

SOLVENT AND PAINT WASTE REDUCTION WITH AN EXPERT SYSTEM FOR INDUSTRIAL WASTE MINIMIZATION

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ABSTRACT

In today's rapidly developing and competitive industrial world, generation of product and process waste has become inevitable. These waste products, be they hazardous or non-hazardous, if improperly dealt with, can threaten both public health and the environment. The application of knowledge-based software systems to waste minimization and waste management in industries seems logical. The expertise gained from Industrial Assessment Center (IAC) research [1] funded by the USDOE Office of Industrial Technologies has led to the development of WASTEX [2, 3], an expert system for industrial waste management and minimization, specifically designed for use by plant managers. This article describes the use of WASTEX for minimizing industrial solvent and paint waste streams. The methodology used in designing the solvent and paint waste minimization modules is described. The execution of WASTEX in this regard is explained in terms of data input and output, with details on economic evaluation.

INTRODUCTION

Pollution can be defined as the addition to our environment of any material(s) having a deleterious effect on life. As far as the industrialist is concerned, the

subject of pollution can be divided into three main categories, namely air, water, and solid waste disposal [4]. Manufacturing industries contribute to pollution by the wastes they generate, both hazardous and non-hazardous. The lists showing the harmful effects of the generated industrial wastes seem endless, and seem to be ever increasing. The true cost of the improper handling of these wastes to the nation, and the necessity for the prevention of waste must not be understated. From a manufacturing plant's perspective, the best approach is one that cost-effectively reduces waste, minimizes worker exposure to toxic materials, and optimizes the efficient use of raw materials. By incorporating practices of pollution prevention and waste minimization, one can significantly reduce the amount of waste that must be treated and disposed in an economically satisfactory manner. Waste minimization and pollution prevention in manufacturing also contributes to maintaining acceptable standards for safe exposures to hazardous substances, so helping to protect public health and the environment.

Rising environmental compliance costs cut into overall profits. With a view to reducing those costs, the design and development of an expert system for waste minimization and efficient waste management in industries is justified by the observation that several opportunities for waste minimization and efficient waste handling are overlooked by manufacturing industries [1]. There are many opportunities for considerable waste minimization and cost savings from the application of existing technology.

Realizing the need for efficient waste handling, waste minimization, and to energy conservation, the United States Department of Energy (USDOE) initiated the Industrial Assessment Centers (IAC) program in association with several American schools of engineering. The main focus of these centers has been industrial energy conservation. The USDOE has folded waste minimization among its top priorities by making it mandatory for the centers to develop recommendations for waste minimization. The waste minimization opportunities described in this article were developed in research and assessment work done at the IAC in West Virginia University's Department of Industrial and Management Systems Engineering.

Artificial Intelligence and Expert Systems

The field of artificial intelligence seeks to develop computer-based software systems that can perform tasks at a level equal to or better than that of human beings [5, 6]. Such systems might simulate higher mental processes at work in perceptual learning, memory organization, and judgmental reasoning [5, 6]. The areas of artificial intelligence that deal with the representation of knowledge, the development of expert systems, the simulation and modeling of natural and behavioral phenomena, and the rapid processing of data and information, have provided methods and tools that help solve many decision problems [5, 6]. In

particular, expert systems are computer-based tools used to address problems that ordinarily require large amounts of human expertise. These systems apply to a knowledge base in a delimited domain the reasoning techniques that a human expert plausibly would employ in analyzing problems [5-8].

The important components of an expert system are the knowledge base, inference engine, and user interface [5-8]. The knowledge acquisition module as shown in Figure 1 is the foundation of an expert system. It consists of production rules developed by the knowledge engineer using information obtained from experts and other sources of information. The production rules used are in IF-THEN format. The inference engine uses information given by the user to select and execute the appropriate production rules using a control strategy and aimed at an acceptable goal. Two of the strategies used are forward chaining and backward chaining [5-8]. Forward chaining simulates reasoning from data to hypothesis. In backward chaining, the information flow begins with the hypothesis and data is gathered to either justify or refute the hypothesis. Expert systems have been widely used to solve problems in the areas of energy conservation, forest stand management, manufacturing process planning, and other applications [9-12].

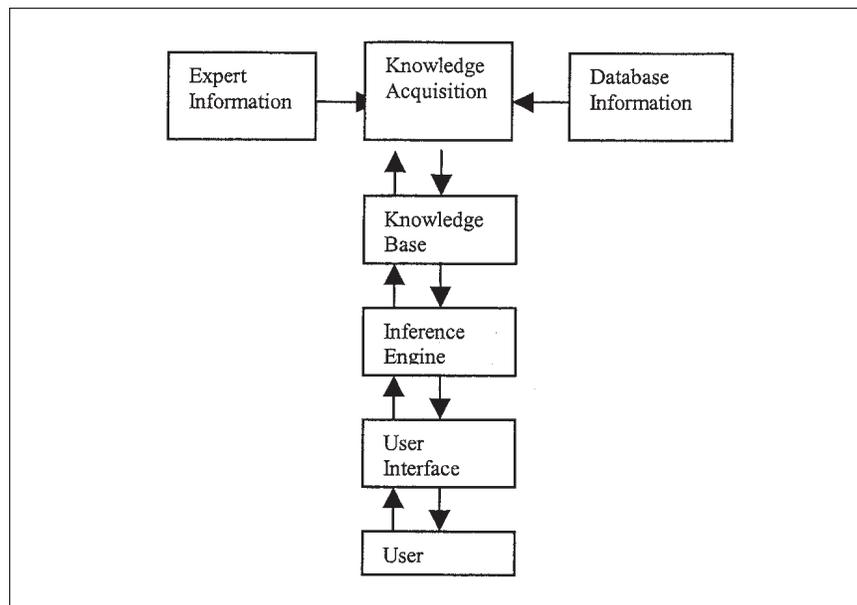


Figure 1. The components of an expert system.

Developing an Expert System

It is of utmost importance that the expert(s) be available throughout the period of the project to ensure that the information included in the knowledge base will have a sufficiently sound technical basis. The system developer must study the vocabulary of the domain expert to get a thorough understanding of the procedures carried out in typical cases. This will give the developer ideas about the essential parameters for the domain, the intermediate steps in reasoning and the preliminary strategies used in tackling the problem. Once the developer gets a clear idea of how a typical problem is solved, the acquired data is then entered into the knowledge base and the system is tested for suitability in the domain.

System Diagram

The system diagram for WASTEX (Figure 2) shows the user interacting with the expert system to identify preliminary waste minimization opportunities (WMOs) based on input data, and then gauging the resulting cost savings for each recommendation. The preliminary waste minimization decision system is a prerequisite for identifying the WMOs in the facility and consists of a series of questions that collect the required data. Then control is passed on to the WMO

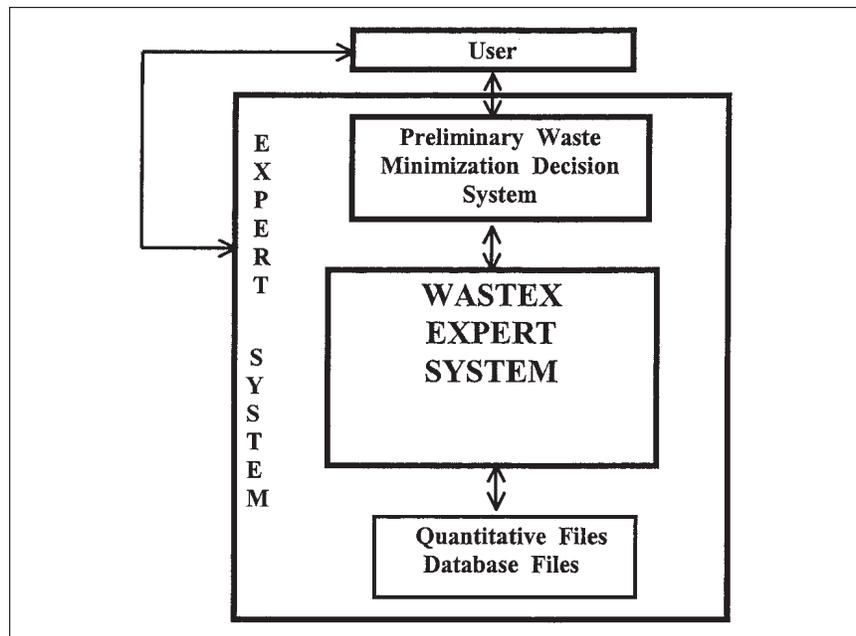


Figure 2. System diagram for WASTEX.

expert system which houses several quantitative programs, data files, worksheet files, and database files whereby each individual waste handling measure is addressed by a corresponding expert system for diagnosis.

DESIGN OF WASTEX

The need for industrial waste minimization and the justification for using an expert systems approach were elaborated in the previous sections. Now the diagnostic aspects of WASTEX are addressed, beginning with the design of the Preliminary Waste Minimization Decision System (PWMDS). In building WASTEX, one of the major areas of concern was to determine the scope of the system in terms of the technical and economical viability of implementing waste minimization methods.

Preliminary Waste Minimization Decision System

The preliminary waste minimization decision system poses a series of questions to the user regarding the energy costs and basic plant information. The initial set of questions attempts to determine the energy costs, as they will be needed as input for determining the costs associated with the WMOs. The user is prompted for the cost of energy in the form of electricity and gas being used by the plant in terms of \$/MMBtu. A choice is provided to the user based on whether prior knowledge about the cost of energy exists or whether the actual billing summaries have to be referred to in order to extract the information. This is shown below as a WASTEX query.

IS IT POSSIBLE FOR YOU TO PROVIDE THE MARGINAL COST OF
ELECTRICITY AND GAS DIRECTLY? IF NOT, WASTEX CAN HELP
YOU DETERMINE THIS.
YES NO

The next set of questions involve the basic plant information, beginning with the maintenance labor rate in \$/hr. The system then proceeds to obtain details about the number of shifts the plant operates in a day, number of working days in a week, and the number of working weeks in a year. This information is used to compute the total number of annual production hours of the plant.

The presence or absence of waste streams in the plant is then required by the preliminary system, for the sake of identifying, at a later stage, any prospective waste minimization or efficient waste management opportunities associated with them. This list of waste streams defines the scope of the manufacturing system, and includes cardboard and office paper waste, glass waste, sludge and waste water generated by various sources such as cleaning and cooling, cooling tower water waste, paint waste, general solid waste, waste wood, and metal processing waste. The system then proceeds to ask certain basic questions specific to the

waste streams selected by the user. The input that the user provides for these specific questions is critical for the preliminary system to decide whether particular waste minimization opportunities exist, and whether they are feasible.

The list of waste minimization opportunities (WMOs) currently addressed by WASTEX is as below. Each of these has been modeled as an expert systems module that functions under the umbrella of the Preliminary Waste Minimization Decision System (PWMDS). This article treats WMOs, namely, solvent and paint waste minimization.

1. Parts cleaning solvent waste reduction
2. Paint waste minimization
3. Waste water minimization
4. Treatment of cooling tower water
5. General trash compaction
6. Wood waste minimization
7. Glass recycling
8. Evaporation of waste sludge
9. Cardboard recycling

PARTS CLEANING SOLVENT WASTE REDUCTION

The cleaning of metallic parts entails the removal of material collected in previous operations from the metal's surface to prepare it for subsequent operations. A cleaning operation reflects the selection of the types of cleaners, the proper cleaning cycle, and most importantly, the proper cleaning equipment. Part cleaners fall into three main categories, namely, organic solvents, semi-aqueous emulsion cleaners, and aqueous (water-based cleaners). Until recently, most manufacturers have employed organic solvents for cleaning the parts. These organic solvents are volatile organic compounds (VOCs) and qualify as hazardous wastes [13-15]. Some of the hydrocarbon solvents frequently used in these applications are terpene, esters, and aliphatic, aromatic, chlorinated, and/or chloro-fluorinated compounds generally terpenes [13-15]. The hazardous nature of these solvents makes their use in cleaning applications not only expensive but also highly regulated.

Cleaning is accomplished by any of the following methods [13-15]: manual application, immersion methods, spray washing, vibratory methods, and vapor degreasing. Some of the common types of equipment used currently are vapor degreasers, immersion tanks, power washing machines, and ultrasonic degreasers. Aqueous cleaners can be used in all cleaning systems except in vapor degreasing applications. Semi-aqueous cleaners are also used; they require precision cleaning with high levels of cleanliness. In a semi-aqueous process, a hydrocarbon-based cleaning agent is first used as a wash to dissolve the oils, greases, and other contaminants on the part. The cleaning agent and the dissolved residues are then

rinsed with water and the parts are dried. The major advantage of these cleaners is that the parts need not be compatible with water.

Aqueous cleaners can be acidic, alkaline, or neutral depending on the pH of the liquid. They allow the cleaner bath to be filtered and reused. The ingredients used for these cleaners are safe and can be easily disposed. Depending on the nature of the cleaner (acid, alkaline, or neutral), they can be applied in specific cleaning purposes. One of the factors in selecting an aqueous cleaner is whether the cleaning agent can be used with the present equipment or if new equipment must be purchased. Acid aqueous cleaners are generally not used for removal of organic oily soils. Aqueous alkaline and neutral cleaners are more common where water can be tolerated. Other ingredients such as alkalinity builders, water conditioners, active surface agents, and inhibitors can be used to enhance the cleaning efficiency.

Costs and liabilities associated with aqueous cleaning are much less than those for organic solvents. The purchase cost of organic solvents is high as compared to semi-aqueous and aqueous cleaners. The organic solvents are disposed of as regulated hazardous waste, so increasing the overall operating costs of metal finishers. Most of the aqueous cleaning systems have a closed-loop system, whereby the cleaning agent can be recycled using filtration techniques, so that only the contaminants retained in the filter media require disposal; thus cuts costs.

Consultation with WASTEX

The following format is used in WASTEX; user input is indicated in bold lettering:

THE FOLLOWING QUERIES ARE RELATED TO METAL CLEANING
SOLVENTS IN YOUR FACILITY. PRESS ANY KEY TO CONTINUE . . .

DO YOU CURRENTLY HAVE PARTS CLEANING OPERATIONS IN
YOUR FACILITY?

YES NO

PLEASE SELECT THE CURRENT METHOD OF CLEANING:
ORGANIC SOLVENT CLEANERS SEMI-AQUEOUS EMULSION
WATER-BASED CLEANERS

The system contains knowledge of the capabilities of various semi-aqueous and water-based cleaners in terms of effectiveness of contaminant removal. The necessity of the parts to be subject to high temperatures and high pressures is a critical consideration in WASTEX:

CAN YOUR PART WITHSTAND HIGH TEMPERATURES (130-140
DEG F)?

YES NO

CAN YOUR PART WITHSTAND HIGH PRESSURES OF IMPINGEMENT?

YES NO

CAN THE PART BE AIR DRIED AFTER THE CLEANING PROCESS?

YES NO

The cleaning process is often electrically operated and the user may select the wattage. High-wattage machines tend to have higher cleaning productivity than low-wattage machines. The electricity consumption is figured in the cost analysis of the waste minimization opportunity.

WASTEX considers water-based alternatives if any of the solvents methyl chloroform, CFC 113, methylene chloride, methyl ethyl ketone, kerosene, toluene, or acetone are used, taking into account the quantity of solvent used and its disposal costs after the cleaning process has been accomplished. For example:

PLEASE SELECT THE SOLVENTS YOU ARE CURRENTLY USING:

METHYL CHLOROFORM CFC 113 METHYLENE CHLORIDE

METHYL ETHYL KETONE KEROSENE TOLUENE

ACETONE

HOW WOULD YOU LIKE TO DESCRIBE THE FREQUENCY OF CHANGES OF SOLVENTS?

1) QUANTITY IN GALLONS/SHIFT

2) QUANTITY IN GALLONS/DAY

3) QUANTITY IN GALLONS/MONTH

4) QUANTITY IN GALLONS/YEAR

WHAT IS THE QUANTITY OF SOLVENT CONSUMED PER MONTH?

100

WHAT IS THE CURRENT DISPOSAL COST (\$/GAL) OF THE CLEANING SOLVENT? **3**

HOW MUCH TIME DO YOU OPERATE YOUR CLEANER FOR (HOURS/SHIFT)? **4**

Once the preliminary waste minimization decision system (PWMDS) has been engaged as above, WASTEX assesses each solvent waste reduction opportunity as feasible or infeasible. This determination is dependent upon the volumes of solvent used, the nature of organic solvents currently being used, the cleaning process parameters currently being used, and the implementation costs. If the implementation costs are too high and the current incurred costs are too low or if the parts cleaning process with water-based solvents is infeasible in the current scenario, WASTEX will not recommend further consideration of this waste minimization opportunity at this stage. If the WMO is found feasible, the WASTEX screen will display (for instance):

THE FOLLOWING WASTE MINIMIZATION OPPORTUNITIES HAVE BEEN IDENTIFIED: ***SOLVENT WASTE REDUCTION***

The user now engages the specific domain of the solvent waste reduction expert system at this stage. WASTEX shows a screen such as the following that the user may choose to learn more about this specific area before entering into the data acquisition phase of the system.

```

#####
#   THE FOLLOWING OPTIONS ARE PROVIDED   #
#                                         #
#           1. INTRODUCTION                #
#           2. INSTRUCTIONS                 #
#           3. CONSULTATION                #
#           4. EXIT                        #
#####

YOU ARE ADVISED TO READ INTRODUCTION AND INSTRUCTIONS
BEFORE PROCEEDING WITH THE CONSULTATION.

Please select one of the following . . .
1           2
3        4
    
```

The idea is to help him better understand the types of data that will be required by the system and the reasons why such data is required.

Specific information on the material being cleaned, the type of contaminants being removed, and the operating conditions is now acquired via queries such as these:

PLEASE SELECT THE TYPE OF MATERIAL OF YOUR PART
STAINLESS STEEL HIGH CARBON STEEL CAST IRON
 ALUMINUM NICKEL MAGNESIUM BRASS

WHAT TYPE OF CONTAMINANTS ARE YOU REMOVING?
 CHLORIDES SALTS COOLANTS **SHOP DIRT** FINGER PRINTS
 PARTICLES PROCESS FLUIDS **GREASE** METAL CHIPS & FINES
 CARBONACEOUS MATERIAL PAINTS RUST OXIDES SCALES

WHAT KIND OF CLEANING EQUIPMENT ARE YOU CURRENTLY USING?
 VAPOR DEGREASER ULTRASONIC DEGREASER
IMMERSION CLEANER POWER WASHING MACHINE
 SPRAY MACHINE

PLEASE SELECT THE SIZE (GALLONS) OF SOLVENT TANK YOU WOULD LIKE TO USE:

10 50 **100** 150 175 200 225

WHERE WOULD YOU LIKE TO STORE THE RESULTS OF THIS CONSULTATION?

SCREEN FILE PRINTER

WASTEX issues its recommendations at this stage, listing current operating costs, annual savings, implementation costs, and the simple payback on investment. For example:

PRESENTLY YOU ARE USING POWER WASHING MACHINE WITH METHYL ETHYL KETONE AS THE CLEANER. ALKALINE AQUEOUS CLEANER CAN BE USED TO REDUCE SOLVENT AND DISPOSAL COSTS

CURRENT OPERATING COSTS:	\$43925
ANNUAL SAVINGS:	\$26069
IMPLEMENTATION COSTS:	\$25200
PAYBACK PERIOD:	12 months

Users are given opportunities to see the effect of varying the input parameters at the PWMDS stage or the main WMO stage.

WASTE MINIMIZATION USING HIGH VOLUME LOW PRESSURE PAINTING SYSTEMS

Surface coating is one of the most commonly practiced operations in many manufacturing units. Selecting the right kind of spray painting system can be a confusing decision: airless spraying, air-assisted spraying, electrostatic painting, high-volume, low-pressure (HVLP) painting, and conventional spraying methods are available [3, 16, 17].

The type of coating material and application method selected have an impact on transfer efficiency, the amount of paint applied to the object being painted divided by the amount of paint used. Conventional spraying methods have typical transfer efficiencies of 35 to 45 percent; HVLP and electrostatic painting methods run up to 85 percent [18]. To achieve the best transfer efficiency, it is necessary to evaluate the equipment performance for each coating material considered acceptable for the application in light of the coating specifications set for the product. Factors governing the selection of the application method include paint material, paint viscosity, material of the object to be painted, surface properties of the object, and production rate (number of pieces/hour or square feet of surface painted per hour).

One of the detrimental side effects of conventional coating atomization processes is the large amount of turbulence produced by the near-instantaneous expansion of the high pressure air [18]. The recently developed HVLP painting

systems deliver high volumes of air (CFM outputs in excess of 11.0) at low pressures (10 psi or less), with high transfer efficiency and reduced overspray in most applications [18]. This method of painting has found wide acceptance in manufacturing, including the aerospace, automotive components, wood cabinets, military gear, consumer electronics, and auto body refinishing industries. The paint module of WASTEX evaluates the possibility of converting from the conventional air spray method to the compressed-air-powered HVLP method.

In a typical painting application, the overall painting cost comes mostly from the costs of paint, replacement of the booth filter, and electric power to the compressor. It is convenient to split the cost of the paint into the cost of the actual paint coated on the object and the cost of the paint lost as overspray. HVLP and electrostatic painting systems prevent paint waste due to bounce back and excessive overspray. Booth maintenance costs include filter cost, filter replacement (or filter disposal) cost, and the labor cost associated with the filter change. Due to reduced overspray by HVLP systems, the frequency of filter change or filter disposal is significantly reduced, yielding considerable savings. Assuming that the same quality of paint is used per shift, one can easily compute the quantity of paint saved, labor saved, and other costs such as paint cost, labor cost, and booth maintenance cost, all expressed in terms of \$/shift. Usually, a compressor is used to run the painting equipment. When converting from conventional air spray to an HVLP system, one can use the existing compressor or install a turbine-operated system. These options give different savings.

The savings associated with the change of painting method principally emanates from savings in the cost of paint wasted, booth maintenance, and electricity, and from reductions in the number of air changes. Equipment costs, features, and installation charges vary from location, and, along with operation and maintenance costs, determine the overall implementation costs and the payback period. As with the parts cleaning module, WASTEX accumulates the basic data from the PWMDS and tells the user whether there is any advantage in pursuing the HVLP option:

THE FOLLOWING QUERIES ARE RELATED TO THE PAINTING OPERATION IN YOUR FACILITY. PRESS ANY KEY TO CONTINUE...

WHICH PAINTING METHOD DO YOU CURRENTLY EMPLOY AT YOUR FACILITY?

CONVENTIONAL AIR SPRAY HVLP ELECTROSTATIC
AIRLESS AIR ASSISTED

PLEASE SELECT THE MATERIAL OF THE PART YOU COAT:

CERAMIC GLASS **PLASTIC**
METAL RUBBER WOOD

PLEASE CATEGORIZE THE VISCOSITY OF PAINT:
 (THIN AND VERY THIN PAINTS ARE NOT SUITABLE FOR HVLP
 METHOD OF PAINTING. CHECK WHETHER YOU CAN USE HEAVY
 OR MEDIUM VISCOSITY PAINTS)

VERY THIN THIN **MEDIUM** HEAVY

PLEASE SELECT THE PAINT YOU ARE CURRENTLY USING:

STAINS FILLERS GLAZES
 LACQUERS **POLYURETHANES** CONTACT ADHESIVES
 VARNISHES EXTERIOR LATEX ENAMEL PRIMER
 EPOXY FLUID VINYL FLUID ZOLATONE

HOW MANY HOURS DO YOU PAINT IN ONE SHIFT? (HRS/SHIFT)

4

In this example, WASTEX recommends pursuing HVLP as a WMO and the user invokes the HVLP expert system module. In a series of queries, the module taking into account the paint gun fluid flow rate, time required to change a filter, number of shifts per filter change, filter disposal costs, air stream inlet and discharge pressures, compressor power, loads, and efficiencies, and other parameters, the module recommends a course of action. For example:

YOUR CURRENT OPERATION COSTS ARE AS GIVEN BELOW:

ANNUAL OVERSPRAY COLLECTION AND
 DISPOSAL COST: \$134845
 ANNUAL ELECTRICAL POWER COST: \$ \$1501
 TOTAL ANNUAL OPERATING COST: \$ \$136480

AN HVLP SYSTEM CAN BE INSTALLED TO REDUCE YOUR PAINT WASTE.

YOUR NEW OPERATION COSTS AFTER INSTALLATION OF

HVLP SYSTEM ARE:
 ANNUAL OVERSPRAY COLLECTION AND
 DISPOSAL COST: **\$24530**
 ANNUAL ELECTRICAL POWER COST: **\$400**
 TOTAL ANNUAL OPERATING COST: **\$25017**

YOUR SAVINGS ARE **\$111,463** AND PAYBACK IS **3 MONTHS**

SYSTEM DESIGN OF WASTEX

The diagnostic section of the expert system consultation begins when the user makes the elections from the list of candidate waste minimization opportunities at the facility as elaborated earlier. This directs the user to the corresponding waste minimization sub-program, where he has options for further consultation, instruction for carrying out the WMOs, and education as to the theories and principles that underlay them. At any time, new values may be entered for the

parameters, allowing the user to prepare a sensitivity analysis. These flexible tools allow the user to tailor the WMO assessments to the breadth and depth required.

Knowledge Collection Domain of WASTEX

The sources of information for developing WASTEX were Industrial Assessment Center reports [1], information obtained from vendors [18, 19] specialized books and journal articles [13], and material from USDOE and other government agencies [20]. IAC studies identify waste stream sources, quantities, and composition for many industrial operations, and alternative means for handling those wastes in an economically viable manner. Vendors are an essential resource for a system such as WASTEX, in getting the recommendations made by WASTEX that turn on matters such as equipment cost, operational capacity, power consumption, and maintenance regimes.

VP-Expert Software

WASTEX employs VP-Expert expert system shell software [21], a rule-based expert system development tool that possesses a number of powerful features. These include easy integration with database files and advanced, user-friendly graphics capabilities. The complete expert system package of WASTEX contains 24 knowledge base files with KBS extension, five DBASE™ [22] files with DBF extension, and seven text files.

While the basic rule structure and the logic employed by the inference engine is standard, certain features of the software enhance the utility and user-friendliness of the modules. These features allow better handling of unknowns and mistakes, an explanation facility that covers every question posed, easy updating of expert database files, internal validation checks, sensitivity analysis capabilities, and hypertext linking [21].

CONCLUSION

Waste minimization is an important activity as resources are finite in nature. High industrial productivity undergirds the standard of living of civilized nations. It is simply not enough merely to encourage industries to achieve maximum waste reductions. Systems such as WASTEX must be developed to help the industrial community to “help themselves” and so contribute to a broad spectrum of environmental benefits. These systems give industrial users the ability to investigate and carry out waste minimization opportunities in an economical, practical, and timely manner.

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