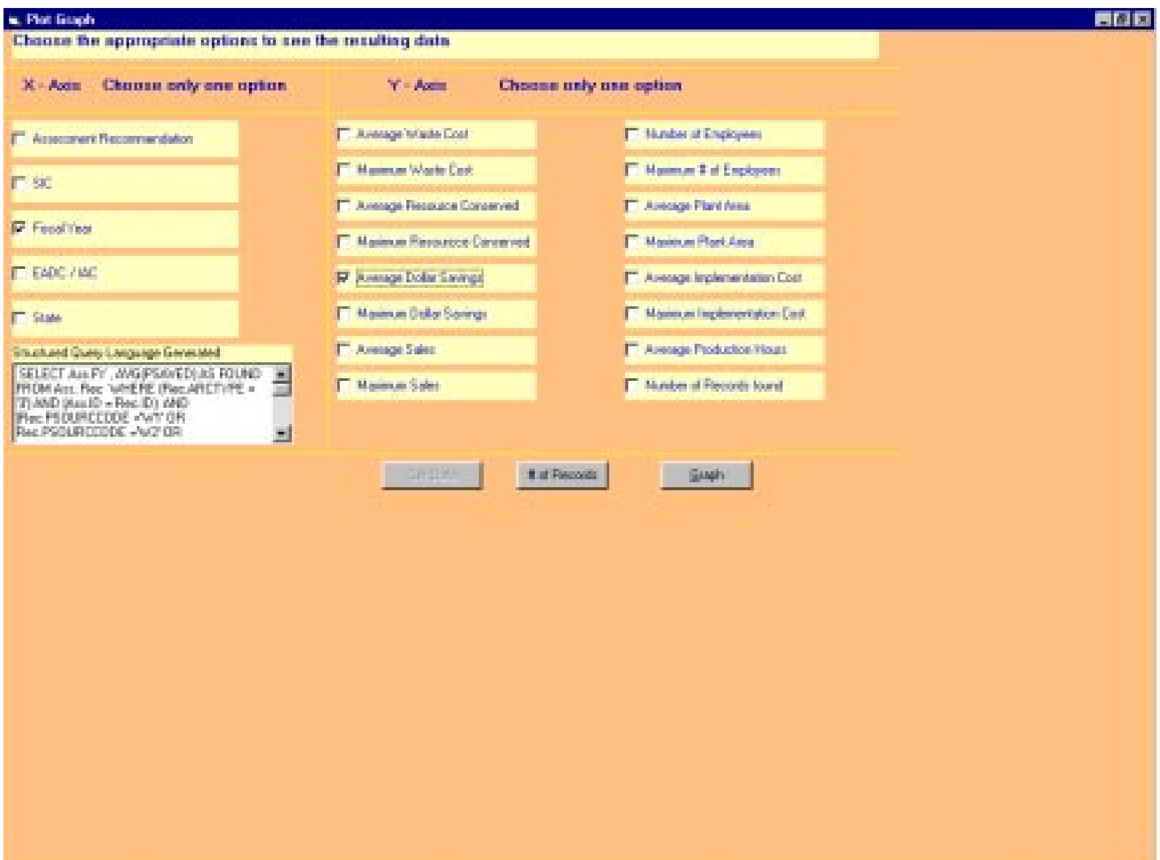
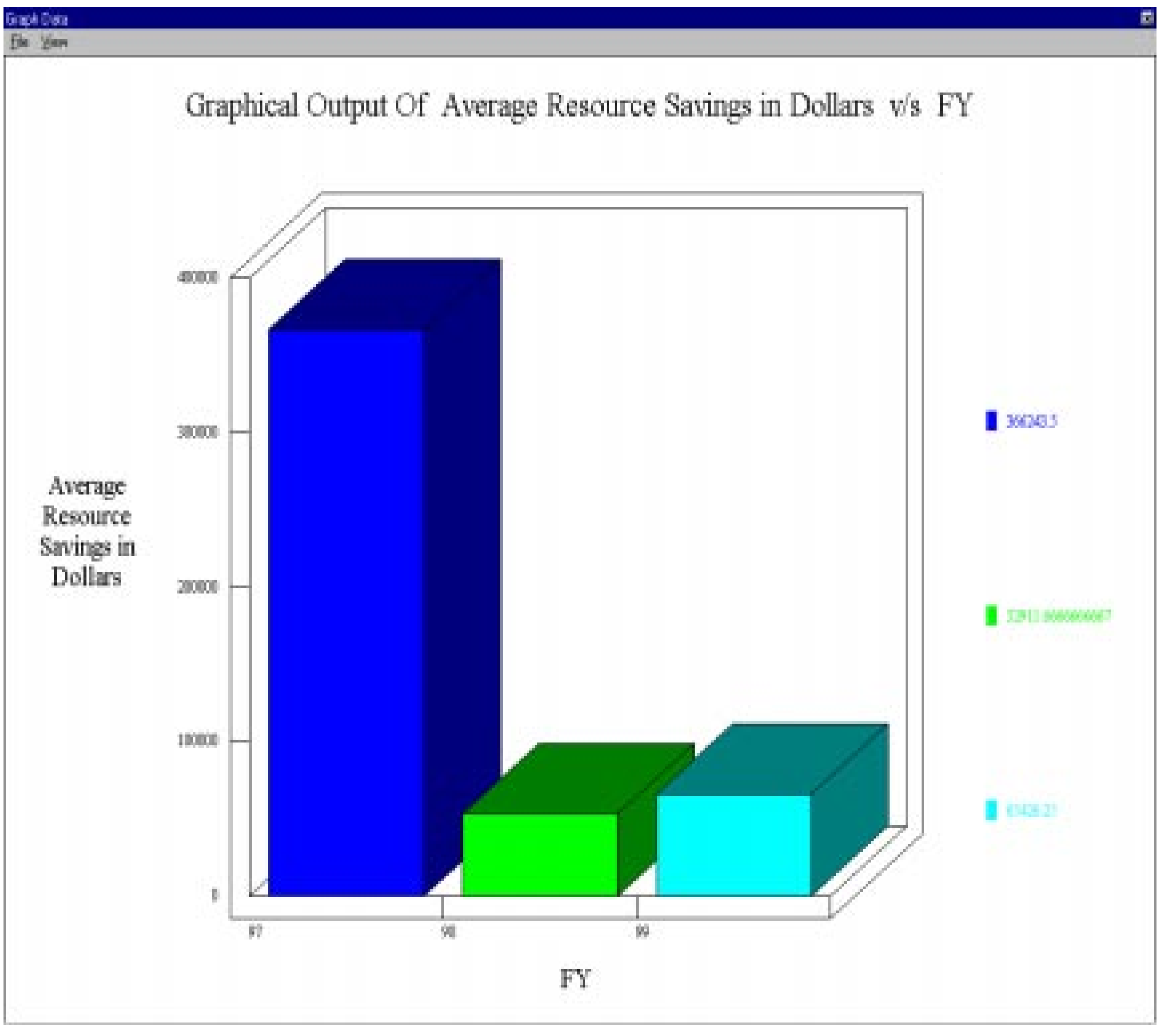


Figure 15: Stage 6 of Development

5.4.7 Development of the Graphic Server

In this stage the SQL generated in Stage 6 is sent to the database. The query returns with the appropriate value. This value is fed to the Graphic Server. The Graphic Server converts the numeric value to appropriate graphical output. The output is shown in Figure16.

Figure 16: Graphical Output of Final Stage



The above graph is for a query about the Dollar savings from Productivity Recommendations by West Virginia University starting 1997.

The Visual Basic 5.0 Code developed for this graphical server is given below.

```
Option Explicit

Enum dgType
   dgPie3d = gphPie3D
   dgBar3d = gphBar3D
   dgLine = gphLine
   dgArea = gphArea
End Enum
```

This section of the code specifies the four types of graphs that could be generated by the server. 3D Pie Charts, 3D Bar graphs, Line Graphs and Area Graphs.

```
Private intGraphType As Integer
Private strDBName As String
Private strSQLSelect As String
Private strfieldpoint As String
Private strTitle As String

Private ws As Workspace
Private db As Database
Private rs As Recordset
Private lngNumPoints As Long
Private lngLoop As Long

Private strLegendField As String
Private strLabelField As String
Private strLeftTitle As String
Private strBottomTitle As String
```

This section assigns all the global variables, sets the database, strings for graph legends, titles and labels.

```
Public Static Property Get GraphType() As Variant
GraphType = intGraphType
End Property
```

The above three lines specifies the initial graph type to be displayed

```
Public Static Property Let GraphType(ByVal vNewValue As Variant)

If IsNumeric(vNewValue) Then
intGraphType = Int(vNewValue)
End If
```

```
If intGraphType < 1 Or intGraphType > 11 Then
Err.Raise 380
intGraphType = 0
End If

End Property
```

This section of the code is an error checking script that trips the error popup when there are insufficient data to display a graph.

```
Public Property Get DatabaseName() As String
DatabaseName = strDBName
End Property

Public Property Let DatabaseName(ByVal vNewValue As String)
strDBName = vNewValue
End Property
```

The above two sets of property codes assigns the values to the database

```
Public Static Property Get SQLSelect() As Variant
SQLSelect = strSQLSelect
End Property

Public Static Property Let SQLSelect(ByVal vNewValue As Variant)
strSQLSelect = vNewValue
End Property
```

The above two sets of code assign SQL variables for retrieving data.

```
Public Static Property Get GraphField() As Variant
GraphField = strfieldpoint
End Property

Public Static Property Let GraphField(ByVal vNewValue As Variant)
strfieldpoint = vNewValue
End Property
```

The above two sets of code specify the graph fields.

```
Public Static Property Get GraphTitle() As Variant
GraphTitle = strTitle
```

```
End Property

Public Static Property Let GraphTitle(ByVal vNewValue As Variant)
strTitle = vNewValue
End Property
```

The above two sets of property code assigns the Graph Titles for the graph.

```
Private Sub Class_Initialize()
'strDBName = ""
strSQLSelect = ""
strfieldpoint = ""
strTitle = "GRAPHICAL RESULTS"
intGraphType = gphBar3D
strLegendField = ""
strLabelField = ""
strBottomTitle = ""
strLeftTitle = ""

End Sub


Public Static Sub ShowGraph()
On Error GoTo LocalErr
Screen.MousePointer = vbHourglass
'OpenDB
'InitGraph
'LoadGraphData
'Screen.MousePointer = vbNormal
'frmGraph.Graph1.DrawMode = gphDraw
'frmGraph.Show vbModal
'db.Close
'Exit Sub
```

This module of Visual Basic code displays the skeleton of the graphical output before the SQL retrieves the data. At this point the screen cursor turns into an hourglass.

```
Set ws = DBEngine.Workspaces(0)
'DBEngine.SetOption dbMaxBufferSize, 5632
Set db = ws.OpenDatabase("C:\thesis\Waste Queries\DATA.mdb")
Set rs = db.OpenRecordset(strSQLSelect, dbOpenSnapshot)
rs.MoveLast
lngNumPoints = rs.RecordCount
```

This is the most critical code in development. In this section the database is first opened. Once the database is opened, the SQL is executed to the database. The value that is returned from running the SQL is picked up and stored

```
Load frmGraph
frmGraph.Graph1.GraphType = intGraphType
frmGraph.Graph1.GraphTitle = strTitle
frmGraph.Graph1.NumSets = 1
frmGraph.Graph1.NumPoints = lngNumPoints
frmGraph.Graph1.AutoInc = 1
MsgBox "I am in load frmgraph", vbInformation, "Frm Graph"
rs.MoveFirst
```

Once the resultant values are returned they are assigned to the variables that is used to construct the graph.

```
For lngLoop = 1 To lngNumPoints
MsgBox "I am in lngLoop", vbInformation, "lngLoop"
frmGraph.Graph1.GraphData = rs.Fields(strfieldpoint)
rs.MoveNext

Next
```

This section stores the SQL result values

```
If Trim(strLegendField) = "" Then Exit Sub
frmGraph.Graph1.AutoInc = 1

rs.MoveFirst
For lngLoop = 1 To lngNumPoints
frmGraph.Graph1.LegendText = rs.Fields(strLegendField)
rs.MoveNext

Next
```

This section specifies the legend text for the graphical display

```
If Trim(strLabelField) = "" Then Exit Sub
frmGraph.Graph1.AutoInc = 1
rs.MoveFirst

For lngLoop = 1 To lngNumPoints
frmGraph.Graph1.LabelText = rs.Fields(strLabelField)
rs.MoveNext
```

```
Next
```

This section specifies the label text for the graphical display.

```
If Trim(strLeftTitle) <> "" Then
frmGraph.Graph1.LeftTitle = strLeftTitle
End If

If Trim(strBottomTitle) <> "" Then
frmGraph.Graph1.BottomTitle = strBottomTitle
End If
```

This section specifies the Bottom title for the graphical display.

```
Screen.MousePointer = vbNormal
frmGraph.Graph1.DrawMode = gphDraw
frmGraph.Show vbModal
db.Close
Exit Sub
```

This section displays the graph. The hourglass cursor returns to normal. The database is closed.

```
LocalErr:
Err.Raise vbObject + 4, App.EXEName, "Error displaying graph"
```

If the data has incoherent data an error popup is displayed.

```
End Sub

Public Static Property Get LegendField() As Variant
LegendField = strLegendField
End Property

Public Static Property Let LegendField(ByVal vNewValue As Variant)
strLegendField = vNewValue
End Property

Public Static Property Get LabelField() As Variant
LabelField = strLabelField
End Property

Public Static Property Let LabelField(ByVal vNewValue As Variant)
```

```
strLabelField = vNewValue
End Property


Public Static Property Get LeftTitle() As Variant
LeftTitle = strLeftTitle
End Property

Public Static Property Let LeftTitle(ByVal vNewValue As Variant)
strLeftTitle = vNewValue
End Property

Public Static Property Get BottomTitle() As Variant
BottomTitle = strBottomTitle
End Property

Public Static Property Let BottomTitle(ByVal vNewValue As Variant)
strBottomTitle = vNewValue
End Property
```

The above eight sets of property code gives the final touch to the graph by giving values to the labels, legends, graph title and bottom title.

5.5 Conclusion

This chapter primarily concentrated on the various development aspects that contributed to displaying the end product, the graphical output. The various stages were discussed with the user interface. Although the code for every stage was not discussed at length, development entailed considerable amount of Visual Basic code. A complete list of the code involved is presented in the Appendix. The SQL generated changes from query to query and is displayed on the screen in the final stage. The graphical output shown in figure 16 shows that the system development works as designed.

CHAPTER 6

SYSTEM IMPLEMENTATION AND VALIDATION

The objective of this chapter is to provide results from real time execution of the application and verify the results obtained. Also this section should provide the user a walk through the entire application. Two queries on waste minimization recommendation and one query on productivity enhancement recommendations are discussed.

6.1 Query 1

Statement: Compare the Average Dollar Savings from Waste Minimization Recommendations of Plants Audited by West Virginia University and the Average Dollar Savings from Waste Minimization Recommendations Audited by all Schools in the IAC/EADC Program over the last 10 years.

Figure 17: Step 1 of Query Generation in Query 1

Solution: This query would require finding out the average waste cost of plants audited by West Virginia University. The steps followed are explained below.

Step1: From the initial screen shown in Figure 17 choose the “Waste Option”. Then hit the next command button. This will take you to step 2 of the process.

Step2: This step prompts the user to enter the type of resources interested in. The three options being Pounds of Material for recommendations involving solid waste generation like paper, cardboard etc., Gallons of Material for recommendations involving liquid waste generation like water, oils etc. and the third one is All Assessments that include solids and liquid waste generation. Figure18 shows the screen shot with the three options. Since we are interested in all kinds of waste generation costs, the third option is selected.

Figure 18: Step 2 of Query Generation in Query 1

After the selection is made hit the “Continue” button to proceed to the next stage.

Step3: This step includes the various assessment recommendations that could be selected. Since All Assessments were selected in step 2 all options in this step are already automatically selected. See Figure 19 for the screen shot of the options. The user has to hit the “Next” Button to proceed to the next level. At this stage if the user required to select specific assessments the he would have to return to the previous step and select the kind of resource quantity that the assessment would fall into. For example, if the recommendation involved paper and cardboard waste, the user should choose Pounds of Material since that would be the type of recommendation that paper and cardboard would fall into.

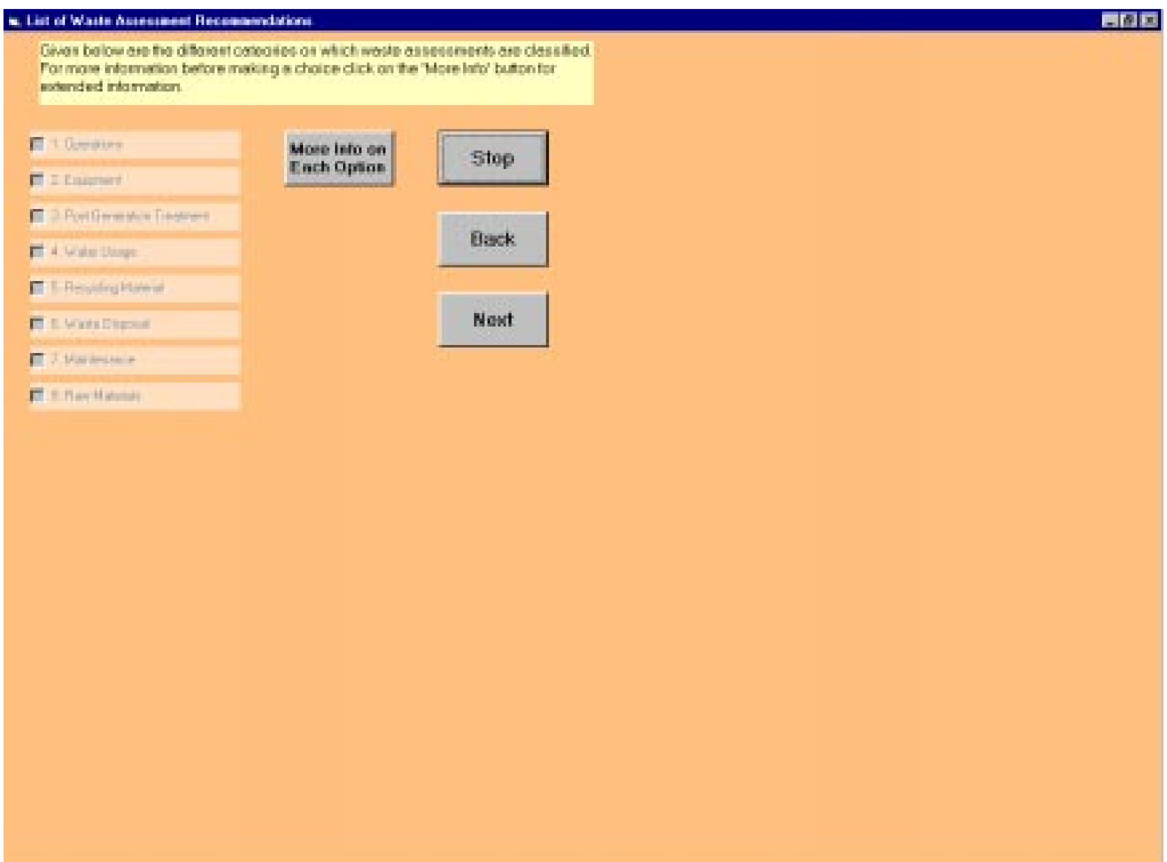


Figure 19: Step 3 of Query Generation in Query 1

Step 4: This step involves the user input of the limiting values for resource quantities and dollar values for waste costs. Since we are interested in all kinds waste costs with no limits at all a range of 0 to 10000000 is input in both the check boxes. All recommendations fall within this value. Figure 20 shows the form for this input.

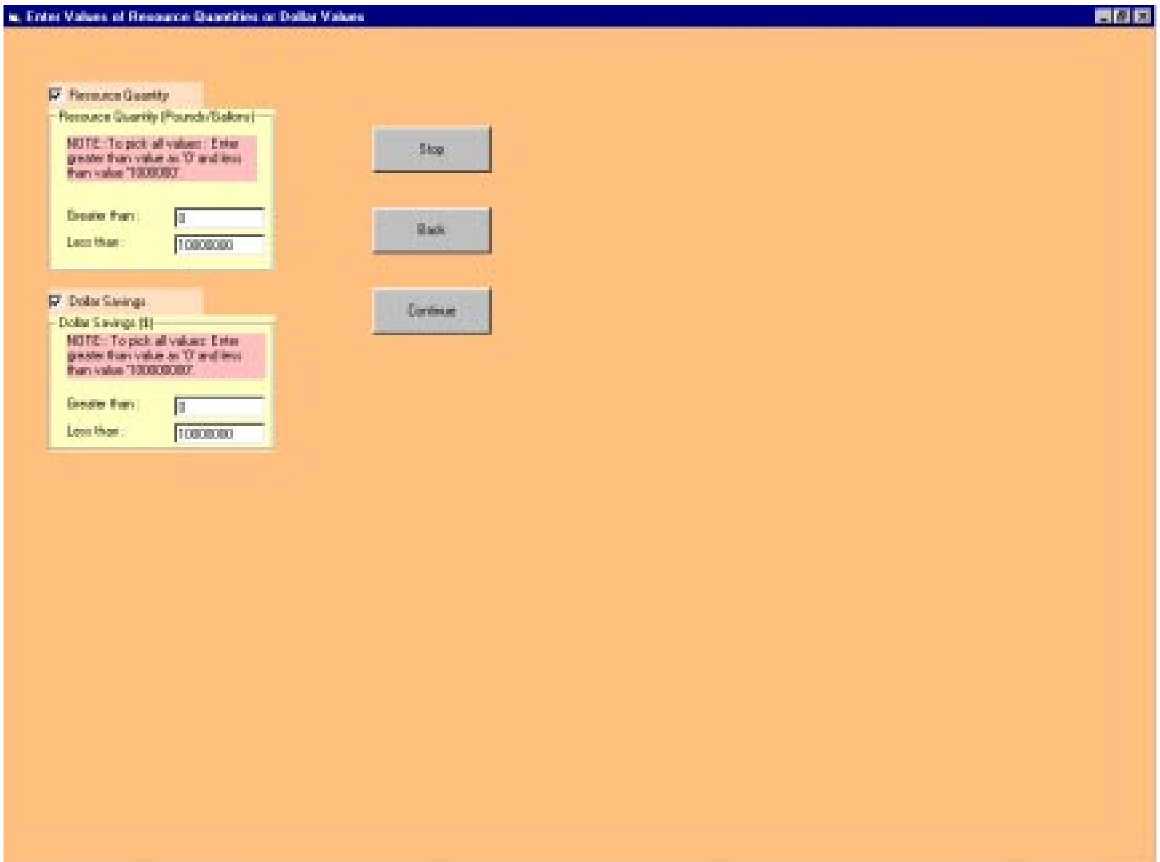


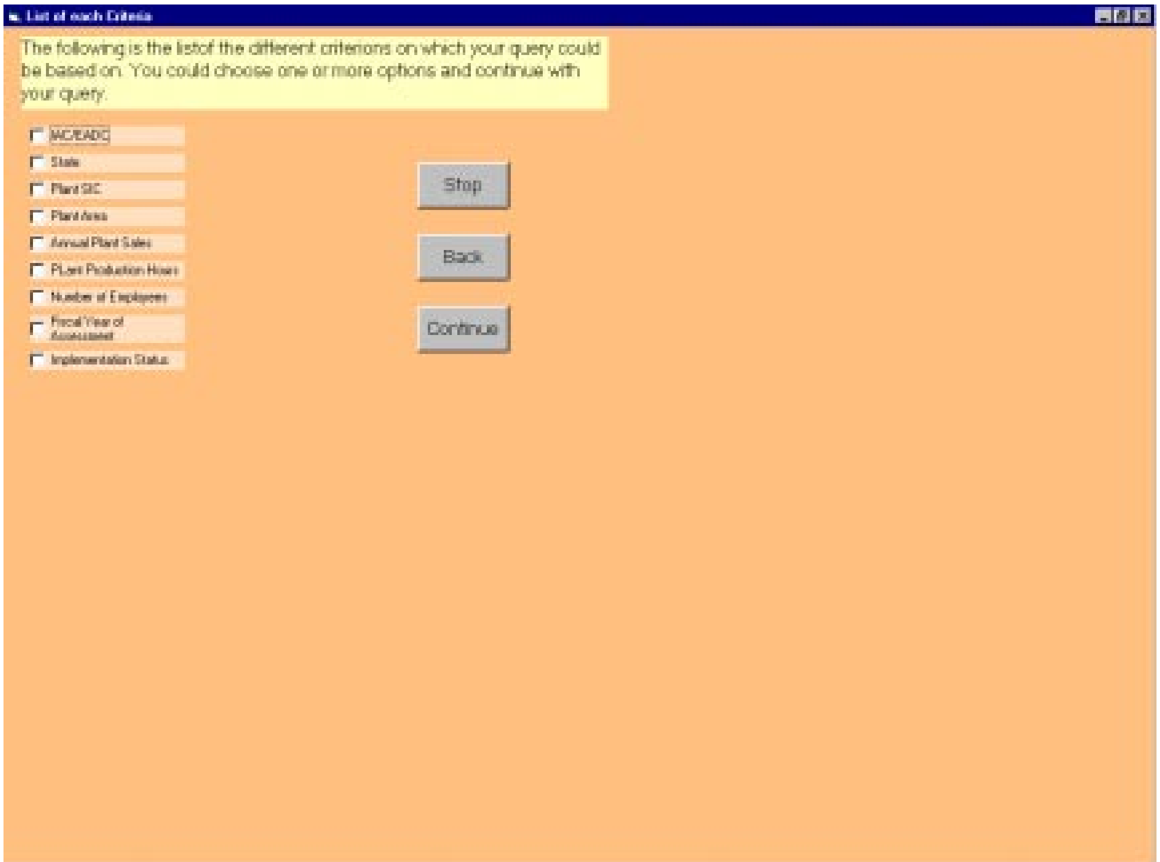
Figure 20: Step 4 of Query Generation in Query 1

If at this stage if the user would like to define any kind of limiting values, he could do so. For example if the user would like to see dollar savings of a range between $1000 and $10000, then the user inputs these values in the “Dollar Savings” option text boxes. The “Greater Than” value would be 1000 and the “Less Than” value would be $10000.

For our case we have already defined the range between the maximum and minimum available values. Hit the “Continue” button to proceed to next level.

Step 5: This step involves choosing the qualifiers from the list of criteria. Since the first part of the query requires information from all assessments, no options are chose and we proceed to the next level. Figure 21 shows the screen layout of this stage.

Figure 21: First Part of Step5 of Query Generation in Query 1



Since the second part of this query requires waste assessments done by West Virginia University, the IAC/EADC check box is selected. Once this selection is made the next screen shot of the various schools that are part of the IAC/EADC program is displayed. On this screen the code for West Virginia University, WV is selected. The user can choose multiple options if necessary. Figure 22 illustrates this screen.

Figure 22: Second Part of Step 5 of Query Generation in Query 1

All the options shown on the screen for List of criteria (Figure 21) have multiple options. On checking the box with the appropriate qualifier, the pertinent following screen is displayed automatically. After the user chooses the option the "Continue" command button is selected to proceed.

Step6: This step involves the assignment of the X-axis and the Y-axis values to the query and the resultant data. The flows of events in this step are

Select X-axis and Y-axis – Hit the "Get Data" Button – Hit the "Graph" Button

Figure 23 displays the screen for X-axis and Y-axis selection.

Hitting the "Graph" button takes you to the interstitial screen where the user hits "Show Graphical Output" Button and the graph is displayed.

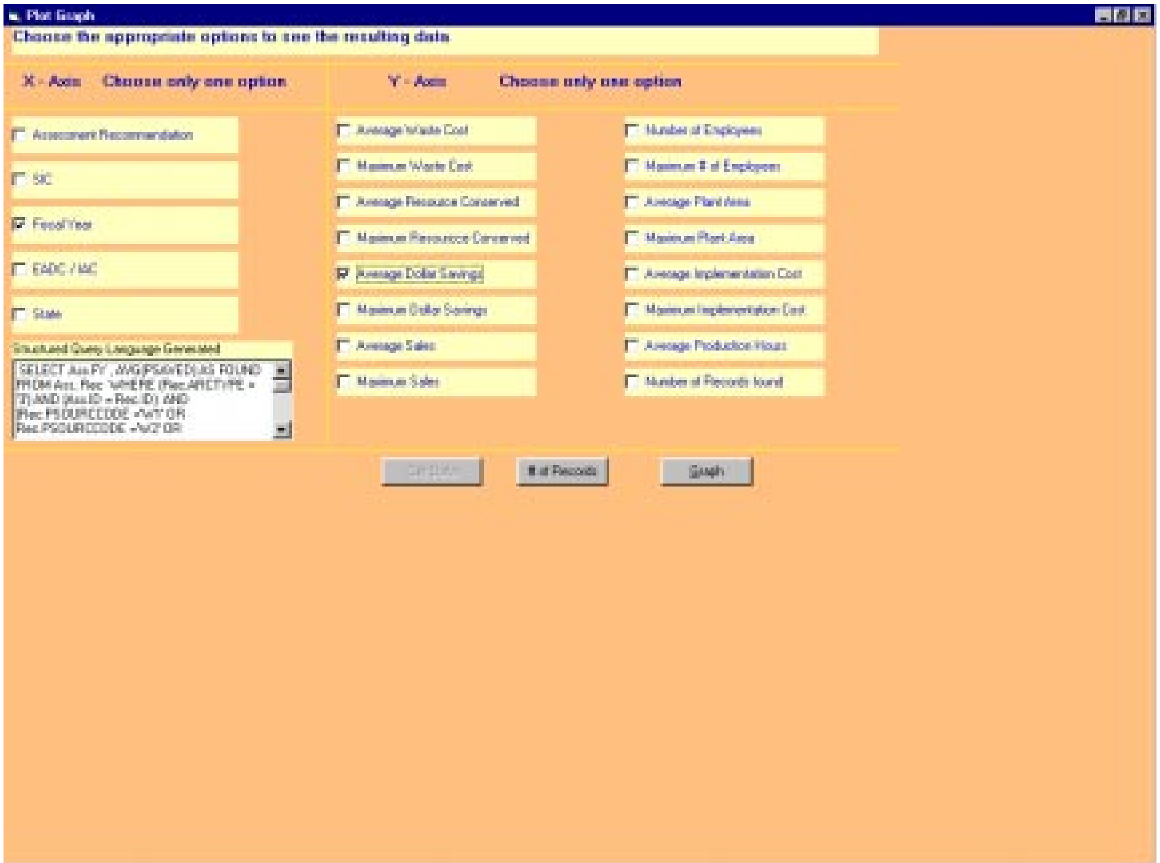


Figure 23: Step 6 of Query Generation in Query 1

Fiscal Year was selected for the X-axis and Average Dollar Savings for Y-axis.

Figure 24 shows the interstitial screen before the final result graphical output is displayed. On the screens shown on figure 23 and figure 24, there are text boxes that display the Structured Query Language that was generated by the users query. This is primarily for users who understand the Structured Query Language and would like to use the generated code for their purpose. This SQL code could be cut out from the text box.

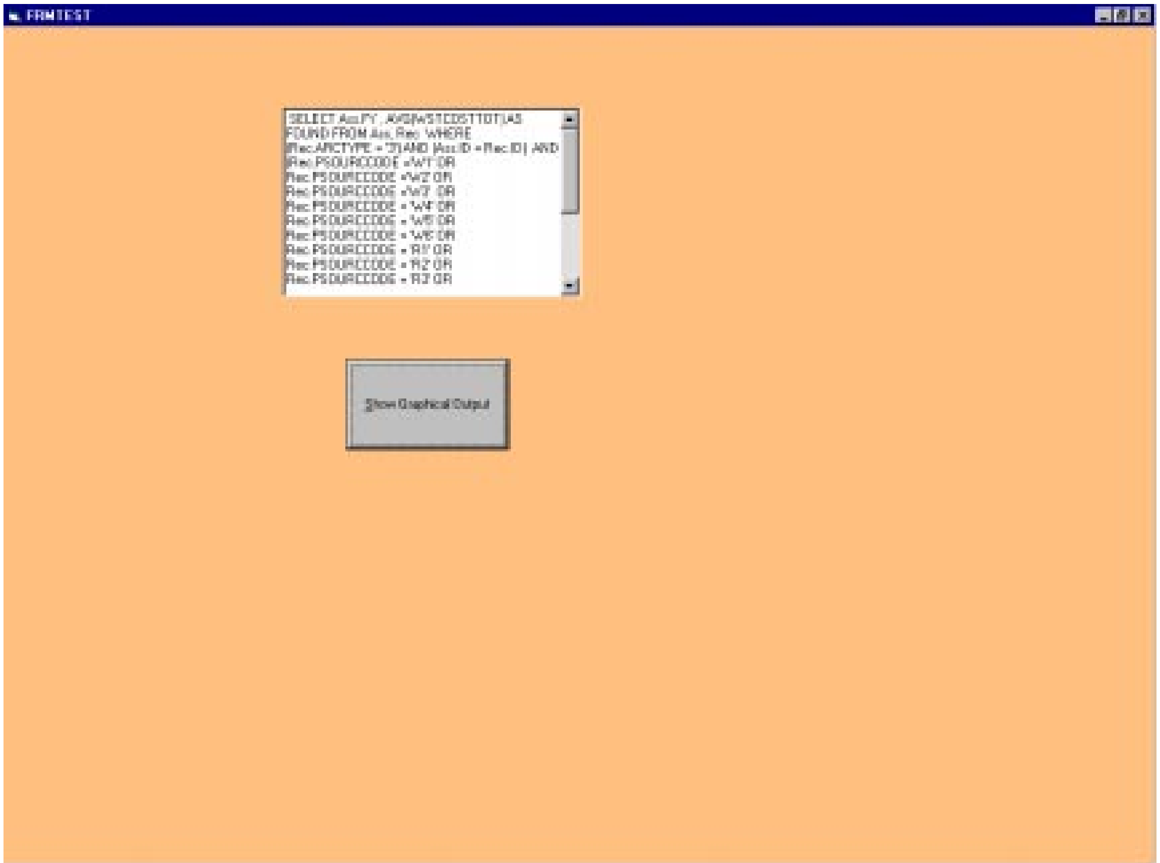


Figure 24: Interstitial Screen for Step 6 in Query 1

Figure 25 shows the graphical output of the query for Average Dollar Savings with respect to West Virginia University. Figure 26 shows the output of the query for Average Dollar Savings for the entire IAC/EADC program

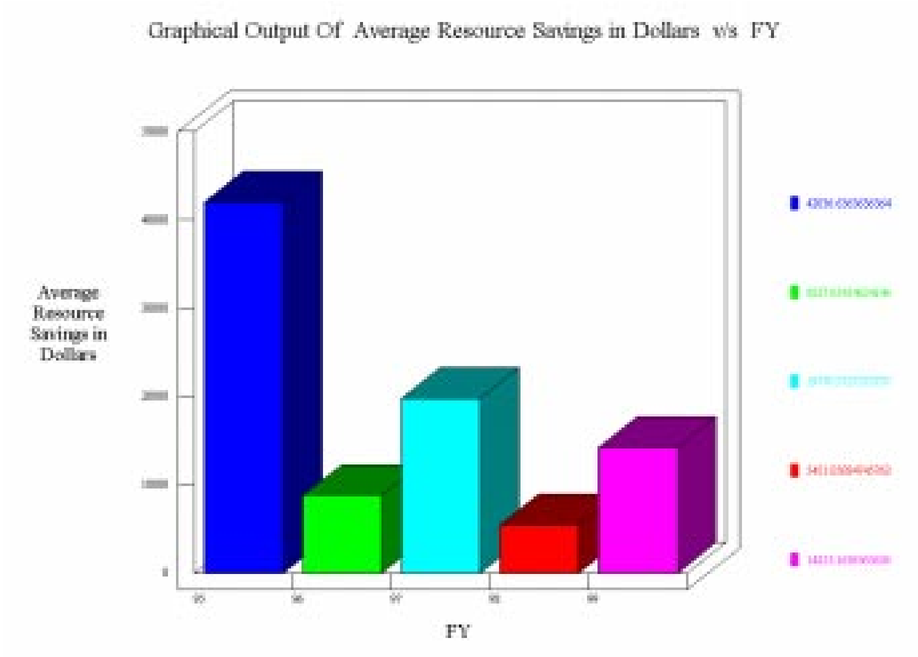


Figure 25: First Graphical Output For Query 1

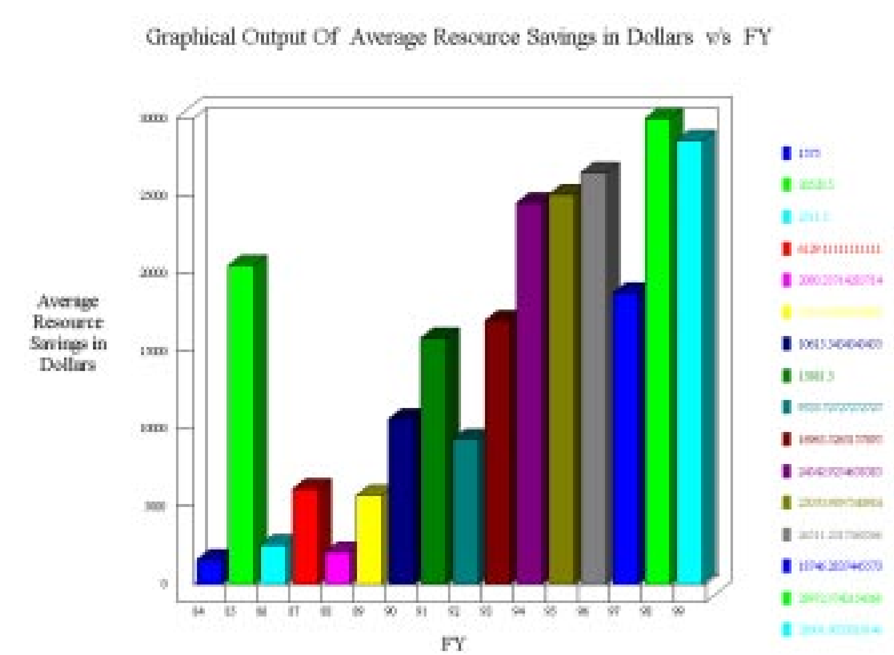


Figure 26: Second Graphical Output For Query 1

Analysis of the Graphical Output for Query 1:

From the two graphs we can observe that West Virginia University started recommendations for waste minimization opportunities in 1995. Various other schools started this activity beginning 1984.

The average dollar savings from waste minimization recommendations by West Virginia University are $42,036, $8,827, $19,770, $5451 and $14213 for the years 1995, 1996, 1997, 1998 and 1999 respectively.

Average dollar savings from waste minimization recommendations for all participating IAC/EADC schools for the same corresponding years are $25050, $26511, $18746, $29972 and $28601.

For the years 1995 and 1997 West Virginia University performed better than average in waste minimization recommendations, but for the other three years it fared below average. I has also to be noted that the numbers for 1999 reflect only data gathered till the third quarter of the year.

6.2 Query 2

Statement: Compare the Average Waste Cost generated due to Paper and Cardboard, Metallic Scrap and Waste Usage for Plants with the following Standard Industrial Code:

2653, 2655, 2671 and 2674.

Solution: The user has to go through the various steps as discussed in query 1. In step 3 the user chooses Paper and Cardboard, Metallic waste and Water Usage for the three queries separately. In the screen prompting for SIC codes the user has to input the four given SIC codes. Once this is done the user chooses SIC on the X-axis and Average waste cost on the Y-axis. The results are shown in the graphical outputs. The graphical outputs are shown in Figure 27, Figure 28 and Figure 29.

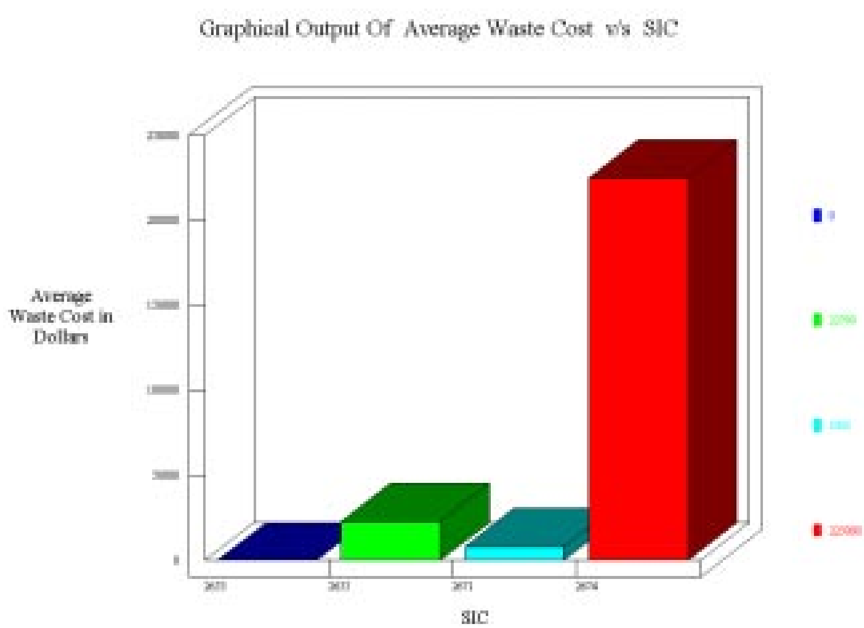


Figure 27: Graphical Output for Paper and Cardboard Average Waste Cost. Query 2

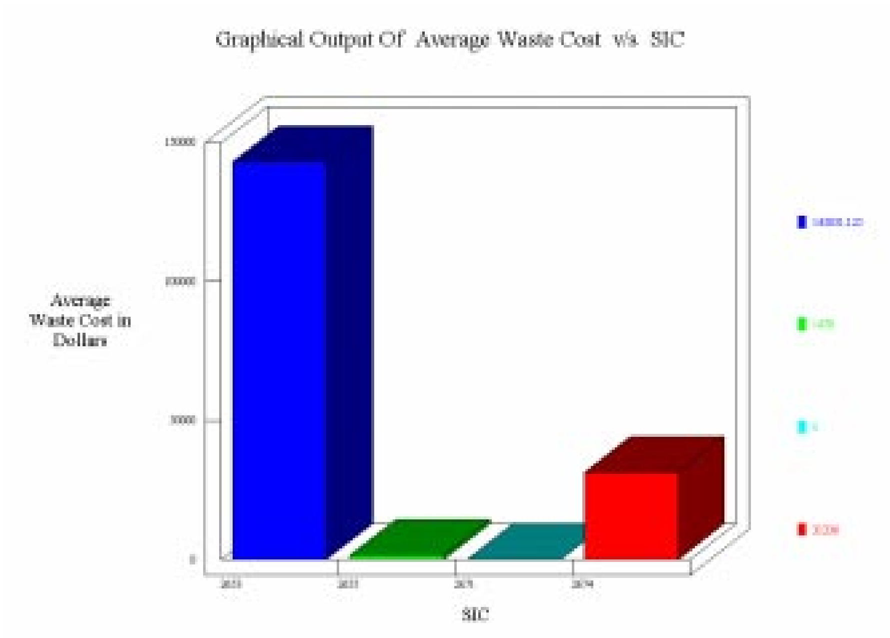


Figure 28: Graphical Output for Metallic Scrap Average Waste Cost. Query 2

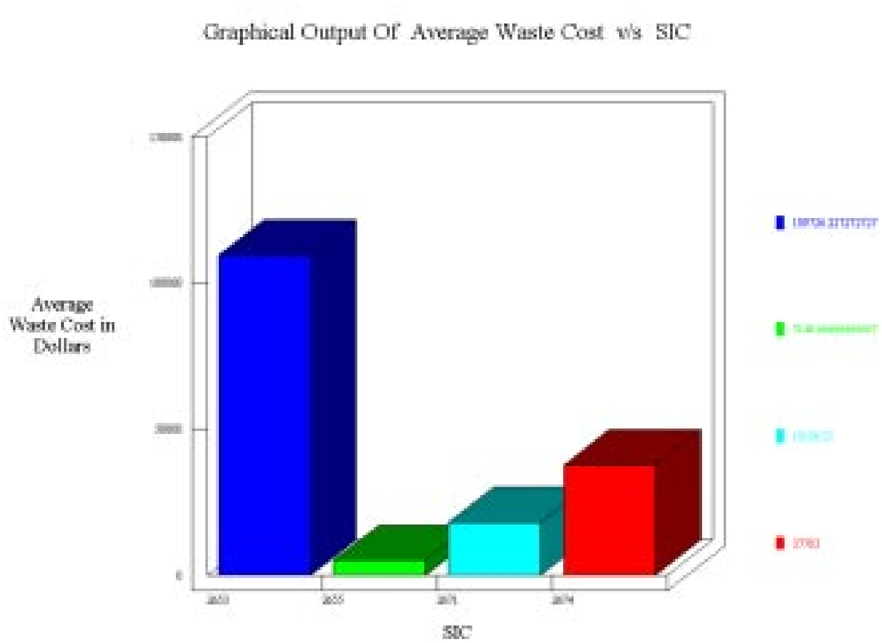


Figure 29: Graphical Output of Water Usage Average Waste Cost. Query 2

Analysis of Graphical Output of Query 2:

From the three graphs we can see the difference in waste costs that different types of industries have to put up with. The different costs from the graphical output are tabulated as shown below.

SIC\COST($)	**Paper & Cardboard**	**Metallic Scrap**	**Water Usage**
2653	0	143031	109726
2655	27790	1470	5146
2671	8400	0	18106
2674	225000	31336	37783

From this we can conclude that among the four SICs discussed, 2653 has the least in Paper and Cardboard costs but has the highest Water Usage cost and Metallic Scrap costs annually. 2655 has high paper and cardboard costs but comparatively lower metal and water usage costs. 2671 has lower costs in all the three categories. 2674 has the highest cost due to all three categories but is particularly high in paper and cardboard costs.

6.3 Query 3

Statement: Compare the Average Dollar Savings from Productivity Recommendations by West Virginia University for the years 1997, 1998 and 1999.

Solution: The user has to go through the various steps involved and prompted by the application. In the list of IAC/EADC schools, West Virginia University was selected.

Fiscal Year was selected on the X-axis and Average Dollar Savings on the Y-axis. The graphical output is shown in figure 30.

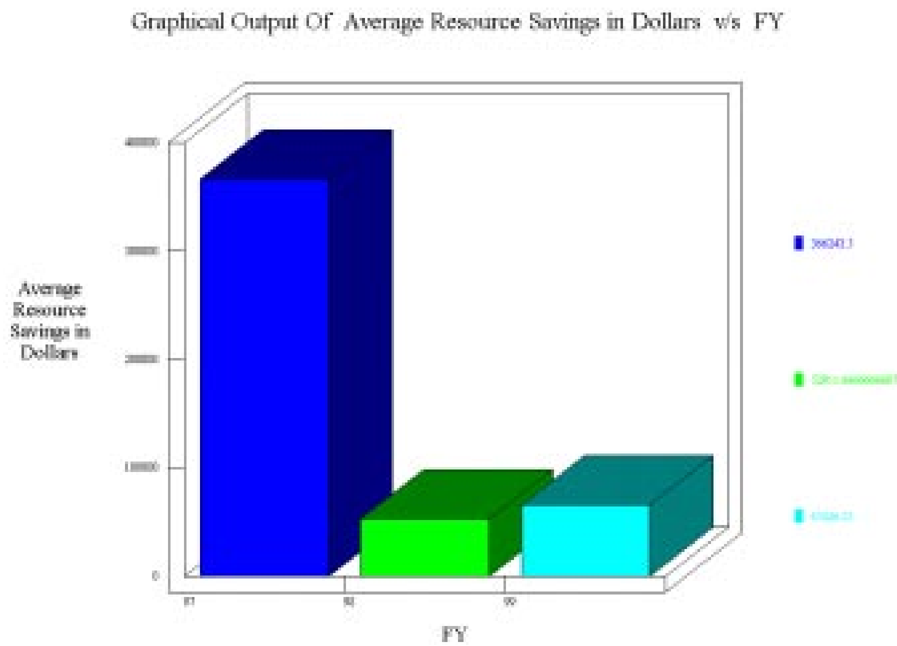


Figure 30: Graphical Output of Average Dollar Savings from Productivity recommendations. Query 3.

Analysis of the Graphical Output from Query 3:

From the graph we can summarize that the average dollar savings from productivity fell from $366,243 in 1997 to $52,911 in 1998 and increased marginally to $65,426 in 1999.

6.3 Conclusion

This chapter validates the working of the system developed. The results obtained from running the queries are displayed. To run these queries manually would require considerable amount of man-hours and variety of tools with different operating procedures. It is therefore justified to build and operate such a decision support system. Another important aspect of this system is very little training time for the user. The user can follow the prompts and instructions on the screen to proceed with queries.

6.4 Future Work

The two aspects of this system that would require future work are:

- Integration of the system with the Energy Analysis tool already developed by Veena[31].
- Make this tool available to be operated from a Web Site. Converting this system to a web based application will make it available to users across continents.

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APPENDIX A : ASSESSMENT RECOMMENDATION CODES

PROCEDURES

Process Specific

1111 COVER INK CONTAINERS WHEN NOT IN USE

1112 USE DEDICATED PRESSES FOR EACH COLOR

1113 USE GLASS MARBLES TO RAISE FLUID LEVELS OF CHEMICALS TO THE BRIM TO REDUCE CONTACT WITH ATMOSPHERIC OXYGEN

1114 REUSE HIGH FERROUS METAL DUST AS RAW MATERIAL

1115 ORDER PAINT PIGMENTS IN PASTE FORM INSTEAD OF DRY POWDER TO ELIMINATE HAZARDOUS DUST WASTE

1116 REPAIR / UPGRADE GRATE CONVEYORS TO MINIMIZE LOSS OF COAL FINES

Material Application

1121 USE MORE EFFICIENT ADHESIVE APPLICATORS

1122 SWITCH FROM AUTOMATIC TO HAND APPLICATION

Stripping

1131 USE MECHANICAL STRIPPING METHODS

1132 USE CRYOGENIC STRIPPING

Scheduling

1141 SCHEDULE JOBS TO MINIMIZE THE NEED FOR CLEANUP (COLORS)

1142 SCHEDULE PRODUCTION RUNS TO MINIMIZE COLOR CHANGES

Desulfurization / Slag Management

1151 TREAT DESULFURIZATION SLAG IN A DEEP QUENCH TANK INSTEAD OF SPRAYING WATER ONTO AN OPEN PILE TO REDUCE AIR EMISSIONS

1152 USE HIGH QUALITY SCRAP (LOW SULFUR) TO REDUCE HAZARDOUS SLUDGE GENERATION

1153 ALTER PRODUCT REQUIREMENTS TO ELIMINATE UNNECESSARY USE OF DESULFURIZING AGENT (CALCIUM CARBIDE)

1154 USE AN ALTERNATIVE DESULFURIZING AGENT TO ELIMINATE HAZARDOUS SLAG FORMATION

Reduction / Elimination

1161 ELIMINATE/REDUCE AN OPERATION

1162 USE LESS WASTEFUL PACKAGING

1163 USE PLASTIC PALLETS INSTEAD OF WOOD

Product Specifications

1171 CHANGE PRODUCT SPECS

1172 REVISE RAW MATERIAL SPECS

1173 USE A DIFFERENT RAW MATERIAL

1174 USE A RECYCLED RAW MATERIAL

By-product Use

1181 ELIMINATE A BY-PRODUCT

1182 MAKE A NEW BY-PRODUCT

Miscellaneous

1191 CHANGE PROCEDURES / EQUIPMENT / OPERATING CONDITIONS

1192 REDUCE SCRAP PRODUCTION

1193 CONVERT FROM BATCH OPERATION TO CONTINUOUS PROCESSING

1194 USE AUTOMATIC FLOW CONTROL

1195 USE SILHOUETTE ENTRY COVER TO REDUCE EVAPORATION AREA

1196 MONITOR SOLUTIONS TO MAINTAIN SOLUTION STRENGTH

Rinsing Strategies

1221 USE REACTIVE RINSING

1222 REDUCE WATER USE WITH COUNTER CURRENT RINSING

1223 USE FOG NOZZLES / SPRAY RINSING INSTEAD OF IMMERSION RINSING

1224 MECHANICALLY AND AIR AGITATE RINSE TANKS FOR COMPLETE MIXING

1225 USE A STILL RINSE AS THE INITIAL RINSING STAGE

1226 USE COUNTER CURRENT WASHING IN PHOTO PROCESSORS

1227 USE COUNTER-CURRENT RINSING TO REDUCE RINSE WATER VOLUME

Dragout Reduction

1241 SLOW INSERTION / WITHDRAWAL OF PARTS FROM DEGREASING TANK

1242 ALLOW DRAINAGE BEFORE WITHDRAWING OBJECT

1243 PRE-INSPECT PARTS TO PREVENT DRAG-IN OF SOLVENTS / CLEANERS

1244 REDUCE SOLUTION DRAG-OUT TO PREVENT SOLUTION LOSS

1245 EXTEND SOLUTION LIFE BY MINIMIZING DRAG-IN

1246 LOWER THE CONCENTRATION OF PLATING BATHS

1247 USE DRAG-OUT REDUCTION METHODS (GRAVURE)-SEE SURFACE COATING

Miscellaneous

1291 ELIMINATE PRACTICE OF MIXING WASTE STREAMS

1292 DEVELOP SEGREGATED SEWER SYSTEMS

1293 SEPARATE TREATMENTS FOR EACH TYPE OF SOLUTION AND RECYCLE

1294 SEGREGATE SPENT SOLVENTS AND REUSE IN SUBSEQUENT WASHINGS

1295 USE SQUEEGEES TO PREVENT CHEMICAL CARRY-OVER

1296 AVOID CONTAMINATION OF SCRAP GLASS AND REUSE AS FEED STOCK

CAD/CAM

General

1311 OPTIMIZE DYE DESIGN

Equipment

GENERAL

Fault Tolerance

2111 INSTALL REDUNDANT EQUIPMENT TO AVOID LOSSES CAUSED BY EQUIPMENT FAILURE AND ROUTINE MAINTENANCE

Painting Operations

2121 CONVERT TO ELECTROSTATIC POWDER COATING

2122 CONVERT FROM WATER CURTAIN SPRAY BOOTHS TO A DRY SYSTEM

2123 CONVERT TO HIGH VOLUME LOW PRESSURE (HVLP) PAINT GUNS

2124 CONVERT TO AIR ASSISTED / AIRLESS PAINT GUNS

Process Specific Upgrades

2131 INSTALL MIXERS ON EACH CLEANING TANK

2132 INCREASE FREEBOARD SPACE / INSTALL CHILLERS ON VAPOR DEGREASERS

2133 ELIMINATE CHEMICAL ETCHING AND PLATING BY USING ALTERNATIVE PRINTING TECHNOLOGIES (PRE SENSITIZED LITHOGRAPHIC, PLASTIC OR PHOTO POLYMER, HOT METAL, OR FLEXOGRAPHIC)

2134 USE HIGH PURITY ANODES TO INCREASE SOLUTION LIFE

2135 EXTEND SOLUTION LIFE WITH FILTERING OR CARBONATE FREEZING

2136 USE "WASH-LESS" PROCESSING EQUIPMENT

2137 USE INDUCTION FURNACES INSTEAD OF ELECTRIC ARC OR CUPOLA FURNACES TO REDUCE DUST AND FUMES

Tank Design

2141 USE CYLINDRICAL TANKS WITH HEIGHT TO DIAMETER RATIOS CLOSE TO ONE TO REDUCE WETTED SURFACE

2142 USE TANKS WITH A CONICAL BOTTOM OUTLET SECTION TO REDUCE WASTE ASSOCIATED WITH THE INTERFACE OF TWO LIQUIDS

System Monitoring

2161 CLOSELY MONITOR CHEMICAL ADDITIONS TO INCREASE BATH LIFE

2162 INSTALL WEB BREAK DETECTORS TO PREVENT EXCESSIVE WASTE PAPER

2163 USE INK WATER RATIO SENSOR

Automation

2171 USE AN AUTOMATIC PLATE PROCESSOR

2172 USE AUTOMATIC CLEANING EQUIPMENT

2173 CONVERT TO ROBOTIC PAINTING

2174 AUTOMATE INK MIXING

2175 USE AUTOMATED PLATE BENDERS

2176 INCREASE USE OF AUTOMATION

Post Generation Treatment / Minimization

GENERAL

Neutralization

3111 ADJUST PH FOR NEUTRALIZATION

3112 UTILIZE OXIDATION/REDUCTION FOR NEUTRALIZATION

3113 USE OTHER METHODS FOR NEUTRALIZATION

Removal of Contaminants

3121 USE SCREENING, MAGNETIC SEPARATION TO REMOVE CONTAMINANTS

3122 USE FILTRATION, CENTRIFUGING TO REMOVE CONTAMINANTS

3123 USE DECANTING, FLOTATION TO REMOVE CONTAMINANTS

3124 USE CYCLONE SEPARATION TO REMOVE CONTAMINANTS

3125 USE DISTILLATION, EVAPORATION TO REMOVE CONTAMINANTS

3126 USE ABSORPTION, EXTRACTION TO REMOVE CONTAMINANTS

3127 USE ADSORPTION, ION EXCHANGE TO REMOVE CONTAMINANTS

3128 UTILIZE OTHER METHODS TO REMOVE CONTAMINANTS

Material Concentration

3131 USE EVAPORATION TO CONCENTRATE MATERIAL

3132 USE REVERSE OSMOSIS TO CONCENTRATE MATERIAL

3133 USE OTHER WASTE CONCENTRATION METHODS

Water Use

GENERAL

Close Cycle Water Use

4111 USE CLOSED CYCLE PROCESS TO MINIMIZE WASTE WATER PRODUCTION

4112 RECOVERY METALS FROM RINSE WATER(EVAP., ION EXCHANGE, RO,ECTROLYSIS, ELECTRODIALYSIS) AND REUSE RINSE WATER

4113 TREAT AND REUSE RINSE WATERS

4114 REPLACE CITY WATER WITH RECYCLED WATER VIA COOLING TOWER

4115 RECOVER AND REUSE COOLING WATER

4116 METER RECYCLED WATER (TO REDUCE SEWER CHARGES)

Water Quality

4131 MINIMIZE CONTAMINATION OF WATER BEFORE TREATMENT

4132 USE DEIONIZED WATER IN UPSTREAM RINSE TANKS

4133 CLEAN FOULING FROM WATER LINES REGULARLY

Water Treatment

4141 REPLACE THE CHLORINATION STAGE WITH AN OXYGEN OR OZONE STAGE

4142 RECYCLE CHLORINATION STAGE PROCESS WATER

4143 USE WATER FROM THE WASHING SYSTEM IN THE CHLORINATION STAGE

4144 PERFORM HIGH CONSISTENCY GAS PHASE CHLORINATION

4145 USE MAGNETIC TECHNOLOGY TO TREAT WATER

Reduction

4151 MINIMIZE WATER USAGE

4152 CAREFULLY CONTROL WATER LEVEL IN MASS FINISHING EQUIPMENT

4153 USE COUNTER CURRENT RINSING TO REDUCE WASTE WATER

4154 ELIMINATE LEAKS IN WATER LINES AND VALVES

4155 METER WASTE WATER

4156 USE FLOW CONTROL VALVES ON EQUIPMENT TO OPTIMIZE WATER USE

4157 REPLACE WATER COOLING ON PROCESSES WITH AIR COOLING

4158 USE MINIMUM COOLING WATER TO BEARINGS

Recycling

LIQUID WASTE

Oil

5111 FILTER AND REUSE HYDRAULIC OIL

5112 REPROCESS SPENT OILS ON SITE FOR RE-USE

5113 SELL OIL TO RECYCLER

Ink

5121 RECYCLE WASTE INK AND CLEANUP SOLVENT

White Water

5131 RECYCLE WHITE WATER

5132 REUSE RICH WHITE WATER IN OTHER APPLICATIONS

Miscellaneous

5141 RECOVER DYE FROM WASTE WATERS

5142 TREAT AND REUSE EQUIPMENT CLEANING SOLUTIONS

5143 RETURN SPENT SOLUTIONS TO THE MANUFACTURER

5144 RECYCLE SPENT TANNING SOLUTION

5145 RECOVER AND REUSE SPENT ACID BATHS

5146 UTILIZE A CENTRAL COOLANT SYSTEM FOR CLEANING AND REUSE OF METAL WORKING FLUID

SOLID WASTE

General

5211 REUSE SCRAP GLASS AS FEED STOCK

5212 REGRIND, REUSE, OR SELL SCRAP PLASTIC PARTS

5213 REUSE SCRAP PRINTED PAPER FOR MAKE-READY

5214 AVOID CONTAMINATION OF FLASHING / REJECT S AND USE AS FEED STOCK

5215 AVOID CONTAMINATION OF END PIECES AND REUSE AS FEED STOCK

5216 RECYCLE NONFERROUS DUST

5217 REUSE / RECYCLE/ SELL PAPER PRODUCTS

5218 REUSE / RECYCLE/ SELL RUBBER PRODUCTS

Sand

5221 RECYCLE CASTING SAND

5222 USE SAND FOR OTHER PURPOSES (EG CONSTRUCTION FILL, COVER FOR MUNICIPAL LANDFILLS)

Metals

5241 SELL USED PLATES TO AN ALUMINUM RECYCLER

5242 RECOVER METALS FROM SPENT SOLUTIONS AND RECYCLE

5243 RECYCLE FILM FOR SILVER RECOVERY

5244 RECOVER METALS FROM CASTING SAND

5245 SEPARATE AND RECYCLE SCRAP METAL TO FOUNDRY

5246 SEGREGATE METALS FOR SALE TO A RECYCLER

5247 SEPARATE IRON FROM SLAG AND REMELT

OTHER MATERIALS

General

5311 RECOVER AND REUSE WASTE MATERIAL

5312 SALVAGE AND RE-USE PROCESS WASTE

5313 INCREASE AMOUNT OF WASTE RECOVERED FOR RESALE

5314 USE IN-PROCESS RECYCLING WHENEVER POSSIBLE

5315 LEASE / PURCHASE BALER; SELL CARDBOARD TO RECYCLER

5316 CONTRACT A WOOD PALLET RECYCLING COMPANY

5317 SELL / OFFER BY-PRODUCT AS ANIMAL FEED

Waste Disposal

GENERAL

Sludge Maintenance

6111 USE ALTERNATIVE FLOCCULENT TO MINIMIZE SLUDGE VOLUME

6112 USE FILTER AND DRYING OVEN TO REDUCE SLUDGE VOLUME

6113 REMOVE SLUDGE FROM TANKS ON A REGULAR BASIS

6114 USE PRECIPITATING AGENTS IN WASTE WATER TREATMENT THAT PRODUCE THE LEAST QUANTITY OF WASTE

Combustion of Waste Products

6121 BURN WASTE PAPER FOR HEAT

6122 INSTALL SOLID WASTE INCINERATOR FOR HEAT

6123 BURN WOOD BY-PRODUCTS FOR HEAT

6124 BURN WASTE OIL FOR HEAT

6125 SELL COMBUSTIBLE WASTE

6126 DIRECT WASTE GASSES TO BOILER COMBUSTION AIR

Miscellaneous

6191 RETURN SPENT SOLUTIONS TO THE MANUFACTURER

6192 USE A LESS EXPENSIVE METHOD OF WASTE REMOVAL

6193 INSTALL EQUIPMENT (eg COMPACTOR) TO REDUCE DISPOSAL COSTS

6194 SHIP HYDRAULIC OIL TO SECONDARY FUEL PROGRAM

Maintenance

CLEANING / DEGREASING

Mechanical Cleaning

7111 USE VACUUM FOR SPILL CLEANUP INSTEAD OF ABSORBENT

7112 USE SQUEEGEES, MOPS, AND VACUUMS FOR FLOOR CLEANING

7113 USE MECHANICAL WIPERS FOR CLEANING OF VESSELS

7114 USE SQUEEGEES TO RECOVER CLINGING PRODUCT PRIOR TO RINSING

7115 CLEAN LINES WITH “PIGS" INSTEAD OF SOLVENTS / SOLUTIONS

Reduction of Cleaning

7121 IMPROVE HANDLING PRACTICES

7122 MAXIMIZE PRODUCTION RUNS TO REDUCE CLEANING

7123 USE CONTINUOUS PROCESSING

7124 INSTALL DEDICATED MIXING EQUIPMENT TO OPTIMIZE REUSE OF USED RINSEATE AND TO PRECLUDE THE NEED FOR INTER-RUN CLEANING

7125 SHORTEN PAINT LINES AS MUCH AS POSSIBLE

7126 USE PEEL COATINGS ON RAW MATERIALS

7127 MINIMIZE PART CONTAMINATION BEFORE WASHING

Rag Use

7131 USE A RAG RECYCLE SERVICE

7132 REUSE RAGS UNTIL COMPLETELY SOILED

7133 USE RAGS SIZED FOR EACH JOB

7134 WASH AND REUSE RAGS ON-SITE

7135 MINIMIZE USE OF RAGS THROUGH WORKER TRAINING

7136 MARKET WASTE MATERIALS AS CLEAN-UP RAGS

7137 REPLACE CLOTH RAGS WITH PAPER TOWELS

Preventive Maintenance

7141 IMPROVE CLEANING EFFICIENCY BY MAINTAINING CLEANING SYSTEM

7142 USE CLEAN IN PLACE (CIP) SYSTEMS

7143 CLEAN EQUIPMENT IMMEDIATELY AFTER USE

Miscellaneous

7191 USE WATER BASED SPRAY ABRASIVES INSTEAD OF BAR ABRASIVES

7192 USE DRY CLEANING METHODS WHENEVER POSSIBLE

7193 USE HIGH PRESSURE WASH SYSTEMS

7194 USE DISPOSABLE LINERS IN TANKS

7195 USE TEFLON LINED TANKS

7196 USE RE-USABLE FILTERS

7197 USE ULTRASONIC CLEANING

7198 REDUCE / ELIMINATE USE OF DISPOSABLE PRODUCT

SPILLAGE

Operations

7211 MODIFY MATERIAL APPLICATION METHODS

7212 IMPROVED MATERIAL HANDLING (MIXING AND TRANSFER)

7213 USE MORE EFFICIENT SPRAY METHOD FOR GELCOAT APPLICATION

7214 REDUCE OR ELIMINATE WASTE

7215 AVOID INSERTING OVERSIZED OBJECT TO REDUCE PISTON EFFECT

Hardware

7221 IMPROVE PROCESS CONTROL TO PREVENT SPILLS OF MATERIAL

7222 MINIMIZE OVERFLOWS BY INSTALLING LEVEL CONTROLS

7223 INSTALL SHROUDING ON MACHINES TO PREVENT SPLASHING

7224 USE PUMPS AND PIPING TO DECREASE THE FREQUENCY OF SPILLAGE DURING MATERIAL TRANSFER

OTHER

Leak Reduction

7311 MAINTAIN MACHINES WITH TO REDUCE LEAKS

7312 IMPLEMENT A REGULAR MAINTENANCE PROGRAM TO REDUCE EMISSIONS FROM LEAKY VALVES AND PIPE FITTINGS

7313 ELIMINATE OXYGEN LOSS

Miscellaneous

7391 IMPLEMENT A MAINTENANCE PROGRAM TO KEEP RACKS AND TANKS FREE OF RUST, CRACKS, OR CORROSION

7392 APPLY A PROTECTIVE COATING TO RACKS AND TANKS

7393 IMPLEMENT A MACHINE AND COOLANT SUMP CLEANING PROGRAM TO MINIMIZE COOLANT CONTAMINATION

Raw Materials

SOLVENTS

Use Reduction

8111 MAINTAIN WATER SEPARATOR AND COMPLETELY DRY PARTS TO AVOID WATER CONTAMINATION OF SOLVENT

8112 USE DEIONIZED WATER FOR MAKE-UP AND RINSE WATER TO INCREASE SOLUTION LIFE

8113 PREVENT EXCESSIVE SOLVENT USAGE (OPERATOR TRAINING)

8114 AUTOMATE PAINT MIXING-USE COMPRESSED AIR BLOWOUT FOR LINE CLEANING PRIOR TO SOLVENT CLEANING

Emission Reduction

8121 COVER CONTAINERS TO MINIMIZE EVAPORATIVE LOSSES

8122 USE TIGHT-FITTING LIDS ON MATERIAL CONTAINERS TO REDUCE VOC EMISSIONS

8123 USE TIGHT FITTING LIDS ON MATERIAL CONTAINERS TO REDUCE VOC EMISSION

8124 INSTALL FLOATING COVERS ON TANKS OF VOLATILE MATERIALS TO REDUCE EVAPORATION

8125 REMOVE ROLLERS FROM THE MACHINES AND CLEAN IN A CLOSED SOLVENT CLEANER

8126 USE FLUE GAS RECUPERATION TO REDUCE VOC

Material Replacement

8131 USE WATER-BASED ADHESIVES

8132 USE LESS TOXIC AND VOLATILE SOLVENT SUBSTITUTES

8133 CONVERT TO AQUEOUS CLEANING

8134 USE WATER-BASED CUTTING FLUIDS TO ELIMINATE NEED FOR SOLVENT CLEANING

8135 USE LOW VOC OR WATER BASED PAINT

8136 SWITCH TO A SOLVENT THAT CAN BE CLEANED AND RE-USED

8137 USE SOY OR WATER-BASED INKS

Solvent Recovery

8141 REGENERATE CLEANING SOLVENT ON-SITE AND REUSE

8142 DISTILL CONTAMINATED SOLVENTS FOR REUSE

8143 RECYCLE CLEANING SOLVENT AND REUSE

OTHER SOLUTIONS

Water-Based Substitutes

8211 CONVERT TO AQUEOUS CLEANING SYSTEM

8212 USE WATER-BASED IMAGE PROCESSING CHEMICALS

8213 USE WATER BASED OR GREASELESS BINDERS TO INCREASE WHEEL LIFE

8214 USE WATER-BASED DEVELOPERS AND FINISHERS

Other Substitutes

8221 USE ALTERNATIVES FOR ACIDS / ALKALINE (WATER, STEAM, ABRASIVE)

8222 USE REACTIVE RINSING TO EXTEND BATH LIFE

8223 USE NON-PHENOLIC STRIPPERS TO REDUCE TOXICITY ASSOCIATED WITH PHENOL AND ACID ADDITIVES

8224 CONVERT TO LESS TOXIC HYDROCARBON CLEANERS

8225 REPLACE HEXAVALENT CHROMIUM SOLUTIONS WITH TRIVALENT SOLUTIONS

8226 USE CYANIDE FREE SOLUTIONS WHENEVER POSSIBLE

8227 REPLACE CADMIUM-BASED SOLUTIONS WITH ZINC SOLUTIONS

8228 REPLACE HEAVY METAL REAGENTS WITH NON-HAZARDOUS REAGENTS

SOLIDS

General

8311 USE SILVER FREE FILMS

8312 USE BUILDING MATERIALS WHICH REQUIRE LESS ENERGY TO PRODUCE

8313 ALTER RAW MATERIALS TO REDUCE AIR EMISSIONS

8314 PURCHASE HIGH MATERIALS IN RETURNABLE BULK CONTAINERS