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The Industrial Assessment Center (IAC) Program: Industrial Manufacturing Providing Practical Experience for Engineering Students

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UNIVERSITY HONORS PROGRAM

SENIOR PROJECT - APPROVAL

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PROJECT TITLE: The Industrial Assessment Center (IAC) Program: Industrial Manufacturing Providing Practical Experience for Engineering Students

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

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The Industrial Assessment Center (IAC) Program: Industrial Manufacturing Providing Practical Experience for Engineering Students

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April 26, 1999

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[1] The term "Pollution Prevention" is commonly abbreviated as P2.

I. ABSTRACT

This project introduces the University of Tennessee Industrial Assessment Center (UTIAC) Program, its benefits for engineering students and its impact on industrial clients. The UTIAC is an outreach program that exposes engineering students to real-life applications of the engineering curriculum. Established in 1976, the UTIAC has served 662 industrial clients to date. The Department of Energy-funded program serves small- to medium-sized clients in a radius of approximately 150 miles from Knoxville, TN. In-plant assessments are performed by faculty-student teams. The program addresses the areas of energy conservation, waste minimization and productivity enhancement. The overall goals of the program are outlined in detail, along with a student's perspective on the benefits it affords industrial clients as well as engineering students and faculty.

Several papers have been written about the UTIAC's impact on industrial manufacturers. One particular paper serves to assist professional consultants by outlining the steps required to successfully perform an assessment with limited resources. Another paper focuses on the factors that contribute to the implementation of recommended waste reduction measures. The third and final paper included in this project analyzes recycling trends and suggests ways to influence recycling alternatives in industrial settings.

The UTIAC has been recognized over the years for its contribution and outreach to the community, which is essential for land grant universities. The most recent award for outstanding service was presented on August 13, 1998, by Ms. Denise Swink, Deputy Assistant Secretary for the Department of Energy Office of Industrial Technologies. Although thirty centers nationwide now participate in the program, the UTIAC continues to be a leader in achieving program goals in a fast, efficient manner.

Personal benefits provided by the UTIAC are the final element of this project. Engineering graduates have obtained valuable skills that are highly sought by future employers. Both written and verbal communication skills are essential to the functions of the program. In addition, graduates are exposed to practical engineering tasks and are encouraged to analyze current production operations to discover new ways to reduce operating costs. Through project work, students are trained in engineering consulting, a dynamic field which employs numerous people from diversified backgrounds.

The main goal of this project is to introduce and explain a long-standing program and evaluate its impact on those involved with the program. The project will outline the benefits of participating in the UTIAC Program and describe the advantages it provides to engineering students at the University of Tennessee.

II. PROGRAM BACKGROUND

In 1976, W. Kirsch of the University City Science Center in Philadelphia and W. Snyder, the former Head of the Department of Engineering Science and Mechanics (and the current Chancellor) at the University of Tennessee, Knoxville developed a concept of universities providing technical assistance to industrial manufacturers. The proposal they wrote to form an organization to provide such assistance was accepted for funding by the U.S. Department of Commerce. Under the proposal, a small number of universities were given the approval to form Energy Analysis and Diagnostics Centers (EADCs) which provided energy audits to small- to medium-sized manufacturing companies. Over the years, others universities across the U.S. formed Centers under this proposal and sole "field management" administration was awarded to the University City Science Center.

Meanwhile in 1988, the Environmental Protection Agency (EPA) provided funding to three universities nationwide, one of which was the University of Tennessee, Knoxville, to operate Waste Minimization Assessment Centers (WMACs). The goal of the WMAC Program was to provide technical assistance to manufacturers in the area of waste minimization. The success of both the EADC and WMAC programs contributed to the Department of Energy (DOE) reorganization of the program into an Industrial Assessment Center (IAC) Program in 1993.

The more broadly focused IAC Program targets both energy conservation and waste minimization. In 1996, productivity enhancement was added as a third new major area of concern. Still today, the program provides DOE funding for service to regional manufacturers based on one-day site visits. Currently, thirty IACs are active at various universities in the U.S. The participants are divided into an Eastern Division for which field management is provided by Rutgers, the State University of New Jersey and a Western Division which is managed by the University City Science Center. The current participant list is provided below:

Arizona State University
Bradley University
Colorado State University
Georgia Institute of Technology
Hofstra University
Iowa State University
Mississippi State University
North Carolina State University
Oklahoma State University
Old Dominion University
Oregon State University
San Diego State University
San Francisco State University
South Dakota State University
Texas A&M University
Texas A&M University-Kingsville
University of Arkansas at Little Rock
University of Dayton

University of Florida
University of Kansas
University of Louisville
University of Maine
University of Massachusetts
University of Michigan
University of Missouri-Rolla
University of Nevada-Reno
University of Notre Dame
University of Tennessee
University of Wisconsin
West Virginia University

Clients served must be small- to medium-sized manufacturers with Standard Industrial Classification Codes between 2000 and 3999 and should be located within a 150-mile radius of the host campus. In addition, the companies are required to meet three of the following four criteria to be eligible for participation in the program.

1. Gross annual sales for the assessed plant are less than $75 million.
2. Fewer than 500 people are employed at the plant site.
3. Annual energy bills are between $75,000 and $1.75 million.
4. No in-house professional staff is available to perform an assessment.

Currently, the University of Tennessee Industrial Assessment Center (UTIAC) serves clients in the states of Tennessee, Kentucky, Virginia and North and South Carolina. In recent years, the traditional 150-mile radius service area has been redefined into specific counties. This prevents overlap of coverage with the neighboring centers of Georgia Institute of Technology, University of Louisville, University of Dayton, West Virginia University and North Carolina State University.

An industrial assessment consists of a one-day visit by engineering faculty-student teams to a regional manufacturer. The DOE provides the university approximately $6,500 per assessment to complete the work; the client does not incur any cost or obligation to act on any recommendations by accepting the assessment. The only real cost to the client is the time spent with the assessment team. The product of the assessment is a technical report focusing on the areas of energy conservation, waste minimization and productivity enhancement. The report and assessment process have some minimum guidelines as established by the DOE. These include:

1. The report must have recommendations addressing all three areas: energy conservation, waste minimization and productivity enhancement.
2. The minimum savings for any given plant must meet or exceed $25,000 annually.
3. The report must be issued within two months of the plant visit date.
4. An anonymous copy of the report must be issued to the division field manager.

5. Follow-up implementation data must be collected six months to a year after the report is issued.

Besides ensuring that these guidelines are met, the DOE extracts characteristic data from each plant which is input into a database. This data is used to compile statistical information about the clients served and overall program impact. Additional information about the management and success of the program can be obtained at the DOE's Office of Industrial Technologies Website, http://www.oit.doe.gov.

The DOE does not regulate how the engineering students associated with the project should be compensated. At some Centers, the IAC work is associated with an undergraduate or graduate level college course. At the UTIAC, student employees are paid apprentice engineers. The UTIAC work is not associated with any class requirements and participants do not receive college credit for work performed. In general, students are selected through a rigorous interviewing process. Characteristics such as high motivation level, exceptional communication skills, an energetic and enthusiastic personality and dedicated work ethic are essential to success in the program. Although students are allowed some flexibility with their work schedules, an average workweek includes fifteen to twenty hours of work. Student tasks include:

1. Telephone solicitation of manufacturers from state directories.
2. Participation in plant site visits.
3. Technical report writing.
4. Collection and compilation of recommendation implementation data.

The professors involved with the UTIAC have certain responsibilities as well. In general, they lead the assessment team during the one-day site visit. During the technical writing phase, they provide technical guidance to the engineering student workers and review the final report draft for technical content and clarity of ideas. The professors play a major role in developing the final reports and enhancing the students' learning experience.

The nationwide IAC Program has achieved considerable success over its history, despite the monetary and time limitations imposed by the program's funding level. "Effective Techniques for the Performance of Resource-Limited P2 Assessments" enumerates the limitations of the IAC Program and outlines how to produce a high-quality technical report given these constraints. The paper also addresses how to effectively collect information from plant management and present suggestions for improvement. The paper, which was presented at the Second Annual Statewide Pollution Prevention Conference in Clearwater Beach, Florida, on June 2, 1998, is reprinted on the following pages.

Effective Techniques for the Performance of Resource-Limited P2 Assessments

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In recent years, environmental management has become a major concern in the United States. In particular, industrial manufacturers are subject to a wide array of evolving regulations designed to implement environmentally friendly alternatives for current production and chemical processing methods. Although more companies are becoming experienced with waste minimization measures that yield favorable results, many others depend on government-supported assistance programs to identify and implement waste reduction measures.

Since 1988, the University of Tennessee, Knoxville (UTK) has operated two notable government assistance programs targeting industrial waste minimization. The first of these programs was the EPA-funded Waste Minimization Assessment Center (WMAC) Program, which involved three universities and operated from 1988 to 1993. The UTK arm of this program served forty industrial clients by the end of 1993 and produced technical reports designed to aid regional manufacturing companies in waste minimization techniques.

Towards the end of 1993, the long-running DOE-sponsored Energy Analysis and Diagnostics Center (EADC) Program, which had provided energy conservation assistance to industrial manufacturers for over fifteen years, was renamed the Industrial Assessment Center (IAC) Program. At this time, the technical assistance provided by the program was broadened to include the area of waste minimization. To date, the UTK IAC has served over ninety industrial clients in the area of waste reduction in addition to providing assistance with energy conservation. Currently, each of thirty universities nation-wide receive DOE funding (approximately \$6,500/assessment) to serve twenty-five clients annually. Including both WMAC and IAC clients, UTK has provided waste minimization assistance to over 130 clients.

Clients are solicited among small- to medium-sized industrial manufacturers within a 150-mile radius from the Knoxville campus. The IAC is required to identify at least two client-specific recommendations targeting waste minimization for each facility. Assessment teams consist of at least one engineering faculty member and one student; however, most teams employ one faculty member and two students. Under the WMAC Program, assessment teams spent from two to three days in client plants observing operations and collecting information. DOE funding of the IAC Program limits in-plant time to a one-day assessment, which substantially challenges the assessment team to collect information in a short period of time. Therefore, it has been necessary to develop techniques for the performance of resource-limited waste assessments.

A major challenge of performing waste assessments is the collection of accurate information from knowledgeable plant personnel. Commonly (in small- to medium-sized plants), only one plant employee is well-versed in waste management and environmental regulatory matters. Therefore, this person must be available during the interview process or have knowledgeable assistants who can provide quantitative waste-related data. In many cases, the assessment team must make some quantity estimations based on an inspection of the facility and the manufacturing processes. After the plant visit, faculty-student teams prepare a comprehensive technical report, which is mailed to the client within two months after the site visit occurs.

The assessment process is fairly straightforward; however, the specific method of obtaining detailed information has evolved to maximize effectiveness of the assessment process. In particular, a clear understanding of the production process, including all material inputs and waste outputs, is essential. This information is compiled into a process flowsheet that identifies all significant material inputs and outputs and process flows throughout the plant. This flowsheet serves as a visual representation of the process and incorporates a mass balance on all of the major classes of materials and waste streams resulting from production operations. Waste information is also presented in spreadsheet form which assigns monetary values to the waste quantities in the categories of raw material replacement costs, handling and record-keeping labor costs and offsite disposal costs. This data tabulation allows facilities to prioritize waste reduction measures to maximize favorable economic impact. The waste stream cost quantification also guides the assessment team in deciding which wastes should be targeted for the development of assessment recommendations.

Although most of the information organization and data analysis occurs after the actual visit, the manner in which the in-plant activities are conducted determines the relevance and quality of the information collected. Several elements of the in-plant interview are critical to the quality of information collected and, therefore, to the success of the entire assessment. For instance, one plant employee may not be able to sufficiently answer all questions posed during the interview. For this reason, additional plant personnel should be available on an "on-call" basis to answer questions as needed. This may require the temporary postponement of the interviewing process or the pursuit of a parallel line of inquiry until an appropriate person becomes available for questioning. If any contact is not available for an extended period of time, recording the name and/or telephone number of this individual will facilitate to later contact during and after the onsite visit. Experience has shown that faxes, emails and telephone calls after the actual visit day are more time consuming and significantly less effective for data acquisition than person-to-person interaction while in the plant.

In-plant interviews should begin with a basic overview of the manufacturing process and the steps required to convert raw materials into finished goods inventory. The assessment team should initially explore all waste streams produced as a consequence of manufacturing operations. This approach identifies waste streams at the point source of their introduction into production operations and focuses the discussion on the collection of relevant waste-related data. A detailed questionnaire is used to guide the sequence of questions asked during the assessment. In addition, the assessment team can review a checklist of prospective recommendations for possible application in the plant's processes. Both of these documents serve the additional purpose of assisting in the orderly training of new student employees.

A physical inspection of operations on the production floor is essential to understanding the cause of waste generation in the plant. Production workers are helpful in obtaining information about the sources and quantities of individual waste streams. All data should be carefully recorded as well as mapped out on a plant layout to facilitate later analysis. Some physical measurements such as flow rates or weights may be taken. Any uncertain quantities (such as the mix of component materials in disposed solid waste) should be determined by a visual inspection.

Valuable information about materials used in the plant that result in waste can normally be obtained from Material Safety Data Sheet (MSDS) forms. The requirement to make this information available for chemicals used in plant processes is required by Occupational Safety and Health Administration (OSHA) standards for industrial companies. Since collecting copies of MSDS forms may be time consuming in the context of a one-day assessment, normally only a few forms are sought for targeted chemicals.

To ensure a quality visit, the faculty team leader must project a high level of professionalism to gain the clients' respect and to maintain student motivation and work output. Some plants may have proprietary methods of production or trade secrets. The faculty team member should assure the clients that they will receive complete confidentiality as mandated by the IAC Program and professional engineering ethics. In addition, students are provided technical training as well as encouraged to conduct themselves as professionals in all aspects of project work. Effective waste assessment reporting requires students to be mature and responsible and to practice good time management. Recruiting the "right kind" of student team members is one of the most essential elements in the maintenance of a successful technical assistance program.

The assessment team size is also an element of the program that must carefully be considered. In general, only two student members participate in each assessment. In most cases, use of a larger number of students reduces the overall efficiency of the team (i.e. the law of diminishing returns). In rare circumstances, three students will participate in an assessment (e.g. two new employees and one veteran to oversee the process and serve as a resource in the report writing process). Encouraging new employees to actively participate in an initial assessment requires the students to learn the process more quickly. Student team members normally interact during the questioning period to expand on each other's ideas and concerns.

In order to optimize the amount of information collected, the assessment team must remain in control of the line and pace of questioning during the interview. Equipment or plant operations yielding relatively large quantities of waste should be inspected and discussed more thoroughly than others. In most cases, a given plant employee will be a specialist in a particular area of the plant operations. Unfortunately, the volume of information required to be collected prevents the assessment team from dedicating large quantities of time to a single unit operation or area of the plant. Therefore, the interviewer must constantly evaluate the quality of information provided as it relates to the comprehensive assessment. As soon as adequate information is collected, the interviewer must prompt the plant employee to discuss the next element of the production operation.

A careful record of all information should be kept by taking notes, tape recording the data provided or entering data electronically with the aid of a laptop computer. Plant personnel should be encouraged to provide ballpark numbers when exact information is unknown or currently inaccessible. Almost without exception, plant personnel can offer better "educated guesses" than the assessment team since they participate in production operations on a daily basis. The data provided can be verified by asking more than one employee the same set of questions. This results in more accurate quantities since several estimates can be considered in determining a "best value." In situations where plant personnel are hesitant to make an educated guess, the assessment team can "guess" and verbalize a number on their own which encourages plant personnel to provide a more accurate value. A final verification of data can occur on the manufacturing floor by asking production workers for their opinions. Collecting data from different people incorporates a checks-and-balances system and ensures the collection of the most accurate information available. Observing actual waste streams in the plant also allows an order-of-magnitude check on data provided by plant personnel.

Many factors contribute to a successful waste assessment. Overall, using a combination of carefully selected student assistants with sound technical training, a well-organized assessment process and common sense prepares most assessment teams for the tasks at hand. The assessment team must always remember the ultimate goal of serving the client by targeting waste streams that can be eliminated, reduced or treated and disposed of in more responsible and cost-effective ways. Understanding these basic principles serves as the cornerstone of a successful resource-limited plant assessment.

III. ENERGY ASSESSMENT

Of the three technical areas addressed in an assessment, energy conservation, waste minimization and productivity enhancement, the energy conservation aspect of the program is the oldest and most developed area of concern. Since the inception of the EADC in 1976, energy conservation had been a major focus of the industrial assessment. The successful completion of the energy assessment requires the following:

1. Obtaining and listing significant plant data including annual sales, production amounts, number of employees and hours of production operations.
2. Sketching the basic layout of the plant and identifying and labeling the major areas of production operations.
3. Identifying and listing goals the plant has previously accomplished in the area of energy conservation.
4. Tabulating, plotting and analyzing the historical energy billing information for all forms of energy used (e.g., electricity, natural gas, fuel oil, coal, wood waste, etc.).
5. Preparing a comprehensive list of equipment utilized in the plant based on the form(s) of energy required for unit operation.
6. Assigning an estimated load and duty for each piece of plant equipment.
7. Totaling the energy consumption of each piece of equipment to obtain the total historical consumption as reported on the energy bills.
8. Preparing summary information comparing the cost and consumption trends for each form of energy.
9. Researching and preparing recommendations that target excessive energy consumption and outlining ways to conserve energy in the plant.
10. Preparing a secondary list of considered energy conservation measures that were not recommended due to minimal savings, lengthy paybacks or other reasons.
11. Organizing all the elements of the assessment into a professional quality technical report.

IV. WASTE ASSESSMENT

After the success of the EPA-funded WMAC Program in the early 1990s, the DOE decided to integrate the energy conservation focus of the EADC Program with the waste minimization focus of the WMAC Program. The result of this merger was the IAC Program which began in 1993. The inclusion of waste minimization as a major goal of the industrial assessment allowed the program to offer a wider range of services to its industrial clients. In addition, some clients who had relatively tight control over energy consumption in their plants were just beginning to address waste minimization in response to newly enacted environmental legislation. For this reason, the effectiveness of the program expanded since an additional area of concern was added to the assessment profile.

The successful completion of the waste assessment requires the following:

1. Composing an overview of the manufacturing process which describes the process required to convert raw materials into finished goods.
2. Graphically depicting the flow of materials and the generation of waste through production with a process flowsheet.
3. Identifying and listing goals the plant has previously accomplished in the area of waste minimization.
4. Tabulating the waste streams generated in the plant and assigning a quantity and cost figure to each. The associated costs include raw material replacement costs, handling and record-keeping costs and offsite disposal costs.
5. Summarizing the major waste-related issues identified in the table mentioned in item four.
6. Researching and preparing recommendations that target possible waste minimization opportunities and outlining ways to reduce waste in the plant.
7. Preparing a secondary list of considered waste minimization measures that were not recommended due to minimal savings, lengthy paybacks or other reasons.

The staff of the University of Tennessee IAC Program has written and presented papers commenting on the relative success and benefits of the waste minimization program. "Factors Affecting the Implementation of Waste Reduction Measures in Small- to Medium-Sized Manufacturing Plants" analyzes the impetus for plant management to implement waste minimization ideas. This information is invaluable to a program whose national success and future funding is based on its implementation rates. This paper, which was presented at the 20th Environmental Technology Expo in Atlanta, Georgia, on November 21, 1997, and published in the Proceedings, Chapter 61, pp. 469-474, is reprinted on the following pages. "Economically Attractive Materials Recycling in Small- to Medium-Sized Manufacturing Plants" evaluates the different types of industrial recycling and compiles historical information from the University of Tennessee IAC database dealing with recycling recommendations. This paper analyzes implementation rates to determine what elements are important to implementation of recycling measures and how to better tailor recommendations to future industrial clients. This paper, which was presented at the 21st Environmental Technology Expo in Atlanta, Georgia, on November 5, 1998, and published in the Proceedings, Chapter 51, pp. 403-411, is reprinted following the previously mentioned paper.

FACTORS AFFECTING THE IMPLEMENTATION OF WASTE REDUCTION MEASURES IN SMALL- TO MEDIUM-SIZED MANUFACTURING PLANTS

Richard J. Jendrucko, Ph.D., Laura M. Buchanan, Jonathan G. Overly, M.S.

ABSTRACT

The DOE-supported Industrial Assessment Center (IAC) at the University of Tennessee utilizes engineering faculty-student teams to perform in-plant assessments for regional small- to medium-sized industrial manufacturing plants. Since 1993, the focus of the program has been broadened from energy conservation to include waste minimization as an area in which recommendations are made.

Since 1993, 43 companies in 16 Standard Industrial Code (SIC) categories have received energy/waste assessments. For these 43 clients, a total of 121 measures were recommended for the reduction of the rates of production of facility waste. The number of recommendations per plant served varied from one to six with an average of about three waste-related recommendations per client.

Within a period of up to one year after submission of a report of findings and recommendations to clients, each was contacted by phone to assess whether or not they had decided to implement the specific waste measures recommended. The overall implementation rate for the recommendations made was about 30%. A first-order trend analysis of the composite data provided evidence of the relative influence of several plant-specific factors in the decision to implement waste reduction measures. Among these, the two most influential factors were the payback period and the perception of the quality of the assessment provided. Other factors including plant annual sales, waste management costs, economic benefit of recommended measures, the cost of capital improvements and the regulatory status of the waste streams were shown to be of limited importance to plant managers making decisions on waste reduction actions.

INTRODUCTION

A number of groups including plant managers, environmental regulators and equipment vendors would benefit from the knowledge of which factors contribute most to the implementation of waste reduction opportunities in the manufacturing setting. Common sense suggests that economic factors such as the cost of a proposed measure and the projected payback period are normally very influential. However, the extent to which these and other seemingly important factors affect actual decisions to implement waste reduction measures usually cannot be examined systematically, primarily due to a lack of sufficient plant-specific quantitative data. In their provision of technical assistance to industry, the authors have had an unusually high level of access to this type of plant data, allowing new light to be shed on the relevance of several factors to the decision making process. The results of a similar study focusing on factors affecting energy conservation in manufacturing plants was published previously (Jendrucko and Binkley, 1991).

Since 1976 the U.S. Department of Energy-sponsored University of Tennessee Industrial Assessment Center (formerly the Energy Analysis and Diagnostic Center) has provided technical assistance to small- to medium-sized regional manufacturers. While in the earlier years of the program the assistance was limited to the area of energy conservation, waste minimization was added as a target technical area in 1993. During the period of November 1993 through July 1996, a total of 43 clients received plant assessments leading to a total of 121 recommendations impacting waste reduction. For individual clients, one to six waste reduction measures (average of three) were recommended dealing with both government-regulated and non-regulated waste streams. While the overall average reported rate of implementation of the recommended measures was a notable 30%, there was a substantial variation in the implementation rate among the clients served. The purpose of this paper is to present a preliminary analysis and discussion of factors which may have influenced the decisions whether or not to implement the 121 waste reduction measures recommended to the clients served.

METHODS OF DATA COLLECTION AND ANALYSIS

For the analyses described below, quantitative data were obtained during interviews of one or more plant representatives at the time of plant inspections or subsequently via follow-up telephone inquiries. The data collected included general company and plant characteristics (e.g. Standard Industrial Code (SIC) category, sales, floorspace) and data specifically relevant to waste streams generated. Table 1 lists several characteristics of the plants in the data pool. In cases when computerized and hard copy records were not available, the data provided (e.g. waste generation rates) were based on best estimates of knowledgeable plant personnel. In a few cases, estimates were made by the University of Tennessee assessment team based on discussions with plant personnel and a physical inspection of plant facilities. Information on the implementation of specific recommendations was obtained by telephone inquiry normally within a period of six months to one year after the plant assessment report (with recommendations) was mailed to clients. The majority of the information analyzed for this work was previously compiled in a study of overall trends in client implementation of recommendations (Overly, 1997).

For convenience the factors considered for affect on waste reduction implementation rates were grouped as economic and non-economic in nature. As indicated above, economic factors are commonly believed to play the largest role in management decisions in manufacturing plants. However, non-economic factors can also greatly influence the degree to which a particular recommendation is seriously considered. Among the economic factors investigated, based on data availability, were the following:

Annual sales for plant
Costs associated with waste management
Savings potential of recommended measures
Project capital costs
Project payback period

In addition to these selected economic factors, consideration was given to two seemingly important non-economic factors:

The environmental regulatory status of plant waste streams
Client perception of assessment quality

The 43 industrial clients served during the indicated four-year period are characterized by a total of 16 of the 20 major manufacturing two-digit Standard Industrial Code (SIC) groups (Table 1). Owing to the relatively small number of plants in each of the individual SIC categories, data trends for specific industries could not be meaningfully investigated. Similarly, the small client pool precluded the use of rigorous statistical methods for analysis. However, the information obtained was deemed sufficient to justify simple trend analyses for pooled data, and for this purpose a series of histograms was prepared and is discussed below.

RESULTS OF DATA ANALYSIS

The first economic factor considered was plant annual sales since "scale factors" may reflect the number of decision makers or general availability of capital which in turn may influence implementation rates. The results of an analysis of the pooled data is presented in the histogram of Figure 1 where the percentage of measures implemented among those recommended for all clients in the pool is expressed as a function of selected ranges of annual sales. The quantities given in brackets are the number of recommendations made for plants in each of the sales level categories depicted.

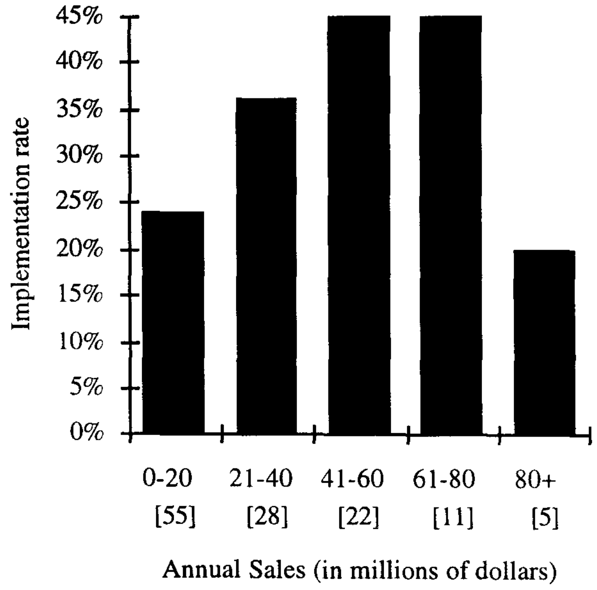

FIGURE 1: IMPLEMENTATION RATE VERSUS ANNUAL SALES

From the appearance of the histogram of Figure 1, the implementation rate of recommended waste reduction measures seems to increase with the sales level for client plants until the level of $80 million/year and greater is reached. However, since there were only five recommendations among 121 in this upper-tier sales range, inferences concerning a possible leveling off of the apparent relationship between the average reported implementation rate and sales must be considered of limited validity.

The next factor considered was the cost of plant waste management activities. These estimated costs included those for raw material replacement, onsite waste pretreatment, onsite handling, administrative management and offsite shipment. In the histogram of Figure 2 the percentage of implemented measures is expressed for selected ranges of estimated total plant waste costs where the quantity expressed in brackets is the number of plants having waste management costs falling in the specified ranges.

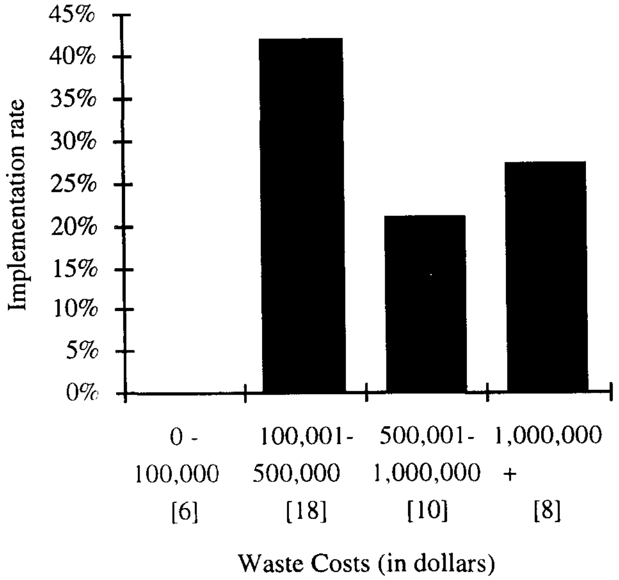

FIGURE 2: IMPLEMENTATION RATE VERSUS WASTE MANAGEMENT COSTS

From this histogram no clear relationship is evident between the implementation rate and plant-wide waste management costs. There was no implementation of measures for plants having $100,000 or less of waste-associated costs, suggesting that relatively low levels of cost may fail to provide an incentive for active waste minimization. Other than this result, the lack of a distinct trend may simply imply that for most plants, the current level of waste management costs is not a significant factor in managerial decisions regarding approval of measures for waste reduction.

Consideration was also given to the category of the potential monetary value of recommended waste reduction measures. In the histogram of Figure 3 the overall implementation rate is expressed as a function of selected ranges of potential economic benefit (cost avoidance or new income) provided by each recommendation where the number of recommendations are expressed in brackets.

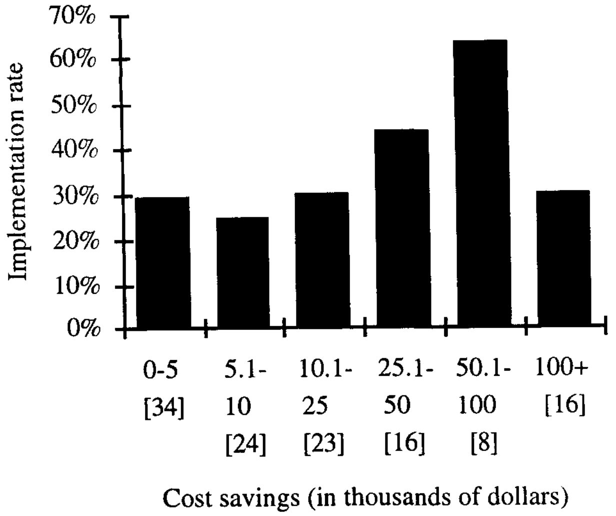

FIGURE 3: IMPLEMENTATION RATE VERSUS COST SAVINGS

The trend illustrated suggests that waste reduction action is generally undertaken more frequently as the projected economic benefit grows (at least up to $100,000/yr). The apparent decline in the implementation rate for savings or new income over $100,000/yr may be difficult to explain. The reduced implementation rate illustrated for the highest range of economic benefit included was averaged for a total of 16 recommendations, a significant number. In an attempt to explain this result, a related histogram plot of implementation rate versus the ratio of potential economic benefit to estimated total waste costs is presented below in Figure 4 where the number of plants is shown in brackets.

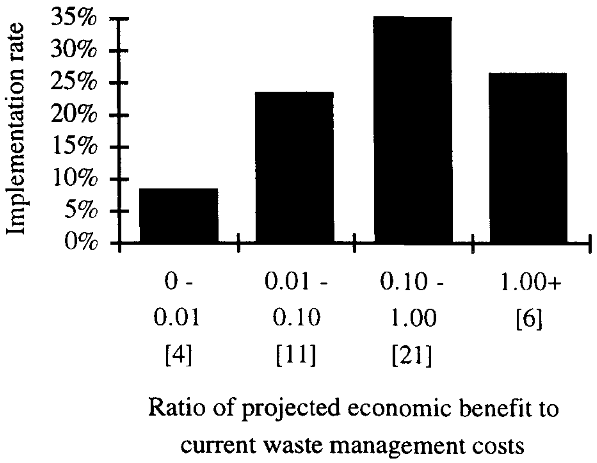

FIGURE 4: IMPLEMENTATION RATE VERSUS RATIO OF PROJECTED ECONOMIC BENEFIT

Interestingly, this histogram reflects a similar trend to that of Figure 3 with a reduction in implementation for the cases in which the potential economic benefit exceeds the current estimated total waste costs (as can occur when waste is used to produce a new salable product). This result suggests that on average implementation costs may be relatively high in order to achieve economic benefit of high relative magnitude.

Based on this observation, the importance of the implementation cost of proposed waste reduction measures was considered. Implementation rate versus selected ranges of projected implementation cost (as estimated by the assessment team) is plotted in Figure 5 below, where the value in brackets is the number of recommendations.

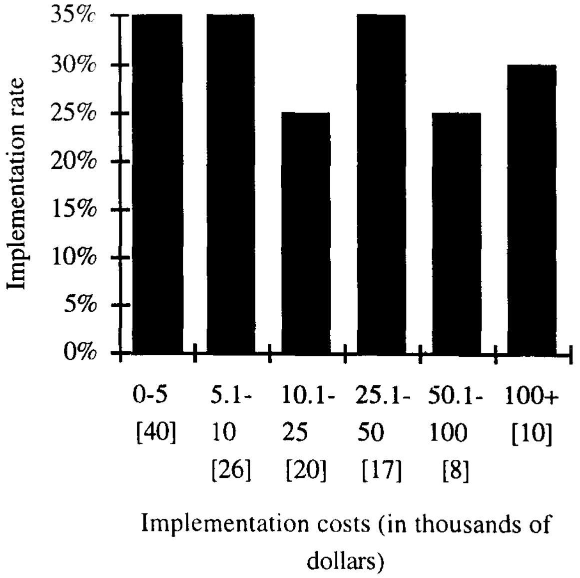

FIGURE 5: IMPLEMENTATION RATE VERSUS IMPLEMENTATION COSTS

Overall, the histogram of Figure 5 does not appear to exhibit a systematic trend in implementation rates as a function of estimated implementation cost. The modest apparent reduction in the implementation rate for the highest two ranges of costs depicted associates with data for only 18 of the total of 121 waste reduction recommendations. Thus, as for a portion of the data presented above, a limited sample size limits the conclusions which can be drawn from the available data.

The last economic factor which was considered is the simple payback period. This type of measure is widely used as a yardstick of the economic attractiveness of proposed capital improvements in industrial settings. In the histogram of Figure 6 the measure implementation rate is plotted as a function of the projected payback period for one-year increments of payback up to three years, where again the value in brackets is the number of recommendations. The apparent trend suggests that the rate of implementation of waste reduction measures decreases substantially as the payback period becomes more lengthy. This result supports common statements of plant managers that paybacks on the order of one year or less are desired to economically justify the expenditure of discretionary capital.

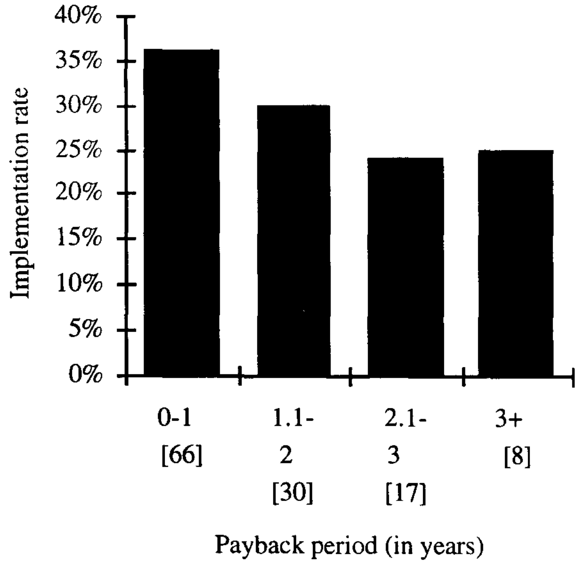

FIGURE 6: IMPLEMENTATION RATE VERSUS PAYBACK PERIOD

As a final component of this preliminary investigation, two non-economic factors were considered for their possible affect on waste reduction decision making. In particular, the regulatory status of the wastes targeted in the recommendations made to pool client companies initially appeared to play an important role in the implementation of the measure. Regulated waste streams included those which are subject to federal, state and local environmental laws based on their chemical composition and methods of release. Non-regulated streams most often included waste metals, wood, cardboard and paper. For the 121 total recommendations made, 33 were associated with regulated waste streams while the balance of 88 recommendations impacted non-regulated streams. For these two groups, the overall implementation rate for the measures related to regulated wastes was 39% while the rate for the non-regulated measure recommendations was 30%. This result suggests that the regulatory status of a waste stream may be a moderately important deciding factor in whether or not to implement a proposed waste reduction measure.

A final question addressed in the context of the available data is to what extent the perceived quality of the assessment performed influenced the rate of implementation of the measures recommended. The data used to address this question were derived from the results of a follow-up telephone survey of clients several months following the mailing of assessment reports containing the recommendations for waste reduction. At this time, plant managers categorized the value of the overall assessment as very helpful, helpful, of limited help or not helpful. In the histogram of Figure 7 presented below, the reported implementation rate is expressed in terms of the verbal assessment of plant representatives in the indicated response categories. The distinct trend in the responses recorded clearly indicates that recommended measures are more frequently implemented in plants for which the assessment provided was viewed as more than marginally helpful.

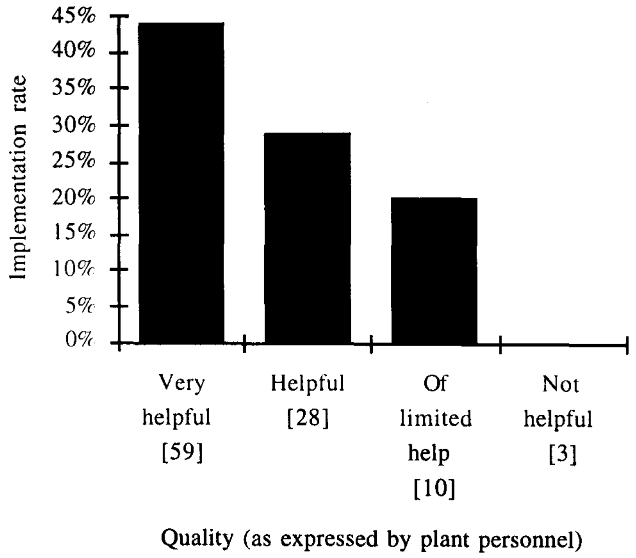

FIGURE 7: IMPLEMENTATION RATE VERSUS QUALITY OF ASSESSMENT

SUMMARY DISCUSSION AND CONCLUSIONS

In order to evaluate the analyses presented above, certain characteristics and criteria of the client pool should be considered. The data used were limited to 43 small- to medium-sized manufacturers most of whom were located within a 150 mile radius of Knoxville, Tennessee. In addition, data accuracy was limited in some cases by program time limitations (one day) allocated to complete assessments and the specific knowledgability of plant representatives. Notwithstanding these limitations, very little similar data is available in other literature sources and thus the preliminary findings presented are of relative importance in providing guidance for further investigations.

Among the most significant results of the data trends previously presented are the following:

Among economic aspects, the implementation rate of recommended waste reduction measures appears to increase over limited ranges of plant production expressed as annual sales and the potential cost savings of the measures specified. Other factors which initially might be considered important (e.g. waste management costs, measure implementation costs) are shown to have minimal effect. As expected, the percentage of measures reported as implemented decreases notably as the projected payback period becomes longer.

For the two non-economic factors considered, both the regulatory status of the waste stream and the quality of the report affect the number of measures implemented. Perhaps these issues ultimately help to distinguish which measures should be further considered for implementation among otherwise attractive alternatives.

In future work, the consideration of additional factors and data which were not available for inclusion in the present analysis may prove important. One such analysis would be to determine the relative importance of the factors considered among industries in various industrial SIC categories. Perhaps one or more of the economic factors seemingly unimportant for the pooled data might be shown to be more important for specific industries (e.g. those which require a relatively high implementation cost). Finally, assessment teams have observed that interest in the recommendations made (and presumably the implementation rate) may depend on the presence of a "champion" among plant managers. Such individuals may promote "pet projects" even to the extent of disregarding normal economic thresholds. Such additional factors may be important in gaining a further understanding of the more unexpected results presented here and may in fact uncover the set of primary factors that determine which waste reduction measures are implemented in manufacturing settings.

REFERENCES

Jendrucko, R. and K. Binkley, "Factors Affecting the Implementation of Energy Conservation Measures Identified During Audits of Manufacturing Facilities'" 14 World Energy Engineering Congress, Atlanta, October 24,1991, and published in the Proceedings, pages 433-434.

Overly, Jonathan G. "Characterization and Statistical Analysis of Industrial Data Compiled by the University of Tennessee Industrial Assessment Center." Master's Thesis, Department of Mechanical and Aerospace Engineering and Engineering Science, University of Tennessee, May 1997.

TABLE 1: FACILITY PRELIMINARY AND WASTE INFORMATION

SIC Group	Products	Plant Annual Sales (in millions)	Floorspace (thousands of square feet)	Waste Recommendations		
				Total #	# Implemented	% Implemented
20	Mints	$10	65	3	1	33%
	Hotdog & hamburger buns	$10	100	2	0	0%
	Frozen poultry products	$50	70	1	1	100%
22	Polyester fabrics	$25	100	4	1	25%
	Finished fabric	$10	115	1	0	0%
23	Public service uniforms	$50	185	1	0	0%
	Uniforms	$18	54	1	0	0%
24	Interior wooden doors	$15	78	5	1	20%
	Hardwood flooring	$36	350	4	1	25%
	Wooden doors & frames	$11	208	1	1	100%
25	Wood furniture	$20	200	3	1	33%
	Indoor metal furniture	$50	50	1	0	0%
26	Cardboard boxes	$18	53	4	1	25%
	Specialty bags	$55	640	3	0	0%
27	Commercial printing	$13	82	3	0	0%
	Brochures & catalogs	$7.5	37	4	0	0%
	Printed publications	$40	148	4	0	0%
	Printed paper products	$10	75	1	0	0%
	Colored envelopes	$70	192	1	1	100%
	Printed business matter	$7	33	3	2	67%
28	Water-based polymers	$50	300	4	2	50%
	Plastic additives	$10	40	1	0	0%
30	Retread materials	$52	80	4	1	25%
	Plastic extrusion molds	$6	50	2	0	0%
	Molded plastic parts	$11	150	1	0	0%
32	Sound insulation	$60	300	5	3	60%
33	Investment castings	$5	20	5	2	40%
	Small electric motors	$65	226	3	1	33%
	Precious material catalysts	$40	215	3	0	0%
34	Electroplated goods	$6	90	5	2	40%
	Icemakers & fuse cables	$88	162	2	0	0%
	Hydraulic valves	$35	150	6	4	67%
35	Mining equipment	$30	65	4	2	50%
	Hydraulic pumps	$18	73	3	1	33%
	Transmisions & reducers	$8	66	2	0	0%
36	BBQ grill and oven racks	$10	60	1	0	0%
	Actuators & controls	$50	93	3	3	100%
	Electric and gas ranges	$300	430	3	1	33%
37	Truck transmissions	$14	98	4	0	0%
	Trailer platforms	$71	160	3	3	100%
	Master cylinders	$65	175	4	0	0%
	Hose connectors	$25	75	2	1	50%
38	Analytical instruments	$30	160	1	1	100%
	Totals	////	////	121	38	////
	Averages	$37	141	3	1	30%

ECONOMICALLY ATTRACTIVE MATERIALS RECYCLING IN SMALL- TO MEDIUM-SIZED MANUFACTURING PLANTS

Richard J. Jendrucko, Ph.D., Laura M. Buchanan and Waldo A. Margheim, B.S.

ABSTRACT

The DOE-supported University of Tennessee Industrial Assessment Center (UTIAC) utilizes engineering faculty-student teams to perform in-plant assessments for regional small- to medium-sized industrial manufacturing plants. Since 1993, the focus of the program has been broadened from energy conservation to include waste minimization as an area in which recommendations are made.

Since November 1993, 66 companies in seventeen Standard Industrial Classification (SIC) categories have received energy/waste assessments and provided follow-up information about the success of the visit. For these 66 clients, a total of 54 recommendations dealing with the recycling of industrial waste materials were made by the UTIAC. The average potential savings for these 54 recommendations was $18,415 with an average associated implementation cost of $16,740.

Within a period of up to one year after submission of a report of findings and recommendations to clients, each was contacted by phone to assess whether or not they had decided to implement the specific waste measures recommended. The overall implementation rate of the recycling recommendations made was 39%. A first-order trend analysis of the composite data provided evidence of the relative influence of simple economic factors in the decision to implement recycling recommendations. Neither cost savings, implementation costs nor payback period appeared to be a major factor in the decision-making process. Other factors including quality of the assessment and potential waste reduction were shown to be of limited importance to plant managers making decisions on recycling actions.

INTRODUCTION

In the development of the Environmental Protection Agency's hierarchy for pollution prevention techniques, source reduction has been identified as the favored approach as illustrated in Figure 1. Through this method, wastes do not have to be handled, treated or disposed, thereby allowing associated costs to be reduced or eliminated. Therefore, source reduction is more environmentally desirable than recycling or treatment (as needed) and disposal.

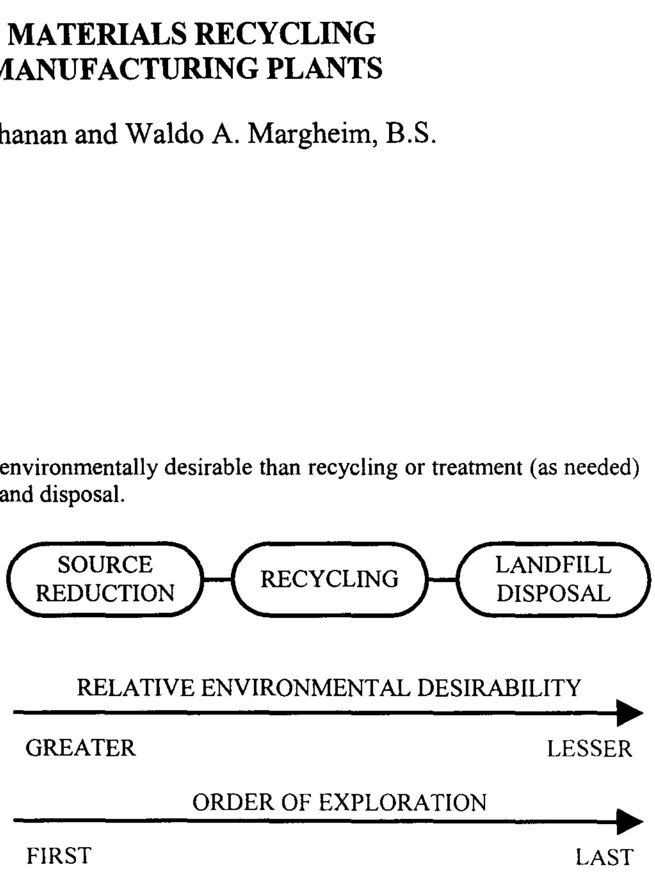

FIGURE 1. HIERARCHY OF WASTE MINIMIZATION. (AFTER DRABKIN, 1988)

Unfortunately, in many industrial processes, elimination or prevention of waste generation is neither technically nor economically feasible. Even for plants which have implemented successful waste minimization programs as discussed in "Defense Programs Benchmarking in Chicago, April 1994" (1995), significant amounts of waste could still be generated in one or more of the following categories:

- Empty raw materials containers
  Examples: cardboard boxes, wooden pallets or crates, metal, plastic or glass containers, gas or aerosol tanks or cans
- Residual or contaminated process raw materials
  Examples: solid and liquid container residuals, solid cut off (end) pieces
- Waste ancillary processing materials
  Examples: contaminated paper, cloth wipes and gloves, waste processing chemicals, contaminated cleaning solvents

In many cases, industry is unable to eliminate wastes through source reduction and still produces and disposes of significant quantities of the aforementioned waste materials. Although recycling may be considered a second-tier approach to waste minimization, it can minimize the adverse environmental effects and costs associated with the disposal of many wastes. As environmentalism and governmental regulation has advanced in recent years, a renewed impetus for recycling materials formerly disposed with landfilled municipal refuse has emerged.

In many cases, the precise location of recycling efforts (onsite versus offsite) and the methods by which recycling will occur may affect an industry's acceptance of recycling as a viable alternative to landfilling. Three classifications of recycling within industrial facilities that can be considered are: in-process, in-plant and offsite. A flowsheet detailing the elements of recycling is shown in Figure 2.

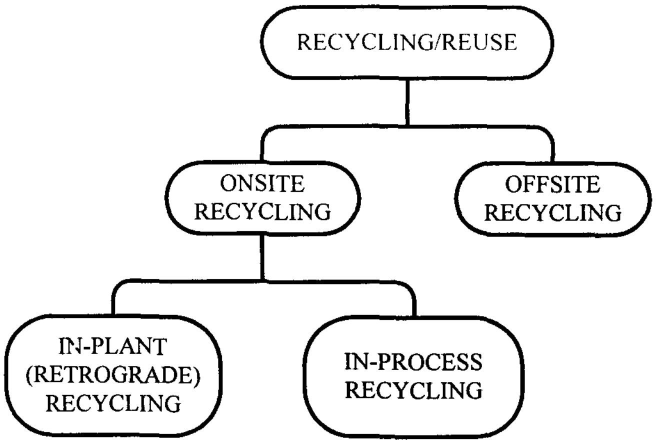

FIGURE 2. THE CLASSIFICATIONS OF RECYCLING. (AFTER DRABKIN, 1988)

Through in-process recycling, a waste material is reused in the same capacity it was originally intended. This may or may not involve the need to recover (as a process feedstock or raw material), clean or treat the waste material prior to use. For example, contaminated cleaning solvents may be distilled and then reused. When recycling materials in-process, trial runs or testing should be completed to ensure that negative impacts on manufacturing productivity or product quality do not result.

Through in-plant recycling, a waste material inside the facility is reused in a different capacity than its original use. Also known as a retrograde use, an example of this type of recycling would be the use of waste oil as fuel in an onsite waste oil heater. In-plant recycling frequently requires creativity and research on the part of plant management to identify alternative uses of waste materials.

Offsite recycling, the most common approach, simply involves shipping the waste material offsite to another facility. The second facility will then use the waste material directly as a raw material in its process, or sell the material to a third facility for use. When acting as a third party, the second facility may or may not have to process the waste before selling it to the third facility. Although offsite recycling may yield smaller returns than in-plant or in-process recycling, many industries are unable to devote the time and resources to this further processing. Therefore, the use of a liaison may be more convenient and attractive to the facility. Currently, the most common form of recycling by industrial facilities involves materials transported offsite. Paper, cardboard, plastic, metal and glass are examples of materials that are commonly recycled offsite.

Before offsite recycling can be considered, a market must be established for the waste, which may result in one of three situations. The waste producer will pay more in transportation and associated costs to have the waste removed than will be realized from the sale of the waste (if the waste is indeed sold instead of just being delivered to a recycling company). The second situation is the most common wherein the cost of handling and transporting the waste is approximately the same as the profit realized from the sale of the waste. Ideally, however, the waste producer will receive payment for the waste materials that will more than pay for the handling and transportation of the waste.

Over time there have been efforts to globalize recycling. Clearinghouses, such as those created by various state agencies in the U.S., have been established to act as third parties which match waste producers with facilities that can utilize the waste in a meaningful fashion. Waste exchanges operate on the principle that discarded waste from one facility may be a valuable resource or serve as a raw material for another. Examples include the Tennessee Materials Exchange developed by the University of Tennessee Center for Industrial Services, the Kentucky Industrial Manufacturing Exchange developed by the Kentucky Pollution Prevention Center and the Southeast Waste Exchange located in North Carolina.

FACTORS MOTIVATING WASTE MATERIALS RECYCLING

In general, two main reasons for recycling materials are considered. The first is to remove the bulk material from the facility so it does not occupy valuable space and impede production operations. In this case, recycling may be an attractive alternative to landfilling since costs of the latter may be reduced. Second, as stricter legislation and landfill disposal laws are promulgated, it is becoming more difficult to dispose of many industrial waste materials in a landfill. Therefore, recycling would be next most logical form of disposal. In addition to these two factors, economics also plays a major role in the decision-making process of deciding whether to recycle a material or dispose of it in another manner.

There are many economic issues involved in recycling industrial materials which may be classified into two sub-categories: waste handling and waste characteristics. There are many costs associated with the handling of wastes from the point of generation to final disposal. The waste must first be transported from the point of production to a container located in the facility. The waste may then need to be processed prior to removal from the site (i.e., segregated from other waste streams, baled or otherwise packaged). Packaged waste must then be transported to the recycling facility.

Transportation fees are generally a major factor when deciding whether or not to recycle a material offsite. Trucking fees are generally based on weight. Even though the facility may receive money from the recycling company for the waste, this is often approximately equivalent to or less than the cost of transporting the waste to the recycling facility.

Waste characteristics also determine costs associated with recycling and disposing of wastes. Many recycling companies require a minimum amount of material before acceptance of the waste. On the other hand, landfills may have a maximum amount of recyclable waste that will be accepted for disposal. Some materials may need to be segregated or packaged in a particular manner. For example, most companies will not accept loose loads of cardboard. The cardboard must be baled to facilitate handling. Also, it is typically much more costly to dispose of hazardous wastes than non-hazardous wastes. In some cases, hazardous materials may be processed in some manner onsite to render them non-hazardous; however, this also requires additional expense. Due to increased environmental regulations and potential liability, many companies are eliminating previously generated hazardous wastes and associated disposal concerns. Currently, the focus is shifting from the elimination of hazardous wastes to the reduction of non-hazardous wastes. In essence, an evolution is occurring in which the next logical step would be further advances in the concept of source reduction.

At the present, as the recycling of non-hazardous materials is taking center stage, there is a lack of data on recycling trends among industrial manufacturers. The "OIT Times," published by the U.S. Department of Energy, Office of Industrial Technologies, reported in the Spring 1998 issue that the industrial recycling of plastic bottles, glass packaging, aluminum, steel cans and paper has been on the rise this decade. Obviously, more of these waste materials are being recycled than in the past, but there appears to be a need for knowledge of specific recycling opportunities. Related to this, there is a lack of knowledge and actual plant data concerning the reasons for recycling. More plant-specific quantitative data is needed to motivate further progress in this area. Data from four years of UTIAC work may provide some insight on the relevance of several factors to the decision-making process. The objective of this study is to analyze case study information to determine if economics and other factors play a role in the decision-making process of plant managers and engineers within industrial manufacturers as to whether or not waste materials are recycled.

UTIAC MATERIALS RECYCLING DATA

During the period of November 1993 through July 1997, a total of 66 small- to medium-sized manufacturers in a variety of industries have received waste reduction technical assistance from the DOE-supported University of Tennessee Industrial Assessment Center (UTIAC) for which recommended measure implementation data is available. Implementation data was obtained by telephone contact with plant management between six months to one year after receiving the final assessment report containing the waste minimization recommendations. A previous study conducted by the UTIAC entitled, "Factors Affecting the Implementation of Waste Reduction Measures in Small- to Medium-Sized Manufacturing Plants," (Jendrucko, et al., 1997) was conducted to provide evidence of the relative influence of several plant-specific factors in the decision to implement waste reduction measures. The two most influential factors for implementation were found to be the payback period of the recommendation and the plant manager's perception of the quality of the assessment provided. The purpose of the following analysis is to discuss the factors which may have influenced the specific decisions of whether or not to recycle various industrial materials.

The 66 clients served reported a total of 287 material waste streams as already being recycled at the time of the assessment. The materials recycled included commonly encountered industrial wastes such as waste cardboard packaging and office paper. Some process-specific materials such as waste cured rubber were also being recycled. In most cases, plant personnel reported an attractive economic benefit from recycling. In other instances, recycling was done on a no-cost/no-revenue basis simply as an alternative means to land disposal.

A total of 54 recommendations dealing with the recycling of industrial materials were made to these clients by the UTIAC. These 54 recommendations were estimated by the UTIAC to yield $994,433 in total potential savings at a total implementation cost of $903,934. The average estimated payback for the 54 recommendations made was 1.2 years. The total estimated annual reduction in waste from these 54 recommendations was 343,411,895 pounds.

Of the 54 recommendations made, 33 (61%) were reported as not implemented or were being considered by the facility while 21 (39%) were reported as implemented. This information, which is compiled in Table 1 using information from the reports containing costs and savings estimates made by the UTIAC, can be used to examine the economics associated with the implemented assessment recommendations (ARs) as compared to the unimplemented recommendations. Although the average payback for the implemented recommendations was shorter than the average payback for the unimplemented recommendations, the initial implementation cost was higher for the implemented recommendations. Therefore, it is unclear which economic factors may be most important when deciding whether or not to implement a recycling opportunity. Since the UTIAC estimates failed to identify clear trends, actual implementation data was also analyzed.

Actual data reported by the clients concerning the 21 recommendations that were implemented show that the average savings is $12,325 with an average implementation cost of $8,304. The average actual payback of these implemented recommendations was 0.7 year. The savings estimated by the UTIAC were very close to the actual savings while the average implementation cost for these recommendations were notably low. This may be due to the fact that the UTIAC typically conservatively estimates implementation costs higher than those actually incurred. However, the actual payback period was almost identical to the estimated average payback for the 21 recommendations.

Figures 3-5 present relationships between the savings, costs and payback periods of recycling recommendations and implementation rates. The histogram of Figure 3 shows no clear trend relating the implementation rate to the estimated cost savings. It would be expected that recommendations with large savings would have a higher degree of implementation while those with minimal savings would remain unimplemented due to insignificance or lack of "exciting" materials recycling opportunities.

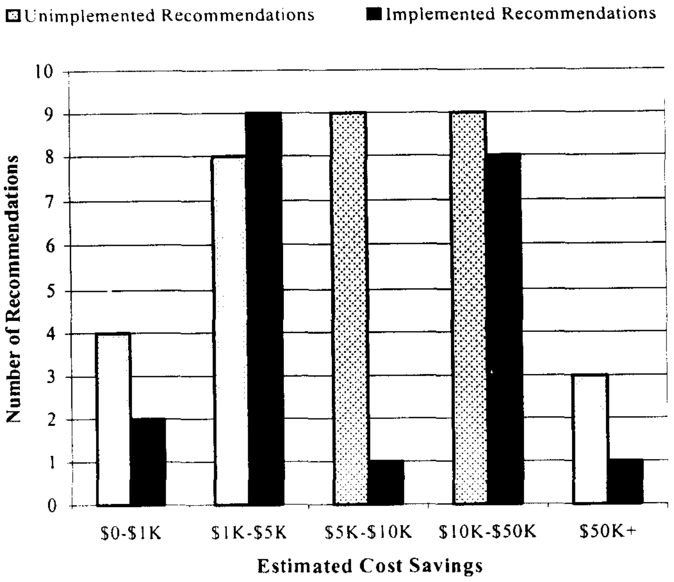

FIGURE 3. IMPLEMENTATION RATES VERSUS ESTIMATED COST SAVINGS.

The histogram of Figure 4 shows that a large number of recommendations with an estimated implementation cost of $1,000 or below were implemented. However, the same number of recommendations with implementation costs of $1,000 or below were not implemented. Since there was a lack of any trends in the data of Figures 3 and 4, Figure 5 was prepared to determine if the relationship between savings and implementation cost was important. It appears likely that recommendations with short payback periods would be implemented often, which is reflected in the histogram trend. However, just as many recommendations with a payback period of six months or less were not implemented. Therefore, based on this data, it appears that recycling decision-making is not necessarily based on simple economic considerations.

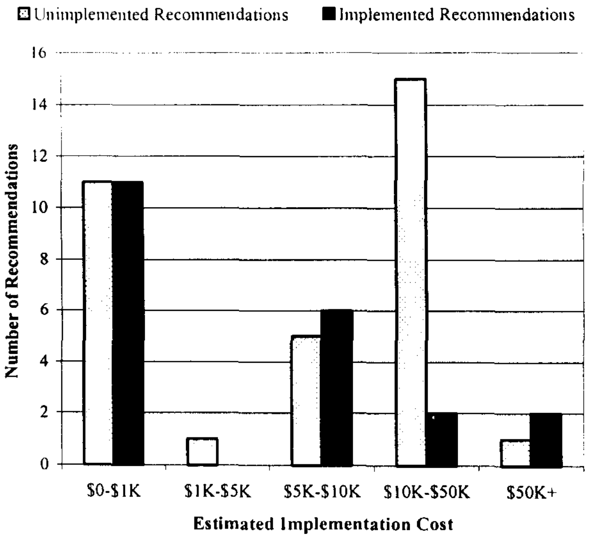

FIGURE 4. IMPLEMENTATION RATES VERSUS ESTIMATED IMPLEMENTATION COST.

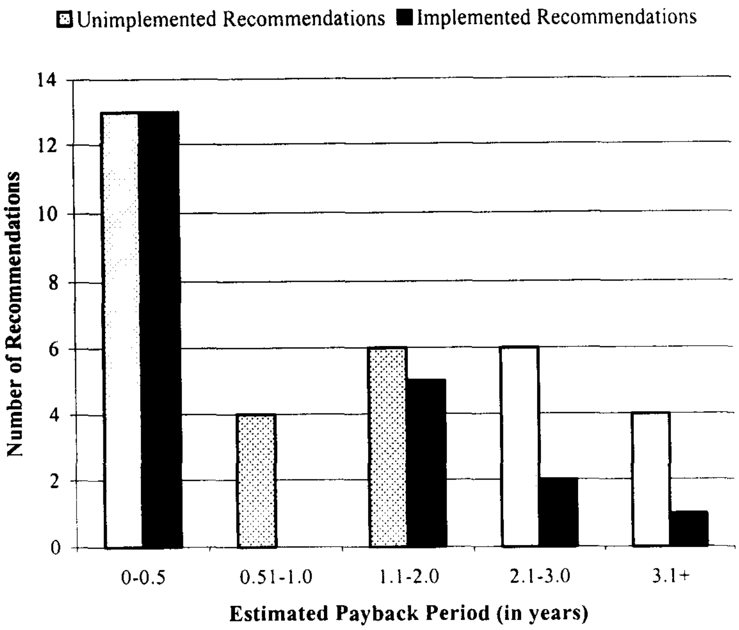

FIGURE 5. IMPLEMENTATION RATES VERSUS ESTIMATED PAYBACK PERIOD.

The amount of potential waste reduction was also considered in this analysis. In general, the more solid waste that is recycled the less landfill disposal costs a facility will incur. Figure 6 reveals that the amount of potential waste reduction has no clear effect on whether or not the recycling recommendation was implemented. It must be noted that this information may be skewed due to a few relatively large waste streams such as process wastewater which may account for many millions of pounds of material which may be recycled.

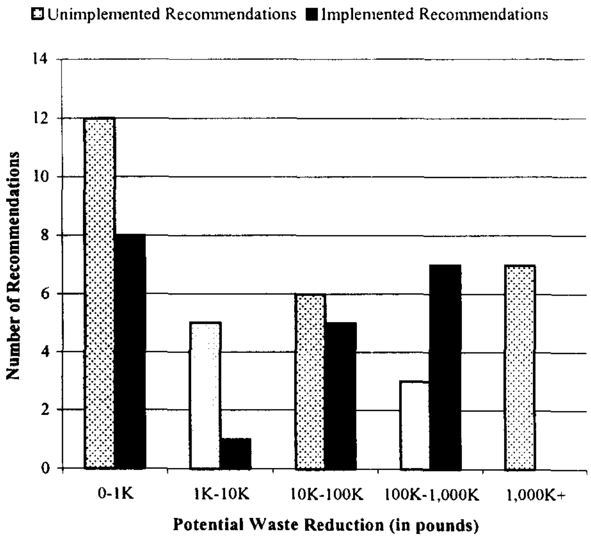

FIGURE 6. IMPLEMENTATION RATES VERSUS POTENTIAL WASTE REDUCTION.

The 54 recycling recommendations were classified based on the material being recycled as shown in Table 2. Waste cardboard and wooden pallets were the materials recommended to be recycled most frequently. This result may not be surprising since almost all facilities receive some raw materials in cardboard containers on pallets. As indicated earlier, many facilities already recycle most of these materials and the recommendations concerning these materials had a high implementation rate.

Table 2 data also reveals that the only recommendations that were implemented more than 50% of the time were those dealing with cardboard. This may be due to the fact that cardboard is generally segregated very easily and has only a moderate density; therefore, transportation costs are relatively low. However, many recyclers mandate that recycled cardboard be baled before acceptance. Cardboard also has a relatively low market value. *Recycling Works*, a publication of the North Carolina Recycling Business Assistance Center, reports a market price of $90 per ton of baled cardboard in the eastern region of the United States as of January 15, 1998. For comparison, the same publication reports the market price for aluminum cans to be $1,100 per ton and baled PETE plastic to be $200 per ton. Again, economics does not appear to be a key factor in the recycling decision-making process.

None of the materials that were unique to a particular facility were recycled even though the amount of waste reduction was high and the payback period for recycling measures was relatively short for these recommendations. Many of the recommendations had a payback period of less than one year as shown in Table 3; however, Table 1 shows this did not seem to correlate with whether or not the recommendations were implemented.

Materials such as paper, aluminum and oil have very few recommendations concerning them mainly due to the fact that most facilities are currently recycling these relatively valuable materials. For a variety of reasons, most facilities are reaping some benefit from recycling these materials. The savings and implementation costs of the paper and aluminum recommendations were fairly low, while the savings possible from the oil recycling recommendations were high. However, the related implementation costs were also high.

The recommendations made by the UTIAC were also analyzed in terms of the form of recycling used: in-plant, in-process or offsite. Table 4 data shows that most of the recommendations were concerning offsite recycling. The histogram of Figure 7 reveals that a large majority of the recommendations that were actually implemented involved offsite recycling. Offsite recycling is the most common form of recycling and probably the easiest and least costly for most situations. In-plant recycling may require the acquisition of new pieces of equipment to handle and process the material such as new materials transportation systems while in-process recycling may require testing and laboratory work to determine if using recycled material will degrade productivity or product quality or performance. In addition, it is generally more difficult for an assessment team to recommend recycling efforts that are very specific to a facility or process, which would be the case for in-plant and in-process recycling, due to project time limitations (one day) allocated to complete assessments.

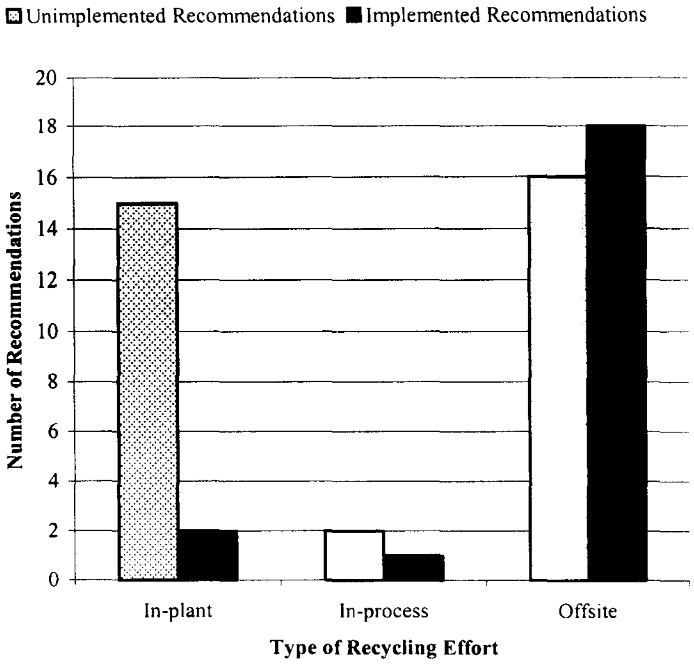

FIGURE 7. IMPLEMENTATION RATES VERSUS TYPE OF RECYCLING EFFORT.

Often, there is a concern on the part of plant management when recycling a material back into a production process. This is often the case when recycling water as reflected in the data of Table 2 in which none of the five water recycling recommendations were implemented. Management may feel that using a recycled material in the production process generates too high a risk of degrading product quality or productivity. For most materials, however, this concern is unwarranted. Many times, referencing published case studies in which the proposed recycling was successful in another similar facility can eliminate these concerns.

Another reason many of the recommendations made were not implemented may be due to the cost of the original material. Water is an excellent example. Water is relatively inexpensive, thus there is less motivation on the part of plant management to reduce the amount of water purchases via recycling within a facility. Many managers believe it would be less cost effective to install the additional piping and pumps and possible treatment equipment necessary for reuse than to continue using utility-supplied water as they have in the past with no concern for reduction. Fortunately, water shortages and quality problems are beginning to alter this type of mindset.

Since basic economics did not appear to play a major role in recycling decision-making, the reasons cited by plant personnel for not implementing the recommendations made was analyzed. These results are shown in the histogram of Figure 8. Of the 28 unimplemented recommendations made for the 66 clients, two plant managers reported the reason to be too large of a capital expense, while one reported the return on investment was too high. Surprisingly, the second most common reason for not implementing recommendations was due to a perception that the recommendation was impractical.

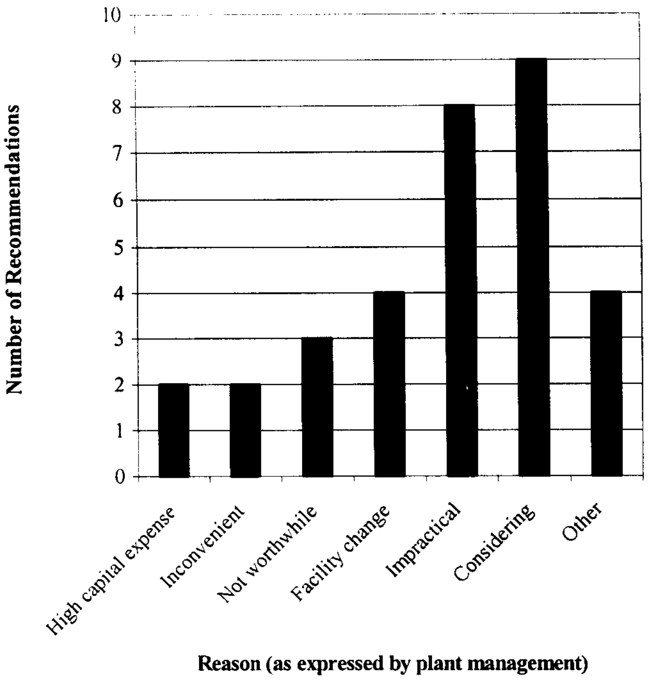

FIGURE 8. REASONS CITED FOR NOT IMPLEMENTING RECOMMENDATIONS.

Finally, the rates of implementation were analyzed according to the perceived quality of the assessment by plant personnel as reflected in the histogram of Figure 9. In general, the greater the quality of the assessment the more recommendations were implemented. However, the same trend occurred for the recommendations that were not implemented.

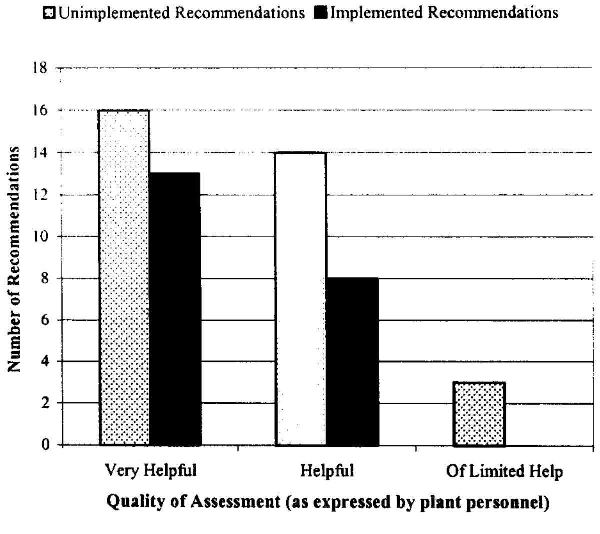

FIGURE 9. PERCEIVED QUALITY OF ASSESSMENT.

SUMMARY AND CONCLUSIONS

The offsite recycling of metals has occurred for many years due to their relatively high market value. The recycling of lower value materials such as cardboard, paper, glass and plastic has been more difficult to justify economically due to their relatively low market value. The data presented here shows that many of the industrial wastes with low market value are being recycled while others are not. The recommendations and actual payback period data presented reveal that there are still economically attractive waste material recycling actions which can be undertaken by industrial manufacturers to reduce waste disposal and, in most cases, to produce additional income. However, no clear correlations exist that show a strict economic motivation for recycling a particular waste material.

In order to put in perspective the limited analyses previously presented, certain characteristics and criteria of the client pool should be considered. The data used were limited to 66 small- to medium-sized manufacturers in a variety of industries, most of whom were located within a 150 mile radius of Knoxville, Tennessee. In addition, data accuracy was limited in some cases by program time limitations (one day) allocated to complete assessments and the specific knowledgability of plant representatives. Notwithstanding these limitations, very little similar data is available in other literature sources and thus the preliminary findings presented are of relative importance in providing guidance for further investigations.

The field data obtained by the UTIAC suggests a high level of variability as to the reasons for recycling industrial waste materials. As shown by the data, the reasons are not simply related to economics and potential payback. Other factors appear to be more important such as the interest of particular plant managers and possibly the limitations in landfill disposal options.

In future work, the consideration of additional factors and data which were not available for inclusion in this analysis may be warranted. Implementation of recommendations presented by the UTIAC seem to "have a significant human element" involved. Assessment teams have noted that interest and possibly implementation rate of the recommendations presented in the UTIAC reports may depend on the presence of a "champion" among plant managers. Such individuals may promote "pet projects" even to the extent of disregarding normal economic thresholds such as long payback periods. Similar ideas have been presented in similar waste minimization assessments performed earlier by EPA-sponsored groups (1). During these EPA-sponsored assessments, Drabkin (1988) reported that the personal interactions between the assessment team and the host facility helped determine the effectiveness of the assessment. Such additional factors may be important in gaining a further understanding of the more unexpected results presented here and may in fact uncover other primary factors that may determine whether or not certain materials are recycled.

The human element is also factor within facilities between plant management and plant production employees. Management must be willing to change and provide the necessary resources to provide this change. Many recycling steps, such as segregation, must involve the cooperation of the plant workers. If management does not believe their employees will cooperate in implementing a recommendation, they may not implement it.

Management must take the time to instill the importance of these ideas in the employees to ensure success.

As a result of this analysis, the UTIAC will modify the approach used to promote recycling recommendations. The implementation section of the recommendation write-ups will incorporate more "industrial psychology" and emphasis on the simplicity of the recommendation. More work must be done to make the recommendations appear worthwhile even when small waste quantities and minimum cost savings are involved. There will be an attempt to provide case studies and published data to reinforce the idea of the potential savings and worthiness of certain recycling recommendations. In addition, to provide more impetus to implement in-plant and in-process recycling recommendations, more implementation costs for laboratory testing and trial runs will be considered. By slightly changing the format in which the recycling recommendations are presented, the UTIAC believes that the implementation rate of its recycling recommendations can be increased significantly.

Although recycling is a second-tier approach to waste minimization, it is an important and valuable waste reduction tool. It is clear that recycling has occurred regularly for some materials, such as metals, but sporadically for others. There is a broad class of waste materials with modest market value that account for a large fraction of the waste streams of most industrial facilities. There are issues besides economics associated with the recycling of these materials because many facilities are still not recycling economically attractive materials. It is desired that the insight provided concerning the reasons for implementing comprehensive recycling programs for all industrial wastes can help industrial facilities evolve their waste minimization programs to the next level: source reduction.

REFERENCES

1. Drabkin, M. (1988). "The Waste Minimization Assessment: A Useful Tool for the Reduction of Industrial Hazardous Wastes." *JAPCA*, 38(12), 1530-1541.

2. "Defense Programs Benchmarking in Chicago, April 1994: Identifying Best Practices in the Pollution Prevention Programs of Selected Private Industries," Contract No. DE-AC01-93DP00249, U.S. Department of Energy, Office of Defense Programs, 1995.

3. "Recycling Works," North Carolina Recycling Business Assistance Center, 4(1), March 1998.

4. "OIT Times," U.S. Department of Energy, Office of Industrial Technologies, Issue 2, Spring 1998.

5. Jendrucko, R.J., L.M. Buchanan, and J.G. Overly (1997). "Factors Affecting the Implementation of Waste Reduction Measures in Small- to Medium-Sized Manufacturing Plants."

Economic Value	21 Implemented ARs	33 Unimplemented ARs
Total Cost Savings	$391,083	$603,350
Average Cost Savings	$18,623	$18,283
Total Implementation Costs	$453,508	$450,426
Average Implementation Cost	$21,596	$13,650
Average Payback	0.8 year	1.3 years
# of ARs with Payback < 1 year	13 of 21 (62%)	17 of 33 (52%)

TABLE 1. COMPARISON OF IMPLEMENTED AND UNIMPLEMENTED RECOMMENDATIONS.

Recyclable Material	**# of Recommendations**	**Implemented**		**Not Implemented**	
Cardboard	17	11	65%	6	35%
Pallets	8	3	38%	5	63%
Solvent	6	1	17%	5	83%
Process-Unique	6	0	0%	6	100%
Water	5	0	0%	5	100%
Rags	3	1	33%	2	67%
Steel	3	1	33%	2	67%
Paper	2	1	50%	1	50%
Coolant	1	0	0%	1	100%
Waste Wood	1	0	0%	1	100%
Oil	1	0	0%	1	100%
Aluminum	1	0	0%	1	100%

TABLE 2. WASTE REDUCTION MEASURE IMPLEMENTATION RATES FOR VARIOUS MATERIALS.

		Total			Average		
Recyclable Material	**Average Payback**	**Estimated Savings**	**Estimated Imp. Cost**	**Waste Reduction**	**Estimated Savings**	**Estimated Imp. Cost**	**Waste Reduction**
Cardboard	1.3	$127,695	$105,060	3,654,001	$7,511	$6,180	214,941
Pallets	1.1	$252,450	$356,900	91,100	$31,556	$44,613	11,388
Solvent	1.6	$106,585	$134,740	63,693	$17,764	$22,457	10,616
Process-Unique	1.5	$163,008	$104,560	25,208,840	$27,168	$17,427	4,201,473
Water	1.6	$117,192	$158,350	314,164,660	$23,438	$31,670	62,832,932
Rags	0.0	$7,600	$0	24,000	$2,533	$0	8,000
Steel	0.0	$67,480	$0	0	$22,493	$0	0
Paper	1.1	$4,510	$8,288	5,000	$2,255	$4,144	2,500
Coolant	0.2	$119,243	$20,200	155,591	$119,243	$20,200	155,591
Waste Wood	0.0	$3,270	$0	0	$3,270	$0	0
Oil	0.8	$19,814	$15,400	43,838	$19,814	$15,400	43,838
Aluminum	1.1	$586	$636	1,172	$586	$636	1,172

TABLE 3. WASTE REDUCTION MEASURE METRICS FOR VARIOUS MATERIALS.

Recyclable Material	**# of Recommendations**	**Type of Recycling**		
		In-plant	**In-Process**	**Offsite**
Cardboard	17	0	0	17
Pallets	8	5	0	3
Solvent	6	5	0	1
Process-Unique	6	1	2	3
Water	5	5	0	0
Rags	3	0	0	3
Steel	3	0	0	3
Paper	2	0	0	2
Coolant	1	1	0	0
Waste Wood	1	0	0	1
Oil	1	0	1	0
Aluminum	1	0	0	1

TABLE 4. FREQUENCY OF RECOMMENDATION TYPE(S) FOR VARIOUS MATERIALS .

V. PRODUCTIVITY ASSESSMENT

The newest area of concern of the industrial assessment is productivity enhancement. In 1996, productivity enhancement was added to the other technical areas of energy conservation and waste minimization. Since this is the most recent addition to assessment work, the IAC Program is still developing effective ways of addressing productivity issues such as Just-In-Time (JIT) inventory planning, optimizing plant layouts, instituting employee motivational programs and reducing equipment downtime. The successful completion of the productivity assessment requires the following:

1. Identifying and listing goals the plant has previously accomplished in the area of productivity enhancement.
2. Compiling productivity metrics including salary and fringe benefit rates, company profit margin, value and quantity of raw material, work in progress and finished goods inventories and inventory carrying costs.
3. Researching and preparing recommendations that target productivity enhancement and outlining ways to improve industrial productivity.
4. Preparing a secondary list of minor productivity enhancement measures that were not recommended due to minimal savings, lengthy paybacks or other reasons.

VI. PROGRAM ACHIEVEMENTS

The University of Tennessee IAC (UTIAC) is the oldest of the thirty Centers operating nationwide. For this reason, the Center Director at the UTIAC, Dr. Richard J. Jendrucko, has trained the staff at other Centers on numerous occasions. In addition to being a highly respected Center from the national standpoint, the UTIAC is still being rewarded for its accomplishments. On August 13 1998, Ms. Denise Swink, Deputy Assistant Secretary for the DOE Office of Industrial Technology, presented the UTIAC with an Outstanding Service Award. This award presentation was accompanied by an overview of the IAC Program and identification of major achievements to date. Although the UTIAC has existed for over twenty years, the Center's effectiveness and contribution to the national program is still being recognized.

VII. FUTURE CAREER OPPORTUNITIES

My individual experience with the IAC Program at the University of Tennessee has benefited both my engineering education and my formulation of future goals for work as a mechanical engineer. My three years working for the UTIAC has taught me skills that are valued by virtually all employers: technical training, written and verbal communication skills, teamwork and motivation. Through the requirements of the program, I have opened many future career opportunities. My immediate post-graduate job will be with Alabama Power, a division of the Southern Company, in Birmingham, AL, designing transmission lines for electrical power service. Another opportunity within the company is with the Industrial Marketing department which performs energy assessments very similar to those performed by the IAC Program.

My experience at the University of Tennessee Industrial Assessment Center has been a great help to my engineering education and future career plans. A major mission of the program is to allow industrial manufacturing to provide practical experience for engineering students.