Development and Field Testing of a Total Assessment Audit Protocol for the Chemical Industry

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Introduction

As part of the State Technologies Assistance Collaborative (STAC) program for the chemicals industry, a team of multi-disciplined engineers, led by the Energy Resources Center (ERC) at the University of Illinois at Chicago was brought together to design an audit program that can be used throughout the industry to help chemical manufacturers reduce operating costs. The program protocol was developed and tested at seven manufacturing sites in Illinois, Indiana and Ohio. This program protocol will be made available throughout the industry to any group wishing to reduce operating costs through site audits.

The protocol for this program is based on the Metal Casters Total Assessment Audit Program (Metal Casters TAA Program). This business assistance program was organized in late 1998 and early 1999 to deliver on-site services to members of the metal casting industry (NAICS 3315, Foundries) within the State of Illinois. Through the use of an audit, recommendation, and implementation model originally field-tested at a foundry in Iowa in 1996, the program team aimed to capture a realistic "snapshot" of the metal casting clients' routine and operations. A multi-disciplinary assessment team formulated a list of observations, leading to the categorization of process flows, problem areas, production bottlenecks, incongruities, opportunities for improvements and efficiencies, and methods for implementation of corrective measures. The Metal Casters TAA Program served nine individual metal casting firms in the State of Illinois. The final report documented the results of the effort through a description of the TAA and relevant case studies. Each of the metal casting firms was provided with detailed operational and process maps, an assessment in areas relevant to production and business operations, and a presentation of the assessment observations and recommendations. For this group of clients, the on-site project teams generated more than 1,000 individual observations and recommendations. More than 100 of these recommendations have been implemented to date.

The Metal Casters TAA Program served as the model for the development of the protocol for the Chemical TAA Program, the results of which are detailed in this report. Like the Metal Casting TAA program, the Chemicals TAA program was completed by a coalition of government agencies, academic institutions, non-governmental organizations and utility companies.

The Chemical and Allied Products Industry (Chemicals Industry) has been chosen for this study because of its overall importance to the U.S. economy and the opportunities for significant improvements in the utilization of energy resources. The Department of Energy's (DOE) Office of Industrial Technologies (OIT) regards the Chemicals Industry as one of the premier industries for energy usage improvement potential. In fact, it is one of the nine DOE Industries of the Future. In 1996, the Chemicals Industry purchased approximately 158.4 billion kWh of electric energy. The cost of this electric energy was almost 5.5 billion dollars.

The cost of purchased fuels was nearly the same at 5.0 billion dollars, suggesting that significant levels of fuel powered system opportunities exist.

Manufacturers included in the program where those in the Chemical and Allied Products Industry (NAICS 325, Chemical Manufacturing) which includes such diverse categories as industrial inorganic chemicals, plastics materials and resins, and cyclic crudes and intermediates. The purpose of this report is to detail the protocol developed for the Chemical TAA Program so that it can be used by any group within the Chemicals Industry.

Protocol Development Results

The primary goal of Chemicals TAA project was to develop and test a protocol for a Total Assessment Audit program within the Chemicals industry. The protocol described below was formulated by the Program Manager, then field tested and optimized during seven subsequent site audits.

Identification of Program Goals

The first step in developing a protocol for the Chemicals TAA Program was to adapt the goals of Metal Casters TAA Program to the chemicals industry. Although many of the procedures and program features from the Metal Casters TAA Program were transferable to the Chemicals TAA Program, the chemicals industry presented many unique challenges due to it's extremely diverse make-up.

The TAA audit process is designed to address manufacturers as whole business entities, capturing the state of the business as it exists at the time of the assessment and making recommendations to improve inefficiencies in a wide range of business areas. Because of the extremely wide scope of this task, it is important that the Chemicals TAA Program goals realistically reflect the resources available to the project. In practice, this means that a TAA program can either address all aspects of a client's business in a limited depth, or the scope can be limited to key business areas which can be analyzed in greater depth.

The Metal Casters TAA Program had a stated goal of including all business areas in site audits. As a result, a large number of recommendations were developed for each site (on average more than 100 recommendations were identified for each site). However, each recommendation was presented in limited detail, with the final assessment report often containing little more than a short description of the existing situation and a short summary of the recommended improvement. This left participating manufacturers with a significant number of recommendations, but with limited knowledge on the benefit and cost of implementing each recommendation. In addition, this format often did not provide room for identifying the process by which the recommendation could be implemented.

In an attempt to improve upon the Metal Casters TAA Program, the Chemicals TAA team acknowledged the need for a greater level of analysis for recommendations by incorporating this need in the goals for the program. The main goal of the program was to develop a comprehensive report on existing business operations within key business areas and identify a comprehensive set of recommendations addressing changes in these operations that will improve site productivity, reduce or eliminate waste generation, and improve energy

efficiency. A secondary goal was to provide a cost/benefit analysis for a limited number of recommendations that clients identified as their top priorities.

In terms of actual numbers of recommendations, the team targeted a realistic expectation that 50 to 75 recommendations should be identified during each assessment. Given the resources of the team, a cost/benefit analysis would be performed for ten to 15 of the highest rated of these recommendations. Furthermore, the remaining recommendations would contain enough detailed information that the client would have a clear understanding of how to go about implementing the recommendation if they chose to do so.

Identification of Program Analysis Area Categories

In order to limit the scope of the program to a manageable size, several key business areas were identified as targets for the STAC Chemicals TAA Program. Within each area, existing business practices were recorded and recommendations for process improvement and cost reduction were identified. The areas were:

- Energy Management – This business area addressed all major energy using systems at each site. It included process energy users such as reactor vessels, drying equipment, distillation columns, etc., as well as process support systems such as steam systems, compressed air systems and lighting. In addition, improvements were identified in broader energy management processes such as utility contracting, energy monitoring and energy accounting.
- Process Safety – Assessment work in process safety encompassed current safety programs and improvements that could be made. In addition, the team detailed any unsafe conditions that exist at the plant.
- Supply Chain Management – This business area included inventory control practices, purchasing processes and sales processes.
- Information Systems – This business area included all systems and processes in place at the local plant level to track accounting, billing, purchasing and production control.
- Waste Minimization – A significant amount of resources in the chemicals industry is dedicated to effectively disposing of wastes generated by production processes. To improve processes in place to dispose of waste, the assessment team investigated methods to reduce the amount of waste generated, improve recycling efforts and improve on-site treatment and processing.
- Green Chemistry – Similar to waste minimization, Green Chemistry is a general set of principles that help to identify ways in that hazardous chemicals can be eliminated from the production process.
- Technology – New technologies were actively promoted wherever their use would support improvements in the business areas identified. New technologies were recommended for both production and non-production areas.

The above areas were chosen as areas of investigation because of their significant effect on the cost of operating chemicals plants and their effect on a plant's environmental impact. In addition, these areas can be readily analyzed by a team of engineers, such as the team assembled for the STAC TAA Chemicals Program. Other business areas that have a significant effect on the cost of operating a chemicals plant but were not targeted for investigation include accounting practices and human resources, among others.

Program Team Selection Procedure

The selection of team members was driven strictly by the need to include expertise in the business areas identified as targets for the program. In looking for members to incorporate into the TAA team, the Program Manager identified available resources from a number of different sources including government agencies, academic institutions, non-governmental organizations, and utility companies. Potential team members were evaluated on the following criteria:

1. Expertise in the each business area – Generally, each team member would be responsible for all work completed in one area of analysis. Therefore, team members were sought that had a high level of expertise in one specific area as it related to the chemicals industry. In this way the Program Manager sought to bring together a diverse group of experts from a wide variety of organizations.
2. General industry experience – Although each team member would be responsible for their own area of analysis, team members were sought that had general chemicals industry experience in order to improve the general knowledge of the team.
3. Audit experience – The Program Manager sought team members who have been part of industrial audit teams in the past to ensure that all would understand the responsibilities of team members when on-site during audits. The main concerns were that the team members would be able to effectively and appropriately communicate their ideas during extensive interactions with clients and that all team members would understand that audit duties may require extended periods in hazardous locations.
4. Project availability – Each team member would be required to dedicate a significant amount of time over the period of approximately one year and be available for three day site visits in the states of Illinois, Indiana and Ohio.

Generally, each business area required specific personnel to effectively complete assessment work, although Waste Minimization and Green Chemistry were eventually brought under the responsibility of one team member, as were Information Systems and Supply Chain Management. No team members were specifically assigned responsibilities for Safety, as all team members were responsible for this area.

The Chemicals TAA Program audit team included the following groups:

Energy Resources Center (ERC) at the University of Illinois Chicago – Program Manager

The Energy Resources Center (ERC) is an interdisciplinary public service, research, and special projects organization dedicated to improving energy efficiency and the environment. The ERC's focus is to conduct studies in the fields of energy and the environment and to provide industry, utilities, government agencies and the public with assistance, information, and advice on new technologies, public policy, and professional development training. The ERC has completed over 200 industrial energy audits in the past 10 years and has extensive experience managing industrial audit programs. The ERC has participated in previous TAA efforts and was a Program Manager for the Metal Casters TAA Program. The ERC served in the role of Program Manger for the Chemicals TAA Program and handled all Energy Management analysis responsibilities.

Indiana Clean Manufacturing Technology & Safe Materials Institute

The Indiana Clean Manufacturing Technology & Safe Materials Institute (CMTI) is a state-supported institute established and operated at Purdue University within the School of Civil Engineering. The institute is staffed by six process engineers, an administrator and four technical and administrative support personnel. CMTI acts as the state's focal point for coordinating and deploying technical assistance, outreach, education, planning services and research to facilitate the adoption of pollution prevention/clean manufacturing strategies by Indiana manufacturing facilities. CMTI has worked with hundreds of Indiana manufacturers in all manufacturing sectors, offering special expertise in plastics (including fiber reinforced plastic), wood products, metal finishing, metal and plastic coatings, foundries and motor vehicle parts manufacturing. CMTI was selected to handle all Waste Minimization and Green Chemistry analysis responsibilities.

Exelon Corporation, Technical Services Division

Exelon is one of the nation's largest electric utilities. The Technical Services Division of the company provides customer assistance in energy efficiency and a host of energy related issues. Exelon's Technical services group has credentialed mechanical and chemical engineers that offer an array of services to clients, including facility energy efficiency evaluations, management of energy efficiency projects and commissioning of facility system performance in accordance with design intent. The Technical Services Division of Exelon was previously a team member during the Metal Casters TAA Program and therefore has extensive TAA program experience. Exelon was selected to handle all Technology analysis responsibilities. Exelon also provided the ERC with support in the areas of Energy Management.

Department of Mechanical and Industrial Engineering, University of Illinois at Chicago

Professor Houshang Darabi contributed services to this Project through evaluation of opportunities to provide enhanced efficiencies to the client sites information systems. Dr. Darabi received his Ph.D. degree in Industrial and System Engineering from Rutgers University, in 2000. He is currently an Assistant Professor at the Department of Mechanical and Industrial Engineering, University of Illinois at Chicago. His research interests include the application of Discrete Event Systems control theory in modeling and analysis of business and manufacturing systems, Computer Integrated Manufacturing, supervisory control, mathematical optimization, Enterprise Resource Planning and Manufacturing Information Systems. Dr. Darabi has worked as a system analyst in a New Jersey based fully automated food packaging plant, where he designed and implemented Supervisory Control and Data Acquisition Systems (SCADA). The developed systems were used to manage the information flow between the device and business layers of the plant and to further improve the production productivity. In another project, funded by Honeywell, Dr. Darabi tested and evaluated the performance of Genetic Algorithms in minimizing the power consumption of sensory networks for target detection. Dr. Darabi is a member of IEEE, ISA and INFORMS and he is listed in Who's Who in Engineering Education. Dr. Darabi was selected to handle all Supply Chain Management and Information Systems responsibilities.

Illinois Department of Commerce and Economic Opportunity (DCEO) – Bureau of Energy and Recycling

The DCEO-Bureau of Energy and Recycling administers the State energy programs. DCEO staff provided in kind support by actively and directly participate in many of the aspects of the audit procedure and other program components. In addition, DCEO was a funding agency for the program.

The City of Chicago Department of the Environment

Chicago's Department of the Environment administers a variety of energy efficiency and renewable energy programs for the City as part of its charge of promoting a cleaner environment for Chicago citizens. The Department helped identify chemical industry participants for inclusion in the project, provided technical support for the development of audit procedures and assisted in the distribution of program results. In addition, the Department of the Environment was a funding agency for the program.

The Ohio Department of Development Office of Energy Efficiency

The Ohio Office of Energy Efficiency is charged with promoting "the efficient utilization of energy, for the preservation or creation of jobs and employment opportunities, the encouragement of economic growth, the promotion of the general welfare, the protection of public health and safety, and the protection of environmental quality." As part of this charge, the Office conducts the Ohio State Industries of the Future Program. The Ohio Office of Energy Efficiency helped identify industry partners in Ohio to participate in the project, provided technical assistance during audits and organized a seminar on the results of the effort.

The Indiana Department of Commerce, Energy and Recycling Office

The Indiana Department of Commerce, Energy & Recycling Office (ERO) is the designated State Energy Office for the State of Indiana. It operates over a dozen programs focused on energy and material efficiency. The industrial program includes the Industrial Energy Efficiency Fund (IEEF) program that offers zero-interest loans to help fund manufacturing process improvements, the Indiana Industries of the Future (INIOF) program, that has received its third Special Project Grant, the Distributed Generation Grant Program (DGGP) that provides grants for high-efficiency cogeneration systems and the Energy & Efficiency Audit program that provides audits on a cost share basis to Indiana companies and organizations. The ERO participated in this program assisting in marketing the program in the state and providing engineering assistance in the development of the protocol development

Program Marketing and Candidate Selection Procedure

The STAC Chemicals TAA Program was marketed in a variety of ways. The primary marketing methods were:

1. Networking with existing clients – Each organizational team member had a strong network of contacts within the industrial community and many had strong contacts within the chemicals industry. These contacts were extremely useful in finding companies that were interested in the program. Two clients were found through existing contacts. As part of the program team, state energy offices from the three participating states of Illinois, Indiana and Ohio were particularly helpful in identifying companies that had shown an interest in improving energy efficiency and making changes to increase productivity at their plants.
2. Direct fax marketing – Faxes containing informational brochures about the TAA program were sent to companies listed as chemicals manufacturers in the Dun and Bradstreet database. This method is fairly easy to execute, requiring very little time, however, response to this method is low. Two clients were found using this method. To be most effective, follow-up phone calls had to be made to fax recipients.
3. Direct mail marketing – Like direct fax marketing, this method of marketing is fairly easy to execute, although response to this method is low and this method was most effective when follow-up phone calls were made to mailer recipients. One client was found using this method of marketing.
4. Direct phone marketing – Phone marketing involved making unsolicited phone calls to companies listed as chemicals manufactures in the Dun and Bradstreet database. In many cases the phone calls were placed to prospective clients as a follow-up to sending a fax. However, additional phone calls were placed to companies that had not previously received any information on the program. Although this method produced two program clients, it is extremely time consuming; the TAA team spent over 40 hours placing phone calls.
5. Marketing through industry trade groups – Nationwide, regional and local chemicals industry trade groups were contacted concerning the TAA program and encouraged to inform their membership about the program. This effort produced mixed results. Trade groups were not as receptive as expected to allowing the program to be marketed to their members. Many trade groups were flatly not interested in telling members about this program, while others were willing to carry out limited marketing, limited primarily to announcements in group newsletters. None were interested in actively promoting the program. Future iterations of this program should rely heavily on these groups, however, in order to ensure that these groups will take an active role in promoting the program, these groups must be involved in the program at the earliest stages. It may also be helpful to make these groups integral members of the program team.
6. Marketing through chambers of commerce – Regional, statewide and local chambers of commerce were contacted to assist in marketing. This proved to be an extremely time consuming and futile effort. Most were not interested in promoting the program, and those that were often had no more than one or two members who were in the chemicals industry.

Audit Site Visit Procedures

The TAA program provided on-site, multi-day evaluations for candidate companies. The program team provided expertise and delivered services in a variety of areas that will had

positive cost, productivity, and revenue impacts on individual firms as well as beneficial impacts to society at large. It was through this coordinated effort and application of all of these disciplines that genuine advances can be made in the competitiveness of the business over the long term. The objectives of this project followed, in concert, the goals of various alliances and road maps developed by the Department of Energy's Office of Industrial Technologies through their Industries of Future program.

Each team member developed a survey covering their area(s) of responsibility that asked general questions about the processes in place already at the plant. These surveys were sent to the Plant Managers to be filled out by plant personnel responsible for the areas in question before the audit site visit. In addition, the Program Manager completed a pre-audit site visit several weeks before each scheduled site audit in order to determine how to best allocate team resources during the audit site visit.

The structure of the actual audit site visit was the subject of extensive planning prior to the start of the Chemicals TAA Program. Because the diverse nature of the TAA team and the varied areas of analysis for which they were responsible, the Program Manager designed the audit process to minimize the amount of time that team members would spend in meetings as a group, preferring instead to give team members as much time as possible with plant personnel responsible for each business area analyzed.

First Day of Audit

- 8 AM – 9 AM: Program Introduction
- 9 AM – 10:30 AM: Plant Tour
- 10:30 AM – Noon: Tour Follow-up and Initial Investigations
- Noon – 1 PM: Brainstorming Session
- 1PM – 4 PM: Interviews with Plant Personnel
- 4 PM – 5 PM: Wrap-up Meeting

Second Day of Audit

- 8 AM – Noon: Interviews with Plant Personnel and Data Collection
- Noon – 2 PM: Lunch Meeting with Plant Personnel
- 2 PM – 4 PM: Interviews with Plant Personnel and Data Collection
- 4 PM – 5 PM: Wrap-up Meeting

Third Day of Audit

- Data Collection

Figure 1. Audit Agenda

At the start of each audit, the Program Manager gave a brief summary of the TAA program and its goals. Following the summary, plant personnel and team members were introduced. Introductions were generally followed by a short overview of the plant given by the plant manager. Next, the plant manager conducted a brief plant tour to familiarize team members with the production process. After the plant walk through, team members began initial investigations of plant systems and scheduled interviews with pertinent plant personnel.

The brainstorming session held during lunch on the first audit day was generally held with only TAA team members present. Representatives from plant staff were invited to attend, but not obligated to do so. The meeting was an informal session dedicated to soliciting recommendation ideas from each team member. The merits of each idea were not discussed during the meeting unless a recommendation idea was clearly not technically feasible or economically viable. The entire hour was

generally dedicated to developing an exhaustive list of potential plant improvements.

The lunch meeting on the second day was unique to the Chemicals TAA Program. Each organization briefly presented its ideas to the rest of the TAA team and plant personnel for group discussion. As the ideas were presented, plant personnel were encouraged to contribute comments or concerns regarding the feasibility and value of recommendations. The client must have its General Manager, Plant Manager and/or Engineering Manager present for the whole meeting to give insight into the feasibility of ideas as they are brought up and also to participate in the "Ranking" part of the meeting. Key plant personnel that are needed for parts of the meeting include the Sales/Marketing Manager, Production Manager, Maintenance Manager and Environmental Compliance Manager. These "high demand" staffers are often intimately involved in with production and cannot attend the entire meeting. The Program Manager scheduled the meeting such that any discussion or ideas that pertained to high demand staff was covered at a set point during the meeting so that these individuals were present for the topics that they are concerned with and then were free to leave to attend to production or other pressing matters.

The bulk of on-site time was dedicated to plant personnel interviews; the afternoon on the first day, morning and afternoon on the second day, and any time needed on the final audit day were used for interviews. In most cases, team members did not need all of this time to complete interviews with plant staff. Some team members, such as those dealing with energy management, required extensive time to collect data at the plant, such as power measurements, equipment inventories, layouts, etc. Other team members, such as those dealing with information systems and supply-chain management had relatively little data to collect other than that collected during interviews. All TAA team members were experts in their areas of responsibility and were able to discuss processes and systems intelligently in detail. This enabled them to quickly adapt general questions and tailor the interviews to the clients' needs throughout the interview.

Ranking Process

An important part of the assessment process is soliciting feedback from clients about what they believed to be important and feasible at their plant. The purpose of ranking each recommendation idea was threefold:

1. Provide Feedback – Feedback was often informally noted during meetings with plant personnel and in the general meeting where all ideas were presented to plant personnel. Ranking each recommendation idea ensured that the whole program team had a consistent view of what was important to clients. Without a systematic ranking of recommendation ideas generated during the audit site visit, there is a risk that the audit team would devote significant portion of their limited resources to recommendation ideas that team members feel should be important to clients, but actually provide little value to the client.
2. Manage Audit Scope – As previously mentioned, the scope of the audits performed in this program is more than can be handled in three days if all recommendation ideas are to be fully investigated. By having clients rank the recommendation ideas, team

members were able to best apply their limited resources to issues that mattered most to the client. The analysis for recommendation ideas that were not a high priority for the client could therefore be limited in scope.

3. Manage Expectations – Clients were made aware that the depth of analysis for each recommendation depended on the ranking which they gave each recommendation. By clearly defining what the team expected to accomplish with each recommendation, clients were made aware that they should not expect a full cost/benefit analysis for every recommendation idea.

Recommendations were ranked using the following criteria:

Ranking #1

These recommendations are a top priority and will be implemented within the next 12 months provided that a suitable economic analysis shows a simple payback within the facility's investment guidelines. Recommendations included in the report that have a #1 ranking included:

- Description
- Savings Analysis with spreadsheet calculations of energy, labor, operational, regulatory and/or material cost savings
- Implementation Cost Estimate
    - Using vendor quotes if provided by the client or prearranged vendor visit during actual audit
    - If possible, using RSMeans, Richardson's or other cost estimating standards
    - Otherwise using expert estimates

Ranking #2

These recommendations are high priority recommendations that will be strongly considered for implementation provided that a suitable economic analysis shows a simple payback within the facilities investment guidelines. Recommendations included in the report that have a #2 ranking will include:

- Description
- Savings Analysis with rule of thumb estimates if possible
- Implementation Cost Estimate based on rule of thumb estimates if possible

Ranking #3

These recommendations are not high priority items, but they may be considered for implementation based on simple payback, feasibility and management priorities. Recommendations included in the report that have a #3 ranking will include:

- Description
- Savings and Cost Discussion

Audit Report Format

After the site audit, the assessment team compiled an audit report detailing all information gathered during the audit process. The report was divided into a front end, which consisted of background information about the plant, and a section containing recommendations for process improvement.

The first part of the report consisted of a detailed description of the plant as it operated at the time of the audit. Major processes were identified and detailed in process diagrams and supplemental written descriptions. Also included in the front end was an analysis of the site's utility bills and energy consuming systems. Individual team members were assigned to develop content for the front end according to their area of expertise.

The actual recommendation write-ups formed the bulk of each audit report. Recommendations were grouped in the final report according to their priority. Those with the top priority and most comprehensive analyses were presented first, followed by other groups of recommendations with successively lower priorities. Each recommendation idea that proved to be technically feasible and economically viable received its own write-up in the final report. Recommendations that were not typically feasible or economically viable generally were given short summaries in the last section of the report. These write-ups included a short description of the existing situation, the proposed solution and reasons why the proposed solution did not prove feasible. It was important to include these recommendations in the final report so clients would understand why these ideas were not feasible.

Field Testing Results

The protocol developed above was the result of initial planning by the Program Manager and was optimized through a series of seven site audits. The Program Manager selected a broad array of clients so that the protocol could be tested in as wide a range of industry sectors as possible. Clients ranged from a manufacturer of specialty paint additives to a pharmaceutical manufacturer. Audit sites ranged in size from a small manufacturer with less than 20 employees to a large manufacturer with over 350 employees.

The protocol was found to be readily applicable to all industry sectors as shown in Table 1. As shown in the table, the program team was able to identify cost saving recommendations at every site audited. The minimum number of recommendations identified at any plant was 33 recommendations, the maximum number identified was 63 recommendations. On average, the team identified 48 recommendations at each site. Quantified recommendation annual savings and costs varied from site to site. The average annual savings totaled $296,918 per site, while the average total implementation costs for these recommendations totaled $921,693, yielding an average simple payback period of 3.1 years.

It is important to note that the total savings and costs quantified in audit reports do not accurately reflect the benefit or cost of all recommendation ideas developed. As previously mentioned, only a limited number of recommendations (an average of eight per report) were the subject of analyses that yielded quantifiable savings and costs. Recommendations that were not top priorities to audit clients, or those that could not accurately be quantified, were analyzed qualitatively.

Table 1. Field Testing Results by Audit Site

Audit Number	Analysis Level 1 Recs.	Quantified Recommendation Annual Savings	Quantified Recommendation Cost	Simple Payback	Analysis Level 2 Recs.	Analysis Level 3 Recs.	Additional Recs.	Not Viable Recs.	Total Recs.
1	4	$48,485	$39,650	0.8	12	8	11	20	55
2	9	$301,015	$395,305	1.3	11	7	10	21	58
3	8	$85,102	$168,945	2.0	10	14	4	15	51
4	9	$208,518	$540,175	2.6	5	3	0	20	37
5	9	$85,215	$179,023	2.1	9	12	3	9	42
6	8	$265,487	$263,025	1.0	10	3	5	7	33
7	10	$1,084,605	$4,865,729	4.5	16	19	0	18	63
Totals	***57***	***$2,078,427***	***$6,451,852***	***3.1***	***73***	***66***	***33***	***110***	***339***
Average	***8.1***	***$296,918***	***$921,693***	***3.1***	***10.4***	***9.4***	***4.7***	***15.7***	***48.4***

The audit protocol was also successful in enabling the team to address all business areas identified as key areas of analysis. As shown in Table 2, all business areas were the subject of a significant number of recommendations, with the exception of the "Safety" category. Safety was the subject of relatively few recommendations because liability concerns over regulatory compliance prevented the program team from making recommendations in this area. As can be seen in the table, the "Energy Management" category was the subject of the largest number of recommendations. This was not because this category received significantly more attention, but rather because recommendations in this area tended to be small issued that could be easily quantified using available data. The benefits and costs of recommendations in other categories, such as "Information Systems" and "Supply Chain Management," are much more difficult to quantify and deal with larger, more complex issues.

Table 2. Field Testing Results by Analysis Area

Analysis Area	No. of Recommendations	Savings	Cost	Payback
Energy Management - Boiler/Steam	56	$1,329,734	$4,843,938	3.6
Energy Management - Compressed Air	40	$89,532	$184,041	2.1
Energy Management - HVAC	13	$73,009	$130,425	1.8
Energy Management - Lighting	12	$27,758	$109,615	3.9
Energy Management - Process Cooling	36	$88,798	$394,643	4.4
Energy Management - Process Energy	33	$56,969	$110,340	1.9
Energy Management - Utilities	18	$1,600	$4,000	2.5
Green Chemistry/ Waste Reduction	10	$3,610	$900	0.2
Information Systems	27			
Other	15			
Safety	3			
Supply Chain Management	14	$24,405	$47,800	2.0
Technology	15	$130,795	$385,050	2.9
Waste Minimization	47	$252,217	$241,100	1.0
Totals	***339***	***$2,078,427***	***$6,451,852***	***3.1***

Conclusion

The TAA process proved to be adaptable to the Chemicals Industry. The Chemicals TAA Program successfully developed a protocol for performing whole business audits at client facilities within the industry. Furthermore, these audits proved to be successful, both in their breadth and depth, with projects providing significant annual savings developed. The existing protocol should be used by any group wishing to perform whole business audits within the Chemicals Industry.