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Economic Analysis for Hazardous
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Economic Analysis of Hazardous Waste Minimization Alternatives

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During this research, the U.S. Army Construction Engineering Research Laboratories (USACERL) developed an economic model for evaluating the life cycle costs for various HW minimization technologies. The resulting model, CEAMHW (USACERL Economic Analysis for Minimizing Hazardous Waste) was written in C language for an IBM compatible personal computer. It contains six submodels based on differing waste types and a general cost submodel.

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FOREWORD

This research was performed for the Army Environmental Office, Office of the Chief of Engineers (OCE) under Reimbursable Project 4A163733, DC79, "Environmental Quality Control Equipment," Work Unit UV8, "Economic Analysis for Hazardous Waste Minimization Options." The Technical Monitor was Nancy Pomerleau, ENVR-EH.

The work was performed by the Environmental and Natural Resources Division (EN), of the Environmental Sustainment Laboratory (EL), of the U.S. Army Construction Engineering Research Laboratories (USACERL). Principal Investigators were Bernard Donahue and Dr. Keturah Reinbold. J. Brian Mount and Seshasayi Dharmavaram were employed by the University of Illinois working at USACERL under Interagency Personnel Agreements. Robert E. Riggins is Chief, CECER-EN and Dr. Edward W. Novak is Chief, CECER-EL. The USACERL technical editor was Gloria J. Wienke, Information Management Office.

COL Daniel Waldo, Jr., is Commander and Director of USACERL and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Approximately 120,000 metric tons* of hazardous waste (HW) are generated annually on Army installations in the continental United States (CONUS). Of this amount, approximately 80 to 90 percent is generated from industrial operations at 60 Army Materiel Command (AMC) installations. Twenty-six Forces Command (FORSCOM) installations and twenty-two Training and Doctrine Command (TRADOC) installations generate most of the remaining HW.[1]

The Department of Defense (DOD) policy is to attempt to eliminate HW generation to the extent possible and treat residual HW for volume or toxicity reduction.[2] All waste streams are to be examined with the goal of reducing generation of HW by 50 percent by 1992. Installation Environmental Managers, however, currently do not have the tools to evaluate minimization alternatives.

Objective

The overall objective of this research was to develop and demonstrate an economic model for evaluating the life cycle costs for various HW minimization technologies. This model was to be consistent with the guidelines for conducting economic analyses specified in DOD Instruction 7041.3.[3]

Approach

Five separate tasks were defined to successfully complete the objective.

1. Identify those waste streams that account for the majority of the HW generation at Army installations.

2. Identify those technologies and process changes that have been shown to be both technologically and economically feasible for minimizing hazardous waste production.

3. Review all current guidance documents on performing economic analyses related to equipment procurement (particularly HW minimization equipment) that have been prepared for DOD and each military service, including their Major Commands (MACOMs). Some economic analysis models used by the private sector were evaluated to develop a working model consistent with DOD's guidance.

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* A metric conversion table is provided on page 69.

[1] Briefing for the Deputy Assistant Secretary of Defense, Environment, subject: Hazardous Waste Minimization (22 September 1987), p 3.

[2] DOD Memorandum for Deputy of Environment, Safety and Occupational Health, OASA (I&L), Deputy Director for Environment, OASN (S&L), Deputy for Environment, Safety and Occupational Health (SAF/MIQ), Director, Defense Logistics Agency, subject: Hazardous Waste Minimization (6 February 1987), p 2.

[3] *Economic Analysis and Program Evaluation for Resource Management*, Department of Defense (DOD), Instruction 7041.3 (DOD, 18 October 1972).

4. Develop a methodology and computer model (with accompanying documentation) that will allow direct comparison of the life cycle costs of alternative HW minimization technologies.

5. Demonstrate the proposed model at installations and Major Command (MACOM) workshops for the various types of HW and waste streams generated.

2 HAZARDOUS WASTE MINIMIZATION LEGISLATION AND POLICY

Hazardous wastes are regulated under the Resource Conservation and Recovery Act (RCRA) of 1976 (40 Code of Federal Regulations [CFR], Parts 260 and following). In 1984, amendments to RCRA, known as the Hazardous and Solid Waste Amendments (HSWA, Title 42 U.S. Code [USC], Section 6901 and following), required significant changes in the way hazardous wastes are managed. With the intent of controlling the way solid waste materials are handled, the main thrust of the RCRA was to enforce the recordkeeping responsibilities of the generators and transporters of hazardous wastes, establishing a manifest or tracking system to provide for accountability. The amendments are in Public Law (PL) 98-616, 8 November 1984, Hazardous and Solid Waste Amendments of 1984. In July 1985, the U.S. Environmental Protection Agency (USEPA) issued a set of regulations that began the process of implementing the 1984 amendments.

The regulations require every generator producing in excess of 1000 kilograms (kg) of HW per month to certify that a hazardous waste minimization (HAZMIN) program is in operation when the HW is manifested. Biennial reports describing efforts taken during the year to reduce the volume and toxicity of waste generated and the changes in volume and toxicity of waste achieved during the year are also required.[4] In October 1986, regulations were issued to clarify the status of small quantity generators of HW (100 to 1000 kg/month).[5] These regulations require small quantity generators to make a "good faith effort" to minimize HW generation and implement the best available treatment, storage, or disposal alternatives where economically feasible.

In November 1986, the USEPA issued the first set of restrictions regarding land disposal of HW.[6] Under these restrictions, certain untreated and concentrated spent solvents and other specified HW are prohibited from land disposal beyond established dates unless the USEPA Administrator determines, based on a case-specific petition, that there will be "no migration" of hazardous constituents from the disposal unit for as long as the wastes remain hazardous. Waste treated in accordance with standards to be established by USEPA are not subject to this prohibition and may be disposed of on land. Deadlines were extended for certain other first third[*] wastes because sufficient nationwide capacity for treatment did not exist at that time or treatment standards were not yet established. The 1984 HSWA identified a schedule for banning all first third hazardous wastes from land disposal by May 1990.

In the broadest sense, minimization may be defined as reducing the net outflow of HW effluents from a given source or generating process, and includes any source reduction and any recycling activities that (1) reduce the total volume or quantity of HW or (2) reduce the toxicity of the HW produced. By this definition, a treatment option such as incineration (thermal destruction) would be considered an acceptable HAZMIN technique. Other waste minimization options include:[7]

1. Chemical/material substitution. Substitute less hazardous chemicals for more hazardous chemicals (e.g., 1,1,1-trichloroethane for trichloroethylene in solvent vapor degreasing).

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[4] *Code of Federal Regulations* (CFR), Title 40, Parts and 262 (1986 rev), "Standards Applicable to Generators of Hazardous Waste."

[5] *Federal Register*, Vol 51, No. 190, 1986, pp 35190-35194.

[6] *Federal Register*, Vol 51, No. 216, 1986, pp 40572-40654.

[*] First third wastes are those wastes that are restricted first—approximately one-third of the USEPA list.

[7] Items 1-6 have been identified by the DOD as appropriate means of HW minimization in a letter to the Deputy Secretary of Defense from the Joint Logistics Commanders, subject: Hazardous Waste Minimization Program, 12 December 1985. For examples of how various authors have attempted to define waste minimization, see Bechtel National, Inc., *Waste Minimization Study for the Lawrence Livermore National Laboratory*, Final Report, UCRL-15883-Vol 1 (December 1987) and *Guide to Solvent Waste Reduction Alternatives*, Final Report (ICF Consulting Associates, Inc., 10 October 1986).

2. Process changes. Adopt process changes that minimize the quantity of chemicals used that produce HW or process changes that lead to safer hazardous chemical uses.

3. Reclaimation, recycling, and reuse of hazardous material (HM) and HW.[8]

4. Improved HM control. Improve handling procedures to ensure that HM does not become HW due to expired shelf life. Materials should be ordered at the rate of use to prevent storing materials beyond shelf life.

5. Delisting.[9]

6. Treatment. Reduce the volume and/or toxicity through destruction or degradation without generating another waste (including incineration).

7. Improved waste management. Improve storage facilities, segregate HW types, and improve the transport and disposal of HW.

To achieve the Army's policy of at least a 50 percent reduction in the quantity of HW produced by the end of calendar year (CY) 1992,[10] AMC has established annual reduction goals that use 1985 HW generation data as the baseline. (The volume of HW generated in 1985 = 100 percent.) These goals are presented in Table 1. Both FORSCOM and TRADOC have established similar HW reduction goals.

As part of its HW reduction plan, DOD initiated a Used Solvent Elimination (USE) program in 1984. The stated goal of the USE program is to eliminate disposal of recyclable solvents as wastes.[11] DOD has also indicated that the disposal of organic solvents as waste is not acceptable. Exceptions are made, however, for that portion of the waste that cannot be recycled (e.g., still bottoms) or for small volume generators (less than 400 gal/year total for all solvents).[12] An economic analysis (EA) detailing the available minimization alternatives and associated costs and savings, is a key component of any successful USE program at the installation level.

A major source of funding for HAZMIN projects has been through the Defense Environmental Restoration Account (DERA). If the projected payback period is expected to be 1 year or less, funding is also available from the Defense Productivity Enhancing Capital Investment (PECI) program. In many instances, minimization is a cost-effective means of conducting business and any account may be used to finance minimization and benefit from the resulting savings. However, with a multiplicity of technologies available to treat various HW streams, it is imperative that installation environmental personnel have at

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[8] The costs and benefits of recycling/reusing industrial wastes are discussed in R. L. Immerman, "Recycle/Reuse: The Right Answer," *The Environmental Professional*, Vol 3, Nos. 1 and 2 (1981), pp 25-28.

[9] Delisting of hazardous wastes, while not discussed here, is a possible option for installations desiring to minimize the generation of hazardous wastes. See Joint Logistics Commanders letter, subject: Hazardous Waste Minimization Program (12 December 1985). See also, M. E. Resch, "Hazardous Waste Minimization Audits Using a Two-Tiered Approach," *Environmental Progress*, Vol 7, No. 3 (1988), pp 162-166.

[10] Briefing for the Deputy Assistant Secretary of Defense, Environment (22 September 1987), p 2.

[11] DOD Memorandum for Secretaries of the Military Department Directors, Defense Logistics Agency, subject: Used Solvent Elimination (USE) Program, (10 January 1984).

[12] DOD Memorandum for Assistant Secretary of the Army (I&L), Assistant Secretary of the Navy (S&L), Assistant Secretary of the Air Force (MRA&L), Director, Defense Logistics Agency, subject: Used Solvent Elimination (USE) Program, Interim Guidance (20 February 1985).

Table 1

Overall AMC Hazardous Waste Reduction Goals

Calendar Year	Percent Reduction Compared to CY 1985
1987	12.5
1988	20.0
1989	25.0
1990	30.0
1991	37.5
1992	50.0

Source: Letter, HQ, AMC, AMCEN-A, subject: CY 1987 AMC Hazardous Waste Minimization Plan (20 April 1987), pp 1-5.

their disposal a uniform and impartial method for evaluating the economic value of these various technologies when requesting DERA funds. In conjunction with the USE program, researchers at USACERL developed a model for performing economic analyses on various alternatives for recycling or disposing of used solvents.[13] This EA model served as the starting point for development of the model discussed here.

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[13] Engineer Technical Note (ETN) No. 86-1, *Economic Analysis of Solvent Management Options* (Office of the Chief of Engineers, 30 May 1986).

3 ECONOMIC ANALYSIS: DEFINITION AND CONCEPTS[*]

Definition

An economic analysis is a conceptual framework for a systematic approach to choosing how scarce resources are distributed. The purpose of an economic analysis is to portray, quantify, and evaluate the relative worth of proposed projects in achieving predefined objectives. Before proceeding any further, however, some important points in this definition bear additional discussion.

1. In any EA, it is assumed that the objectives to be reached are clearly specified and agreed upon in advance.

2. The above definition implies that EA, as a conceptual framework, is a mental process for focusing informal thinking into a defined pattern of logical steps.

3. As a systematic approach to problem solving, an EA outlines all alternative methods available to reach the objectives and specifies all assumptions inherent in the analysis (including both hidden and presumed assumptions).

4. An EA is concerned with the distribution of scarce resources. The scarce resource of primary concern is money. The goal of an EA, therefore, is to determine how best to allocate scarce or limited resources to projects that will achieve the greatest return on each dollar spent.

5. Because economic analyses are quantifiable, they may be replicated easily and documented, and the results readily portrayed and communicated to others.

6. Because economic analyses deal with proposed expenditures, they are oriented to the future and thus involve uncertainty.

Economic analysis is an approach to representing all costs and benefits accruing to a project or alternative. An attempt to capture and represent the random nature of real world phenomena and subsequent attempts to project the analysis into the future (i.e., predicting future outcomes) is the art of modeling.

Developing a Conceptual Framework for EA: Modeling

A model is simply an abstraction of reality; a systematic set of conjectures about real world observations. A model seeks to approximate real world phenomena by specifying a set of relationships and their eventual projected outcomes. It can be a series of highly complex mathematical equations or it may be a simple pictorial representation of relationships.[14] The enormous complexity of interactions in the real world effectively prohibits including all variables in the modeling process. Consequently, a

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[*] Much of the information in this chapter comes from *Economic Analysis Handbook*, NAVFAC P-422 (Naval Facilities Engineering Command [NAVFAC], June 3, 1986), and *Economic Analysis*, Defense Logistics Agency Manual (DLAM) 7041.1 (Defense Logistics Agency [DLA], 31 May 1985).

[14] For additional background information on economic models and mathematical modeling in general, refer to A.C. Chiang, *Fundamental Methods of Mathematical Economics*, 3rd Edition (McGraw-Hill, 1984), pp 3-34. A less mathematical approach to modeling phenomena in the social sciences is presented in C.C. Lave and J.G. March, *An Introduction to Models in the Social Sciences* (Harper & Row, 1975). Other publications on the topic of modeling that may be of interest include: C.W. Clark, *Mathematical Bioeconomics: The Optimal Management of Renewable Resources* (John Wiley & Sons, 1976); H.P. Williams, *Model Building in Mathematical Programming* (John Wiley & Sons, 1978); and J.A. Spriet and G.C. Vansteenkiste, *Computer Aided Modelling and Simulation* (Academic Press, 1982).

number of models, each of which considers different aspects of the same item, could be constructed to explain a single phenomenon. The key to accuracy in model building is to identify, in the initial stages of model formulation, those features of the real world that are most relevant to the problem being analyzed and attempt to capture them in the model's parameters. It cannot be overstated that the model builder's decisions about which variables are included will greatly influence the applicability and accuracy of the model.

In developing a model for analysis, certain characteristics are essential to the model building process and should be incorporated into the model's construction:

1. A model should be dynamic. It should capture the complex and changing nature of the system it seeks to explain.

2. A model should be simple. It should capture the most important features of the problem being analyzed and suppress those factors that are less important.

3. A model should be comprehensive. It should include all relevant factors in its formulation (subject to the limitations of simplicity noted above).

4. A model should be constructed to allow specific components (or variables) to be evaluated independent of other variables (i.e., the model must readily lend itself to sensitivity analysis).

5. A model should be designed so it may be easily manipulated and altered based on real world experiences.

These five features are incorporated into a paradigm (Figure 1) that illustrates the evaluation process of model building.

The Process of Economic Analysis

Military publications typically identify six or seven key steps in performing an economic analysis.[15] These steps provide a broad overview but may allow the uninformed or uninitiated user to overlook one or more essential steps hidden within the general framework. For clarification, and to ensure that no steps in the EA process are overlooked, the standard steps have been expanded to 14 distinct, essential steps.

1. Define the Problem

The single most important step in the EA process is to carefully identify the problem to be addressed. Unfortunately, this step is often overlooked and analysts find themselves in a situation where an EA has been performed but is of limited use because the problem was not carefully defined in the initial stages of the investigation. Proper problem identification will naturally lead to the second step: goal definition.

2. Set Goals and Objectives

It is important that the analyst establish a definite goal. This implicitly establishes the criteria for weighing the costs and benefits of each alternative.

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[15] See *Economic Analysis Handbook*; and *Economic Analysis: Concepts and Methodologies*, AMC-P 11-28 (Army Materiel Command, [AMC], July 1985), pp 2-1 through 2-13.

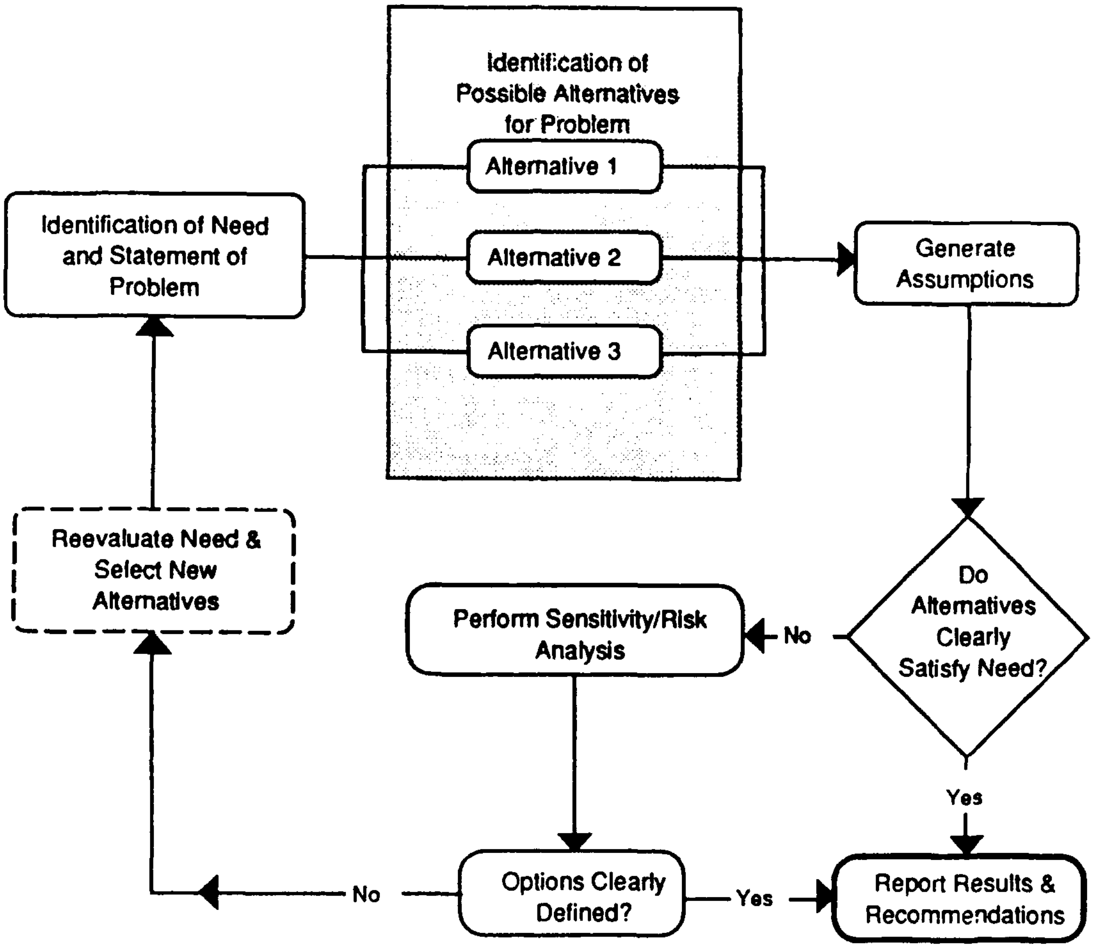

Figure 1. The basic evaluation process in modeling.

3. Define the Constraints and Limitations

In indicating where it may be difficult to meet the stated goals, the analyst is forced to rethink the definition of the problem and possibly alter the goals. Resources may be limited (e.g., funding, manpower, or equipment) and the limitations must be carefully evaluated when considering the feasibility of goals. Indicating constraints also logically leads to the fourth step; defining alternatives.

4. Generate Alternatives to Meet the Goals Within the Specified Constraints

It is vital that the analyst be exhaustive in considering and presenting alternatives so the most cost-effective alternative, not merely the least cost solution, is identified.

5. Formulate and Specify Assumptions

Because economic analyses are concerned with future expenditures, uncertainty enters into the decisionmaking process. In projecting costs and benefits into the future, certain assumptions have to be made regarding the inflation rate, the economic lives of alternatives, the period of comparison for evaluating alternatives, the discount rate to be used, etc. Failure to document assumptions forces the reader to assume how the analysis was performed and severely undermines the credibility of the analysis. The major assumptions inherent in life cycle costing, the method used in this analysis, are documented in Chapter 6.

6. Quantitatively Identify Costs and Benefits

For each alternative, the costs and benefits involved must be identified. The present value of costs is easy to determine and provides a way to measure actual project outlays. Benefits, on the other hand, are much more difficult to explicitly identify and often require qualitative assessments of an alternative's worth.

7. Specify the Evaluation Criteria to be Used

Based on the type of benefits and costs identified in step 6, and depending on whether the economic lives of the alternatives being considered are either equal or unequal, the analyst may identify the evaluatation methods that can be used.[16]

8. Compare Costs and Benefits

Generally, both costs and benefits of alternatives may be either equal or unequal, generating four possible configurations to consider:

a. Equal costs/Equal benefits

b. Unequal costs/Equal benefits

c. Equal costs/Unequal benefits, and

d. Unequal costs/Unequal benefits.

9. Develop a Cost and/or Benefit Model

At this stage, the analyst formulates the cost and/or benefit model from the information obtained in steps 6 and 8.

10. Test and Validate the Model

With the cost and benefit information obtained, the analyst should test the model by running it. To ensure that all appropriate parameters were considered in the model's formulation, data from similar projects should be gathered and entered into the model to validate the responses.

11. Reevaluate the Model and Adjust the Parameters as Necessary

Where weaknesses in the model's formulation were identified in step 10, the analyst should rework the model and run the analysis again.

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[16] For a consideration of permissible methodologies conforming to the type of economic analysis undertaken, the economic lives of alternatives, and the types of benefits and costs, refer to R.D. Neathammer, *Economic Analysis: Description and Methods*, Technical Report P-151/ADA135280 (U.S. Army Construction Engineering Research Laboratory [USACERL], October 1983), pp 5-25.

12. Analyze the Results and Rank Alternatives

A proper analysis indicates how the results were achieved and what assumptions were made in the process. This step is more than just a reiteration of the final numbers.

13. Perform an Analysis of Uncertainty

Because uncertainty is always present when projecting an alternative's costs and benefits, it is necessary to vary the dominant costs and assumptions made in the model's formulation to see if these variations have a significant impact on the results. Three commonly used techniques for addressing questions of uncertainty include:

1. *A fortiori* analysis. Deliberate assumptions are made by the analyst to either favor or disfavor a particular alternative and examine the effect on the alternative's ranking.

2. Contingency analysis. Contingency analysis attempts to capture the effect of broad technological, organizational, and mission changes on alternatives.

3. Sensitivity analysis. Variables contained within the analysis are considered under different assumptions so the impact of these assumptions might be studied to determine the final ranking of alternatives.

Of the three methods, sensitivity analysis is the most commonly used. It is easily applied and deals directly with variables considered most important. *A fortiori* analysis requires the analyst to have a well-developed rationale for either favoring or disfavoring a particular alternative; contingency analysis often requires judgments about technological advances and mission requirements beyond the analyst's area of expertise.

If an analyst is unsure about the variability of labor costs, for example, and labor costs account for a significant portion of the alternative's operating costs, sensitivity analysis could be used to vary the input of labor costs by a percentage and see what impact this has on the final ranking of alternatives. For example, if labor costs were estimated to be $20,000 a year and could be expected to vary by as much as 20 percent due to uncertainties in just how many man-hours would be required to operate the alternatives, the model should be run once with the $20,000 amount and again with the labor costs at both $16,000 (80 percent of estimated labor costs) and $24,000 (120 percent of estimated labor costs) to see if the ranking changed.

14. Prepare Conclusions and Recommendations

The final step in any EA includes selecting the preferred alternative. It is important that any assumptions inherent in the ranking be carefully specified at this time.

In performing an economic analysis, all 14 steps must be completed sequentially to arrive at a proper conclusion. Figure 2 provides a schematic of the EA process. Note the feedback, reassessment, and verification loops, which are an important part of the model. Constant fine tuning of the model's parameters and reassessment of its assumptions and alternatives is an ongoing process dictated by refinements in the data base and changing goals/objectives.

Types of Economic Analyses

In step 6, the process of determining costs and benefits begins by selecting the type of analysis to be used. In Military Construction, Army (MCA) projects, two types of economic analyses are identified for use: Fundamental Planning Analysis (FPA) and Design Analysis. FPA is used to identify all feasible

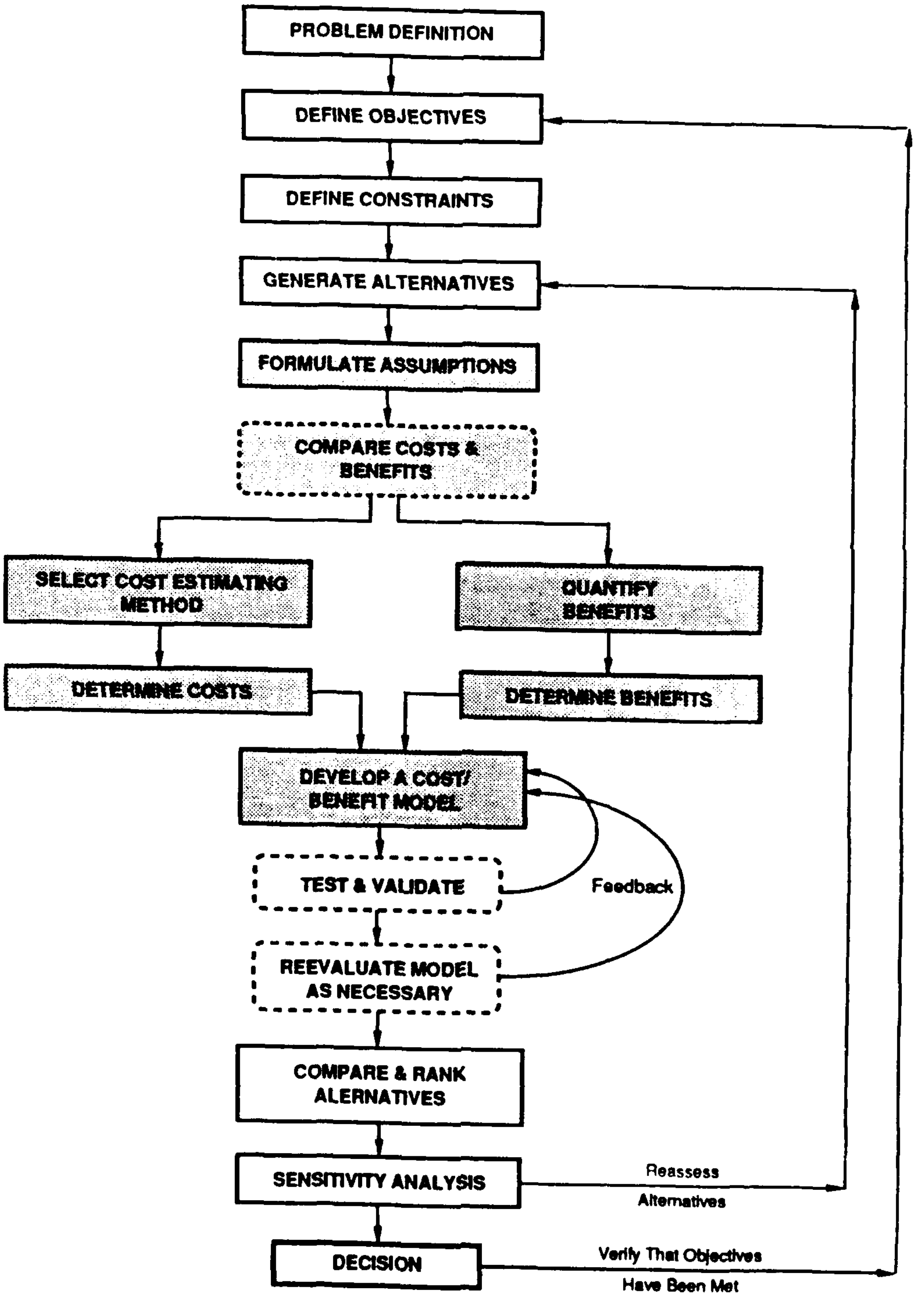

Figure 2. The process of economic analyses.

alternatives to accomplish an identified objective. Design Analysis covers economic analyses of a building design once the decision to procure a particular facility has been made and often occurs after an FPA. Thus for considering the economics of minimization alternatives, research focused solely on FPA.

Within FPA, there are two rather broad categories into which proposals for Army investment fall. The first is a primary FPA (also known as a Type I analysis) that addresses "the basic need and economic justification for some change to present conditions."[17] The second is a secondary FPA (or Type II analysis) conducted to analyze alternatives "after a deficiency or changed requirement has been identified."[18]

Primary FPAs are conducted to justify investments where a cash outlay already exists. Secondary FPAs are used to justify new investments (where a cash outlay is to be initiated). Perhaps the easiest way to view the difference between the two is to remember that primary FPAs must promise an absolute savings in costs and always require an existing alternative (or status) for comparison while secondary FPAs do not always result in an absolute cost saving (although they may) and do not always have a status quo for comparison.

When considering alternatives, a minimization project does not always have to save money but it does have to reduce the volume of hazardous waste generated, thereby reducing disposal costs.[19] In such situations, the economic analyses would be secondary or Type II FPAs. However, with high disposal costs (either for landfilling, deep-well injection, or incineration) and with these costs expected to increase as the cost of complying with both new and proposed EPA regulations and future liability costs skyrocket, most alternatives for HAZMIN should produce absolute cost savings to the installation by eliminating or reducing HW disposal. Where these absolute cost savings occur, the economic analyses would be primary or Type I FPAs.

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[17] *Economic Analysis Handbook*, pp 11-12.

[18] *Economic Analysis Handbook*.

[19] DOD Memorandum (6 February 1987), p 4.

4 SELECTING WASTE STREAMS

Problem Definition

The process of conducting an EA can now be applied to the particular problem at hand–that of identifying alternatives for HAZMIN. The first step in the EA process is to define the problem. In this case, the problem is how to achieve at least a 50 percent reduction in the quantity of HW generated by the end of 1992 (from 1985 baseline data). To put this reduction figure in perspective, Table 2 provides estimated annual quantities of HW generated by the DOD by major waste categories. For comparison, Table 3 lists the HW generated by major processes performed at AMC installations.

The magnitude of the volume reduction (approximately 35 million kilograms from AMC 1985 baseline figures), funding limitations, and a projected era of fiscal austerity for Army environmental

Table 2

Annual Quantities of HW Generated by DOD for Major Waste Categories

Waste Category	Annual Waste Quantities Generated (Metric Tons)	Percent of Total Annual DOD Hazardous Waste Generation
Aqueous solvents	198,673	34
Toxics	97,976	17
Aqueous oils	94,347	17
Corrosives	44,452	8
Industrial waste treatment (IWTP) sludges	39,916	*
Pesticides	39,009	7
Ignitables/flammables	36,287	6
Paints and paint sludges	22,680	4
Concentrated oils	15,422	3
Concentrated solvents	8,165	1
Reactives	6,350	1
Spill residues	4,536	<1
Empty containers	3,629	<1
Batteries, lithium	1,814	<1
Batteries, nonlithium	11,814	<1
Total	615,070**	100

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* Percentage breakdown is not provided because IWTP sludges result from the management of some of the other 14 categories of waste types.

**72,575 metric tons of demilitarized ammunition are excluded from the total.

Source: *Least-Cost DOD Hazardous Waste Management Strategies*, Draft Report (ICF Consulting Associates, Inc., 15 June 1987), pp 2-2 through 2-4.

Table 3

Annual Quantities of HW Generated at AMC Installations

Process	Quantity Generated (metric tons)
Load and pack operations	25,000
Waste treatment sludges	16,773
Pyrotechnic operations	13,759
Munitions demolition	5920
Metalwork	2221
Plating	1629
Cleaning	1409
Painting	1259
Other hazardous wastes	818
Vehicle maintenance	804
Paint stripping	159
Electrical maintenance	98
Battery shop operations	29
Fuel operations	0
Total	69,878

Source: Quantity estimates compiled from AMC data base.

projects point out the need for careful consideration of costs and benefits in achieving the reduction goal. In focusing the analysis, however, the first problem is that of identifying the hazardous wastes/waste streams to be considered for analysis.

Waste Stream Selection

Data on hazardous waste streams generated by AMC, TRADOC, and FORSCOM were presented to environmental personnel from Army Headquarters, and the three MACOMs at an In-Progress Review (IPR), 6 and 7 October 1987 at USACERL. Personnel at the IPR selected six waste streams to be addressed in this project. Two of the waste streams were predominantly from AMC processes, two from TRADOC and FORSCOM waste types, and two were shared by all three MACOMS. The six waste types/waste processes selected for further analysis were (presented in no particular order):

1. Used solvents from cleaning and degreasing operations (AMC, TRADOC, and FORSCOM),
2. Wastes from paint stripping operations (AMC, TRADOC, and FORSCOM),
3. Wastes from electroplating operations (AMC),

4. Sludges from industrial wastewater treatment plant operations (AMC),
5. Waste petroleum oils and lubricants (POL, primarily TRADOC and FORSCOM), and
6. Batteries and battery acids (primarily TRADOC and FORSCOM).

5 TECHNOLOGICALLY FEASIBLE ALTERNATIVES

After identifying the waste streams, the next step in the EA process is to identify the minimization alternatives that had been previously demonstrated as technologically feasible. To ensure that the proposed model would include options that environmental personnel could readily implement, experimental technologies (or those that had been demonstrated in laboratory-scale operations only) were excluded from analysis.

HAZMIN techniques corresponding to the six waste types/processes were evaluated based on the following strategy suggested by Freeman.[20]

I. Source Reduction

  A. Product Substitution
  B. Source Control

    1. Good Housekeeping Practices–including waste stream segregation, inventory control, employee training, spill/leak prevention, and objective measurement methods to determine useful remaining life of a hazardous material,
    2. Input Material Modification–including input purification and input substitution, and
    3. Technology Modification–including improved controls, process modifications, equipment changes, energy conservation, and water conservation.

II. Recovery/Reuse

  A. Use/Reuse–as an ingredient in a process or an effective substitute and
  B. Reclaim–process to recover usable and/or regenerated product.

III. Treatment

Destruction or degradation that reduces the volume and/or toxicity with minimal generation of residual hazardous materials.

Cleaning and Degreasing Solvents

Army facilities typically use large quantities of solvents to remove grease, wax, dirt, and paint from metals. Solvent operations include cleaning vehicle parts at motor pools, degreasing industrial equipment, cleaning operations before metal finishing, and cleaning before metal plating.[21]

The types of cold cleaning operations commonly used at Army installations include wipe cleaning, dip tank cleaning, and diphase cleaning. Aliphatic hydrocarbons such as Stoddard type solvents, kerosene, varsol, and other mineral spirits are used in these operations. Degreasing of metallic substrates is normally performed in vapor phase by using trichloroethylene, perchloroethylene, or 1,1,1-trichloroethane solvent

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[20] H. M. Freeman, "Hazardous Waste Minimization - A Strategy for Environmental Improvement," *International Journal of Air Pollution Control and Waste Management*, Vol 38, No. 1 (1988), pp 59-62.

[21] T.E. Higgins, R.B. Fergus, and D.P. Desher, *Evaluation of Industrial Process Modifications to Reduce Hazardous Wastes in the Armed Services*, paper presented at the 40th Annual Purdue Industrial Waste Conference, Purdue University (14-16 May 1985), pp 5-7.

vapors. These solvents have a high solvent power, evaporate quickly, and exhibit low residue properties.[22]

Used halogenated or nonhalogenated solvents that contain little or no water are produced by both cleaning and degreasing operations. Spent concentrated organic liquids (50 to 95 percent organics) mixed with various contaminants are the major wastes generated. To a lesser extent, organic sludges (greater than 2 percent solids) from the bottoms of existing batch distillation stills have to be considered for treatment. A detailed discussion of methods for waste reduction and treatment is available in the literature.[23]

Source Reduction

Solvent use can be minimized by substituting aqueous cleaners and/or peel coatings in certain applications.[24] Various chemicals, such as caustic soda (sodium hydroxide), are possible substitutes and are available in a variety of formulations. Substitution minimizes workers' exposure to hazardous organic fumes and can achieve significant waste reduction, thereby reducing treatment costs. Aqueous cleaners are sometimes unable to provide the degree of cleaning required or are incompatible with the substrate, and they require a drying process. Also, use of these cleaners or coatings will require existing equipment to be modified or replaced. Peel coatings can be used to remove oil or grease that protect metallic substrate against corrosion. Such coatings (e.g., polyethylene shrink-wrap) eliminate the eventual need for vapor degreasing.

Among the good housekeeping practices, efforts to reduce air emissions are probably the most beneficial. For both cold cleaning and vapor degreasing operations, tank covers or lids should be installed and closed when not in use. Using the lids could reduce solvent loss by 24 to 50 percent. Increasing the freeboard height (the distance from the top of the liquid to the top of the tank) could reduce the solvent emissions from 27 to 46 percent. Installing a freeboard refrigeration device to chill the air above the vapor zone can reduce solvent consumption by 60 percent.[25] Protecting the equipment from air currents and excessive turbulence near exhaust ducts can reduce solvent losses. Drag-out of solvent from a degreaser into liquid and vapor phases can be minimized by limiting the hoist system speed (maximum 11 ft/min) and limiting the load cross-sectional area (less than 50 percent of top open area).[26] Other beneficial housekeeping practices include maintaining solvent quality, and standardizing and consolidating solvent use.[27] Solvent testing methods, such as visible absorbance and acid acceptance, should be used to maximize solvent bath life, rather than disposing of solvent when it "looks dirty."[28] These measures not only reduce the amount of solvent used, but are also important for recovery/reuse options.

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[22] *Guide to Solvent Waste Reduction Alternatives; Solvent Minimization and Substitution Guidelines*, Technical Note 86-2 (Department of the Army [DA], 30 January 1987); T. E. Higgins, *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities, Phase 2 Report: Evaluation of 18 Case Studies* ADA159239 (CH2M Hill, 15 July 1985), pp 3-26 through 3-29.

[23] S.B. Joshi, et al., *Methods for Monitoring Solvent Condition and Maximizing its Utilization*, paper presented at the annual meeting of American Society for Testing Materials (November 1987); B.L. Blaney, "Alternative Techniques for Managing Solvent Wastes," *International Journal of Air Pollution Control and Waste Management*, Vol 36, No. 3 (1986), pp 275-285; B.A. Donahue, and M.B. Carmer, *Solvent "Cradle-to-Grave" Management Guidelines for Use at Army Installations*, Technical Report N-168/ADA137063 (USACERL, December 1983); T.E. Higgins; *Used Oil and Solvent Recycling Guide: Final Report* (Robert H. Salvesen Associates, June 1985).

[24] *Guide to Solvent Waste Reduction Alternatives.*

[25] *Guide to Solvent Waste Reduction Alternatives*, pp 4-4 through 4-24.

[26] *Guide to Solvent Waste Reduction Alternatives*, pp 4-5 through 4-12.

[27] *Guide to Solvent Waste Reduction Alternatives*, pp 4-4 through 4-24.

[28] S.B. Joshi, et al.

Multistage countercurrent cleaning is a technology modification that can reduce solvent use.[29] With this modification, the solvent is allowed to become much more contaminated through use and a limited amount is replaced on a regular basis.

Recovery/Reuse

Spent cleaning and degreasing solvents can be reclaimed easily and reused. Pretreatment of the wastes, however, is generally necessary to remove solids, water, and other contaminants. Techniques for removing solids include: sedimentation, filtration, centrifugation, flotation, and evaporation.[30] The organic component can then be separated by: fractional distillation, solvent extraction, resin adsorption, steam-stripping, and air-stripping.[31] Pretreatment may not be necessary if steps are taken throughout the process to maintain solvent quality. Batch distillation is perhaps the most commonly used cost-effective means of reclaiming spent solvents.[32] The reclaimed product can be reused to clean and degrease. Batch distillation recycling of solvents can be done either onsite or offsite by a contractor.

Treatment

Incineration of an organic solvent waste stream can result in its complete destruction, forming carbon dioxide and water. Since it destroys the solvent, incineration should be performed only after recycling has been attempted.

Still bottoms (the solid residue left after distillation) from solvent reclamation must also be treated. Solvent sludge (greater than 2 percent solids) is treated to remove organic components by air/steam stripping, evaporation, or drying.[33] The organic components can then be destroyed by incineration or wet air oxidation.[34] Before land disposal, the untreated sludges can also be solidified or stabilized using fixating agents if sufficient reduction in their organic content has occurred.

Paint Stripping Wastes

Many facilities contain both painting and paint stripping operations in the same area. In comparison to the disposal of HW from painting, paint stripping wastes are more problematic in that a greater volume of HW is generated and significantly greater wastewater flows result.[35]

Several wet and dry paint stripping operations are used at Army installations to remove paint from equipment surfaces during rebuilding operations, etc. Dry stripping is done with sand, glass beads, or vegetable matter (corn cobs, rice hulls, walnut shells, etc.). Wet chemical stripping using a solvent such as a methylene chloride/phenol based mixture is the most common technique. Paint is stripped from the substrate by soaking, spraying, or brushing with a stripping agent (mixture of methylene chloride, phenols, or acids).[36] The metallic parts are soaked in the stripping agent until the paint is loosened and are then washed with water.

Three categories of wastes generated from wet stripping operations are: stripper/paint residue, washwater, and volatile organic emissions. The largest volume waste stream is the washwater consisting of 50 to 95 percent water with varying contents of phenols (17.7 to 45.2 mg/L), methylene chloride (3.82

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[29] *Guide to Solvent Waste Reduction Alternatives.*

[30] B.L. Blaney.

[31] B.L. Blaney.

[32] B.A. Donahue, and M.B. Carmer.

[33] B.L. Blaney.

[34] B.L. Blaney.

[35] T.E. Higgins.

[36] *Guide to Solvent Waste Reduction Alternatives*, pp 4-4 through 4-24.

to 219.2 mg/L), hexavalent chromium (0.1 to 1.12 mg/L), total chromium (0.164 to 1.187 mg/L), cadmium (0.024 to 1.09 mg/L) and lead (<0.001 to 0.002 mg/L). All characteristics of the washwater, including pH (6.2 to >10.0), depend on the type of paint/solvent, the amount of solvent, and the volume of washwater used.[37] The minimization of aqueous solvent or washwater wastes from paint stripping operations is discussed in greater detail on the following pages.

Source Reduction

Solvent-based stripping agents can be replaced by aqueous, abrasive, cryogenic, molten salt, or thermal stripping agents.[38]

Sand blasting residue (containing lead and cadmium) may be used as an admixture for concrete.[39] Disposal, therefore, is accomplished within the construction process and no additional disposal costs are incurred by the installation.

Waste from glass bead blasting is primarily composed of fractured glass beads and paint particles. Adding this waste stream to a concrete admixture will result in a decrease in concrete strength. It is possible, however, to alter a standard concrete mix while maintaining its structural strength by adding more cement with the glass bead.[40]

Plastic bead blasting, an abrasive blasting technique that has been tested successfully by the Air Force[41] and the airline industry,[42] has been determined to be an effective substitute for solvents. The advantages of this method include: elimination of solvents (including associated total toxic organic discharges and emissions),[43] reduced liability and disposal problems, control over the amount of coating removed, reduced raw material costs, and faster stripping times.[44] The DOD is promoting the use of this stripping method throughout the military.

Good housekeeping practices are necessary to ensure that minimal quantities of washwater are used. After dipping or spraying the substrates with a stripping agent, they should be allowed to drip for a long time so the stripper/paint residue can be collected on paper or plastic sheets on the floor. The concentrated stripper/paint residues should be collected (using proper segregation methods) into troughs or drums for proper handling. Thus, very limited amounts of the stripper have to be washed off the substrate, minimizing concentration of the stripper and other contaminants in the washwaters. The volume of washwater that requires treatment is thus reduced.

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[37] T.E. Higgins, pp 3-1 through 3-4.

[38] Guide to Solvent Waste Reduction Alternatives, pp 4-4 through 4-24; *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities, Phase 3 Report: Appendix B - Workshop Manual for the Waste Reduction Project Pertaining to Innovative Hard Chrome Plating at Pensacola Naval Air Rework Facility*, Pensacola, Florida (CH2M Hill and Peer Consultants, Inc., December 1985).

[39] R.E. Benson, H.W. Chandler, and K.A. Chacey, "Hazardous Waste Disposal as Concrete Admixture," *Journal of Environmental Engineering*, Vol 11, No. 4 (1985), pp 441-447.

[40] R.E. Benson, H.W. Chandler, and K.A. Chaney.

[41] *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 3 Report: Appendix B - Workshop Manual for the Waste Reduction Project Pertaining to Innovative Hard Chrome Plating at Pensacola Naval Air Rework Facility, Pensacola, Florida.*

[42] G.B. Duhnkrack, "Plastic Blast Media - An Alternative to Chemical Stripping," *Pollution Engineering*, Vol 19, No. 12 (1987), pp 54-57.

[43] C.B. Wolbach and C. McDonald, "EPA Project Summary: Reduction of Total Toxic Organic Discharges and VOC Emissions from Paint Stripping Operations Using Plastic Media Blasting," *Journal of Hazardous Materials*, Vol 17 (1987), pp 109-113.

[44] *Guide to Solvent Waste Reduction Alternatives*, pp 4-4 through 4-24.

In addition, the amount of stripper used can be reduced by: maximizing the dedication of process equipment; avoiding unnecessary cleaning; proper production scheduling; inhibiting deposit buildup rates; proper equipment selection; efficient cleanup procedures; and use of automation.[45]

Recovery/Reuse

If proper segregation is followed, stripping agents can be collected, stored, and reused. The waste strippers can also be reformulated into low-grade stripping agents.

Reclamation of stripping solvents from the mixed aqueous/organic waste stream may or may not be economical, depending on the concentration of those solvents. A phase separation stage, required for the separation of solids, is usually achieved by decantation/sedimentation, filtration, flotation, or centrifugation.[46] The organic component can then be separated by air/steam-stripping, fractional distillation, solvent extraction, or carbon or resin absorption.[47]

Treatment

The aqueous or mixed aqueous/organic waste streams generated from paint stripping operations have to be treated to remove the organic components before being discharged to a sewage treatment plant In addition to the phase separation and organic component separation techniques mentioned above, preliminary treatment of the water for pH adjustment and separation of solids, and organic component transformation methods such as biological degradation, chemical oxidation, wet air oxidation, and incineration can also be used.[48]

Metal Plating Wastes

Many types of metal plating operations are common at AMC installations for both corrosion protection and reworking/rebuilding metallic parts of military vehicles and weapons. Hard chrome plating is used to rebuild wornout parts. The parts remain in a chromic acid/sulfuric acid plating bath for a few hours to a day or more. Decorative chrome plating uses the same plating bath but has a much shorter residence time (a few hours). Cadmium plating is the second largest plating operation in terms of use frequency. The plating bath consists of cyanide salts of cadmium and sodium, cadmium oxide, and sodium hydroxide. Other metals that are commonly plated, but to a much lesser extent than chromium and cadmium, are nickel, zinc, and copper.

Plating rinsewater contaminated with heavy metals is the largest volume waste stream. Treatment of rinsewaters typically results in the production of a hydroxide sludge (an EPA-listed F006 waste). Minimizing the use of rinsewaters can greatly lower water treatment and sludge disposal costs. These wastewaters are assumed to be primarily acid/alkali rinse waters, hexavalent chromium wastewaters, cyanide wastewaters, and cadmium wastewaters.[49]

Treatment of electroplating wastes typically involves five steps: (1) chromium reduction, (2) cyanide oxidation, (3) neutralization/precipitation (4) clarification (gravity settling for separation of suspended solids), and (5) sludge handling (including both dewatering and solidification techniques). These steps

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[45] *Guide to Solvent Waste Reduction Alternatives*, pp 4-4 through 4-24.

[46] B.L. Blaney

[47] B.L. Blaney.

[48] B.L. Blaney.

[49] M. Sittig, *Metal and Inorganic Waste Reclaiming Encyclopedia* (Noyes Data Corporation, 1980).

have become so widely used in industrial applications that they are generally referred to as "conventional" treatment.[50]

The other wastes of concern from plating operations are spent plating bath solutions (F007), sludges from the bottom of plating baths (F008), and spent cleaning and stripping bath solutions (F009).[51] A large volume of literature exists on metal plating operations, related waste streams, and their treatment. The following discussion is limited to some of the relevant minimization techniques.

Source Reduction

Aluminum has been found to be a good substitute for cadmium when electroplating on steel. Many other applications have been found for aluminum coatings produced by an ion vapor deposition (IVD) process.[52] The parts are held in a low pressure argon environment. Argon and aluminum are in an ionized state. Ionized argon not only cleans the part by bombardment but also accelerates the movement and deposition of aluminum. The resulting uniformly thick deposit provides good sacrificial corrosion protection. IVD aluminum does not embrittle like cadmium, and it can be used at high temperatures. The main advantage is that no pollutant stream requiring treatment is produced.[53]

Good housekeeping practices are extremely important in minimizing the wastes produced. Proper maintenance of tanks and related equipment is required to prevent leaks. Periodic inspection and maintenance of plating racks and anodes prolongs equipment life. Dry cleanup should be used instead of water whenever possible. Unnecessary water use should be reduced by installing flow control valves, antisiphon devices, drip trays, and splash guards.[54]

Substitution of input material in plating baths can reduce the treatment costs. In the case of decorative chrome plating, trivalent chromium formulations can be used in the bath in place of hexavalent chromium plating solutions. Substituting noncyanide baths for cyanide baths has been used successfully for zinc plating.[55]

Purification of plating baths can result in savings in the disposal costs (usually occurring twice a year). Also, considerable savings can be realized in the cost of replacing chemicals for plating solutions. There are five basic purification techniques: filtration, chemical treatment, carbon treatment, physical/ chemical treatment, and electrolytic treatment. The combination of treatment techniques and operating conditions depends on the type of bath.[56]

Process modifications that reduce the amount of rinsewater used may be very simple to implement. Such modifications include installing water supply control valves and/or conductivity controllers and

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[50] *Environmental Pollution Control Alternatives: Economics of Wastewater Treatment Alternatives for the Electroplating Industry*, EPA/625/5-79-016 (EPA, June 1979), p 3.

[51] D.W. Grosse, "Treatment Technologies for Hazardous Wastes: Part IV, A Review of Alternative Treatment Processes for Metal-Bearing Hazardous Waste Streams," *International Journal of Air Pollution Control and Waste Management*, Vol 36, No. 5 (1986), pp 603-614.

[52] D.E. Muehlberger, "Ion Vapor Deposition of Aluminum: More Than Just a Cadmium Substitute," *Plating and Surface Finishing*, Vol 70, No. 12 (1983), p 24; E.R. Fannin, "Ion Vapor Deposited Aluminum Coatings," in *Proceedings of the Workshop on Alternatives for Electroplating in Metal Finishing*, EPA/560-2-79-003 (EPA, 1979).

[53] *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 3 Report: Appendix B - Workshop Manual for the Waste Reduction Project Pertaining to Innovative Hard Chrome Plating at Pensacola Naval Air Rework Facility, Pensacola, Florida.*

[54] *Environmental Pollution Control Alternatives: Reducing Water Pollution Control Costs in the Electroplating Industry*, EPA/625/5-85-016 (EPA, September 1985); *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 3 Report: Appendix B Workshop Manual for the Waste Reduction Project Pertaining to Innovative Hard Chrome Plating at Pensacola Naval Air Rework Facility, Pensacola, Florida.*

[55] G.C. Cushnie, Jr., *Electroplating Wastewater Pollution Control Technology* (Noyes Publications, 1985).

[56] G.C. Cushnie, Jr., (1985), pp 2-23.

timers. Rinsing methods can be modified to use either spray or fog rinse. In certain applications, still or "dead" rinse tanks may be effective.[57] Mixing or agitating rinse tanks can improve and hasten the rinsing process. The most effective rinsewater modification is to use multiple rinse tanks and move the parts countercurrent to the rinsewaters. The amount of rinsewater required is drastically reduced as the number of tanks is increased from one to three.[58]

The drag-out of chemicals from the plating baths into rinsewaters depends on: the design of racks or barrels that hold the parts; shape and orientation of the parts; plating procedure; and the process solution characteristics. The process solution characteristics of importance are temperature, viscosity, surface tension, and the concentration of chemicals. Drag-out can be reduced by: using drain-boards, drip bars, drip tanks; removing films by air knives or spray-rinsing; decreasing the viscosity; and/or decreasing the surface tension. Changes to process conditions can only be implemented properly after studying specific systems and determining changes in evaporation, recycle, and makeup water flow rates.[59]

The current hard chrome plating process used throughout the Army can be modified and retrofitted as demonstrated successfully by the U.S. Navy in their Naval Rework Facilities.[60] The standard method of hard chrome plating uses three bus bars and amperage regulation, requires unique racking of parts, and produces large quantities of chromium-contaminated rinsewaters. The "Cleveland" process, adapted by the Navy, uses two bus bars, reversible racks, conforming anodes, voltage regulation, bath purification, and a zero discharge spray-rinsing system. This process is being promoted by DOD to be implemented at all military installations. In addition to the reduced amount of hazardous waste generated, a higher quality product is produced in less than half the time.[61]

Recovery/Reuse

Many types of material recovery processes can be used onsite to recover chemicals and recycle them into the plating baths. A reduction in the loss of raw materials and a decrease in the pollutant load to the IWTP are incentives to encourage the recovery of drag-out chemicals. Some of the material recovery processes applicable to plating rinsewaters are: evaporation, electrodialysis, reverse osmosis, ion exchange, electrolytic cell processes, Donnan dialysis, ion transfer membranes, and coupled transport membranes.[62] The use of each process is limited to specific waste streams.[63] All of the processes concentrate the dragged-out chemicals so they can be returned to the plating baths, thus forming a closed loop. Further treatment of rinsewaters may thereby be minimized or eliminated.

The material recovery processes and the bath purification methods mentioned earlier can be implemented onsite. Spent plating solutions and plating bath dumps are conventionally placed in drums and shipped to an offsite treatment and disposal facility. In some cases, it may be possible for an offsite contractor to recover material that can then be recycled.

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[57] T.E. Higgins, R.B. Fergus, and D.P. Desher, pp 7-10.

[58] *Environmental Pollution Control Alternatives: Reducing Water Pollution Control Costs in the Electroplating Industry*, pp 1-17.

[59] G.C. Cushnie, Jr. (1985).

[60] *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 2 Report: Evaluation of 18 Case Studies.*

[61] *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 3 Report: Appendix B - Workshop Manual for the Waste Reduction Project Pertaining to Innovative Hard Chrome Plating at Pensacola Naval Air Rework Facility, Pensacola, Florida.*

[62] E.T. Oppelt, *Pretreatment of Hazardous Waste*, EPA/600/D-87/047 (EPA, January 1987), pp 58-70.

[63] G.C. Cushnie, Jr. (1985).

Treatment

Hexavalent chromium present in rinsewaters must be reduced to a trivalent form before it can be precipitated as a hydroxide at a conventional wastewater treatment plant. Among the processes commercially practiced are: hydrosulfide precipitation, sulfur dioxide reduction, and ferrous ion precipitation.[64] These chemical reduction processes are very efficient and reliable. The pH in such a system is maintained (at approximately 2.5) by adding sulfuric acid. The sulfuric acid (reducing agent) is added based on an oxidation-reduction potential (ORP) controller set-point. The ORP controller is sensitive to pH.[65]

Most of the cyanide rinsewater streams are treated conventionally by alkaline chlorination. Cyanide is destroyed by direct addition of sodium hypochlorite or chlorine gas and sodium hydroxide. Cyanide ions are completely oxidized to cyanate under alkaline pH conditions and continuous mixing. In a second stage (at pH 8.5), further chlorination leads to complete conversion of cyanate to carbon dioxide and nitrogen gases.[66] Cyanides that cannot be destroyed by alkaline chlorination may be destroyed by incineration or a variety of other processes.[67]

Industrial Wastewater Treatment Plant Sludges

AMC installations that typically conduct industrial operations have IWTPs to comply with effluent discharge limitations. The plants treat general wastewaters, metal-plating rinsewaters, blowdown from steam boilers, acid/alkali wastewaters, oily wastes, treated explosives manufacturing waters, wastewaters resulting from steam cleaning operations, etc.

Conventional treatment plants include hexavalent chromium reduction and cyanide oxidation as pretreatment steps.[68] All waste streams go through flow equalization tanks and are then mixed in a pH adjustment tank. Either caustic soda or lime is used as a reagent to neutralize the wastewaters and precipitate the heavy metals. Initial settling of metal hydroxide precipitates is obtained in a clarification tank by further flocculation/coagulation. Material from the bottom of the clarifier is usually transferred to a sludge holding tank for gravity thickening (2 percent or more of solids). The supernatant from the top of the clarifier is drained through sand filters and discharged to the sewage treatment plant. The thickened sludge is pumped to a mechanical dewatering device to further increase the solids content (20 to 35 percent). The minimization options for the sludges are examined below.

Source Reduction

Source reduction can be achieved by exploring wastewater treatment technologies that can substitute for the conventional hydroxide precipitation. Sulfide precipitation is used to remove heavy metals from wastewaters as metal sulfide precipitates. Two common processes are: (1) soluble sulfide precipitation (SSP) using water-soluble sodium sulfide (Na_2S) or sodium hydrosulfide (NaHS) and (2) insoluble sulfide precipitation (ISP) using ferrous sulfide (FeS). Each process has advantages and disadvantages.[69] A major disadvantage of the ISP process is that the quantity of sludge produced may be larger than for

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[64] D.W. Grosse, pp 609-611; *Hazardous Waste Treatment Technology*, EPA/600/D-86/006 (EPA, January 1986), p 17.

[65] G.C. Cushnie, Jr. (1985).

[66] G.C. Cushnie, Jr. (1985), pp 15-129.

[67] *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 3 Report: Appendix B - Workshop Manual for the Waste Reduction Project Pertaining to Innovative Hard Chrome Plating at Pensacola Naval Air Rework Facility, Pensacola, Florida.*

[68] M.R. Bradbury and D. Thompson, *Electroplating Sludge Treatment Technology Development: Final Summary Report*, AMXTH-TE-CR-86080 (U.S. Army Toxic and Hazardous Materials Agency [USATHAMA], February 1986).

[69] *Soluble Sulfide Precipitation Study* (Arthur D. Little, Inc., December 1986); A.A. Balasco, et al., *Soluble Sulfide Precipitation Study*, AMXTH-TE-CR-87106 (USATHAMA, December 1986).

hydroxide precipitation. The advantages of both sulfide processes compared to hydroxide precipitation are: a higher degree of metal removal, low residence time requirements in the reactors due to higher reactivities of sulfide, selective metal recovery, better sludge thickening, and less leachability than hydroxide sludges.[70] The conventional treatment system can be easily modified or retrofitted to use either SSP or ISP.

Other wastewater treatment technologies that can be considered as substitutes to the conventional metal hydroxide precipitation and, in some cases, pretreatment or post treatment (polishing) methods for certain waste streams are: sodium borohydride precipitation, insoluble starch xanthate precipitation, ion exchange, ozone oxidation, thermal oxidation, freeze crystallization, sacrificial iron anodes, ultrafiltration and microfiltration, ferrous sulfate reduction, and integrated treatment.[71]

Recovery/Reuse

In certain applications, sludges have been treated to recover organics and heavy metals.[72] Most of these reclamation methods are used at dedicated offsite facilities. Reclamation of material from sludges may not be practical for most Army installations.

Treatment

Minimization of sludges can be realized by a reduction in their volume and thereby their disposal costs. Dewatering of sludges, produced by the use of thickeners, is the first step in volume reduction. Sludges can be dewatered by: filtration (filter press, pressure belt filter,[73] or rotary drum vacuum filter[74]); centrifugation (basket, disk, or solid bowl centrifuges); or drying beds.[75] Mechanical dewatering devices (filters and centrifuges) can produce a cake containing 25 to 35 percent solids.[76] The performance efficiency of these devices is dictated by the nature of the waste, degree of chemical conditioning, frequency of use, and maintenance practices. After dewatering, the sludge can be further treated by: aging, heat drying, washing, incineration, or solidification.[77] Sludges can be dried by many of the commercially available dryers; performance of a particular type of dryer is determined by particle size, capillary voids, mixing action, and sludge makeup.[78] Drying can increase the solids content up to 85 to 95 percent. Stabilization/solidification of sludges can be achieved by using fixating agents such as lime-flyash, cement/soluble-silicate, urea-formaldehyde, or other stabilization systems.[79] Stabilization/ solidification is usually the last step before land disposal.

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[70] D.W. Grosse, pp 603-614.

[71] G.C. Cushnie, Jr. (1985).

[72] T.F. Stanczyk, "Sludge Treatment for Volume and Risk Reduction," in *Waste Minimization Manual* (Government Institutes, Inc., 1987), pp 100-109.

[73] E.T. Oppelt, 42-44.

[74] E.T. Oppelt, pp 39-41.

[75] M.R. Bradbury and D. Thompson.

[76] T.F. Stanczyk.

[77] M.R. Bradbury and D. Thompson, pp 1-45.

[78] T.F. Stanczyk.

[79] D.W. Grosse, pp 603-614; J.A. Alleman and N.A. Berman, "Constructive Sludge Management: Biobrick," *Journal of Environmental Engineering*, Vol 110, No. 2 (1984), pp 301-311. As a way of reducing the volume of sludges for disposal, the authors note it has been successfully shown on multiple projects that vitrified brick can be created from a combination of clay shale and sludge and subsequently used in the course of normal construction.

Used Petroleum and Lubricating Oils

The types of used oils generated at Army installations are: crankcase oils, transmission oils, final drive oils, hydraulic fluids, and other petroleum- and synthetic-based products. Waste oils and lubricants are generated from maintenance of tactical, support, and facility engineering vehicles. The most common contaminants in waste petroleum, oils, and lubricants (POLs) are gasoline, additives, combustion products, wear metals, dirt, and coolant. Many of the contaminants, such as solvents and water, are present because of poor handling practices.[80] Some of the minimization techniques applicable to used oils are presented below.

Source Reduction

Good housekeeping practices are necessary to minimize the quantity of contaminants in used oil. These practices include proper segregation, use of screens and filters on tanks, and avoiding solvent contamination.

Techniques for draining and transferring oil from motor vehicle crankcases can be modified for source reduction. A fast lube oil change system (FLOCS) has been developed that can minimize contamination, reducing the costs of recycle/disposal.[81]

Recovery/Reuse

Before reclamation or burning used oil for energy recovery, the oil has to be tested to determine the heavy metal and total halogen content and flashpoint limitations that would make it a hazardous waste (or waste oil).[82] Certain pretreatment processes necessary for removing solids and water are: filters, filter-coalescers, gravity separators, centrifugation, or distillation.[83]

Onsite reclamation of used oils is usually not an economical alternative because only small amounts of used oil are generated. Commercial re-refining of used oils offsite is, however, a practical option. Energy recovery by burning used oils in industrial boilers is the best possible onsite recycle/disposal method. If the used oil does not meet specifications, it can in certain cases be blended with virgin oil and burned in industrial boilers.

Treatment

If the used oil is considered a hazardous waste, it can only be disposed of in a permitted treatment/storage/disposal facility.[84]

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[80] L.C. Chicoine, G.L. Gerdes, and B.A. Donahue, *Reuse of Waste Oil at Army Installations*, Technical Report N-135/ADA123097 (U.S. Army Construction Engineering Research Laboratory [USACERL], September 1982).

[81] D.W. Brinkman, M.L. Whisman, and C.J. Thompson, *A Guide to Management of Used Lubricating Oil at Department of Defense Installations* (DOD Environmental Leadership Project Office [DELP], 1986).

[82] 50 *Federal Register* Vol 50, No. 230 (November 29, 1985), pp 49, 164-49, 212.

[83] *Used Oil and Solvent Recycling Guide: Final Report* (Robert H. Salvesen Associates, June 1985), pp 43-62.

[84] *Used Oil and Solvent Recycling Guide: Final Report*, pp 43-59.

Batteries and Battery Electrolytes

Many different types of batteries are used at Army installations,[85] the most common are the lead-acid battery (containing lead, lead salts, and sulfuric acid) and the nickel-cadmium (NICAD) battery, (containing cadmium, cadmium salts, and potassium hydroxide). Lithium-sulfur dioxide ($Li\text{-}SO_2$) batteries are used in equipment as a reserve power source. Lead-acid, NICAD, magnesium, alkaline, mercury, and LeClanche ($Zn\text{-}MnO_2$)[86] batteries are used in vehicles.

Battery disposal practices at Army installations may involve the reuse of the batteries (donation to another agency through The Defense Reutilization and Marketing Office [DRMO]) or sale either solid or as casings (with the electrolytes drained) to an approved recycler. Only the latter instance generates revenue for the installation. Typically, this revenue is insignificant compared to the costs of storage and transportation of the used batteries. The most common drained electrolyte that installations have to deal with is corrosive sulfuric acid contaminated with lead and other heavy metals. Some of the possible minimization options are outlined below.

Source Reduction

A reduction in procurement of new batteries could lower the quantities of spent batteries and electrolytes that have to be discarded properly. Use of solid batteries that can be easily disposed of could eliminate the problem of dealing with battery electrolytes.

Many installations drain the acids (or alkalis) from used batteries. This practice creates the problem handling and disposing of corrosive electrolytes in addition to the battery shells. Used batteries containing electrolytes may have more salvage value than empty shells.

Recovery/Reuse

It is a common practice at Army installations to charge and recharge batteries until they cannot be used anymore. The extent of this recycling process for any battery depends on the judgment of the operators. Standard operating procedures should be modified to extend continued use of batteries and thus limit their disposal problems.

Once the installation has determined that a battery has served its useful life, it can be sold to salvage operators for reclamation. Thus it is possible to recycle the reclaimed batteries.

Treatment

If batteries cannot be salvaged, they must either be disposed of in a commercial landfill or incinerated in a permitted facility. Drained electrolytes, on the other hand, must be neutralized in a batch neutralization tank before discharge into a sewage treatment plant.[87]

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[85] *Battery Disposition/Disposal Handbook* (U.S. Army Communications-Electronics Command [CECOM], November 1986), p 1-1.

[86] *Battery Disposition/Disposal Handbook*, pp 1-1 through 1-6.

[87] G.R. Hartup, "Company Gets Lead Out – and More," *Pollution Engineering*, Vol 19, No. 12 (1987), pp 66-71.

6 DETERMINING COSTS AND BENEFITS

General

Having identified the feasible alternatives for minimizing hazardous waste production, the next step in the process of performing an economic analysis is to identify the costs and benefits associated with each alternative. Although costs must be extrapolated into the future, they are often easy to measure in terms of current dollars spent. Benefits, on the other hand, present a much more complex measurement problem for the analyst because they are often quite difficult to measure explicitly.

The Role of Life Cycle Costing in Economic Analysis

In performing economic analyses, the scarce resource of primary concern is money, although other scarce resources such as labor may also be considered. Since the scarcity of labor, however, will generally be reflected in the price, the analysis need only deal with the cost variable. The process of allocating limited funds to alternative projects for minimizing hazardous waste production requires an understanding of all expected costs for the alternative over its projected life. The concept of costing an alternative's components over the entire system/product life cycle is known as life cycle cost analysis (LCCA).

Life cycle costing is simply one method of determining the total cost of acquisition and ownership of an alternative over the its useful life. LCCA generally encompasses four broad categories of costs: (1) research and development (R&D); (2) production and construction; (3) operation and maintenance; and (4) equipment retirement and disposal. Life cycle costs generally occur either at the beginning of the alternative's life cycle, or throughout the operation of the alternative. These costs may be further grouped into two broad categories: those that occur only once (nonrecurring costs), and those that occur on a regular basis (recurring costs).

The Time Value of Money

Because life cycle costing deals with projecting costs into the future, it is necessary to understand the concept of the time value of money. A dollar received today is worth more than a dollar received a year from now for two reasons. First, inflation will eat away at the purchasing power of the dollar (e.g., if inflation is at a 6 percent annual rate, a dollar received today will buy only $0.94 worth of goods at the end of 1 year because the price of these goods has increased by 6 percent. Second, the use of money is viewed as a productive asset in our society. It can be "rented" in much the same way an apartment is rented. Money lenders will seek a return on their loans (which is a fee for the use of the money). Borrowers are willing to pay this fee for the right to use that money over the life of the loan. This willingness of individuals to pay interest for the use of money is at the heart of LCCA.

Simple Interest

To illustrate the concept of the time value of money, assume that a certain amount of money is borrowed from a bank for 1 year. The amount of money lent is referred to as principal [P], and represents the face value of the loan. The bank, however, must earn a return on the loan to pay its operating expenses and provide a return on investment to its shareholders. Consequently, the bank will charge an interest rate [i] on the loan. The total amount that must be repaid by the borrower, therefore, is the original amount plus the interest charged on the loan which is equal to P times i. The total amount that must be repaid in the future [F], is equal to:

$$F = P + Pi = P(1+i) \qquad \text{[Eq 1]}$$

Compound Interest

Equation 1 is known as the formula for calculating "simple interest." In reality, however, interest is calculated more commonly on a "compound" basis. Compounding means that the interest from any previous period is included in the principal amount in determining the interest payments for any future periods. The total amount of a future value at an annual interest rate is:

$$F = (P\,[1 + i])\,(1 + i) = P\,(1 + 1)^2 \qquad \text{[Eq 2]}$$

Extending Equation 2 to encompass more than two periods, the formula for compound interest over n periods becomes:

$$F = P(1 + i)^n \qquad \text{[Eq 3]}$$

Equation 3 captures the fact that lenders are willing to forego P dollars in the present time period to receive $P(1 + i)^n$ at the end of n time periods. (For convenience, the time period n shall be used throughout the rest of this report to represent years. The analyst should note, however, that n can represent any time period--days, weeks, or months--and not just years.) Equation 3 represents the future worth of P dollars to the lender. Borrowers, on the other hand, are willing to pay $P(1 + i)^n$ to secure the use of P dollars today.

The Concept of Net Present Value

In compounding, present sums of money were projected into the future to determine a future worth. In LCCA, the interest is in knowing the inverse--the present value of a future cash flow. This movement from the future back to the present is known as discounting. Discounting is simply the inverse of compounding. Algebraically manipulate Equation 3 to arrive at the formula for determining the net present value (NPV) of a stream of future dollars:

$$NPV = F * 1/(1 + i)^n \qquad \text{[Eq 4]}$$

The NPV has the same value as P used above. Equation 4, however, assumes that all payments are made at yearend. The present value of a single amount received not at yearend, but in a uniform manner throughout the year can be developed from Equation 4 as:

$$NPV = F * (e^{n*\ln(1 + i)} - 1) / \ln(1 + i)e^{n*\ln(1 + i)} \qquad \text{[Eq 5]}$$

where e = 2.718... (the base of the natural logarithm).

Equation 5 may be simplified to:

$$NPV = F * (e^{nr} - 1) / re^{nr} \qquad \text{[Eq 6]}$$

where $r = \ln(1 + i)$.

In Equation 6, $(e^{nr} - 1)/ re^{nr}$ is known as the cumulative uniform series factor and is often represented as b_n. Equation 6 is the basis for discounting used in all the formulas developed in Appendix A.

Uniform Annual Cost

If alternatives have economic lives of differing time periods, direct comparison of net present values may not produce an accurate ranking of the alternatives. In such instances, it is necessary to determine the Uniform Annual Cost (UAC) which is the average discounted cost per year for each alternative. For alternatives with no lead time, UAC is calculated by:

$$UAC = NPV * re^{nr} / (e^{nr} - 1) \qquad [Eq\ 7]$$

The UAC is the amount required to amortize, or completely retire a principal amount (NPV), over n years at i percent interest. In end-of-year discounting tables, the end-of-year equivalent to $re^{nr} / (e^{nr} - 1)$ is often referred to as the capital recovery factor (R). Note that Equation 7 is merely the reciprocal of Equation 6.

When alternatives possess a lead time before the economic life of the project begins (e.g., 2 years of R&D before equipment is purchased), the formula becomes:

$$UAC = NPV / (bx - by) \qquad [Eq\ 8]$$

where bx = same formula as b_n where $b_n = (e^{nr} - 1) / re^{nr}$, but x represents the length of the project's life,

by = same formula as b_n but y represents the lead time associated with the project.

The value determined for the UAC represents the amount of funding required to finance the alternative if it were budgeted in equal installments for each time period (in this case, years). In conducting secondary or Type II economic analyses, if benefits are judged to be equal but the costs of alternatives are unequal, UAC is the appropriate method to use.

Assumptions Inherent in LCCA

The goal of this literature review is not to reiterate all of what has already been written on performing economic analyses and using LCCA. Many publications can provide information on the basic principles and procedures for conducting an LCCA. Those publications are reviewed in a subsequent chapter. It is necessary, however, to discuss some of the assumptions inherent in applying life cycle costing to comparing the worth of alternatives because these assumptions place some limitations on the procedure.

Mid-Year Convention

Contrary to most economic analysis textbooks that follow the end-of-year convention (whereby all receipts and disbursements are assumed to occur at the end of the year), current guidelines from the AMC and the Defense Logistics Agency (DLA) stress the use of mid-year accounting factors in performing economic analyses. These mid-year or "continuous" factors are derived from standard present value formulas and approximate an average of the "end-of-year factors." Two reasons for using continuous discounting techniques rather than "end-of-year" techniques that assume that cash flows occur precisely at the ends of years are:[88]

1. Subsequent to initial investment costs, most annually recurring costs associated with a project occur throughout the year and not at the end of the year as suggested by "end-of-year" discounting techniques. As an example, salaries and most operating costs are incurred throughout the year. To approximate these payments with a single end-of-year calculation, therefore, would be inappropriate.

2. As the exact time of occurrence of any costs for a project cannot be predicted with any great certainty, there is no valid reason for assuming that these costs occur only on the anniversary date of the

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[88] *Economic Analysis.*

project's initiation. Lacking specific information, the mediating impact of continuous discounting should average out the effects of both high and low estimates of time of occurrence.

Sunk Costs

The essence of life cycle costing in economic analysis is evaluating the differences between alternatives. When evaluating alternatives, costs that have occurred in the past have no bearing on future events. It is the current and future difference between alternatives that is relevant in conducting an economic analysis, not past costs.

Inflation and Deflation

Both inflation and its opposite, deflation, have important consequences for economic analyses. As costs and benefits are projected into the future, anticipated increases or decreases in these costs and benefits, if substantial, may alter the ranking of alternatives. Wherever possible, therefore, the analyst must pay careful attention to inflation and deflation.

Viewpoint of the Economic Analysis

The point of reference from which the EA is conducted may bias the results. The point of reference adopted in this model is that of the installation, not that of the Department of Army as a whole. In some instances, primarily due to high investment costs and economies of scale in treating and reducing hazardous wastes, minimization technologies are best applied at a regional, rather than at an installation level.[89]

Discounting

In economic analyses, either cost/benefit (C/B) or LCCA, where projects generate streams of costs and benefits over many years, the standard procedure for comparing alternatives is to discount the costs and benefits to compute the NPV of each project. By discounting to present dollars, the analyst accounts for the time value of money. Inflation diminishes the value of the dollar received in the future, while the rate of return expected from investing that same dollar increases the value.

Opponents of applying the discounting procedure to environmental issues argue that it discriminates against individuals who would only enjoy the benefits of the project in the future.[90] Others note that a failure to discount future cash flows ignores the reality that there is a time value associated with the cost of money. Because money may earn interest, it should be considered as a productive asset. This position has generally prevailed.

Discounting is not required for DOD projects concerning alternatives whose costs and benefits extend over a period of 3 years or less.[91] For alternatives with longer lives, however, it is necessary to discount the future cash flows to present values as indicated above. The Office of Management and Budget (OMB) has mandated a discount rate of 10 percent for all DOD projects.[92] The 10 percent rate

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[89] *Least-Cost DOD Hazardous Waste Management Strategies*: Draft Report (ICF Consulting Associates, Inc., 15 June 1987), Chapter 7.

[90] T. Page, R. Harris, and J. Bruser, *Removal of Carcinogens from Drinking Water: A Cost-Benefit Analysis*, Social Science Working Paper 230 (California Institute Of Technology, 1979). The referenced paper is an example of a study that attempts to measure the cost/benefit (or cost/effectiveness) of programs aimed at saving human lives by chosing to ignore the time element in assessing costs, in effect applying a 0 percent discount rate to the analysis. To achieve intergenerational equity, costs and benefits should not be discounted but should be compared in their "steady-states."

[91] *Economic Analysis Handbook*, 2nd Edition, AD-784 339 (Assistant Secretary of Defense [Comptroller], 1974, p 41.

[92] Office of Management and Budget (OMB), Circular No. A-94, *Discount Rates To Be Used in Evaluating Time-Distributed Costs and Benefits* (OMB, 27 March 1972).

established by OMB subscribes another, admittedly broader interpretation to the interest rate in including within the 10 percent discount rate the expected rate of return for the government.

The 10 percent discount rate incorporates an estimate of a nominal rate of return for the economy as a whole that is an agglomeration of the total rate of return demanded by private industry and government. Historically, the nominal rate of return for government investment has been estimated at between 7 and 13 percent. The single most important contribution to OMB's selection of a 10 percent discount rate, however, was a 1969 paper in which J.A. Stockfish sought to estimate the rate of return on capital for the private sector between 1949 and 1965.[93] Stockfish's premise was that the rate of return on investment for government proposals should equal the rate of return demanded by the private sector as a whole.

Stockfish determined that during the period under study, the nominal rate of return (ROR) was 12 percent. This figure, however, represented a ROR that was not adjusted for inflation. The average annual increase in the GNP Price Deflator Index for the period was 1.6 percent, leaving an adjusted, real rate of return on private sector investment of 10.4 percent. The OMB subsequently selected the 10 percent discount rate to represent the real ROR (one that is adjusted for inflation) on government investments.

Economic Life vs. Physical Life Cycle

In conducting an LCCA, it is common to assume a time period shorter than the total physical life cycle of a project. This period, identified as the "economic life" of the project, is that time period deemed directly relevant to the analysis at hand. As an example, batch stills used in solvent distillation may last for 15 or 20 years--the physical life of the equipment. However, when acquiring enough economic data to make decisions, 10 years is a reasonable length of time. When the economic life differs from the physical life of a product, it is important to note the distinction and the reasons for selecting either time period.

Determining Costs

Selecting a cost estimating technique is the province of the economic analyst and depends on such factors as the quantity and detail of available data, the resources available to develop the cost estimate, time, and the degree of accuracy desired in the results. Generally, there are five basic cost estimating procedures available to the analyst considering hazardous waste minimization alternatives:[94]

Cost Curves

If the construction, operation, and maintenance of facilities have been analyzed before, cost curves may be developed by plotting a linearly regressed relationship of cost data to design parameters (e.g., flow rate for a municipal wastewater treatment plant). While this method may be the easiest to use, it relys on historical data; errors in interpreting exact positions on the cost curves lead to a decrease in reliability of the estimates.

Industrial Engineering Method

Estimates are based on the actual cost of equipment, material, and the cost of labor for constructing, installing, and operating the equipment. While this method can be extremely exact, allowing for rather

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[93] J.A. Stockfish, *Measuring the Opportunity Cost of Government Investment*, IDA Research Paper R-490 (Institute for Defense Analysis, March 1969).

[94] *Reference Guide for Industrial Wastewater Treatment*, Technical Report N-85/06/ADA166500 (USACERL, September 1985), pp 8-1 and 8-2.

small components of the total cost to be studied in detail, it can also be quite time consuming and is commonly used when an accuracy of plus or minus 10 percent is desired.

Cost Per Unit Pollutant Loadings

For some technologies, engineers have correlated construction and operating costs with the size of the technology's treatment capacity. The more complex the operating technology, however, the greater the number of variables that must be considered and the greater the number of relationships to be modeled. For complex systems, therefore, this method is not recommended.

Parametric Costing Method

If adequate cost data are not available, total costs for an alternative are estimated based on historical costs of the component parts of the alternative. A parameter, therefore, is any explanatory cost-related attribute to which various values may be subscribed. An alternative might possess many parameters that define the alternative's operation and to which particular cost information may be assigned.

The quality of parametric costing estimates depends on the analyst's ability to directly establish relationships between parameters and historical cost data and to identify all pertinent parameters. This method is preferred only when accurate costing information is not available, such as when undertaking a new or innovative technology.

Analogy Method

If there is little historical cost data on which to base the estimate, a comparison with alternatives possessing similar physical and performance characteristics may be the best method available to estimate costs. The problem with the analogy method is that as a judgment process, its accuracy depends solely on the analyst's expertise. Moreover, such judgmental efforts are difficult, if not impossible for analysts to replicate in the future.

Nonrecurring Costs

Nonrecurring costs include all costs associated with acquiring real property, land, and equipment, and the associated startup costs. The following nonrecurring costs should be considered in an economic analysis.

Research and Development Costs

Research and Development costs include all expenditures necessary to design the alternative, its component parts, and test laboratory or bench scale operations before initial startup but subsequent to the decision point to proceed with the alternative. In other words, R&D does not include any "sunk" costs. (A sunk cost is one that occurred before the base year.)

Facility Investment Costs

The subcategories in this category include expenditures associated with:

Property Acquisition Costs. Expenditures associated with the acquisition of real estate or easements necessary for the alternative's operation; including all legal and title costs. Note that for most hazardous waste minimization projects, this amount will be zero as the Army already owns the land and facilities to be improved or added to.

Site Preparation. Site preparation costs include both new construction costs and demolition and rehabilitation construction costs.

One-time Personnel Costs. An example would be labor costs associated with initial training of equipment operators.

Equipment Costs. Direct capital costs of machinery and equipment.

Equipment Installation Costs. All costs associated with installing the alternative, including materials (piping, wiring, etc.) and labor for electricians and plumbers.

Freight/Shipping Costs. Equipment may be free on board (FOB) from the point of manufacture. Consequently, costs associated with transporting the equipment to the installation should be included in the analysis.

Major Equipment/System Replacement Costs. It is also a good idea to identify and include any costs associated with replacing major equipment in the alternative. If the economic life of the alternative is estimated to be 20 years, but the manufacturer stipulates that a major component will have to be replaced after 10 years, the component's cost (properly discounted) should be included in the facility investment costs.

Terminal Value

Terminal value is an estimate of the worth of the proposed investment at the end of its economic life and as such may not represent a cost, but a benefit to the installation. Present value of terminal values with long economic lives is relatively small, but should be included in the analysis. In many instances, any value from the investment may be more than offset by costs associated with removal, dismantling, storage, or disposal. If these costs are significant, the terminal value may well be a cost.

Recurring Costs

Recurring costs are those that occur periodically throughout the proposed project's economic life. Generally, these costs include all costs associated with the actual operation and maintenance of a project and are sometimes referred to as operations and maintenance (O&M) costs.

It is particularly important to note that only those recurring costs that change as the result of the alternative being implemented should be considered. To illustrate this point, assume two alternatives. Alternative A, the status quo operation, requires two people to operate for each 8-hour shift. Alternative B, the new alternative under consideration, requires only 1 person to operate for each 8-hour shift. Only the difference in labor between the two alternatives needs to be considered in comparing the attractiveness of the second alternative to the first. The analyst should note that by including all labor costs associated with both alternatives in the calculations of recurring costs, complete accounting of the differential is provided. Included below are the main categories of recurring costs to be considered in an economic analysis.

Labor Costs

For civilian personnel, appropriate adjustments are required for leave and fringe benefits such as retirement and health insurance. Adjustments for sick leave, annual leave, and holidays are currently set at 18 percent. The rate for fringe benefits is presently 36.2 percent. These two factors are not additive and must be applied separately. To illustrate how these percentages are used, assume an alternative is operated 5 days a week, 52 weeks a year (260 days). Assume a labor rate of $10.00 an hour. If the alternative is operated by one person for one shift or 8 hours a day (total yearly man-hours = 2,080), the adjusted man-hours are: 2080 + (.18 * 2080) = 2454.40 hours. The adjusted base cost for operating the alternative is: 2454.40 hours * $10.00/hour = $24,540.00. The fringe benefit factor is subsequently applied to determine the total annual personnel costs for operating the alternative: $24,540.00 + ($24,540.00 * 36.2) = $33,423.48.[95]

Operating Costs

Operating costs include all recurring costs other than labor and all expenses associated with the operation and maintenance of the alternative.

<u>Transportation Costs</u>. Costs associated with transporting a HM/HW include pickup trucks, forklifts, hand carts, and flat-bed trailer trucks used to transport waste from the generation site to a storage site or point of recycling. Labor and equipment use costs associated with this support function must be determined.

<u>Sampling and/or Testing Costs</u>. Before recycling or incineration, it is necessary to have sufficient and reliable information concerning the makeup of the material. If proper segregation and handling procedures are followed, the generator's knowledge of the initial material, knowledge of the process, and a history of known and expected contamination may be sufficient. If this information is unavailable, or there is suspicion of contamination, laboratory analysis may be necessary. Sampling and testing costs can be as little as $5.00 per batch for a simple test on used solvents,[96] to as much as 10 percent of direct labor costs for more complex laboratory analysis.[97]

<u>M&R Costs</u>. The costs of regular repair to buildings and equipment used in the alternative's operation. This includes parts and filters replaced in the normal operation. As a guideline, anywhere from 5 to 15 percent of the initial purchase price for the technology may be used.

<u>Replacement Materials Costs</u>. This subcategory includes the costs of new chemicals for IWTP treatment or virgin solvent that must be purchased to account for still bottom losses in a distillation process.

<u>Support Costs</u>. Differential costs associated with support and overhead including accounting, supervisory, legal, medical, fire, and local procurement are included in this subcategory. Only those support costs that would change as a result of the alternative's implementation should be considered.

<u>Liability Costs</u>. Liability costs represent potential costs that may arise as a consequence of a release of HM/HW into the environment. Liability costs may occur either directly as the result of a spill or accident (including costs for cleanup and legal expenses), or indirectly through increased prices charged by operators of HW disposal operations to cover their increased liability costs. DOD has indicated that "a probability . . . no greater than 0.01, mav be assigned to the occurrence of a possible event (such as a spill, illegal disposal, or breached landfill) for which DOD would incur an estimated monetary liability." The amount of liability is to be justified in the analysis.[98] ICF Consulting Associates, Inc., has developed a methodology for calculating average liability costs per ton of HW/HM produced.[99]

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[95] *Economic Analysis*, p 7-3.

[96] R.W. Bee and K.E. Kawaoka, *Evaluation of Disposal Concepts for Used Solvents at DOD Bases* (The Aerospace Corporation, February 1983), pp 6-22.

[97] *Feasibility of Regionalized Treatment or Disposal of DOD Hazardous Materials/Wastes for Selected Regions of the U.S. Phase II - Rocky Mountain Region* (Hazardous Materials Technical Center [HMTC], April 1985).

[98] DOD Memorandum (6 February 1987). This 1 percent figure is based on principles expounded in E.L. Grant, W.G. Ireson, and R.S. Leavenworth, *Principles of Engineering Economy*, 7th Edition (John Wiley & Sons, 1982), Chapter 15.

[99] *Least-Cost DOD Hazardous Waste Management Strategies*.

Disposal Costs. Disposal costs include the costs for final treatment and disposal of the hazardous wastes, either by landfill, deep-well injection, or incineration. Disposal costs typically include the cost of transportation from the installation to the site of final disposal.

Utility Costs. Utility costs are an operating and maintenance cost that should be treated separately due to the highly variable and differentially escalating nature of energy prices.

Determining Benefits

Four basic categories of benefits that may be measured or estimated: (1) benefits arising from direct cost savings, (2) benefits arising from increases in productivity that may be measured in dollars, (3) benefits arising from increases in productivity that cannot be measured in dollars, and (4) intangible or nonquantifiable benefits. These four basic categories may be further divided into other benefit categories that may or may not apply to the problem.[100]

The first two categories of benefits are quantifiable and are relatively easy for the analyst to effectively measure. If no quantifiable relationship exists, however, the estimation of benefits becomes more complex and subjective. One suggestion in such instances is to establish relationships between alternatives and rank alternatives on an index of all other alternatives.

If benefits become even less quantifiable, an analyst must often resort to verbal descriptions for comparison. In such instances, it is recommended that the analyst compare and rank alternative benefits on a 1-7 scale with 1 being a very low or poor score and 7 being the best or an excellent score. (This scaling procedure is borrowed from the discipline of psychology and is known as Likert scaling.)

Comparison of Alternatives

Cost/Benefit Ratios (Type II Analyses)

Once benefits have been determined, they may be expressed in secondary analyses as a benefits to costs ratio (BCR):

$$\text{BCR} = \text{NPV of Benefits} \,/\, \text{NPV of Costs} \qquad [\text{Eq } 9]$$

In conducting economic analyses for HAZMIN alternatives, there will be few situations where the costs for each alternative will be equal. Likewise, in most instances, each alternative will generate unequal benefits; they will reduce the amount of hazardous waste generated by unequal amounts. Since the goal of each alternative is to reduce production of hazardous waste, each alternative may be quantified by the amount of HW it eliminates for disposal. A dollar cost may be assigned to this amount (dollars required to dispose of an equivalent amount of HW) and the BCR may be calculated for each alternative.

If alternatives have unequal economic lives, benefits must be calculated on an annual basis and divided by the UAC to arrive at comparable BCRs:

$$\text{BCR} = \text{Annualized Benefit/UAC} \qquad [\text{Eq } 10]$$

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[100] *Economic Analysis.*

Savings to Investment Ratio (Type I Analyses)

If absolute cost savings are evident between the alternatives, the first step for the analyst is to compare the alternative against the status quo to calculate the amount of savings generated by each new dollar of investment. The savings to investment ratio (SIR) is the amount of future costs that will be saved as a result of the new alternative, divided by the amount of investment required to undertake the project. The SIR is mathematically expressed as:

$$\text{SIR} = \text{NPV of savings/NPV of investment} \qquad [\text{Eq } 11]$$

The net present value of savings is the net present value of the difference between expenditures under the status quo and those occurring as a result of the new alternative. The SIR must be greater than 1 for the proposed alternative to be considered economically effective. If the SIR is less than 1, the investment will incur total costs greater than or equal to its price and is not a practical option for the Army to consider.

Discounted Payback Period (DPP)

The discounted payback period (DPP, usually expressed in fractions of years) is the time required for a project to accumulate enough savings or benefits to offset the investment costs. Discounted payback analysis incorporates a time element into the calculations. The DPP is simply the time it takes for the total accumulated present value of savings to offset the total present value costs of the alternative. (The gradual extinguishment of a debt or its offsetting is known as amortization.)

For an investment that occurs during the base year and produces uniform annually recurring savings:

$$I = S * b_n \qquad [\text{Eq } 12]$$

where I = NPV of the investment,
S = net present value of annual savings.

We are interested in finding, n, the number of years that it takes for the annual savings to equal the present value of the initial investment. From Equation 6, the cumulative uniform series factor, b_n, was determined to be:

$$b_n = (e^{nr} - 1) / re^{nr} \qquad [\text{Eq } 13]$$

Substituting Equation 13 into Equation 12 yields:

$$I = S * (e^{nr} - 1) / re^{nr} \qquad [\text{Eq } 14]$$

Transposing the terms in Equation 14:

$$I/S = (e^{nr} - 1) / re^{nr} \qquad [\text{Eq } 15]$$

$$I/S * re^{nr} = e^{nr} - 1 \qquad [\text{Eq } 16]$$

$$I/S * re^{nr} - e^{nr} = -1 \qquad [\text{Eq } 17]$$

Setting Equation 17 equal to 1:

$$e^{nr}[1 - (I/S)r] = 1 \qquad [\text{Eq } 18]$$

Again, by transposing terms, Equation 18 becomes:

$$e^{nr} = 1 / [1 - (I/S)r] \qquad \text{[Eq 19]}$$

Taking the natural logarithm of each side of the equation:

$$\ln e^{nr} = \ln\{1 / [1 - (I/S)r]\} \qquad \text{[Eq 20]}$$

$$\ln e^{nr} = \ln 1 - \ln[1 - (I/S)r] \qquad \text{[Eq 21]}$$

The natural log of 1 is zero:

$$nr = -\ln[1 - (I/S)r] \qquad \text{[Eq 22]}$$

Equation 22 can now be solved for n, the number of years required for annual savings to equal the net present value of investment (the DPP):

$$n = -\ln[1 - (I/S)r]/r \qquad \text{[Eq 23]}$$

For readers who are more familiar with calculations of DPP using R, a capital recovery factor, it should be noted that R = S/I which is merely the reciprocal of Equation 12. Equations 13 through 23 would be adjusted accordingly.

7 LITERATURE REVIEW: ECONOMIC ANALYSIS PUBLICATIONS

General

This chapter briefly summarizes and discusses a number of economic analysis publications reviewed to select the most appropriate analysis method and to identify the significant parameters to be included in constructing a model of HAZMIN alternatives.

DOD and Military Service Publications

1. Technical Manual (TM) 5-802-1, *Economic Studies for Military Construction Design-Applications* (Headquarters, Department of the Army [HQDA], 31 December, 1986).

This manual describes criteria and standards for economic studies for projects in the military construction plan (MCP). Conventional methods for determining costs via present worth discounting are presented with extensive examples. The manual includes complete and thorough treatment of life cycle costing in economic studies, including calculations to determine continuous, cyclical, and annually recurring costs.

2. *Economic Analysis: Concepts and Methodologies*, AMC-P 11-28 (United States Army Materiel Command, July 1985).

This pamphlet provides a basic framework for the concepts and methodologies of economic analysis used by AMC. Cost estimation, benefit analysis, and sensitivity analysis are discussed at length. Examples and illustrations are provided for all major economic analysis techniques (including calculation of present value [PV], UAC, SIR, incremental analysis, break-even analysis, and DPP).

3. *Economic Analysis and Program Evaluation for Resource Management*, DOD Instruction 7041.3 (DOD, 18 October 1972).

This instruction outlines DOD policy for conducting economic analyses on both ongoing and proposed military programs and projects. Factors to be taken into consideration in determining both costs and benefits are outlined. Procedures for determining the economic life of projects, estimating inflation, and ranking competing alternatives are included.

4. TM 5-800-2, *Cost Estimates for Military Construction* (HQDA, 12 June 1985).

This manual outlines methods for direct costing of items including unit costs for labor (Chapter 7), equipment (Chapter 8), and materials (Chapter 9). These methods are useful in preparing economic models of HAZMIN alternatives.

5. *Economic Analysis Handbook*, NAVFAC P-442 (Naval Facilities Engineering Command, June 3, 1986).

This handbook discusses the process of economic analysis in general and the concepts of LCCA and benefit analysis in some detail. Basic EA techniques such as calculations of economic life, DPP, SIR, and UAC are presented. The use of inflation and sensitivity analysis in the LCC process is also included. Appendix F of the handbook summarizes Department of Energy (DOE) life cycle costing rules.

6. *Economic Analysis*, DLAM 7041.1 (DLA, 31 May 1985).

This manual provides basic, practitioner-oriented guidance in conducting and reviewing economic analyses. Starting with basic concepts (Chapter 1), the manual proceeds through the steps in conducting an economic analysis, from determining economic life and inflation to quantifying benefits (Chapters 2 through 10). Discussions of assets with unequal economic lives, using UUAC methods, break-even analysis, and computational methods for determining savings to investment ratios and discounted payback are also included (Chapters 11-14).

USACERL Publications

1. A.K. Mallik, *Uncertainty Assessment in Life Cycle Cost Analysis*, Special Report (SR) P-85/12/ ADA157414 (USACERL, May 1985).

Several of the leading methods for evaluating and measuring uncertainties in life cycle costing are examined. Approaches to statistical testing and determining confidence indexes for assessing uncertainty are described in some detail. The report recommends setting confidence levels as a cost-effective method for dealing with uncertainties often found in life cycle cost data. A simplified confidence index method is presented to be used in assessing uncertainty in life cycle costs.

2. E.L. Murphree, Jr., *Economic Analysis Models for Evaluating Costs of a Life Cycle Cost Data Base*, Technical Report (TR) P-164/ADA146801 (USACERL, September 1984).

This report discusses the techniques and data characteristics in LCCA necessary for developing a model for economic analysis. With the data characteristics for LCCA clearly defined, two possible situations for data availability were considered: (1) the existence of a centralized computer data base providing data on R&D, capital, cyclical, and recurring costs, and (2) an ad hoc approach to data acquisition where the analyst locates data for each analysis performed. A general economic model outlining the necessary data elements and their relationships for each mode is supplied. While the analysis is geared toward LCCA for building design, it should prove useful in highlighting relationships in an economic model for comparing HAZMIN alternatives.

3. R.D. Neathammer, *Economic Analysis: Description and Methods*, TR P-151/ADA135280 (USACERL, October 1983).

This report discusses the basic concepts and methods of economic analysis (Chapters 3 through 5). Both one- and two-variable uncertainty analyses are discussed and examples are provided (Chapter 6). Basic reporting formats for military economic analyses are outlined (Chapter 7). Midyear present value and cumulative uniform annual series values escalated at varying differential rates are included in Appendix B in tabular form for easy reference.

Other EA/LCCA Related Publications

1. W.R. Park and D.E. Jackson, *Cost Engineering Analysis: A Guide to Economic Evaluation of Engineering Projects*, 2nd Edition (John Wiley & Sons, 1984).

As a general tool for aiding in economic analysis, this book is helpful in assessing the functions and objectives of economic analysis for engineering projects. Different approaches to analyzing and evaluating prospective investments (e.g., return on investment [ROI], capital recovery factor [CRF], and internal rate of return [IRR]) are covered, in addition to methods of estimating economic life and recovering capital expenditures (Chapters 5 and 6). Considerable attention is paid to estimating, analyzing, and allocating costs and expenses (Chapters 7 through 9). Alternative approaches to capturing uncertainty in economic analysis are also presented (Chapters 10 and 11). Finally, the information is drawn together to illustrate how economic models can be developed. While the models presented are geared specifically toward the private sector and thus include allowances for depreciation and tax considerations, the general formats provide an excellent basis for EA for military projects as well.

2. R.J. Brown and R.R. Yanuck, *Introduction to Life Cycle Costing* (The Fairmont Press, 1985).

This introductory textbook discusses the concept and basic methodologies involved in life cycle costing. Careful treatment is given to calculating energy costs (Chapter 5) and determining inflation/escalation in cost analysis (Chapter 10).

3. B.S. Blanchard, *Design and Manage to Life Cycle Cost* (M/A Press, 1978).

This book provides coverage of the concept of life cycle costing through an introduction to the principles of LCCA (Chapters 1 and 2), the applications and the process itself (Chapter 3), case studies (Chapter 4), and management aspects of LCC (Chapter 5). Appendix A contains a complete analysis and breakdown of costs to be included in an LCCA. Although somewhat dated, the book also provides an excellent bibliography pertaining to LCCA in military applications.

4. J.R. Couper and W.H. Rader, *Applied Finance and Economic Analysis for Scientists and Engineers* (Van Nostrand Reinhold, 1986).

Chapter 3 of this text provides sources for cost indices. Chapter 5 discusses the concept of time value of money which is applied in an analysis. Chapter 8 reviews profitability measures. Chapter 9 reviews the concepts of sensitivity and uncertainty analysis and provides examples with computations. Chapter 11 reviews both quantitative and qualitative factors impacting investment decisions. Although this analysis is geared toward the private sector, the information may be appropriate for evaluating the economic worth of DOD projects, particularly in today's climate of increased budgetary concern.

Computerized Models for Economic Analysis

1. L.K. Lawrie, *Development and Use of the Life Cycle Cost in Design Computer Program (LCCID)*, TR E-85/07/ADA162522 (USACERL, November 1985).

This program and accompanying documentation is designed to perform LCCA of new military facilities. The menu-driven program is designed to be used by personnel with minimum computer experience and allows users to examine parameters and input data into the model from a variety of possible elements to be considered in building design. Extensive use of online help provides the user with guidance on the meaning of questions and possible inputs into the model. Although the LCCID model is developed for specific applications in building design, the general framework of the model and the algorithms used in calculating present worth, discounted payback, and SIRs are directly applicable to the design of an economic model for evaluating HAZMIN alternatives.

2. R.M. Roberts, *HAMTAM* (U.S. Navy Civil Engineering Laboratory [NCEL], 1985).

With the intent to cost-effectively reduce the volume of HW generated at Naval facilities, the Hazardous Materials Technology Assessment Manual (HAMTAM) software package is designed to rank

HAZMIN alternatives according to five calculable criteria: (1) logistics (a measure of the difficulty of implementation), (2) equivalent uniform annual costs (EUAC, measuring the cost effectiveness of the HW management option over the option's economic life), (3) the percent reduction in HW from the status quo, (4) the earliest date at which the minimization option can be operational, and (5) the risk level associated with the option (probability of successful technical operation of the option).

The first step in using the HAMTAM software is to input the economic data on the HAZMIN option being considered. Next, subjectively weight the importance of the five criteria outlined above. The program then calculates the parametric values for each option and normalizes these values to a 0-1 scale. Finally, the options are scored by multiplying the parametric weights by the normalized values and are ranked in ascending order.

As a departure point, the HAMTAM software is useful in providing a method for incorporating criteria other than economic parameters into the process of considering various HAZMIN alternatives. The Initiation Decision Report (IDR) that accompanied the HAMTAM software outlined several minimization alternatives for various waste streams produced by Navy operations. Economic data provided on these alternatives, however, was "rolled up" to the point where it was difficult, if not impossible, to separate the component parts of capital and operating costs. Nevertheless, the general form of the EUAC calculations incorporated into the HAMTAM software should provide the basis for those items considered by this study.

3. S.L. Gamble, *Economic Analysis Model Program Documentation. Volume 1: User's Guide, and Volume 2: Programmer's Guide*, Technical Memorandum 4108 (Naval Weapons Center [NWC], April 1981).

This computer program was developed and used by Project 2000, a study begun in 1978 and funded by the Naval Weapons Center to review and project the Center's needs for facilities, equipment, land, and personnel into the year 2000.

The computerized economic analysis model comes in two versions. The first is based on DOD Instruction 7041.3 (reviewed here) and generally lends itself best to equipment procurement. The second is based on the Naval Facilities Engineering Command (NAVFAC) Document P-442 and is best suited for projects involving Military Construction (MILCON).

The program allows consideration of up to five alternatives, each composed of up to six types of costs (investment costs for buildings and equipment, maintenance costs, operations costs, direct project costs, and the terminal value of the equipment or buildings involved). Terminal value is considered an investment or nonrecurring cost. Because some costs are concerned with investment costs for buildings (e.g., MILCON), they are not considered within the scope of this model.

The program asks the user to enter the cost values for each category. The user is allowed to enter values for costs for each year of the project's economic life, or may choose to let the program escalate the values (from inflation rates provided by the Office of the Secretary of Defense [OSD]). The program then outputs the inflated input costs provided by the user; the inflated costs are discounted back to present values. It also outputs the total NPV and EUAC. Recurring savings are printed graphically, accompanied by SIRs.

4. *The Automated Prospectus System "TAPS" Volume 1: Procedures Manual* and *Volume 2: Programmer's Manual* (General Services Administration [GSA], November 1987).

The TAPS program (in IBM Compiled BASIC) is designed to perform an economic analysis, determining the minimum cost alternative and equivalent annual cost advantages of leasing, buying, or building government offices.

Because TAPS is designed for facility analysis, its direct applicability to a HAZMIN model is limited. Many of the categories included in the TAPS economic analysis of alternatives for facility planning are not applicable in examining hazardous waste minimization alternatives where equipment costs are the single greatest nonrecurring cost and labor tends to be the single greatest recurring cost (in performing economic analyses for building construction/leasing, construction costs tend to be the dominant nonrecurring costs and operations costs, particularly utilities, dominate the annual recurring costs). However, the usefulness of TAPS, LCCID, and other computerized models for economic analysis lies not in their ability to be directly imported into the model described in this report, but in how these models handle the calculations and subroutines that are important to calculating costs and benefits for HAZMIN alternatives.

8 LITERATURE REVIEW: GUIDANCE DOCUMENTS FOR HW EQUIPMENT PROCUREMENT

General

Having defined the technologically feasible HAZMIN alternatives to be considered (Chapter 4), it is important to assess the possible costs and benefits associated with each alternative as inputs into the model. The following literature review, organized by the six waste streams to be examined, briefly summarizes and comments on the existing state of the art for evaluating recurring and nonrecurring costs and benefits associated with the various minimization alternatives.

Cleaning and Degreasing Solvents

1. R.W. Bee and K.E. Kawaoka, *Evaluation of Disposal Concepts for Used Solvents at DOD Bases* (The Aerospace Corporation, February 1983).

For a 50-gal/h continuous vacuum distillation unit, using a 20-yr economic life, a reclamation potential of 19,250 gal/yr, and investment costs of $60,000 for an installed unit, amortized capital costs over the expected lifetime were estimated to be 15.5 cents/gal of recovered solvent.

Three major components were included in the operating costs: labor, utilities, and maintenance. Labor costs of $12.50/h were used to calculate a labor cost of $0.25/gal of reclaimed solvent ($12.50/h divided by 50-gal/h throughput). The high end of utility costs represented $0.05/gal for cooling water and electricity. Maintenance costs were conservatively estimated at $0.01/gal. Total utilities and maintenance costs, therefore, were $0.06/gal or only 20 percent of the total annual operating costs.

Annualized total operating costs for onbase recycling, including amortized capital costs, labor costs, and utilities and maintenance materials were conservatively estimated at $0.465/gal.

The study went further to compare annual savings for an installation producing 400 drums of used 1,1,1-trichloroethane annually for four alternatives: (1) disposal, either by incineration or landfill, (2) sale, (3) offbase recycling, and (4) onbase recycling. The 1983 costs per gallon for each of the four alternatives, respectively, was: (1) $6.94, (2) $3.71, (3) $1.92, and (4) $1.21. The projected annual savings to the hypothetical installation from using onbase recycling as the preferred alternative resulted in a payback period of approximately 7 months.

2. R.W. Boubel, *Recovery, Reuse, and Recycle of Solvents* (Defense Environmental Leadership Project, December 1985).

This publication lists criteria for determining economic feasibility of solvent recycling options and has a sample worksheet.

3. *In-House Solvent Reclamation*, NEESA 20.3-012 (Naval Energy and Environmental Support Activity [NEESA], October 1984).

This publication contains case histories of installed investment and operating costs of solvent reclamation units. Requirements for economical solvent reclamation (with cost curves for payback periods as related to the volume of solvents processed) are included in Appendix B.

4. *Economic Analysis of Solvent Management Options*, Engineer Technical Note (ETN) 86-1 (Office of the Chief of Engineers [OCE], 30 May 1986).

This note contains life cycle cost calculations for four solvent management options: recycling onbase, recycling offbase, recycling by using the services of a full-service contractor, and burning in an industrial boiler.

A complete model, including subroutines for calculating storage and transportation costs, is developed and supplemented with sample numbers to illustrate calculations of NPVs, SIRs, and DPPs.

5. B.A. Donahue, D.W. Sarver, and E.M. Bellino, *Field Test of Life-Cycle Cost Analysis Method for Solvent Management*, Special Report N-86/21/ADA173479 (USACERL, September 1986).

This report documents the field test of USACERL's procedures for calculating the life cycle cost (developed in ETN 86-1) of two alternatives at Rock Island Arsenal, Rock Island, IL. Of the two alternatives considered (onpost recycling by distillation and offpost recycling by a private contractor), onpost recycling was shown to result in significant savings over the projected 10-yr economic life of the project.

6. *Army Materiel Command Solvent Study: Trip Report-Holston Army Ammunition Plant, Kingsport, Tennessee*, (Hazardous Materials Technical Center, July 1986).

This report discusses alternatives and economics for recycling used solvent at Holston Army Ammunition Plant. Calculation methods, with the computer outline of the program used, are included in Appendix A. Calculations included deductions for depreciation, which is a tax item and should not have been included. Capital recovery factors were end-of-year factors; this is inconsistent with stated Army policy to use midyear continuous discounting factors. Also, downtime for the operation of distillation units was estimated at 25 percent, an extremely high figure that has not been witnessed at any other installation. No explanation of how this percentage was obtained is included, so it is believed that this was merely an estimate.

7. *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 2 Report: Evaluation of 18 Case Studies* (CH2M Hill and Peer Consultants, Inc., July 1985).

This report discusses the economics of a 200-gal/h solvent recovery system at Tyndall Air Force Base. The system was underused because many of the original users switched to a cleaning solution other than Stoddard. Also, difficulties were encountered in the collection, transport, and storage of waste Stoddard solvent that was being generated in many small shops. These problems, however, appear to have stemmed from an inadequate involvement and commitment of operating personnel that may have been rectifiable with proper training and supervision.

8. *Army Materiel Command Solvent Study: Trip Report-Red River Army Depot, Texarkana, Texas* (Hazardous Materials Technical Center, July 1986).

Four alternatives were evaluated for the three major solvents used at Red River Army Depot: a Stoddard-type solvent used in cold cleaning, 1,1,1-trichloroethane used in vapor degreasing, and a methylene chloride-based mixture used in paint stripping of vehicles. The four alternatives considered were: (1) status quo--disposal of used solvent in a permitted landfill or sale to a licensed solvent reclamation company, (2) centralized distillation using two 55-gal/shift batch stills, (3) decentralized distillation using three 5-gal/shift batch stills, and six 15-gal/shift batch stills, and (4) full service contracting--Safety Kleen Corporation's annual operating costs for supplying solvent and servicing parts washers for Stoddard and the methylene chloride-based paint stripper only. Safety Kleen did not provide services for 1,1,1-trichloroethane.

Paint Stripping Wastes

1. *Least-Cost DOD Hazardous Waste Management Strategies* Draft Report (ICF Consulting Associates, Inc., 15 June 1987), pp 4-5, 4-6, and 5-3 through 5-17.

ICF investigated substituting plastic bead media for solvents in paint stripping as a process alternative. Total capital costs for a system capacity of 180,000 tons per year were estimated to be $1,239,000. Total operating and maintenance costs were estimated to be $441,000.

2. C.H. Darvin and R.C. Wilmoth, *Technical, Environmental, and Economic Evaluation of Plastic Media Blasting for Paint Stripping*, EPA/600/D-87/028 (EPA, January 1987), pp 10 and 11.

Plastic media blasting (PMB) was evaluated with two other alternative processes for paint removal: (1) using organic chemicals, primarily solvents such as methylene chloride, and (2) sandblasting. PMB was slightly more expensive than sandblasting. Total process costs for sandblasting were estimated at $0.35/sq ft and for PMB, $0.47/sq ft. It is important to note, however, that the plastic media recycle rate was estimated at 82 percent in making these calculations. The EPA determined this as a low estimate due to experimental limitations in the evaluation process. The EPA also estimated that most PMB operations would operate in the range of a 90 to 95 percent plastic media recycle rate. At a 90 percent recycle rate, assuming the sandblasting wastes were hazardous wastes, the projected costs for sandblasting were estimated at $0.50/sq ft while PMB was only $0.31/sq ft. It is also important to note that the USEPA assumed a labor rate of $10/h in its calculations. At a labor rate of $15/h, total process costs become $0.47/sq ft for sandblasting and $0.52/sq ft for PMB–a much narrower gap than first estimated. With a 90 percent recovery rate, assuming disposal of sandblasting wastes as HW, the gap is significantly wider than that calculated above; $0.62 for sandblasting and $0.36 for PMB. With a labor rate of $15/h, PMB is almost 42 percent cheaper than conventional sandblasting.

PMB is slower than sandblasting, yet faster than chemical stripping on flat surfaces. On more complex surfaces, where hand sanding may be required, PMB is faster than either alternative. The disposal volume generated by PMB is significantly lower than that generated by sandblasting. As disposal costs increase, the economics of using PMB over sandblasting should favor PMB even more than estimated in this USEPA report. Finally, the quality of surface finish for PMB is greater than that achieved by sandblasting.

3. *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 2 Report: Evaluation of 18 Case Studies* (CH2M Hill and Peer Consultants, Inc., July, 1985).

Costs for disposal of contaminated glass and plastic beads (1984 dollars) are discussed. Plastic media stripping uses approximately 50 percent less energy in heating and ventilation. PMB is also less time consuming in many instances because glass, chrome, and rubber surfaces do not need to be masked before stripping. Finally, using PMB instead of solvent paint stripping has been shown to generate only 1/100th of the waste sludge and eliminates wastewater (which must be treated at an IWTP before discharge) from solvent stripping operations.

4. C.D. Wolbach and C. McDonald, "EPA Project Summary: Reduction of Total Toxic Organic Discharges and VOC Emissions from Paint Stripping Operations Using Plastic Media Blasting," *Journal of Hazardous Materials*, Vol 17 (1987), pp 109-113.

Three paint stripping processes were evaluated: (1) chemical stripping, (2) sandblasting, and (3) plastic media blasting. Disposal costs based on the wastes generated in stripping 100 square meters of painted surface significantly favored sandblasting ($6.40/100 square meters of stripped area). Disposal costs for PMB were estimated to be $17.50/100 square meters. Disposal costs for chemical stripping were $112.00/100 square meters for sludge disposal, and $120.00/100 square meters for wastewater treatment.

Metal Plating Wastes

1. *Least-Cost DOD Hazardous Waste Management Strategies* (ICF Consulting Associates, Inc., 15 June 1987), pp 4-4, 4-5 and 5-3 through 5-17.

Countercurrent rinsing, whereby rinsewaters from electroplating operations are circulated through a series of rinse tanks so that a work piece is first dipped in the least pure water and last in the cleanest water, was considered as the most economical of the representative electroplating modifications. By adding 2 tanks to a 2-tank countercurrent system, the wastewater flow rate for a 4-gal/h dragout system was reduced from 740 gal/h to 53 gal/h (a reduction of almost 1400 percent in wastewater flow).

The cost of installing the two additional rinsing tanks was estimated to be $19,000 (1987 dollars), of which $10,000 was budgeted for actual equipment costs. Assuming an economic life for equipment of 20 years and a closure cost of $3000, total O&M costs for a facility were estimated to be $6000, of which labor accounted for $4000 (67 percent). The annual costs to an installation were estimated to be $2300/yr, although it was further estimated that this value could vary by as much as 44 percent or $1100 per year.*

2. G.C. Cushnie, Jr., *Navy Electroplating Pollution Control: Technology Assessment Manual*, CR 84.019 (CENTEC Corporation, February 1984).

Economic penalties (replacement costs, treatment costs, and disposal costs) for losses of plating chemicals (nickel, zinc cyanide, chromic acid, copper cyanide, and copper sulfate) are listed in 1983 dollars per pound. Capital costs for bath purification (bright nickel or cadmium bath, periodic carbon treatment, electroless nickel, and hard chromium), primarily the costs for pumps and filters, are discussed.

This report also lists installed costs for 10-gal/min and 33-gal/min chromium reduction units and treatment costs for sulfur dioxide and sodium bisulfite, assuming a hexavalent chromium concentration of 12 mg/L, were $0.05 and $0.15 per 1000 gallons, respectively.

Installed costs for a cyanide oxidation treatment system (10 gal/min and 33 gal/min) are listed. Treatment costs for sodium hypochlorite and chlorine, assuming a cyanide concentration of 15 parts per million (ppm) were $0.50 and $0.20 per 1000 gallons respectively.

Installed costs for a neutralization/metal hydroxide precipitation unit (30 gal/min and 100 gal/min) are listed. Treatment costs for sodium hydroxide (NaOH) were determined to be site specific and varied from $0.15 to $0.50 per 1000 gallons. Hydrated lime [CA(OH)2] resulted in treatment costs of approximately half those of sodium hydroxide for equivalent water volumes.

Costs are given for major process components of ion exchangers of various capacities, and for capital and installation costs for single-effect rising film evaporators. No cost data were available for coupled transport at time of the report. Also included are capital costs and annual cost factors for

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* Cost calculations for converting cost elements to total annualized costs by ICF cannot be directly incorporated into the parameters of this model for a number of reasons. First, ICF inflated all rates at an annual rate of 8 percent, then discounted all costs by a 3 percent factor. These figures do not agree with instructions for discounting in DOD Instruction 7041.3 Furthermore, ICF depreciated all direct capital costs over a 5-year period using the 150 percent declining balance method permitted by the Economic Recovery Tax Act of 1981. As depreciation is only an accounting measure useful for tax consideration, it should not have been considered in the ICF analysis and will not be included in the model developed in this research.

electrodialysis recovery of cadmium cyanide plating baths, including estimated savings from cadmium and cyanide recovery and for reductions in solid wastes as well as capital equipment cost curves for reverse osmosis systems (capital cost by membrane surface area). A detailed economic analysis of a reverse osmosis system includes all equipment and operating costs with estimated savings. Capital costs for electrolytic cell processes are discussed but no cost data were available for Donan dialysis at the time of the report. Annual savings from nickel plating drag-out recovery is shown as well as cost/benefit analysis of an ion transfer chromium recovery unit (Chrome Napper, 1983 prices).

3. G.C. Cushnie, Jr., E.D. Handel, and C.G. Roberts, *An Investigation of Technologies for Hazardous Sludge Reduction at AFLC Industrial Waste Treatment Plants. Volume 1: Sodium Borohydride Treatment and Sludge Handling Technologies*, ESL-TR-83-42 (CENTEC Corporation, December 1983).

This report contains costs for wastewater treatment chemicals (1983 prices); chemical costs per 1000 gallons of water treated for cyanide oxidation, chromium reduction, pH adjustment/precipitation; and sludge hauling costs.

The following seven metal removal technologies were evaluated by the Air Force at its Air Logistics Centers: (1) sodium borohydride precipitation, (2) end-of-pipe electrochemical removal of metals, (3) ion exchange plus batch treatment, (4) water softening, (5) oxide precipitation, (6) hydroxide precipitation (lime), and (7) sulfide precipitation. Sodium borohydride was the most practical treatment technology for mixed plating and metal finishing wastewaters (after pretreatment by alkaline chlorination for cyanide reduction).

4. G.C. Cushnie, Jr., P. Crampton, and C.G. Roberts, *An Investigation of Technologies for Hazardous Sludge Reduction at AFLC Industrial Waste Treatment Plants. Volume 2: Literature Review of Available Technologies for Treating Heavy Metal Wastewaters*, ESL-TR-83-42 (CENTEC Corporation, December 1983).

Chromium reduction unit costs, cyanide oxidation unit costs, and neutralization/hydroxide precipitation unit costs are listed. This report discusses substitute treatment technologies, installed investment costs and variable operating costs for: (1) insoluble sulfide precipitation treatment systems, (2) ozone oxidation systems, and (3) reverse osmosis systems for nickel salt recovery.

5. *Environmental Pollution Control Alternatives: Economics of Wastewater Treatment Alternatives for the Electroplating Industry*, EPA/625/5-79-016 (EPA, June 1979).

Capital, operating, and raw materials costs for chromium reduction units, cyanide oxidation units, and neutralization/precipitation techniques (in 1978 dollars) are included. Chemical and sludge disposal cost curves are also included. Cost/benefit analyses are performed for dragout reduction modifications in a typical nickel-chromium plating process.

6. H. Gold, et al., *Purifying Air Force Plating Baths by Chelate Ion Exchange*, ESL-TR-85-48 (Foster-Miller, Inc., October 1986).

Current practice at Air Force Air Logistics Centers for plating baths contaminated with heavy metals is to replace the baths and dispose of the contaminated liquids. Chelate ion exchange was used successfully on a pilot basis to treat and reuse four plating baths: (1) electroless nickel, (2) electrolytic nickel, (3) nickel strike, and (4) hydrochloric acid etch. Chromic acid baths were also treated but with less than satisfactory results. For the four plating baths capable of being treated, typical operations indicated that about 24,300 gallons of plating bath are replaced annually at a cost of approximately $120,000.

Costs of treatment for a three-column chelate ion exchange system on skids, bath replacement, and disposal (the status quo), and neutralization/precipitation treatment are compared to show ion exchange is by far the cheapest treatment alternative.

7. *Environmental Pollution Control Alternatives: Reducing Water Pollution Control Costs in the Electroplating Industry*, EPA/625/5-85-016 (EPA, September 1985).

This is an update of the 1979 EPA publication discussed in paragraph 5 above. All prices in this report are in 1984 dollars. Based on the volume of wastewater passing through the system and the concentration of pollutants in the wastewater, capital and operating costs (including sludge disposal and wastewater treatment chemicals) are described for six components of a "conventional" treatment system: (1) wastewater collection, (2) chromium reduction, (3) cyanide oxidation, (4) neutralization/precipitation, (5) wastewater clarification, and (6) sludge handling.

Cost curves are presented for each component based on wastewater flow rates and chemical concentrations. Sample costs for components and typical wastewater treatment (both nonrecurring and recurring costs) are also included. Process modifications to reduce costs, including reducing rinsewater use and reducing dragout loss with a simple cost/benefit analysis are discussed.

8. K.J. McNulty and J.W. Kubarewicz, *Demonstration of Zinc Cyanide Recovery Using Reverse Osmosis and Evaporation*, EPA/600/2-81-132 (EPA, July 1981).

Capital costs of a reverse osmosis system to recover zinc cyanide from rinsewaters were $25,000. An additional $40,000 was required for a small evaporator to concentrate rinsewaters (1981 dollars). Operating costs for the system were $12,000 per year with only a $10,000 savings per year in wastewater treatment and chemical costs. The savings resulting from the operation of the system, therefore, were insufficient to offset the annualized costs of operation and investment.

9. *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 2 Report: Evaluation of 18 Case Studies* (CH2M Hill and Peer Consultants, Inc., July 1985).

This report states that significant differences in the operating costs of ion exchange systems may occur, depending on the assumptions made regarding the regeneration frequency and resin life of the system. Annual operating costs of continuous flow rinse tanks as part of a hard-chrome plating system at Pensacola Naval Air Rework Facility varied from $7000 to $28,000 based on rinse flows of 3 to 12 gal/min, freshwater costs of $0.34/1000 gal and wastewater treatment costs of $5.81/1000 gal.

Industrial Wastewater Treatment Plant Sludges

1. *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 2 Report: Evaluation of 18 Case Studies* (CH2M Hill and Peer Consultants, Inc., July 1985), pp 4-64 through 4-66.

Capital costs for installation of electroplating wastewater treatment equipment at Tobyhanna Army Depot are listed. The costs include installation costs for cyanide, chromium, solids separation, sludge dewatering, support equipment, and labor costs. Average sludge disposal costs and average monthly treatment costs are also included.

2. L. Smith, et al., *Characterization and Treatment of Wastewater Treatment Sludges at Radford Army Ammunition Plant*, AD-B078 453 (Hercules, Inc., December 1983), pp 17-24.

Capital and recurring cost estimates with breakdowns (in 1982 dollars) for converting the wastewater treatment sludges to lime and sulfur dioxide (SO_2) using a fluidized bed reactor are provided based on a bench-scale study. Substantial savings were expected to be realized from the recovery of lime and SO_2, but the most substantial savings were expected to accrue from the elimination of 58.75 tons per day of sludges for disposal. The report also includes a literature review of various sludge drying equipment with process descriptions.

3. *Environmental Pollution Control Alternatives: Sludge Handling, Dewatering, and Disposal Alternatives for the Metal Finishing Industry*, EPA/625/5-82-018 (EPA, October 1982).

Comparative total investment and annual operating costs for sludge dewatering of electroplating wastes is included for four alternative methods for sludge dewatering: filter presses, precoated rotary vacuum filters, basket centrifuges, and pressure belt filter. Installation and modification costs are provided along with annual operating costs including sludge disposal fees (in 1981 dollars). At all feed sludge volumes (as measured in gallons per hour), conventional filter presses (either recessed plate or plate and frame presses) presented the lowest installed investment costs and the lowest annual operating costs (including costs for sludge disposal).

Transportation costs were estimated to be \$3 to \$5 per mile (loaded), partial loads are typically charged the same price as a full load (typical loads are 40,000 lb or 5000 gal). Fees at disposal sites ranged from \$25 to \$50 for each drum (\$0.60 to \$1.20/gal based on a 42-gal drum).

If disposal costs were estimated at less than \$15,000/yr for sludges, the EPA recommended direct disposal of dilute sludges. Under the 1984 HSWA, however, hazardous wastes with a free liquid content may no longer be disposed of in a landfill without further treatment. Some further drying, therefore, is required of the dilute sludges, regardless of the disposal costs.

4. G.C. Cushnie, Jr., *Navy Electroplating Pollution Control: Technology Assessment Manual*, CR 84.019 (CENTEC Corporation, February 1984), pp 55-79.

This report contains installed investment and annual costs (in 1981 dollars) for filter presses, precoated rotary vacuum filter presses, basket centrifuges, and pressure belt filters for varying feed sludge volumes (50 to 300 gal/hr). Recessed plate and plate and frame filter presses (both being a series of parallel plates compressed by a hydraulic ram), offered both the lowest installed investment and the lowest annual operating costs at all volumes.

5. G.C. Cushnie, Jr., E.D. Handel, and C.G. Roberts, *An Investigation of Technologies for Hazardous Sludge Reduction at AFLC Industrial Waste Treatment Plants. Volume 1: Sodium Borohydride Treatment and Sludge Handling Technologies*, ESL-TR-83-42 (CENTEC Corporation, December 1983).

The capital and operating costs, with estimated annual savings for treating sludges by heat are listed in 1982 prices. The same information is given for sludge washing, sludge aging, solidification, and sodium borohydride precipitation. The report includes a summary of installed costs, operating costs, and annual savings for heat treatment, sludge washing, sludge aging, solidification, and sodium borohydride precipitation.

6. G.C. Cushnie, Jr., P. Crampton, and C.G. Roberts, *An Investigation of Technologies for Hazardous Sludge Reduction at AFLC Industrial Waste Treatment Plants. Volume 2: Literature Review of Available Technologies for Treating Heavy Metal Wastewaters*, ESL-TR-83-42 (CENTEC Corporation, December 1983).

This report discusses total investment and annual operating costs for four sludge dewatering methods: (1) filter presses, (2) precoated rotary vacuum filter, (3) basket centrifuge, and (4) pressure belt filter by varying feed sludge volumes. Sludge disposal costs (in 1981 dollars) for status quo and the four dewatering alternatives, are listed.

7. J.A. Robinson, E. Martinez, and A. Tatyrek, *Chemical Fixation of Lead-Contaminated Sludge: Pilot Scale Study,* ARAED-CR-86001 (U.S. Army Armament Research and Development Center, March 1986).

A pilot scale study was undertaken after laboratory analysis suggested that chemical fixation of lead-contaminated sludges produced at the Lone Star Army Ammunition Plant would result in a sludge that was no longer hazardous. Based on the construction of the pilot plant, cost estimates for facilities, chemicals, and operating costs are obtained (in 1985 dollars) for processing 400 gallons of sludge per day (2000 gallons of sludge per week).

8. M.R. Bradbury and D. Thompson, *Electroplating Sludge Treatment Technology Development: Final Summary Report,* AMXTH-TE-CR-86080 (U.S. Army Toxic and Hazardous Materials Agency, February 1986), pp 50-60.

Equipment installation costs, annual operating costs, and disposal costs (in 1985 dollars) are presented for varying feed sludge volumes for three dewatering options: (1) filter presses, (2) precoated rotary vacuum filters, and (3) pressure belt filter systems. Capital and operating costs are also presented for solidification of sludges, generally resulting in costs that are higher than those experienced in dewatering. The higher costs are expected because the solidification processes require dewatering to remove excess liquid before solidification. Since the resulting solidified materials have been shown to be nonhazardous (reference 6 above), there may be potential savings to offset these higher costs.

Used Petroleum and Lubricating Oils

1. *Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities. Phase 2 Report: Evaluation of 18 Case Studies* (CH2M Hill and Peer Consultants, Inc., July 1985), pp 5-10 and 5-17.

Hazardous waste solvents and oil generated at two central vehicle wash facilities constructed on Fort Polk in Leesville, LA, in 1982 generated recyclable oil and solvents that were sold through the Defense Property Disposal Office (DPDO) at $0.39/gal (approximately $16.38 for a 42-gal drum). At Fort Lewis in Tacoma, WA, recyclable oil was sold for $0.30/gal (approximately $12.60 for a 42-gal drum).

2. *Least-Cost DOD Hazardous Waste Management Strategies/Draft Report* (ICF Consulting Associates, Inc., 15 June 1987), pp 5-3 through 5-17.

Equipment costs for an oil filtration system (Advanced Filtration and Separation, Inc.) were estimated to be $20,000 (in 1987 prices) for a 50-gal/h capacity unit. The system is assumed to operate 260 days/yr, 8 h/day with 30 percent downtime. The estimated total processing capability, therefore, is 72,800 gallons per year. Total investment costs including installation, utility hookups, startup expenses, freight, and allowances for contingencies were estimated to be $41,000.

Operating and maintenance costs for the same system, assuming an economic life of 20 years, a closure cost of $7000, labor rates of $20/h for managers and $15/h for laborers, laboratory analysis costs of 10 percent of direct labor costs, $0.05 per kilowatt hour electric costs, and a credit of $0.35/gal for recovered oil were assumed to be $21,000, of which annual labor costs accounted for $16,000 or 76 percent of the total O&M costs. Total savings from the system's installation were estimated to be $20,000.

For cleaning and burning the waste oil in industrial boilers for recovery of the oil's energy value, ICF estimated that the costs of major equipment would be $40,000. The total capital cost was estimated at $109,000. Part of the total capital costs included the costs for obtaining a permit for burning the used oil. Total O&M costs of $50,000 were estimated, of which the costs for labor comprised $36,000 or 72 percent.

For the circumstances examined, ICF found that the lowest operating cost to DOD facilities resulted not from onsite filtration and cleaning of oils, but from large-scale regional facilities designed to accomplish the same tasks.

3. Personal Communication with Sales Manager, Defense Reutilization and Marketing Office [DRMO], Anniston Army Depot, 17 November 1987.

Used oil and solvents, not filtered or otherwise cleaned, and disposed of in 55-gal drums are sold under a 1-year term contract for $7.00 each (approximately $0.17/gal credit assuming a 42-gal capacity). Prices may vary by as much as 50 percent.

4. V.S. Kimball, *Waste Oil Recovery and Disposal, Pollution Technology Review No. 20* (Noyes Data Corporation, 1975), p 210.

Annual maintenance costs for waste oil burned in an industrial burner were estimated to be 7 percent of the capital equipment cost. The admittedly high figure (representative of that normally found for corrosive processes) was used because waste oil combustion was a relatively new technology. At today's level of sophistication, an amount of 2 to 5 percent is more appropriate.

5. Auburn Waste Oil Laboratory, *Demetallation of Waste Oils* (EPA, 1987).

40 CFR Part 266 defines used oil as "any oil that has been refined from crude oil, used, and as a result of such use, is contaminated by physical or chemical impurities." Used oil is not a federally designated hazardous waste but is classified as a hazardous waste in some states. Waste oil, on the other hand, refers to a broader category, encompassing four classes of oils: (1) EPA specification-grade used oil, (2) EPA nonspecification grade used oil, (3) hazardous waste fuel oil, and (4) hazardous wastes.

Waste oil may be: (1) blended to burn in a furnace or boiler (not an option for hazardous waste fuel oil), (2) recycled for energy recovery (either specification or off-specification used oils may be burned in industrial furnaces or boilers; specification used oils may also be burned in nonindustrial boilers; hazardous waste fuel may be burned in an industrial boiler or industrial furnaces where recovery of materials or energy is accomplished), (3) re-refined for use as a lubricating oil, (4) treated to separate hazardous wastes into hazardous and nonhazardous components, (5) disposed of by incineration or landfill, and (6) exchanged with an industrial facility that uses waste oil as a raw material.

For generators of specification and off-specification used oil and hazardous waste fuel oil, recycling as a fuel supplement is currently the only acceptable reutilization option. Re-refining technology is currently prohibitively expensive with extremely small economic returns. Waste oil classified as hazardous waste must be disposed of in an EPA-approved disposal facility.

6. L.C. Chicoine, G.L. Gerdes, and B.A. Donahue, *Reuse of Waste Oil at Army Installations*, Technical Report N-135/ADA123097 (USACERL, September 1982).

Three possible technologies for reusing waste oil were examined: (1) commercial re-refining operations, (2) recycling of used oil as a supplement to boiler fuel, and (3) recycling used oil through a closed-loop arrangement whereby the used oil is processed by a re-refiner and returned to the installation.

In this study, the closed-loop arrangement was proposed as an economically feasible alternative for the reuse of oil. The absence of major re-refiners and the plummeting price of oil since 1982 are likely to make this option much less attractive for current use.

7. *Used Oil/Solvent Recycling Guide*, Draft (Department of the Navy, Naval Facilities Engineering Command, July 1983).

This guide contains steps/procedures to consider in formulating an economic analysis of used oil recycling/segregation procedures (pp 3-9 to 3-15).

Batteries and Battery Acids

After an exhaustive search, no publications were found that discussed equipment and technologies appropriate to recycling/reusing, or otherwise minimizing the amount of hazardous wastes generated from used and discarded batteries. Publications for handling the disposition of batteries for recycle or sale are available.[101]

Other Waste Streams/Technologies

1. Acurex Corporation, *Capital and O and M Cost Relationships for Hazardous Waste Incineration. Addendum No. 1 - Ionizing Wet Scrubber Costs*, EPA/600/2-85/004 (Environmental Protection Agency [EPA] Hazardous Waste Engineering Research Laboratory, January 1985), pp 1-10.

This report provides a basis for calculating the (1) capital costs, including waste storage and handling equipment, pollution controls, (2) installation costs, and (3) indirect costs for design, and construction and annual operating costs such as utilities, chemicals, labor, and maintenance for an ionizing wet scrubber (example design of a venturi scrubber/packed bed absorber for controlling particulate HCl emissions), the system of choice for the vast majority of hazardous waste incineration facilities. The parametric relationships developed here allow capital and operating costs for incineration facilities "to be estimated as a function of waste characteristics and quantities, facility size or capacity, generic incinerator system design, energy recovery and utilization, air pollution control requirements, facility operating schedule, and facility location in the United States."

2. R. McCormick and L. Weitzman, *Preliminary Assessment of Costs and Credits for Hazardous Waste Co-Firing in Industrial Boilers*, EPA/600/2-85/013 (EPA Hazardous Waste Engineering Research Laboratory, February 1985), pp 7-44.

A more complete analysis than the addendum cited above, this report provides parametric cost estimating methods for equipment, incremental O&M costs, and fuel savings for waste disposal credits and hypothetical cost/credit calculations for two sample scenarios.

3. *Least-Cost DOD Hazardous Waste Management Strategies* (ICF Consulting Associates, Inc., 15 June 1987), pp 6-1 through 6-20 and 7-8 through 7-19.

Costs for expected cleanups due to spills, legal claims, and total liability costs were assessed for five waste management technologies: (1) commercial landfills, (2) commercial deep-well injection, (3) onsite and regional tank storage, (4) drum storage, and (5) hazardous waste transportation (spills due to accidents). For the 15 waste categories considered, liability costs were estimated to comprise between 1 and 5 percent of all DOD waste management costs.

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[101] *Battery Disposition/Disposal Handbook* (U.S. Army Communications-Electronics Command, November 1986).

4. R.J. McCormick, et al., *Costs for Hazardous Waste Incineration: Capital, Operation and Maintenance, Retrofit, Pollution Technology Review No. 123* (Noyes Publications, 1985), p 207.

Indirect costs associated with retrofit of hazardous waste incineration equipment was estimated to be: (1) 10 percent of direct capital costs for engineering, (2) 10 percent of direct capital costs for construction field expenses, (3) 8 percent of direct capital costs for construction fees, and (4) 2 percent of direct capital costs for startup.

9 THE ECONOMIC MODEL FOR EVALUATING HW MINIMIZATION ALTERNATIVES

Overview

The hazardous waste minimization techniques presented for the six waste streams have been incorporated into a computer model for performing an engineering economic analysis. Written in C language for an IBM compatible PC, the CEAMHW (USACERL Economic Analysis for Minimizing Hazardous Waste) model is a tool that installation managers can use to assess the life-cycle costs of implementing various minimization alternatives. Because the model resides on a personal computer, careful consideration has been given to the organization and format of the questions the user is prompted to answer. A conceptual decision tree that underlies the logic used in the computer model is shown in Figure 3.

Assumptions Behind the Model

In designing the general form of the model for economic analysis, the following assumptions were made and incorporated into the model's parameters:

1. Treatment, storage, and recycling technologies are assumed to be possible at every installation. The costs for each installation, however, will vary by the size of the technology used, which depends on the quantity of hazardous waste generated.

2. When source reduction technologies are suggested as a minimization alternative, it is assumed that these technologies will only be used at an installation generating a waste stream where source reduction is a feasible option for implementation.

3. Onsite storage costs of hazardous wastes include actual construction costs as well as the costs of complying with RCRA regulations. For example, RCRA Part B permits are required for storage facilities designed to store hazardous wastes for more than 90 days.

4. All transportation services for moving hazardous wastes off the installation are assumed to be privately owned. All transportation costs for moving hazardous wastes are assumed to include costs for offsite disposal (whether the wastes are being recycled, landfilled, or incinerated).

5. Onsite landfills for disposal of HW on Army installations are not considered in the development of this model because DOD least-cost hazardous waste management strategy stipulates that landfilled wastes should be sent to commercial facilities rather than to landfills on DOD installations.[102]

6. Further, it is assumed that all technological alternatives considered in the model can be installed on an Army base. This assumes that space for the equipment exists, that no environmental constraints prohibit the installation of the technology, and that installation personnel are both capable and willing to be trained to use the technology.

7. Army liability for hazardous waste management may occur either: (1) directly as a result of cleanup costs incurred by the release of HW into the environment, or (2) indirectly, through increased prices charged by commercial landfills or incineration facilities in anticipation of future legal liabilities.

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[102] *Least-Cost DOD Hazardous Waste Management Strategies*, Draft Report (ICF Consulting Associates, Inc., 15 June 1987).

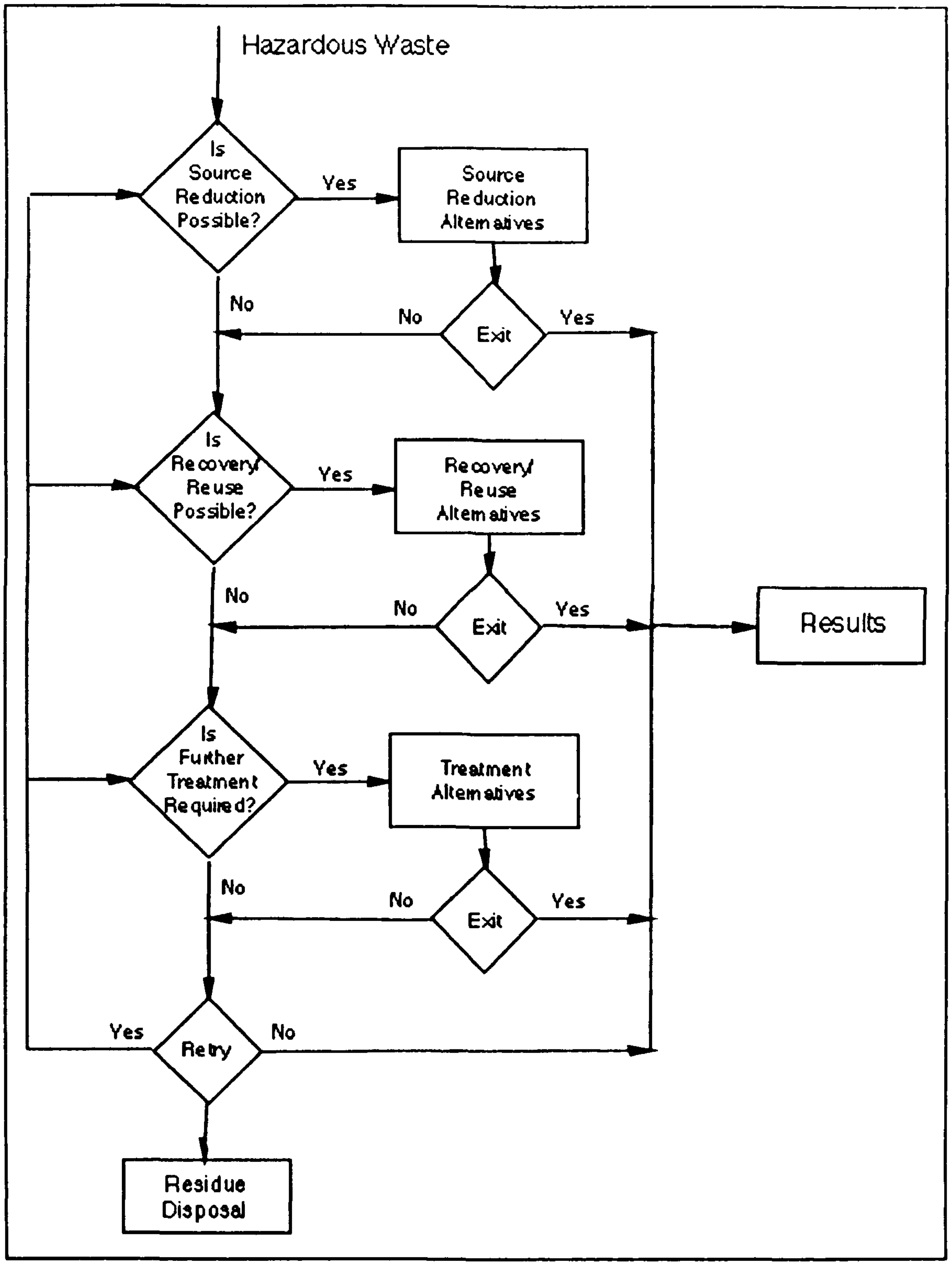

Figure 3. The conceptual decision tree underlying the CEAMHW model.

The CEAMHW model allows the user access to specific submodels for calculating the life cycle costs of identified minimization alternatives for each of the six waste streams, along with a generalized form of a life cycle cost model applicable to any minimization alternative or waste stream—whether it be hazardous or nonhazardous (Figure 4). Once the user chooses a waste type, a File Menu (Figure 5) appears. This menu lists all previous files of this same waste type (e.g., all solvent files or all general model files) and contains a selection for entering new problem information. A separate screen allows entering and altering default values.

For the minimization alternatives identified in the model, default values for fixed cost parameters such as equipment costs (equipment, property acquisition, site preparation, etc.), research and development costs, and expected equipment replacement (all in 1988 dollars) are provided based on production volume. The user may elect to either accept these default values or input different values. Expenses for installation, logistics and procurement, and startup are estimated as percentages of appropriate fixed costs (e.g., logistics and procurement is estimated as 7 percent of installed equipment costs).[103] Again, the user may choose to either accept the default values provided by the model or enter other estimates.

Default values for recurring costs such as labor, maintenance and repair, utilities, sampling and testing, disposal, etc., are also provided by the model. Again, the user may choose to accept the default values provided (e.g., annual maintenance and repair is estimated at 5 percent of equipment costs), or enter other values. Default values may be changed either globally or within a particular submodel (i.e., the default value of $11/h for laborers may be changed for all alternatives and all waste streams, or only for a particular minimization alternative such as onsite solvent distillation).

If the user selects a new problem, the Minimization Options screen (Figure 6) appears. Within the Minimization Options screen is the Problem Information screen, where the user is required to input information on the amount of waste produced, whether the waste is hazardous or nonhazardous, and any other information that may be necessary to estimate costs and is applicable to all minimization alternatives for this particular problem.

Having entered the problem information, the user can select between the three broad categories of minimization efforts previously defined–source reduction, recovery/reuse, and treatment. Selecting source reduction, for example, provides a screen that further defines the minimization alternatives according to whether they are product substitution or source control strategies. Selecting either of these alternatives would then take the user to the specific alternatives associated with that particular waste stream. By further selecting the source reduction and product substitution alternatives, a screen would be brought up identifying the substitution strategies "costed out" by the model (i.e., those alternatives where operating parameters, cost calculations, and default values are contained within the model). For example, selecting product substitution for trichloroethylene would present the following alternatives to the user: (1) substitution of 1,1,1-trichloroethane for trichloroethylene and (2) substitution of aqueous cleaning solvents. An "other" alternative is also available for the user to enter cost parameters for options other than those considered directly by the model.

Once the user selects a specific minimization alternative, the system asks for more information which is used in the specific calculations nested within that submodel. For substitution of aqueous cleaners for trichloroethylene, for example, one of the questions asked is the number of degreasing tanks. This value is subsequently used to calculate either costs or savings in such categories as disposal costs, potential liability costs, and replacement materials/raw materials.

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[103] *Economic Analysis Handbook.*

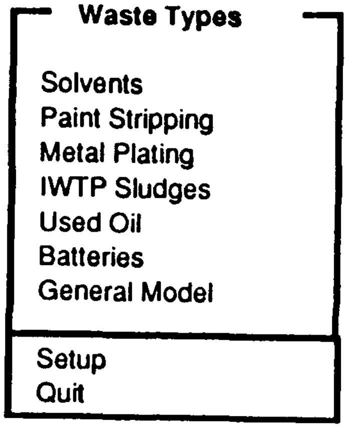

Figure 4. Waste types screen.

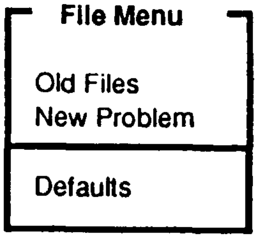

Figure 5. File menu screen.

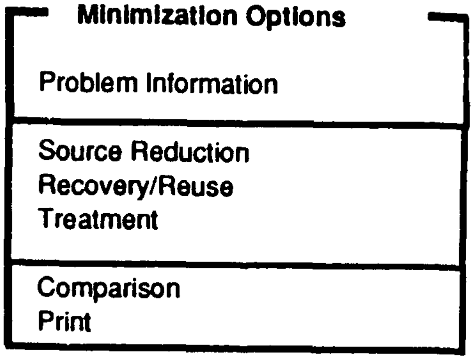

Figure 6. Minimization options screen.

The general model, or the seventh "waste type," does not contain default values for equipment. Some defaults, however, such as the values for logistics and procurement, installation, etc., are active and will calculate values for the appropriate cost categories (e.g., installation costs are calculated as a percentage of the total equipment costs the user enters). Figure 7 provides an example of what the user might see when selecting the various options to move from screen to screen.

Once the user has entered the appropriate cost information, the model will calculate net present values of investment over any time period using midyear or "continuous" discounting equations that approximate an average of end-of-year discounting factors commonly presented in many economic textbooks. End-of-year techniques assume that cash flows occur precisely at the ends of years. Continuous

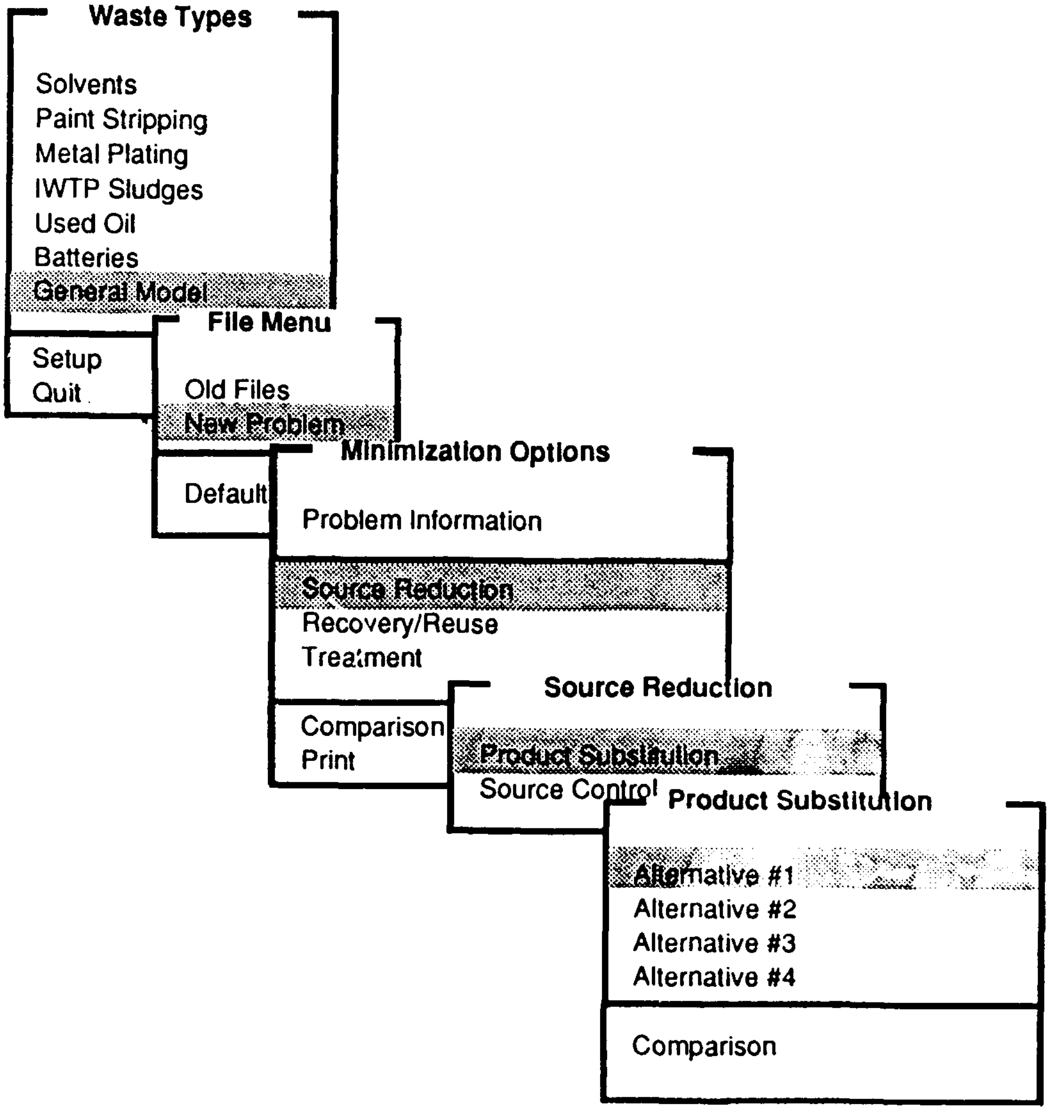

Figure 7. Various CEAMHW model screens.

discounting equations are more appropriate as they more closely resemble the steady disbursement of funds to cover project costs (e.g., salaries are typically paid either weekly or monthly).[104]

In comparing minimization alternatives, the model allows the user to calculate a SIR, which is the amount of future costs that will be saved divided by the amount of investment required to undertake the alternative, and/or the DPP, which is the time required for a project to accumulate enough savings to offset its investment costs. If the economic lives of the alternatives being compared are unequal, a UAC is calculated (UAC is determined by dividing the total discounted project cost by the sum of the discount factors for the years that the alternative yields benefits).

The Cost Model

The general model contains a generalized form of the life cycle cost model on which all of the other specific submodels are based. The general model prompts the user to enter information in broad cost and saving categories (within the specific submodels, default cost information [e.g., equipment prices] will be provided for the particular alternative). Investment and operating costs to be entered in the general model include those categories listed in Figure 8. Operating costs are subsequently entered and totaled on a second screen (labor costs [Figure 9] are calculated from data entered on a screen separate from other operating costs [Figure 10] and the total labor costs then appear again in the operating costs screen).

Each of the six alternative waste streams/waste types, are built around the general form of the model. Savings associated with each alternative are captured within the differential costs attributed to each alternative.

Capabilities and Limitations of the Model

It is important to note exactly what the model is as well as what it is not so that both the capabilities and the limitations of the model can be understood. CEAMHW is a deterministic model, dealing largely with certain, quantifiable cash flows (e.g., capital investment costs, O&M costs, etc.). The flexibility of the model, and the ease in which the default values and cost information can be changed, however, allow the user to develop multiple scenarios or assumptions that can be compared easily. This process is commonly referred to as sensitivity analysis.

CEAMHW is not a stochastic model that allows the user to select a range for a category upon which probability distributions for cash flows are calculated. The defaults contained within the model, while general, allow the unsophisticated user to perform a comprehensive economic evaluation of various hazardous waste minimization alternatives. By tailoring these defaults to the actual costs experienced at an installation, the model allows the sophisticated user to fully explore the potential costs/savings resulting from implementing a minimization alternative. Because of this sophistication, it was felt that a stochastic model, which would allow the user the opportunity to express confidence about the value of a parameter by specifying an uncertainty range around the best estimate, was unnecessary and offered significant potential for abuse of the model. For users desiring such a stochastic approach, however, a financial analysis model developed by ICF Consulting Associates, Inc. and based on Lotus 1-2-3, offers generators of hazardous waste the opportunity to specify confidence ranges of "best estimates."[105]

The flexibility afforded by the CEAMHW model is readily apparent to the first-time user. The extensive defaults file for each waste stream allows the user to enter the model and with minimal input,

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[104] Economic Analysis.

[105] J.G. Karam, C. St. Cin, and J. Tilly, "Economic Evaluation of Waste Minimization Options," *Environmental Progress*, Vol 7, No. 3 (1988), pp 192-197.

Equipment:			
Major equipment	$0.00		
Storage tanks		$0.00	
Feed lines		$0.00	
HW handling equipment	$0.00		
Freight/shipping	$0.00		
Subtotal, equipment costs			$0.00
Property acquisition costs			$0.00
Site preparation and installation (including labor and materials):			$0.00
Subtotal, installed equipment costs:			$0.00
Other Investment Costs ($/yr):			
Start-up expenses	$0.00		
One-time personnel		$0.00	
Permit fees		$0.00	
Logistics & procurement	$0.00		
Contingencies		$0.00	
Value of existing assets employed:		$0.00	
Value of existing assets replaced:	$(0.00)		
Subtotal, other investment costs			$0.00
Total, nonrecurring costs			$0.00

Figure 8. Screen of major nonrecurring costs.

perform an economic analysis on any number of waste minimization alternatives contained within the model. By adjusting the default values to reflect specific operating conditions at an installation (e.g., labor rates, disposal costs for solvents, etc.) the user can achieve an accurate picture of the total costs and benefits of the minimization options.

Extensively documented, context sensitive helps are available to the user simply by pressing the appropriate function key. Not only do the help screens provide the user with information on how default values were obtained, what default values are used in the calculations, and what the calculations contained within the program are actually accomplishing, but the helps also contain equipment prices for various size models of minimization equipment, producer addresses and telephone numbers (where available), and documentation of any assumptions made in creating the various equations comprising the submodels.

Although designed primarily for performing economic analyses of hazardous waste minimization options, the CEAMHW model is not limited to hazardous wastes. Designed to incorporate all Army regulations for performing an economic analysis, the "general model" submodel can be used to evaluate the economics of any equipment purchases or product substitution strategy.

The model has been approved by the Army Environmental Office for the economic analysis that must accompany requests for DERA funds to purchase equipment for hazardous waste minimization projects. With this approval, it is likely to be implemented at every Army installation as a standard

Annually Recurring Personnel Costs ($/yr)

Laborers:	
Labor Rate	$_____/hr
# of personnel per shift	_______
Labor time per individual	_______ man hr/yr
# of shifts per day	_______ shifts per day
Management personnel:	
Labor Rate ($/hr)	$_____hr
# of personnel per shift	_______
Labor time per individual	_______ man-hr/yr
# of shifts per day	_______ shifts per day
Subtotal, direct labor costs	$0.00

Figure 9. Annually recurring (O&M) costs.

methodology for determining techniques and assessing costs of hazardous waste minimization efforts. Depending on the availability of funding, efforts will be made to expand the model to address minimization aspects for many of the other hazardous waste streams listed in Tables 2 and 3. Upon continued testing and data gathering, the potential exists to develop a knowledge-based system that can both teach and "learn" from the users.

Construction costs for tanks and other storage facilities and processing equipment costs were obtained from engineers, manufacturer estimates, and/or recently published studies and are considered the best available cost estimates. Likewise, costs for chemicals, labor, space, etc., were obtained from information gathered from installation visits, wage board pay scales, the Defense Logistics Agency, and private contractor estimates. In every model where operating costs are estimated, the supplied costs are averages; each installation must use local salaries, climatic conditions, available transportation facilities, and other local operating parameters in determining the actual cost for a given unit's operation. These average costs, presented as default values in the formulas and formats for estimating operating costs, should be examined and altered to reflect local operating conditions before the user proceeds to examine the various minimization alternatives contained within the program.

The models contained within this program for estimating the investment and operating costs of various hazardous waste minimization alternatives should provide a useful guideline for any Army individual concerned with hazardous waste minimization and allow for an economic assessment and comparison of current and proposed operating parameters. No attempt is made in this model to either direct or make decisions for installation personnel. Rather, the facts and default values provided in the submodels are presented as realistically as possible, with the final decision for hazardous waste minimization being the sole responsibility of managers and installation personnel. Costs and savings are ultimately assigned to each of the hazardous waste minimization options to allow for a comparison that could lead to the most economically practical management practices.

Raw materials/replacement material	$0.00
Maintenance & repair	0.00
Liability	0.00
Disposal	0.00
Other materials and supplies	0.00
Sampling/Testing	0.00
Transportation & warehouse/storage	0.00
Logistics & procurements	0.00
Program administration	0.00
Utilities	
Natural gas	0.00
Water	0.00
Steam	0.00
Compressed air	0.00
Subtotal, utilities	$0.00
Wastewater treatment costs/savings	$0.00
Sewer fees	0.00
Other O&M costs	0.00
Total Operation & Maintenance costs	$0.00

Figure 10. Recurring (O&M) costs.

10 SUMMARY

The USACERL Economic Analysis for Minimizing Hazardous Waste (CEAMWH) computer model developed during this research can help installation Environmental Managers evaluate the life cycle costs for various hazardous waste minimization technologies. The model (as discussed in Chapter 9) was developed after identifying the waste streams that account for the majority of HW generated at Army installations, identifying those technologies and process changes that are technologically and economically feasible for minimizing hazardous waste production, and reviewing current economic analysis and procurement documentation.

The CEAMHW model contains seven submodels: one for each of the six major waste streams and a general life cycle cost model applicable to any minimization alternative or waste stream. The user can accept default values in the six submodels or enter other estimates for equipment, research and development, and replacement costs. The life cycle cost submodel does not contain default values for equipment, but other values (e.g., logistics and procurement) are active and will calculate values for the appropriate cost categories, yielding the net present value of the investment over any time period.

Although designed primarily for performing economic analysis of hazardous waste minimization alternatives, the model is not limited to hazardous waste. Because it incorporates all Army regulations for performing economic analyses, the life cycle submodel can be used to evaluate the economics of any equipment purchase or product substitution strategy.

METRIC CONVERSION TABLE

1 gal = 3.78L
1 sq ft = 0.093m^2
1 ton = 1016 kg
1 lb = 0.453 kg
1 ft = 0.305m
1 oz = 28.35g

CITED REFERENCES

Acurex Corporation, *Capital and O and M Cost Relationships for Hazardous Waste Incineration. Addendum No. 1 - Ionizing Wet Scrubber Costs*, EPA/600/2-85/004 (Environmental Protection Agency [EPA] Hazardous Waste Engineering Research Laboratory, January 1985).

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Army Materiel Command Solvent Study: Trip Report-Red River Army Depot, Texarkana, Texas (HMTC, July 1986).

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APPENDIX A: LIFE CYCLE COST ANALYSIS (LCCA) COMPONENTS AND PRESENT VALUE FORMULAS FOR CONTINUOUS DISCOUNTING

Types of Costs in LCCA

In LCCA for the military, costs are divided into five categories: development, production, military construction, fielding, and sustainment.[106] Generally, however, life cycle costs may be classified according to the nature of the costs themselves, i.e., whether they occur only once or throughout the project's economic life. For simplification, therefore, all costs may be classified as either nonrecurring or recurring.

Nonrecurring Costs

Nonrecurring costs are those incurred on a one-time only basis. Generally, these costs include all costs associated with the acquisition of real property, land, and equipment, and the associated startup costs. It is important to note that while these costs occur only once, the costs themselves may be spread out over more than 1 year (e.g., research and development [R&D] costs may occur for a number of years before the technology is implemented). Furthermore, nonrecurring costs need not be incurred in only the initial years of a project's economic life. Some nonrecurring costs, such as the replacement or repair of a major system component, may occur many years after the project starts. The terminal value of an item is an example of a nonrecurring cost that would occur at the end of the alternative's economic life. Categories of typical nonrecurring costs considered in this analysis include:

1. Research and development costs.
2. Property acquisition costs.
3. Site preparation (including both construction costs for site preparation of equipment used in minimization and construction costs for warehousing/storage of hazardous materials produced).
4. Equipment costs.
5. Freight/shipping costs.
6. Equipment installation costs.
7. One-time personnel costs (initial training, etc.).
8. Major equipment/system replacement costs (estimated costs for repair per failure). This figure is equal to the [labor rate (dollars per hour) times the man-hours required for repair, times the frequency of repair (mean time between failure of system/economic life), plus the cost of materials] times the number of sites.
9. Terminal value.

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[106] *Instructions for Reformatting the BCE/ICE*, DCA-P-92(R) (15 May 1984).

Present Value (PV) Formulas for Continuous Discounting of Nonrecurring Costs

The present value of a single amount received not at year end, but uniformly manner throughout the year is equal to:

$$PV = FV * (e^{r} - 1) / re^{nr} \qquad [\text{Eq A1}]$$

where PV = present value of a future cash flow,
FV = future cash flow (future value of a sum),
n = year cash flow occurs (i.e., number of years from base year of investment). Note that for nonrecurring costs such as R&D costs that might occur over many years, the above equation would be summed for each value of n,
e = 2.718281828459..., the base of the natural logarithm,
R = the effective annual discount rate (0.1 mandated by OMB), and
r = ln(1+R) = ln(1.1) = 0.09531018....

Consequently, with the discount rate equal to 10 percent, Equation A1 becomes:

$$PV = FV * 0.1 / r(1.1)n \qquad [\text{Eq A2}]$$

Equation A2, which represents the present value of a single payment/cost receivable or payable in n years, should be used in all calculations involving one-time, nonescalating, nonrecurring costs.

Note that the discount factor presented in Equation A1 differs from the conventional end-of-year discount factor of 1/(1+R)n for calculating the present worth of a future cash flow. The end-of-year discount factor is commonly presented as the "typical" method for calculating present values in most financial and economic analysis texts. Current DLA and AMC guidelines, however, use midyear or continuous factors [Equations A1 and A2] that are derived from standard present value formulas and approximate an average of the end-of-year factors. Chapter 5 presents a justification for using the midyear or continuous factors.

Note that the base year of any alternative being considered is the first year in which initial investments actually occur or initial costs are incurred. The minimum value that n can take, therefore, is n=1. Should n=0, Equation A1 would return a value greater than 1.000. This is because the midyear discount factors calculated by Equation A1 would assume that an investment made in year 0, would actually occur at midyear in the previous year (6 months before the initial investment). Obviously, such an occurrence cannot happen. An investment made (or cost incurred) in the base year, occurs between time 0 and the end of year 1. When n=1, Equation A2 returns a discount factor of approximately 0.954. In other words, if $1 is invested now, its value at midyear (6 months from now) is $1 * .954 = 95¢.

PV Formula for Differentially Escalating Nonrecurring Costs

If it is anticipated that some one-time costs that occur in the future will escalate at a rate higher than the general inflation rate and at a constant level (e.g., the replacement costs for a major system/equipment component are expected to increase at a rate 2 percent higher than the rate of inflation), the formula to be used is:

$$PV = FV * \frac{e^{(r-d)} - 1}{(r-d)\,(e^{n(r-d)})} \qquad [\text{Eq A3}]$$

where D = the effective annual differential escalation rate (e.g., 2 percent), and

$d = \ln(1+D)$.

Note that where $d = 0$, Equation A3 reduces to the form of Equation A1.

Annually Recurring Costs Considered in LCCA for HW Minimization

Recurring costs are those that occur every year. Generally, these costs include all costs associated with the actual operation and maintenance of a project and are sometimes referred to as operations and maintenance (O&M) costs. The following list contains the main categories of recurring costs to be considered in an economic analysis:

1. Labor costs
2. Transportation costs
3. Sampling/Testing costs
4. Maintenance and repair costs
5. Replacement materials cost (virgin solvent, new chemicals, etc.)
6. Changing support costs (differential accounting, supervisory, legal, and local procurement costs associated with the alternative)
7. Liability costs
8. Disposal costs
9. Utility costs.

It is important to note that the LCCA of HW minimization alternatives compares only the differences in costs associated with each alternative. Care must be taken to identify and include only those costs associated with each alternative that change as a consequence of the alternative's introduction. For example, the transportation and storage costs associated with removing a HW may be the same when comparing onpost recycling of used solvents with offpost recycling. In both instances, the HW must be transported and stored onsite before being transported offsite. If one of the alternatives being considered is to use the services of a full-service contractor, however, transportation and storage costs usually are assumed by the contractor and included in the contract. In this instance, it would be vitally important to consider the costs of transportation and storage for the other alternatives as they are now being compared to an alternative where transportation and storage costs are negligible or nonexistent.

PV Formulas for Continuous Discounting of Annually Recurring Costs

For those O&M costs with no differential escalation (generally items 1 through 6 above, and possibly items 7 and 8), the present value of O&M, disposal, and liability costs with no differential escalation will be:

$$PV = F * \frac{e^{(yrs * r)} - 1}{re^{(yrs * r)}} - \frac{e^{nr} - 1}{re^{nr}} \qquad \text{[Eq A4]}$$

where yrs = the estimated project life.

In Equation A4, $(e^{(yrs * r)} - 1)/re^{(yrs * r)}$, is known as the cumulative uniform series factor and is applicable when a cash flow accrues in the same amount each year. This factor may be found in any discount factor table. The second part of the equation, $e^{nr}-1/re^{nr}$, may not be familiar. It is included in this model to capture those somewhat unusual incidents where recurring costs may not begin in the year immediately following the base year of analysis. If investment occurs in year 1 and recurring costs begin the subsequent year (the usual case), this part of the equation would reduce to 0.

With the discount rate = 10 percent, Equation A4 becomes:

$$PV = F * \frac{(1.1)^{yrs} - 1}{r(1.1)^{yrs}} - \frac{(1.1)^{n} - 1}{r(1.1)^{n}} \qquad [Eq\ A5]$$

To illustrate a situation where recurring costs do not occur in the year immediately following the base year, assume an example case where R&D costs precede the actual beginning operation of a project for 2 years. Assume that the R&D costs are $100,000 a year for these first 2 years, and operating costs begin in year 3 and are $20,000 a year for 5 years of operation. As before, the discount rate equals 10 percent. In this example, the economic life of the project is 5 years (the number of years during which benefits accrue). R&D costs occur over a 2-year lead time, so the total estimated project life is 7 years (project life = economic life + lead time). Using Equation A2 to calculate the present value of R&D costs yields:

$$\begin{aligned} PV \text{ of } R\&D &= \frac{100{,}000 * 0.1}{.0953(1.1)^1} + \frac{100{,}000 * 0.1}{.0953(1.1)^2} \\ &= 95{,}383 + 86{,}711 \\ &= \$182{,}094 \end{aligned}$$

To calculate the present value of the operating costs for the subsequent 5 years, use Equation A5:

$$\begin{aligned} PV \text{ of } O\&M &= \frac{20{,}0000 * (1.1)^7 - 1}{.0953(1.1)^7} - \frac{(1.1)^{2-1}}{.0953(1.1)^2} \\ &= 20{,}0000 * (.9487/0.1857 \quad - 0.21/0.1153) \\ &= 20{,}0000 * (5.108 - 1.821) \\ &= \$\ 65{,}740 \end{aligned}$$

The total present value of the project is $182,094 + 65,740 = $247,834.

PV Formulas for Differentially Escalating Recurring Costs

If costs are expected to escalate at a rater higher than the general rate of inflation, they may do so at a constant rate, or they may vary in the amount of the escalation from year to year.

Constant Escalation

If it is anticipated that the recurring costs will escalate at a rate higher than the general inflation rate and at a constant level (e.g., the costs for disposal of HW might be expected to compound at a rate 5 percent higher than the rate of inflation; the increased costs being attributable to the increased burden of legislative compliance), Equation A6 should be used.

$$PV = F * \frac{e^{yrs(r-d)} - 1}{(r-d)\ (e^{yrs(r-d)}} - \frac{e^{n(r-d)} - 1}{(r-d)\ (e^{n(r-d)}} \qquad [Eq\ A6]$$

The model is programmed for a 10 percent discount rate as directed by DOD Instruction 7041.3. This discount rate assumes an inflation rate of approximately 5 percent. Should the annual rate of inflation exceed 5 percent, users may wish to input the difference into the differential inflation rate (D), in Equation A6. For example, if the rate of inflation was expected to continue at a rate of 8 percent annually over the remaining economic life of the project, then D could be adjusted for the difference of 3 percent (8 - 5 = 3). If, on the other hand, the rate of inflation was expected to grow at a rate below 5 percent (e.g., only 4 percent), then D could be adjusted downward (for the example given, D = 4 - 5 = -1).

As a general rule, however, the analyst is cautioned to use the above equation to input differential escalation rates only for cost items where specific differential escalation rates are projected and not try to enter differential escalation rates for the rate of inflation in general. Remember that the 10 percent figure represents historical averages and over an economic lifespan of 20 or more years will probably represent the single best estimate of the rate of inflation and the expected rate of return on the investment. Predictions of inflation are accurate for a very limited time (typically 2 to 3 years or less) using even the most sophisticated of econometric models. Inexperienced analysts would do well to leave the manipulation of differential escalation rates to the experts.

Variable Escalation

In some instances, annually recurring costs may escalate at a rate higher than the general rate of inflation, and they may do so at varying rates over the alternative's economic life. Most notable of the recurring costs that fall into this category are utility costs. The Department of Energy (DOE) has calculated variable energy escalation values (1 = no variable escalation, 1.02 = 2 percent variable escalation, etc.) for regions throughout the United States. This model incorporates the variable energy escalation values into its parameters with the following formula:

$$PV = \sum (F * v) \qquad \text{[Eq A7]}$$

where v = the variably escalating differential rate as supplied by DOE.

Under those circumstances where an annually recurring cost is expected to escalate at one rate for a portion of the economic life, and at another rate for another portion of the alternative's economic life, Equation A6 may be used and the time parameters, yrs and n, would be adjusted accordingly.

APPENDIX B: CENTRALIZED/DECENTRALIZED STILL OPTION

General

At most Army installations, cleaning and degreasing operations using organic solvents are performed in more than one location. Often, similar cleaning operations take place in several buildings at disparate locations around the base. Consequently, it was felt that in comparing minimization alternatives for cleaning and degreasing solvents, consideration of onpost recycling of used solvents required that both centralized and decentralized distillation alternatives be evaluated.

Problem Definition

It was not clear at what point one distillation alternative would be preferred over the other. In fact, it was not even clear which parameters were the most significant in determining which distillation alternative would be preferable under varying circumstances.

It was hypothesized that with few generating points, centralized distillation would be preferable because the costs of collection and redistribution of spent and recycled solvent would be outweighed by the cost savings resulting from operation of a single still. It was further hypothesized that at some point, call it x, the costs of transportation would exceed the cost savings associated with a single still, and that multiple stills at selected sites would be the most cost effective alternative.

The initial problem, therefore, was to determine at what point decentralized distillation would be preferred over centralized distillation (i.e., determine the breakeven point, x). The second problem was, once x was reached, were only two stills called for or were multiple stills, conceivably as many as one still at each generating site, necessary?

Objective Definition

Because the answer to the first problem was not intuitive, it was felt that the best solution was to build a model and conduct an economic analysis to determine the point when decentralized distillation would be favored over centralized distillation.

Alternatives

Centralized Distillation

Centralized distillation assumes that when a given solvent is used at more than one location on an installation, the used solvent will be segregated and stored at the site of production, transported to a centralized site, distilled, and returned to the original generating site for reuse (Figure B1).

One or more large stills are required for this option. Transportation of used solvent must be provided from the collection points to the still and back again once the solvent is recycled. Virgin solvent must also be supplied to each generating site to replace solvent lost during use. Still bottoms are collected at this single still site for disposal or are transported to a central HW storag facility for subsequent offpost disposal.

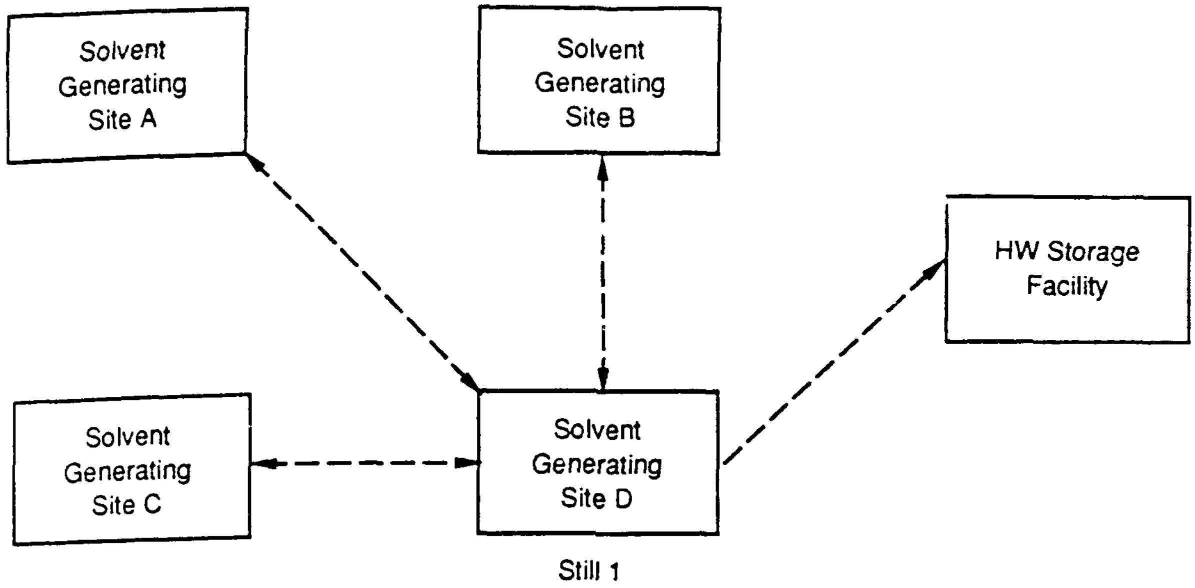

Figure B1. Centralized distillation options.

Decentralized Distillation

Decentralized distillation assumes that at least one still is purchased and installed at each generating site. As used solvent is recovered, it is collected and stored until a sufficient quantity for distillation is reached. The spent solvent is then distilled and immediately redistributed for reuse.

Many smaller stills are required for this option. No transport across the installation is required although, as in the centralized distillation option, it is necessary to deliver virgin solvent to each generating site to replace solvent lost during cleaning and degreasing operations. In the decentralized distillation option, still bottoms from each still would have to be collected, transported, and stored at a central HW storage facility for subsequent offpost disposal (Figure B2).

Assumptions

The following simplifying assumptions were made to construct the model:

1. For generators of less than 150 gal of used solvent per day, stills that recycle solvent in a batch mode (as opposed to continuous recycling where x gallons of solvent are recycled per hour) are the most economical to operate.

2. Batch mode stills typically take 6 to 8 hours for one complete cycle (6 hours for solvents with lower boiling temperatures and 8 hours for solvents with higher boiling temperatures, thus requiring vacuum distillation).

3. There is one shift per working day.

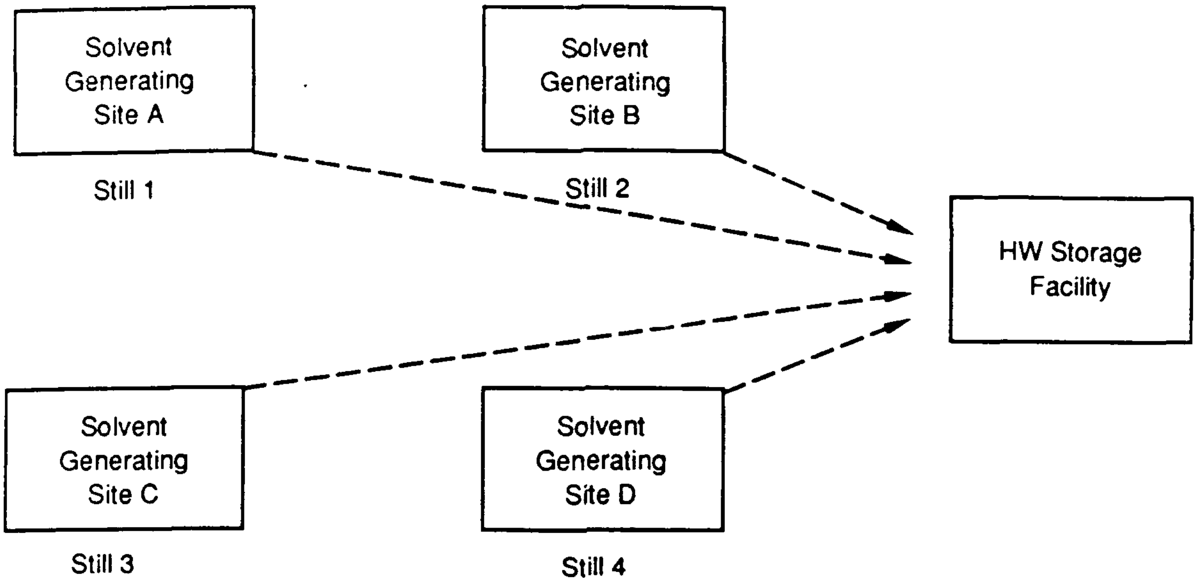

Figure B2. Decentralized distillation option.

4. The most efficient use of a still would occur when the still is operated at a maximum capacity.

5. Maximum still capacity is reached when the number of batches per day equals one.

6. The number of batches per day is equal to the quantity of used solvent to be recycled (gallons/day) divided by the still's capacity (measured in gallons). Mathematically:

$$B = Q - SC \qquad [\text{Eq B1}]$$

where B = number of batches distilled per day,
Q = quantity of used solvent to be distilled (gallons per day), and
SC = still capacity (gallons).

The number of batches distilled per day may be interpreted as a measure of the efficiency of still use. In other words, a still that processes only 0.27 batches per day is operating at only 27 percent of total capacity. Table B1 presents the number of still batches that would be processed each day for stills of 5-, 15-, 55- and 110-gallon capacities.

Table B1 may be interpreted in the following manner. Take as an example an installation producing 5 gal of used solvent per day. The installation operates a single still capable of recycling 55 gal of used solvent per 6- to 8-hour cycle. From Table B1, the number of still batches capable of being processed per day under these conditions would be 0.09. Put another way, the efficiency of use is only 9 percent of the still's total capacity. Optimal use of the still would be to operate only when a full batch is ready to be processed (assumption 4). The reciprocal of the figures in Table B1 will result in a measure of the number of days necessary to accumulate a full batch for a given still capacity. Continuing with the

Table B1

Efficiency of Still Use

Number of Stills	Still Capacity (gallons)	Quantity of Solvent Processed/Day (gallons)								
		5	10	15	20	25	30	40	50	60
1	5	1.0	-	-	-	-	-	-	-	-
2	5	.50	1.0	-	-	-	-	-	-	-
1	15	.33	.67	1.0	-	-	-	-	-	-
2	15	.17	.33	.50	.67	.83	1.0	-	-	-
1	55	.09	.18	.27	.36	.45	.55	.73	.91	-
2	55	.05	.-0	.14	.18	.23	.27	.36	.45	.55
1	110	.05	.09	.14	.18	.23	.27	.36	.45	.55

example, optimal use of the still under the above conditions would be once every 11 days (1/0.09 = 11.11). In other words, when 5 gal of used solvent are produced each day, it will take 11 working days to accumulate 55 gal of solvent for recycling.

7. In comparing solvent distillation alternatives, labor costs are the single greatest recurring cost, accounting for 66 to 90 percent of total annual operating costs.[107] Labor costs include the costs of labor for still operation, transportation of used solvent to the still, and associated handling costs with still bottom disposal.

Furthermore, of the total O&M costs, still bottom disposal costs and costs for the replacement of virgin solvent would be identical for both alternatives. The only other variable O&M cost would be utilities, and utilities are virtually an insignificant expense, typically less than 1 to 7 percent of total annual recurring costs. More importantly, it should be noted that utility costs are roughly equivalent for stills of varying capacities when processing equivalent amounts of solvent. For example, if spent solvent output equals 15 gal/day, a 15-gal capacity still must operate for one complete shift of 6 to 8 hours every day, whereas a 55-gal capacity still would only need to be operated roughly once every 4 days to process the same amount of spent solvent (from Table B1). Although the larger still consumes more electricity and water (manufacturer estimates roughly 2.5 times as much), the fact that it is required to be used less often makes the operation of a single larger still slightly more attractive (i.e., less expensive to operate) than two smaller stills capable of processing the same quantity of used solvent.

Mathematically, labor costs are equal to:

$$LC = LR * HRS * N * WD * B \qquad \text{[Eq B2]}$$

where LC = labor costs,
LR = labor rate ($/hour),
HRS = number of hours required to operate the still for one complete batch,

---

[107] *Hazardous Waste Minimization, Red River Army Depot, Texarkana, Texas, 12-16 January, 1987*, Hazardous Waste Study No. 37-26-1663-87 (U.S. Army Environmental Hygiene Agency [AEHA], 8 April 1987); AEHA Memorandum for the Commander, U.S. Army Materiel Command, subject: Erratum for Hazardous Waste Minimization, Red River Army Depot, Texarkana, Texas, 12-16 January 1987, Hazardous Waste Study No. 37-26-1663-87 (10 June 1987); B.A. Donahue, D.W. Sarver, and E.M. Bellino, *Field Test of Life-Cycle Cost Analysis Method for Solvent Management*, Special Report N-86/21, ADA173479 (USA CERL, September 1986), p 18; AEHA Memorandum for the Commander, U.S. Army Materiel Command, U.S. Army Training and Doctrine Command; U.S. Army Forces Command, subject: Volume and Cost Calculations for Spent Solvent Recycling Alternatives (8 June 1987).

N = number of stills in operation,
WD = number of work days in a year, and
B = still batches distilled per day (from Equation B1).

8. Operator time required per still per shift is 2 hours. This standard of 2 hours is used throughout the calculations incorporated into the model. With 2 smaller stills in operation, and provided that the stills are properly positioned, it is likely that the time involved in the collection of spent solvents and the delivery of recycled solvents would be less than the time required if only a single larger still was used. On the other hand, the time to fill the still and empty the still bottoms would be considerably greater for two stills than a single still. For this reason, the 2-hour time is used throughout the calculations as representative of the average time required for efficient operation.

Cost Determination

From the above assumptions, the costs of equipment and labor for each of the alternatives were calculated. Equipment costs were based on representative GSA schedule prices for solvent distillation units available from the Finish Engineering Company.

Because most bases use Stoddard type solvents in cold cleaning operations, all equipment prices include the cost for a vacuum attachment for high-boiling solvents (320 to 500 °F).

The LS-Jr. V model is capable of distilling 5 gal/6- to 8-hour shift. The LS-15II DV model is cable of processing 15 gal/shift. The LS-55IIDV distills 55 gal/shift (one drum). The LS-15IIDV and LS-55IIDV models come equipped with temperature shutoff and electric shutoff timers. These items have been added to the price of the LS-Jr. V model.

Tables B2 - B4 present the calculations for investment costs and labor costs used in this model.

Cost/Benefit Analysis

The benefits arising from centralized verses decentralized distillation will be the same. The only differences will be in the costs for the equipment and labor involved in the operation of each alternative. (See Tables B5-B7.)

Table B2

Equipment and Installation Costs for 5-, 15-, and 55-gal Stills

	L-S-Jr.V	LS-15IIDV	LS-55IIDV
Equipment			
Unit	$4,338.00	$13,361.00	$24,609.00
Temperature shutoff w/timer	836.00		
Nonexplosion-proof electric timer			
Export boxing	56.00		
	150.00	600.00	850.00
Installation			
Electrician: 2 hrs. @ 22.58 + labor burden & overhead	74.51		
Plumber; 2 hrs @ 23.20 + labor burden & overhead	76.56		
Materials	75.00		
Electrician: 4 hrs. @ 22.58 + labor burden & overhead		149.03	149.03
Plumber: 4 hrs @ 23.20 + labor burden & overhead		153.12	153.12
Materials	100.00	125.00	
Space Costs			
Includes space required for still + additional workspace @ $19 sq. ft.	402.80	862.60	1,333.80
Transfer Pump	785.32	785.32	785.32
Total investment costs	$6,794.19	$ 16,011.07	$28,005.27

* Prices for equipment and space estimates taken from Finish Engineering Catalog, 87-90, contract prices ffrom GSA schedule.

** Includes 25 percent for labor burden and 40 percent for overhead. Average national rates taken from *Labor Rates for the Construction Industry: 1987, 14th Annual Edition* (R.J. Means Company, 1987).

Table B3

Still Operator Labor Rates

1. Annual pay - sample rates used for enlisted Army personnel, Grade #7 with 3 years service[*]	$16,070.40
2. Working hours per year - 52 weeks/yr x 5 days/week-10 holidays- 15 leave days x 8 hrs/day	1,880 hrs. yr
3. Labor rate per hour - $15,998.80 year/1,880 hours per year	$8.51 hr.
4. Overhead - (17 percent for retirement and 23 percent for other personnel costs [e.g., quarters, medical, etc.])[**]	$3.40 hr.
5. Labor burden - (associated costs of commissioned and supervisory personnel @ 25 percent)	$2.13 hr.
6. Total hourly rate for still operator (equivalent to an annual pay rate of approximately $26,395 yr.)	$14.04 hr.

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[*] *Federal Employees' Almanac*, 1987, edited by D. Mace and J. Young (Federal Employees' News Digest, 1987), pp 37 & 119.

[**] R.D. Neathammer, *Economic Analysis: Description and Methods*, Technical Report P-151, ADA135280 (USACERL, October 1983).

Table B4

Annual Labor Costs for Still Operations

From Equation B2, the labor costs can be factored as a constant times the number of batches/day:

1. Labor rate (from Table B3)	$14.04/h
2. Still operating time per shift (from manufacturer - estimated to take 1/4 to 1/2 hour to fill still, 1/4 to 1/2 hour to empty, and deliver spent and recycled solvent.)	2 h
3. Number of stills (assumed)	1
4. Number of shifts per day (typically, solvents with lower boiling temperatures will take 6 hours to process, those with higher boiling temperature, 8 hours. A still may be filled at the end of the shift when equipped with a timer and the reclaimed solvent emptied the following morning.)	1
5. Working days per year (52 weeks x 5 days/week - 10 holidays - 3 downtime days for maintenance & repair)	247
6. Still labor costs (lines 1 x 2 x 3 x 4 x 5)	$6,935.76
7. Annual labor costs = $6,935.76 x number of batches per day (From Table B1)	

Table B5

Economic Comparison of Still Alternatives: 5-, 15-, and 55-gal Stills

	Q* (gallons)			
	5	10	15	20
Annual savings from labor, 150 v. 5-gal still	$4,646.96	$2,288.80	-	-
Additional cost of investment for 15- v. 5-gal still	$9,216.88	$2,422.69	-	-
15-gal alternative:				
Discounted Payback Period (DPP)	2.2 years	1.1 years	-	-
Savings to Investment Ratio (SI)***	3.25	609	-	-

---

* Q, the quantity of solvents to be recycled in each day should ideally include a 25 percent backup factor as insurance against overifliing stills which might result in spills or operator injury. Thus, the maximum amount to be placed in a 5-gallon still would be: 5 - (5 x 0.25) = 4 gallons.

** Payback period: PV of additional cost of investment/annual savings = x, which is the cumulative uniform discount factor corresponding to year of payback.

*** Savings to Inv estment Ratio: PV of total savings/PV of net total investment where useful economic life of the still is assumed to be 10 years.

Table B6

Economic Comparison of Still Alternatives: 55- v. 15-gal Still

	Q (gallons)			
	5	10	15	20
Annual savings from labor, 55-v. 15-gal still	$ 1,664.58	$ 3,398.52	$ 5,063.10	$2,150.09
Additional cost (savings) old investment for 55-v. 15-gal still	$11,994.20	$11,994.20	$11,994.20	($4,016.00)
55-gal alternative:				
PP	12.2 years	4.3 years	2.7 years	-
SIR		1.83	2.72	-

Table B7

Economic Comparison of Still Alternatives:
110- v. 55-gal Still

	Q (gallons)			
	5	10	15	20
Annual savings from labor, 100-v. 55-gal still	$1,248.44	$1,942.01	$2,566.23	$3,190.45
Additional cost (savings) old investment for 110-v. 55-gal still	$7,193.03	$7,193.03	$7,193.03	$7,193.03
110-gal alternative:				
PP	8.4 years	4.6 years	2.7 years	2.6 years
SIR	1.12	1.74	2.3	2.86

Analysis of Alternatives

What this analysis so dramatically points out, is that as labor is the principle component of annual recurring costs, the labor savings resulting from the purchase of a single large still that would only be operated when a full batch of used solvents was collected for recycling, would optimize economic returns.

Contrary to the original hypotheses, the results of this simple economic analysis indicated that under no circumstances would decentralized distillation be preferred to centralized distillation. Installations wishing to maximize their total dollar return and minimize their outlays on recurring expenses, would do well to buy stills capable of processing significantly larger amounts of used solvents than the average daily volume of used solvents produced by the installation. For small generators (1.62 to under 5 gal/day, roughly equivalent to 400 to 1,235 gal/yr) it would be advisable to purchase a 15-gal capacity still. For those installations that generate between 10 and 25 gal/day, a 55-gal still would be most economical, while those installations generating between 25 and 100 gal/day should consider a still that can process 110 gal/day.

By maximizing the operating parameters of the distillation units, installations will not only save significantly large dollar amounts, but will also free up personnel to perform other duties.

APPENDIX C: COMMERCIAL AND GOVERNMENTAL DATA SOURCES/COST INDICES

Building Construction Cost Data (Annual) (R.S. Means Co.).

Building Systems Cost Guide (Annual) (R.S. Means Co.).

Conceptual Military Construction Cost Engineering Data, NAVFAC P-448 (Naval Facilities Engineering Command).

Dodge Assemblies Cost Data (Annual) (McGraw-Hill).

Economic Indicators (Monthly) (Council of Economic Advisors, GPO).

Marshall and Swift Index,

> Tracks equipment costs in the cement, chemical, clay products, glass, paint, paper, petroleum products, and rubber industries. Both equipment costs and installation labor are tracked which means the index reflects changes in installed equipment costs.

Mechanical and Electrical Cost Data (Annual) (R.S. Means Co.).

National Construction Estimator (Annual) (Craftsman Book Co.).

Structures Cost Manual (Annual) (Craftsman Book Co.).

GLOSSARY

Base year

The first year in which initial investments are made or in which costs are incurred. The base year used in the calculations in Appendix A, is year 1, covering the time period from t=0 to t=1 (the beginning of the year to its end).

Benefit/Cost analysis

A comparison of alternatives by analyzing the present value of all benefits accruing from an alternative divided by the present value of all costs.

Benefit/Cost ratio

A measure of efficiency, determined by dividing the net present value of benefits by the net present value of costs.

Compound interest

The interest that accrues on both the principal amount and previously accrued interest.

Deflation

A persistent decrease in the general level of prices over time.

Differential escalation rate

The rate at which the costs for an item increase faster than those for the economy as a whole. (Remember that the discount rate already incorporates an inflation factor [escalation rate] of approximately 5 percent in its composition.) Note that an item could also increase at a rate which is slower than the general rate of inflation for the economy. In such an instance, the escalation rate would be negative (it deflates the discount factor).

Discounted payback period

The time period over which the net present value of savings accumulates to offset the total present value of investment costs of an alternative compared to the status quo.

Discounting

Reconciliation of future cash flows (both cost and benefits) to present values. Inherent in discounting is the cost for investment opportunities demanded by the private/government sector (the "rate of return"), the rate of inflation, and the preference of individuals for current over future dollar incomes.

Disposal

As used in this report, disposal refers to a DOD-purchased service for the off-base removal of hazardous waste. Wastes are typically collected from the process generating area and disposed of either directly by the installation or through the Defense Reutilization and Marketing Office (DRMO).

Hazardous wastes removed by a private contractor are either landfilled or incinerated. While these disposal options may be environmentally sound if conducted in a proper fashion, this method typically results in higher costs and will generally not be an economically attractive alternative. As an example, DRMS has indicated that disposal costs for solvents, based on 20 representative CONUS contracts and including costs for off-base transportation for restricted solvents (not able to be landfilled) average $2.21/lb for sludges and $3.44/gal for liquid solvent wastes (approximately $145/drum assuming a 42-gal capacity). For disposal of solvents that are not restricted in the method of disposal (may be landfilled), average costs were $3.66/lb for sludges and $5.27/gal for liquid solvent waste (approximately $221/drum).

Economic life

The period of time (usually measured in years) over which the benefits to be gained from an alternative may be reasonably expected to accrue to the Army. Determination of an alternative's economic life is constrained by the feasibility of acquiring enough economic data for decision making. An alternative's economic life begins the year the alternative is put into operation (its base year).

For most purposes, the economic life of an alternative need not be considered beyond the 25th year (i.e., economic life should be limited to a 25-year analysis), because the single amount discount factors become so small after 25 years that any differences between alternatives would be negligible.

Equivalent uniform annual cost

See uniform annual cost.

Inflation

A rise in the general level of prices (as measured by an indicator such as the Consumer Price Index [CPI]) over time.

Lead time

The time from the beginning of year 1 (t=0) to the beginning of the economic life. Economic life begins when the alternative begins to yield benefits to the Army. Should a project require extensive research and development outlays before it becomes operational or should there be a delay between the start of construction and the beginning of an alternative's actual operation, the lead time could be substantial and should be carefully considered in the economic analysis.

Midyear convention

An assumption that costs and benefits do not accrue at the end of years but rather as a stream of payments throughout the year (e.g., salaries are commonly paid on a weekly or monthly basis, not in a lump sum end-of-year payment). The midyear convention is at the heart of using continuous discounting techniques.

Net present value

Same as present value.

Nonrecurring costs

Those costs typically incurred on a one-time only basis. Generally, nonrecurring costs include the costs associated with research and development, investment in equipment and land, and any costs for dismantling and removing the equipment once the project has come to an end (this terminal value may be a positive cash flow rather than a cost, depending on the costs of removal and disposal).

Objectives

Goals or results the analyst sets for alternatives to attain.

Parameter

A numerically quantifiable characteristic of a population that may be estimated by sampling; a constant.

Physical life

The estimated number of years that a machine or piece of equipment can be used to accomplish the project for which it was originally purchased. Physical life will often exceed the economic life of a project.

Present value

The estimated present worth of future cash flows (either benefits or costs). Present value is determined by discounting future cash flows with a predetermined discount rate (i).

Project life

The time period from the beginning of year 1 (t=0) to the end of a project's economic life. Project life is the sum of the project's lead time plus its economic life. A project with an economic life of 10 years and R&D costs that occur for 2 years prior to the project being brought on-line would have a project life of 12 years.

Recurring costs

All expenses associated with the operations and maintenance of an alternative. Recurring costs are expected to reoccur at regular intervals throughout a project's life. Major recurring costs for hazardous waste minimization alternatives include the annual costs for personnel, materials, utilities, maintenance and repair, and disposal costs.

Research and development costs

Those costs incurred in the development of an alternative (by year) starting from the base year of the analysis (i.e., excluding any sunk costs).

Sale

A transaction where DOD either reuses, transfers, or donates the material to eligible organizations or receives some financial compensation through the sale of the waste material. Hazardous materials turned in to DRMO are screened according to the normal DRMS system of: (1) reuse, transfer, and donation, (2) sales, and (3) abandonment and destruction. Used solvents, used POLs, and used batteries are typical of the hazardous materials commonly donated or sold through DRMO operations.

Salvage value

An estimate of the worth of an item at the end of the item's useful life. Note that for analysis purposes, a project's economic life may be much shorter than that time period for which an asset is actually expected to perform properly—its useful life. Care must be taken, therefore, to properly identify terminology.

Savings/investment ratio (SIR)

The savings to investment ratio is the amount of future costs that will be saved as a result of the new alternative divided by the amount of investment required to undertake the project. SIRs allow for the comparison of one project's "profitability" with that of another.

Sensitivity analysis

Manipulation of an alternative's major parameters to assess the extent to which reasonable changes in the assumptions of cost and benefit inputs may affect the ranking of alternatives.

Simple interest

The interest calculated on the principal amount only, not including interest accrued from prior periods.

Sunk costs

A cost that has occurred in the past (before the base year). As sunk costs have been previously committed, they are not considered in evaluating alternatives.

Terminal value

An estimate of the worth of an item at the end of a project's economic life. The terminal value may be a positive figure if the asset can be disposed of for a profit after dismantling and removal, or it may be negative where it becomes necessary to pay for the asset's removal or dismantling.

Time value of money

Money is viewed as a productive asset and the use of money costs money. Consequently, $1 received today is worth more than $1 received in the future as interest costs will be levied on the receipt of that future dollar to compensate the lender. This acknowledgment is at the heart of discounting, which is an attempt to reduce future cash flows to current prices.

Uniform annual cost (UAC)

A technique used to compare alternatives with different economic lives. UAC divides the total discounted project cost by the sum of the discount factors for the years that the alternative yields benefits (i.e., its project life).

LIST OF ABBREVIATIONS

AMC:	U.S. Army Materiel Command
AR:	Army Regulation
ARDC:	Armament Research and Development Center
BCR:	Benefit/Cost Ratio
C/B:	Cost Benefit (analysis)
CE:	Corps of Engineers
CECOM:	Communications-Electronics Command
CFR:	Code of Federal Regulations
CONUS:	Continental United States
CPI:	Consumer Price Index
CRF:	Capital Recovery Factor
CVWF:	Central Vehicle Wash Facility
CY:	Calendar Year
DA:	Department of the Army
DAEN:	U.S. Army Office of Engineers
DELP:	Defense Environmental Leadership Project
DERA:	Defense Environmental Restoration Account
DLA:	Defense Logistics Agency
DLAM:	Defense Logistics Agency Manual
DOD:	Department of Defense
DOE:	Department of Energy
DOT:	Department of Transportation
DPP:	Discounted Payback Period
DRMO:	Defense Reutilization and Marketing Office
DRMS:	Defense Reutilization and Marketing Service
EA:	Economic Analysis
EPA:	Environmental Protection Agency
EUAC:	Equivalent Uniform Annual Cost
FLOCS:	Fast Lube Oil Change System
FOB:	Free On Board
FORSCOM:	U.S. Army Forces Command
FPA:	Fundamental Planning Analysis
GSA:	General Services Administration
HAAP:	Holston Army Ammunition Plant
HAMTAM:	Hazardous Materials Technology Assessment Manual
HAZMIN:	Hazardous Waste Minimization
HM:	Hazardous Material
HMTC:	Hazardous Materials Technical Center
HQ:	Headquarters
HSWA:	Hazardous and Solid Waste Amendments
HW:	Hazardous Waste
HWERL:	Hazardous Waste Engineering Research Laboratory
i:	Interest (also used as Rate of Return)
IDA:	Institute for Defense Analysis
IDR:	Initiation Decision Report
IPR:	In-Progress Review
IRR:	Internal Rate of Return
ISP:	Insoluble Sulfide Precipitation
IVD:	Ion Vapor Deposition
IWS:	Ionizing Wet Scrubber
IWTP:	Industry Waste Treatment Plant
LAP:	Load, Assembly, and Pack (munitions)

LCC:	Life Cycle Cost
LCCA:	Life Cycle Cost Analysis
MACOM:	Major Command
MCA:	Military Construction Army
MCP:	Military Construction Plan
MILCON:	Military Construction
NAVFAC:	Navy Facilities Engineering Command
NEESA:	Naval Energy and Environmental Support Activity
NICAD:	Nickel-Cadmium (battery)
NPV:	Net Present Value
NWC:	Naval Weapons Center
O&M:	Operations and Maintenance
OCE:	Office of the Chief of Engineers
OMB:	Office of Management and Budget
ORP:	Oxidation-Reduction Potential
OSD:	Office of the Secretary of Defense
P:	Principal
PL:	Public Law
PECI:	Productivity Enhancing Capital Investment
PMB:	Plastic Media Blasting
POL:	Petroleum, Oils, and Lubricants
ppm:	parts per million
PV:	Present Value
R&D:	Research and Development
RAAP:	Radford Army Ammunition Plant
RCRA:	Resource Conservation and Recovery Act
ROI:	Return on Investment
ROR:	Rate of Return
RRAD:	Red River Army Depot
SIR:	Savings to Investment Ratio
SO_2:	Sulfur Dioxide
SSP:	Soluble Sulfide Precipitation
TM:	Technical Manual
TAD:	Tobyhanna Army Depot
TRADOC:	U.S. Army Training and Doctrine Command
TSD:	Treatment, Storage, and Disposal
UAC:	Uniform Annual Cost
USC:	U.S. Code
USE:	Used Solvent Elimination
USACERL:	U.S. Army Construction Engineering Research Laboratory
USEPA:	U.S. Environmental Protection Agency
USATHMA:	U.S. Army Toxic and Hazardous Materials Agency

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