CHAPTER 58

Plant and Facilities Engineering with Waste and Energy Management

James R. Ross
Resource Management Systems (RMS Inc.)

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1. OBJECTIVES AND CONTENT OF THE CHAPTER

This chapter is intended to identify linkages between industrial engineering and plant and facilities engineering, to create an understanding of the scope and breadth of plant and facilities engineering, and to explain selected activities and issues of which industrial engineers assigned to plant and/or facilities engineering duties need to be aware. Where possible, industrial engineering methodologies and techniques will be applied to the design, installation, and management of plant facilities, utilities, and service systems to improve cost effectiveness, productivity, quality, operations, and environment.

While many fundamental principles from the previous edition of this Handbook remain the same, technology, analytical tools, and managerial style that have changed the world in which plant and facilities engineers live and work have been added to make the chapter as current as possible.

2. SCOPE OF PLANT AND FACILITIES ENGINEERING

2.1. Definition of Plant Engineering

Plant engineering may be defined as the entity responsible for providing and maintaining a safe, productive work environment in a constant state of readiness in support of the organization's mission in a cost-effective manner. Facilities engineering deals more specifically with the building, its equipment, utilities, grounds, and closely associated issues rather than those functions that directly support production or general operation (Rosaler and Rice 1983; Rosaler 1994, Higgins 1988).

2.2. Emerging Concept of Enterprise Asset Management

Although the definition of plant and facilities engineering remains the same from the previous edition, a key difference is that plant engineering in many organizations has moved from a discrete functional area within a corporation to providing an enterprise asset management function. The plant or facilities engineer is the steward of assets and resources used by a company and consequently must assume greater responsibilities than in the past. The facility is now viewed as a value-added key to business productivity and competitiveness. As a workplace, the facility is integrated with all other business functions. Specific techniques to facilitate these changes and improve the plant or facility engineer's qualifications are presented throughout this chapter (Davis et al. 1999).

2.3. Relationships between Plant Engineering and Other Departments

2.3.1. Relationships between Plant Engineering and Maintenance

Maintenance is often the operational arm of the plant engineering function, and it may consume over 50% of a plant engineer's total time. Plant engineering and facilities engineering have commonalities with maintenance in problem-solving methods, scheduling, assignment of tasks, and preventive maintenance on the facility and equipment that are used plant-wide. Because many plant engineers are in direct charge of maintenance, procedures for managing both maintenance and plant engineering functions become intermingled. If maintenance is a separate function from plant and facilities engineering, the plant engineer must form strong relationships with maintenance managers to get quick response when critical maintenance problems arise. Chapter 59 of this Handbook describes maintenance in detail (Tatum 1997).

2.3.2. Relationship between Plant Engineering and Production or Operations

In the past, plant and facilities engineering was a separate entity that provided service to production and operations management. With the advent of team management, plant and facilities engineering personnel may be assigned to work directly with production and operations people. The linkage between plant engineering people and production or operations has become indistinct, especially in manufacturing, where line mechanics may report directly to production managers or team leaders. With greater emphasis on just-in-time production, plant engineering must have greater flexibility to meet fast-track schedules and reduce process cycle time.

Allocation of effort between plant engineering and production depends on the type of operation. Generally speaking, operation and maintenance of plant equipment, such as air compressors, chillers, boilers, electric systems, and HVAC systems remain the sole responsibility of plant engineering, but where production equipment is involved, the trend is to have maintenance readily available to assist in repairing production equipment quickly. Production workers are often trained to do first-line or routine maintenance tasks including preventive maintenance. If specialists such as electricians, instrument mechanics, and electronics technicians are needed, these are normally supplied by the central maintenance group, but on occasion these people are also integrated with production operations.

2.3.3. Relationship between Plant Engineering and Upper Management

Despite the blurring of assignments relative to plant and facilities engineering, the plant and facilities engineer will be held accountable for the proper maintenance and operation of facilities-related systems. It is incumbent upon the plant and facilities engineers to communicate with the managers of all departments to obtain their input on situations that need attention and to report progress to upper management using a variety of measures, some of which are described under the section on productivity improvement in this chapter. Ideally, the plant engineer should report directly to the plant manager or general manager, depending on the senior executive in charge of the facility. Because plant engineering is an extremely important and vital function, lines of communication with decision-makers must be as short as possible to minimize reaction time for decisions, optimize allocation of resources, solve problems, and maintain an effective operation.

2.3.4. Relationship between Plant Engineering and Product and Process Design and Introduction

The concept of concurrent engineering in product design and planning is intended to avoid the ‘‘throw it over the wall’’ approach by including everyone concerned with design, marketing, engineering, manufacturing, human resources, warehousing, packaging, and distribution of the product on the product-planning committee. The plant engineer should be involved from the inception of each new product as a member of a team or committee and can contribute to successful product development or introduction in the following ways:

Participate in value analysis studies and help to verify new product manufacturability.
Assist in developing the manufacturing process, flow, and plant layout.
Direct a team to determine facilities needed to produce the new product.
Identify maintenance, utilities, or service requirements for the new product.
Specify, obtain quotes, procure, or fabricate new equipment.
Advise on tooling design and cost with manufacturing engineering.
Determine level of maintenance staffing needed to support the new product.
Manage equipment relocation or new equipment installation.
Concentrate on problem resolution during the startup phase and beyond.
Contribute creative ideas throughout the process.

2.4. Roles of Plant and Facilities Engineers

In some organizations, the plant engineer manages all engineering, maintenance, shops, security, utilities, buildings, and grounds. In other organizations, the plant engineer directs design and construction of new facilities. Often, peripheral functions such as plant safety and security, fire protection, recycling, waste disposal, property records administration, risk management, and pressure vessel inspection and maintenance are included in the plant engineering function. Where no one else is available, the plant or facilities engineer may be called upon to perform other diverse functions that are not engineering but must be done by somebody. This is a compliment to the flexibility of the typical plant engineer. The facilities engineer's scope deals more specifically with the building, its equipment, utilities, and grounds rather than those functions that directly support production. The proliferation of team management in the last few years has changed the character and style of plant and facilities engineering. These changes are addressed throughout this chapter.

Although called an engineer, the plant or facilities engineer in a large corporation may manage a multimillion-dollar operation, a greater responsibility than that of the president of many small companies. By contrast, a small plant may have one engineer whose responsibilities include plant and facilities engineering. Both large or small plants need to have the functions of plant engineering performed. If these functions are not performed, deterioration in equipment, buildings, grounds, and other facilities can cause cost penalties when repair of damage due to neglect is required later. Every organization pays for plant engineering, whether or not it is actually performed. Plant engineering is a ‘‘pay me now or pay me later’’ profession.

The classical functions of management for plant engineers who have managerial responsibility include planning, organizing, motivating, analyzing, controlling, instructing, delegating, disciplining, and communicating, the same as for managing any other type of enterprise. Not all plant engineers have managerial responsibility, but most have technical responsibilities. Some typical responsibilities of plant engineering managers and technical plant engineers include:

Set departmental strategic and tactical objectives.
Develop policies for the department.
Recruit employees to build an effective organization to perform essential functions.
Devise motivational programs for plant engineering employees.
Participate in development and functioning of team management activities.
Plan, schedule, and assign work directly or though supervisors or team leaders.
Prepare and control capital and expense budgets.
Survey condition of the facility, issue work orders for correction of deficiencies.
Acquire a cutting-edge knowledge of all facility equipment and practices.
Conceptualize, prioritize, and manage improvement or major repair projects.
Procure and install new equipment.
Keep an updated layout of the plant.
Develop and execute productivity and quality measurement systems.
Assess training needs and train employees to perform tasks correctly and quickly.
Establish a program of preventive and predictive maintenance.
Manage maintenance work order, cost, and information systems.
Conduct value analysis studies on equipment, parts, and supplies.
See that material inventory is carefully controlled.
Build the status of plant engineering within the organization with peers.
Communicate with top management to get support for the plant engineering function.
Develop and follow procedures as required under ISO 9000 or ISO 14000.
Manage an integrated information technology/data-management system including CMMS.
Assure that computer support systems are adequate for present and anticipated needs.
Coordinate telecommunications systems installation and maintenance.
Oversee contracting and outsourcing of services.
Assure dependable and cost-effective utility services.
Maintain utility systems in optimum condition.
Direct the safety program and proactively find and correct hazards.
Maintain fire-protection systems in a constant state of readiness.
Perform environmental audits and correct deficiencies quickly.
Negotiate with insurance carriers for maximum protection at the best rate.
Manage the security program for the facility.
Establish and maintain the buildings and ground program for the facility.
Conduct an effective energy-management and conservation program.

This list of responsibilities is intended not to be all inclusive, but to describe the diversity of duties that plant and facilities engineers encounter. Additional duties not included above may be suggested throughout this chapter (Tomlingson 1988a,b).

2.5. Industry Characteristics That Affect Plant Engineering

Although plant and facilities engineering may have originated in manufacturing, there are many other industries and businesses that need plant and facilities engineers. Each of these organizations has a set of unique problems that may not be common to manufacturing. Some examples of nonmanufacturing facilities that require plant or facilities engineers are:

- Public buildings have plant engineers to ensure that heating ventilation and air conditioning, utilities, building maintenance, telecommunications, security, and computerized building management are available and properly maintained.
- Military installations have extensive and unique needs for technologies that are available through plant engineers.
- Research laboratories have, in addition to the usual plant engineering activities, reduction and disposal of hazardous biological ands chemical agents that require highly specialized handling.
- Hospitals and other health-care facilities have long had plant engineers to ensure the facility is in top condition, as the lives of patients depend on a perfectly functioning facility.
- Electric utility generating stations rely heavily on plant engineers to maintain equipment and facilities under adverse conditions.
- Coal mining, oil drilling, and other mineral extraction all require extensive maintenance and plant engineering assistance, also under adverse conditions.

Industrial engineers can bring a wealth of skills to plant and facilities engineering positions in any of the above-named facilities and others not previously mentioned. In preparing this chapter, efforts have been made to make materials as generic as possible so that they apply to any industry or business to which an industrial engineer functioning as a plant or facilities engineer may be assigned.

3. INTEGRATING INDUSTRIAL ENGINEERS INTO PLANT AND FACILITIES ENGINEERING

3.1. Why Industrial Engineers Make Good Plant Engineers

An industrial engineer is an excellent choice to be a plant or facilities engineer. By definition, an industrial engineer is a systems designer who integrates materials, machines, people, technology, and energy to produce goods or services in a productive manner. IE's possess a wealth of analytical tools that can be creatively focused on plant engineering problems. The academic course known as facilities planning and design is fundamental for an industrial engineer becoming a plant engineer. The IE plant engineer can overcome a lack of specific knowledge about technical aspects of plant engineering by keeping many details in clear focus simultaneously and by applying good reasoning, system-integration abilities, creativity, judgment, communication skills, flexibility, adaptability, and quality consciousness, excellent human relations skills, and the principles of industrial engineering.

3.2. Problems That May Face an Industrial Engineer as Plant Engineer

Although an industrial engineer brings an impressive array of skills to the job as a plant engineer, long-time employees, for example, may not readily accept a person who has not previously held a plant engineering position. Selling oneself to the existing workforce should take high priority. The new plant engineer must also be a fast learner, and take steps to become familiar with details of the facility itself, in addition to the engineering, business, and human resource aspects of the new job. Seldom is time available to step back and reflect on these issues, as plant engineering, by design, is a pressure job in which the incumbent must take charge immediately.

3.3. Facilities Management as a Resource-Utilization Issue

As the manager responsible for a multimillion-dollar facility, the plant engineer is accountable for utilization of all resources, under the command of the enterprise manager. When the facility is available for use, people, machines, equipment, and the facility itself are well utilized. If the facility fails, all resources are underutilized and materials can be wasted as well. The plant engineer must also be cognizant of energy use at all times and optimize its use.

3.4. Training Needed by Industrial Engineers to Become Good Plant Engineers

3.4.1. Knowledge Needed in Other Engineering Disciplines

The many technological, analytical, and managerial changes that have occurred concurrently both complicate and simplify the work of a plant engineer. An industrial engineer functioning as plant or facilities engineer must acquire knowledge outside of industrial engineering. Some examples of technologies and equipment related to mechanical, electrical, and civil engineering with which the industrial engineer may be unfamiliar include, but are not limited to, the following:

Mechanical	Electrical	Civil
Piping and valving	Primary power system	Site design
Boiler operation/maintenance	Transformers	Surveying/contours
Machine design	Electrical distribution system	Soil test results
Heating, ventilation	Machine hookup	Structural design
Air conditioning	Building automation	Building envelope
Hydraulics, pneumatics	Electrical maintenance	Water, sanitation
Instrumentation and control	Cogeneration	Waste management

In a large organization, specialists in each of these areas may be available, but in a small organization, the plant engineer may be required, without prior training, to address the above issues plus many more. To achieve a level of competence and expand his or her knowledge base, the engineer can acquire additional skills and knowledge through intensive independent study, academic courses, focused short courses, retraining with outside experts, courses sponsored by equipment vendors, or in some cases, conversation with vendors.

3.4.2. New Skill Requirements for Plant and Facility Engineers

In addition to the above, successful plant engineers will be required to be skilled in the following technologies and techniques:

3.4.2.1. Management Skills Classical management skills of planning, organizing, motivating, controlling, and communicating will continue to be essential, but knowledge of emerging managerial techniques will be the key to future success. Team management in many different forms is growing rapidly, and hence it behooves the plant engineer to become skilled in that managerial style. Authoritarian leaders may survive in some organizations if that is the prevailing managerial style, but with changing workforce attitudes, a more democratic/participative managerial style using team approaches is likely to emerge in the future. A description of team management appears in Chapter 37.

3.4.2.2. Project Management Plant engineers are often called upon to manage major construction or installation projects plus innumerable repair projects. While the level of formality differs from large to small projects, the methodologies of concurrent activity, prioritization, and cost control remain the same. Project-management software is available to optimize utilization of resources as well as remove some routine charting and computational work associated with managing projects. See Chapter 46.

3.4.2.3. Training Skills As the plant engineering field becomes more complex and the availability of trained people diminishes, the need for training increases. Training of engineers and hourly employees in everything from basic maintenance techniques to computer building-control systems will help maintain productivity. The topic of training is addressed in detail later in this chapter due to its current and future importance.

3.4.2.4. Computers Applications for computers in plant engineering organizations are almost endless. As industry becomes more computerized, plant engineers must learn computer skills to compete. A few computer systems applicable to plant engineering are:

Computerized maintenance management systems
Management information systems
Computer-automated facilities management systems
Computer-aided design
Computer-assisted manufacturing
Computer numerical control (CNC)
Programmable logic controllers (PLCs)
Machine-specific computer controls

See Chapters 46, 59, and 72 for more details on the above.

3.4.2.5. ISO 9000 In recent years, the use of ISO 9000 has proliferated. ISO 9000 is often mistaken for a quality system, but it is in fact an organized way to document procedures used in managing an enterprise or department, including quality. Plant engineers are often involved in documenting maintenance procedures and systems, such as work order processing, equipment inspections, predictive or preventive maintenance, and data collection using the documentation discipline of ISO 9000. If a computerized maintenance management system (CMMS) is available, converting data to ISO 9000 requirements should be relatively easy. Although the benefits of documenting procedures can be significant, conversion to ISO 9000 is very time consuming and expensive, and records must be open to auditors who verify that documented procedures are actually followed. See Chapter 74.

3.4.2.6. Quality The need for continuous improvement through application of statistical techniques and the permeation of quality thinking into all aspects of plant and facilities engineering are now a reality. It is no longer possible to accept ''pretty good''quality of workmanship or to solve problems by guesswork. The only acceptable approach is to identify the problem, find the root cause, and eliminate the cause. An attitude of quality must permeate every aspect of organization, including plant and facilities engineering. See Chapters 66, 67, and 73.

3.4.2.7. Energy Plant engineers are often responsible for energy within a facility. With deregulation of energy, great opportunities for cost reduction exist. Energy conservation must also have a high priority to improve profits. A section of this chapter is devoted to energy management and conservation.

3.4.2.8. Telecommunications Many plants and office buildings have telecommunications systems to support electronic commerce, voice and data transmission, computer networking, and many emerging technologies. Transmission may be by wire, cellular, radio, or satellite. Because technology in this field requires frequent upgrading of equipment and supporting software, a successful plant engineer must work closely with information systems engineers and equipment vendors to maintain the state of the art in telecommunications.

3.4.2.9. Environment More stringent environmental laws and regulations continue to force plant engineers to spend massive amounts of time and money to avoid legal penalties for failure to comply with the laws. Despite this, reduction of hazardous waste, solid waste, air pollution, and water pollution offers significant cost-saving opportunities for industrial, plant, and facilities engineers whose key function is the effective utilization of all enterprise resources. More details on waste reduction appear later in this chapter and in Chapters 16 and 19 of this Handbook.

A new tool to ensure environmental compliance and waste reduction is ISO 14000, in which environmental procedures are documented. The documentation and auditing requirements to maintain ISO 14000 certification, although somewhat cumbersome and time consuming, tend to pressure organizations to comply with their own procedures. Environment must be a consideration in every management and engineering decision.

3.4.2.10. New Maintenance Techniques Advances continue in maintenance technology, including more sophisticated techniques of vibration-signature analysis, tribology, motor meggering, oil and wear particle analysis, laser alignment, infrared thermography, acoustic leak detection, and nondestructive testing. These techniques give plant engineers tools to diagnose and predict and/or prevent equipment failures. The concepts of equipment durability, availability, maintainability, and reliability-centered (or based) maintenance are converting maintenance from a reactive to proactive mode. Concurrently, the emphasis has shifted from a power organization to an empowered organization, a shift largely brought about by total productive maintenance. Successful plant engineers must have the vision to utilize all available techniques and technologies to improve maintenance in a new, more demanding environment.

3.4.2.11. New Problem-Solving and Analysis Techniques For many years, the typical five-step problem-solving technique seemed adequate, but new problem-solving techniques seem to appear almost weekly. These techniques center around finding the real problem and the root causes of the problem, leading to a more effective solution. There is seldom a shortage of problems to be solved by a plant engineer, but how the engineering handles those problems can make the difference between success or failure. New problem-solving techniques such as kaizen, 5 ws, 8d, 5s, and others are described in other chapters in this Handbook and in supplemental books and training programs.

3.4.3. Training as a Motivator

Training is intended to develop and enhance employee understanding of current or new responsibilities and skills, help employees keep abreast of new technologies, and improve employee morale, performance, and productivity. It can also be a motivator and reward to employees. Training should also be regarded as an investment in the future of the company by helping management retain valuable employees. It is usually more cost effective to retrain an employee than to hire someone new.

3.4.4. Assessing Training Needs for Plant Engineering Employees

To determine training needs, the plant engineer may ask questions including the following to make an initial assessment:

Are some plant engineering services lacking?
Is quality of work and service substandard?
Are primitive work methods instead of modern techniques being used?
Is there dependence on one individual for certain essential services?
Are some people failing to reach their full potential?
Are some skills lacking or in short supply?
Are new skills needed for plant expansion or new processes?
Are excessive accidents occurring?
Is labor turnover abnormally high?
Is downtime on equipment excessive?
Do some people lack training in teamwork?
Do people have problems in using computers and technology?

A ''yes'' answer to the above questions can verify the need for training.

A skills inventory that lists each piece of equipment or operation and the skills required for operating or maintaining that equipment can indicate the need for training to fill voids in available skills (Peele and Chapman 1989).

3.4.5. Types of Training

The plant engineer must determine the type, level, method, material, and media to be used in the program. A blend of the following types of training will normally be required for a comprehensive training effort:

3.4.5.1. Orientation An orientation program gives basic information about the organization, its history, mission, organization, benefits, policies, products or services, and mode of operation. Time spent in orientation is well worth the cost because it makes the employee feel part of the organization. Omission of this step may lead to labor turnover and low productivity.

3.4.5.2. On-the-Job Training While employees may learn the job themselves, monitored on-the-job training administered by supervisors can save months of unlearning bad habits acquired from self-instruction. The job instruction training (J.I.T. or show and tell) technique, with adequate explanation, is effective for training in manual skills and repetitive or semirepetitive operations. The J.I.T. method is as follows:

1. *Prepare for training:* Learn the job, write the method if possible, see what the employee already knows, explain value of training, establish rapport with the trainee.
2. *Present training:* Demonstrate and explain each step in the job, point out quality and safety expectations, trouble spots, shortcuts, specifications, and other key points, repeat process as required to ensure understanding.
3. *Practice training:* Let employee do the job while explaining to the supervisor the steps just learned, make corrections as necessary.
4. *Pursue:* Follow up to make frequent checks to ensure training has been absorbed, retrain as required, compliment trainee on progress.

Typical plant engineering tasks suitable for this training approach include scheduled lubrication, boiler water testing and blowdown, lift truck battery filling, belt tightness testing, sprinkler system testing, recurring parts replacement, setup and changeover, and repetitive preventive maintenance activities. If a video camcorder is available, a training tape can be recorded to explain the task, for use when new employees are being trained.

3.4.5.3. Internal or External Training The decision on where to obtain training depends on in-house training skills, organizational needs, educational level of trainees, and expected quality of training. Commercial self-study training programs can be integrated into an in-house program to save development time. External training can be cost effective if new skills must be learned quickly. Equipment suppliers may offer training on equipment-specific topics (boilers, air conditioning, computers). Packaged courses on maintenance and plant engineering, in programmed instruction and/or interactive video or computer, can reduce course training development and presentation time (Phelps 1988).

Apprentice training for machinists , electricians, boiler operators, mechanics, or other jobs requiring exceptional skill levels is one solution for skill deficiencies. An apprentice program may be established by assessing the need for such training, determining interest of employees in becoming certified in their job disciplines, designing the work processes and training sessions, obtaining approval for the Department of Labor or other accrediting agency, presenting the program, and rewarding employees who complete the program.

Training of the new plant engineer and all plant engineering personnel is an excellent investment that deserves high priority for the benefit of the organization.

4. MANAGING PLANT AND FACILITIES ENGINEERING

4.1. Organization and Management of the Plant or Facilities Engineering Function

The plant engineering organization is shaped by many factors that vary widely among enterprises, including the following:

4.1.1. Strategy for Plant Engineering

First and foremost, be in harmony with the strategic plan of the enterprise. Not all enterprises have the same strategic plan for plant engineering, so the organization must be shaped to support the unique objectives for the specific enterprise. Functions assigned to plant engineering can lead companies into businesses the mission statement does not recognize. A plant engineer may, by default, become the manager of such businesses as real estate, vehicle repair, electric generating, telephone, building construction, machine building, and scrap metal. Management should make a conscious decision to get into or stay out of a business depending on corporate objectives, skills availability, funding sources, and volume and type of business. Without the strategic decision, the company may be in unwanted businesses it can neither manage nor run profitably. Many companies assign side businesses to contractors. Despite higher unit prices, this may be more cost effective than running an unfamiliar business.

4.1.2. Size of Operation

In a larger organization where delegation is possible, the plant or facilities engineer performs chiefly managerial functions, such as assigning and reviewing the work of others and communicating with superiors, peers, and subordinates. In a smaller organization, the plant engineer may perform many of the engineering, managing, and implementation steps individually.

4.1.3. Type of Operation

The plant engineering organization must be patterned to achieve the mission and objectives of the operation being served. A large, continuous chemical complex will have different organizational needs than a five-day-per-week automotive parts manufacturer or an office building. In a small, light manufacturing plant, the plant engineer often has full responsibility for maintenance, support equipment, and the facility itself, with no subordinate employees. Plant engineers in large plants usually have executive status, but inroads by teams and the level of technology and automation are changing organizational relationships and structures. The degree of automation also has an impact on organization of plant engineering.

4.1.4. Managerial Style and Structure

Until recently, plant engineering organizations were essentially hierarchical, but now team management techniques are being used increasingly in industries and businesses. This is particularly true when total productive maintenance is used. In this concept, maintenance people who were formerly in a separate department are integrated into manufacturing or operating departments, where they are part of a close-knit team rather than outside. While maintenance and plant engineering people may lose some of their individuality and visibility, the benefits of teams in improving productivity are well documented. One advantage of TPM is that intradepartmental conflicts are avoided and everyone is motivated toward a single goal of maintaining production in the most efficient manner.

Another new paradigm is that plant and facilities engineering operates as a professional-services firm composed of multifunctional teams of experts who provide services to other departments within the organization. Charges against departmental or activity budgets are made for services rendered.

4.1.5. Area of Responsibility

The organization of the plant engineering activity depends on top management's perception of its responsibilities in relation to other departments. Plant engineering often acquires unwanted or inappropriate, but necessary, functions that do not fit within other departments. In a TPM situation, traditional reporting relationships of plant engineering personnel may be blurred because individuals may report to operating or administrative departments rather than directly to the plant engineer. The plant engineer is obliged to adopt a new organizational structure and concentrate on communicating with manufacturing or other departments that manage plant engineering people. The plant engineering function should report to the plant manager, general manager, chief engineer, or assistant plant manager. This direct line to key executives can facilitate obtaining the resources necessary to keep the facility operating optimally.

4.1.6. *Availability of Qualified Personnel*

The availability of qualified personnel relative to operational requirements may force a more pragmatic approach to organization. In highly technical operations, unavailability of qualified people to perform specialized tasks may cause the plant engineer to seek such expertise outside of the organization.

4.1.7. *Budgetary Constraints*

If upper management views plant and facilities engineering functions as just more overhead, it may be excessively frugal when authorizing budgets. Top managers must realize that plant and facilities engineering are interdependent with production and that adequate funding to perform an optimum job is essential because "You pay for plant engineering whether you have it or not."

Graphical representations of the typical hierarchical organizational structure followed by one of many team configurations are shown in Figure 2 (Lewis and Marron 1973).

MAINTENANCE SKILLS INVENTORY FORM

Equipment Type: Compressors Trade: Mechanic

APPLICABLE EQUIPMENT/SYSTEMS: Compressor #1, #2, #3, #4, #5, #6

MAINTENANCE SKILLS	NAMES OF QUALIFIED MAINTAINERS	CAPABILITY (check one): Fully capable	Partially capable	Not capable
A. SERVICING AND LUBRICATION	1. Tim P. 2. Bob C. 3. Ray W. 4. Tony G.	✓		
B. ROUTINE PREVENTIVE MAINTENANCE	1. Tim P. 2. Bob C. 3. Ray W. 4. Tony G.	✓		
C. TROUBLE-SHOOTING (problem identification)	1. Tim P. 2. Bob C. 3. Ray W. 4. Tony G.		✓	
D. MINOR REPAIR	1. Tim P. 2. Bob C. 3. Ray W. 4. Tony G.	✓		
E. MAJOR REPAIR	1. Tim P. 2. Bob C. 3. Ray W. 4. Tony G.			✓
F. OVERHAUL	1. Tim P. 2. Bob C. 3. Ray W. 4. Tony G.			✓

TRAINING ASSESSMENT/RECOMMENDATION: Schedule a class on troubleshooting and major repair of compressors for the mechanics. Contract overhauls of compressors with local manufacturer's representative.

Figure 1 Example Skills Inventory for Plant Engineering Personnel. (Courtesy of Plant Engineering Magazine)

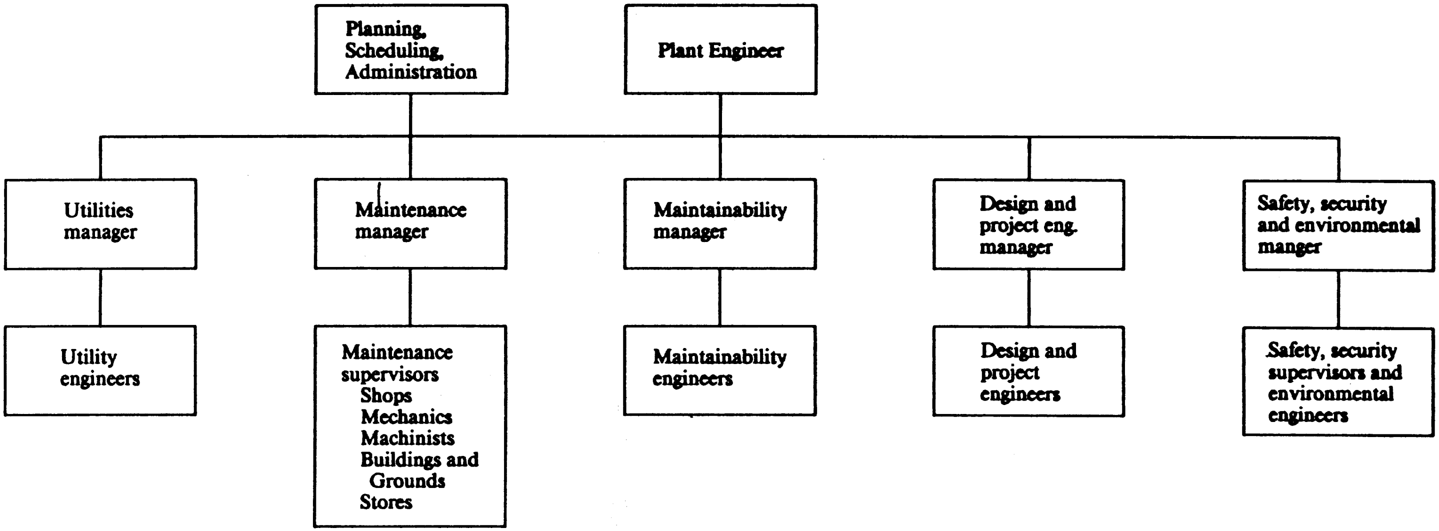

Figure 2 Classical Plant Engineering Organization Chart.

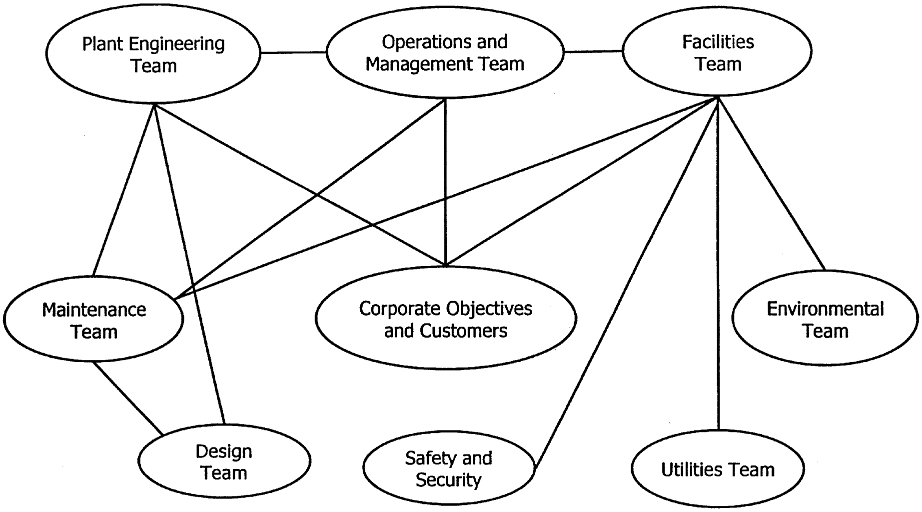

Figure 3 Team-Oriented Organization Chart.

4.2. Applying Industrial Engineering Techniques to Plant Engineering Problems

4.2.1. Determining Personnel Requirements

Determining personnel levels is best done by determining the workload for each activity in the plant or facilities engineering department through time study, work sampling, work order estimation, predetermined times, standard data, video camcorder, or other accepted work measurement technique. Although plant engineering work is often regarded as impossible to measure, there are many repetitive or semirepetitive operations that can be measured with reasonable accuracy. The fact that *not all* operations can be measured accurately should not deter the plant engineer from obtaining times for those that can be measured.

When the forecast workload becomes available, the plant engineer should compare total hours needed with those available and compute the difference. A workload and backlog report (Figure 4) prepared on any spreadsheet software or by a CMMS and issued monthly to management can help to justify requests for additional employees.

Station jobs (such as boiler operator), which involve continuous attendance vs. jobs where the workload varies according to assignment or demand for service, should be measured according to the actual work content in the operation. If other work can be done on a station job without sacrificing the primary mission, productivity of the operation can be improved.

Factors affecting personnel requirements include type of industry, size and age of the plant, degree of automation, equipment complexity, amount of capital work, level of preventive maintenance, quality requirements, degree of excellence expected and the qualification, availability of labor, and training level of the existing workforce (Palko 1989). Difficulty in finding qualified people to fill plant engineering and maintenance jobs motivates some companies to invest in retraining to improve employee competence.

Because plant engineering and maintenance labor cost are visible, these functions are frequent targets of cost cutters. Invisible to top management and buried in overhead or other categories are

Workload/Backlog Spreadsheet

A	B	C	D	E
Skill/Craft	Hrs. Avail.	Hrs. Required	Surplus/Deficit	Staffing Change
			(B-C =D)	(D/160 = E)
Totals				

Figure 4 Example Workload and Backlog Report.

costs of excessive downtime, obsolete equipment, utility outages, poorly maintained machines, or other causes of low productivity. Identifying such problems using activity-based costing or value stream analysis allows adequate staffing for plant engineering activities to be justified.

4.2.2. Decision Making and Problem Solving/Data Analysis

As a manager of a significant part of the operation, the plant engineer must be an effective decision maker and problem solver. Unlike the manager of a production operation, the plant engineer is typically faced with new challenges, unusual problems, and nonrecurring decisions almost every minute of every day. Solutions and decisions must be made quickly and accurately for the benefit of the organization. The decision-making and problem-solving process is as follows:

1. Identify the problem, not symptoms—use statistics to find the real problem.
2. Collect all available causes and other data—make fishbone diagrams.
3. Analyze data—develop creative ideas.
4. Select and test alternatives.
5. Pick the best solution—test and implement the solution.

Seldom does a hands-on plant engineer have the luxury of time to implement the formalized approach. Using the above thought process coupled with other industrial engineering knowledge, the plant engineer can intuitively and informally develop solutions to many diverse problems instantaneously. While the above basic method for problem solving is valid, familiarity with kaizen, Ishikawa, 8D, 5 why, brainstorming, decision tree, and other solution-generation methods is advantageous.

4.2.3. Benchmarking Plant Engineering

A plant engineer who wants an organization on the cutting edge of technology should consider benchmarking the organization against others in comparable fields. The benchmarking process involves sharing information with other companies and emulating best practices in critical areas (Gulati and Lach 1997; Raymond 1993).

4.2.4. Productivity and Quality in Plant Engineering

Plant engineering in both manufacturing and service facilities and operations use the same resource inputs of capital, equipment, humans, materials, and energy, but outputs can be quite different. The outputs of manufacturing are chiefly discrete products measured in pieces, tons, gallons, dollars, or other similar measures. Measures of output in a service facility may be in industry-specific terms such as meals served, patients treated, students enrolled, cars parked, nights occupied, or the dollar value thereof.

Productivity measurement is expressed as:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

Using the basic formula, meaningful measures of productivity for a variety of inputs and outputs can be developed to track progress toward a more productive plant engineering activity. Examples of productivity measures for plant engineering concerns are:

$$\text{Productivity (Facility)} = \frac{\text{\$ Value of Production}}{\text{\$ Facility Cost}} \text{ or } \frac{\text{Pieces Produced}}{\text{Ft}^2 \text{ Floorspace}}$$

$$\text{Productivity (Equipment)} = \frac{\text{productive hours}}{\text{hours scheduled}} \text{ or } \frac{\text{pieces produced}}{\text{equipment hours}}$$

The use of industrial engineering techniques in plant engineering can be the key to improvement of productivity. Work measurement, work sampling, computerized maintenance management, equipment down time analysis, predictive maintenance, proper layout, effective floor utilization, and effective strategy planning for facility utilization all tend to improve productivity of resources. Due to the close relationship between maintenance and plant engineering, the following productivity measures for maintenance can be applied or modified to measure plant engineering effectiveness:

MTBF—mean time between failures
MTTR—mean time to repair
FMEA—failure mode effect analysis
Uptime of equipment or downtime avoided

Accidents avoided/accident rate

Energy losses eliminated

Material costs reduced

The use of productivity formulas is limited only by the imagination of the user. Formulas must be relevant, meaningful to the user, and motivate positive action and continuous improvement in productivity (APC 1981; Steele 1997).

The success of the plant engineering function must be measured not only in quantity but also in quality of work produced and quality of the organization. There are many assessment tools for quality that address plant engineering. If the organization is competing for the Malcolm Baldrige Award, Shingo Prize, North American Maintenance Excellence, or other awards of excellence, going through the process will motivate maintenance and plant engineering to improve performance. Assessment tools such as Tompkins Associates' Maintenance Scoreboard can highlight gaps that when remedied can lead to significant improvements.

4.2.5. Work Measurement Techniques in Plant Engineering

Although there is a widely held perception that maintenance and plant engineering work is not measurable, there have been many successful applications of work measurement to these functions. A number of consulting firms offer maintenance standards, based on MTM or other predetermined time systems, that can be applied to maintenance and plant engineering work. Measurement of plant engineering activities uses a combination of work sampling, time study, and time recording. These times can be used to determine the level of effort and the number of the people required to perform plant engineering tasks.

In some instances, maintenance standards have been developed from extensive time study and converted to standard data, which are then applied to specific jobs being performed by mechanics. The actual time taken by the mechanic is then compared to the computed standard based on work content and the percentage is used to calculate a day work or incentive efficiency. Station jobs such as boiler operators may use a simple reporting system which indicates that assigned work is being done. See Chapter 54 for more information on work measurement.

4.3. Financial Aspects of Plant and Facility Management

4.3.1. Plant Engineering as a Profit Center

Most plant engineering, maintenance, and facilities engineering activities have been viewed by accountants and management as expense items or cost centers. Only recently has the concept of viewing these entities as profit centers been promulgated. While this may seem like a minor change, it can add to the profitability of the enterprise through reducing or controlling cost of the facility. Plant engineering and maintenance activities are viewed in some circles as value-added components of the value stream. By applying preventive and predictive maintenance and effective plant engineering practices, plant engineering departments can increase availability of the facility and equipment, thus adding real value to the organization.

4.3.2. Budgeting

Plant engineers are required to submit budgets for materials, suppliers, labor, and capital investment. The budget is a list of proposed sources of income and expected expenditures. When approved, the budget may be viewed as a bank account against which charges can be made. In some cases, departments are charged as a professional service, and it is possible for plant engineering to earn a surplus.

Many organizations still use the analysis-of-variance method to determine whether cost objectives are being met within budgeted amounts. This approach gives some indication of actual vs. planned expenditures, but because data are released months after actual events occur, it is difficult to trace how activities could have been performed better.

Activity-based budgeting is ideal for tracking plant engineering functions. Identifying activities actually performed along with the cost drivers allows real-time information to be generated and problem areas identified quickly. Cost distributions between plant engineering and other departments can be done more equitably, and non-value-added activity can be spotted more easily.

4.3.3. Costing

As noted in the section on budgeting, it is incumbent on plant engineers, like all managers, to maintain close control of costs, and make decisions based on accurate cost data. While other chapters in this Handbook detail costing systems, and other cost issues have been noted elsewhere in this chapter, a plant engineer should utilize activity-based costing data to identify non-value-added activity, both within the plant engineering function and throughout the organization. Plant engineers are often blamed for breakdowns, power outages, and other situations that produce non-value-added activity. Elsewhere in this chapter it is noted that a well-run plant engineering function adds value and can enhance profitability for the organization. Activity-based costing is one of the best methods available for collecting cost data and assigning responsibility to the appropriate entity. To implement activity-based costing for plant engineering, the principles are the same as for any other part of the organization, but data from the computerized maintenance management system may be more readily available than in other departments.

4.3.4. Cost Control and Reduction

Plant engineering can add dramatically to the profitability of the company by controlling and reducing costs. A well-run plant engineering organization should establish an annual cost-reduction objective and measure itself against actual achievement. Although careful planning and execution of plant engineering activities can lead to cost reduction and control, the following are specific initiatives plant engineers can take to reduce costs:

1. Ensure cost-effective building designs that have:
   - **(a)** Minimum enclosing ratio (wall area/floor area)
   - **(b)** Minimum partitions
   - **(c)** Efficient heating and air conditioning
   - **(d)** Best utilization of the site (possibly through multiple floors)
   - **(e)** Low maintenance costs
   - **(f)** Standard components
   - **(g)** Lowest-cost material to fulfill function and aesthetics
2. Prepare accurate cost estimates of all construction and repair work.
3. Obtain competitive bids from qualified/reliable contractors.
4. Control construction and repair costs to avoid overruns.
5. Avoid engineering change orders with contractors to control costs.
6. Conduct work sampling studies on plant engineering personnel to solve problems and improve efficiency.
7. Apply methods improvement/work simplification techniques to plant engineering operations.
8. Assist other departments in building equipment jigs, fixtures for cost-improvement projects.
9. Practice effective maintenance management using computerized maintenance management systems if appropriate.
10. Provide optimum machine maintenance to improve productivity and avoid downtime.
11. Train and retrain plant engineering personnel to perform efficiently.
12. Apply incentives to plant engineering activities to motivate higher levels of performance.
13. Motivate plant engineering personnel to improve attitudes and reduce absenteeism and labor turnover.
14. Provide a safe workplace for all employees.
15. Involve plant engineering personnel in teams, problem-solving groups, or other participative groups to solve plant engineering problems. Implement total productive maintenance principles throughout the department
16. Reduce parts and stores inventory.
17. Conduct value engineering studies on repair parts or supply items.
    Use activity-based costing to identify and eliminate non-value-added activity.
18. Use good environmental practices to reduce or recycle solid waste.
19. Apply productivity and quality measures to plant engineering work.
20. Reduce machine setup time through careful planning.
21. Justify capital expenditures on strategic and competitive bases, not solely on discounted cash flow or hurdle rates.
22. Ensure employee comfort through environmental controls and good ergonomic design.
23. Take energy audits and control demand and power factor charges.
24. Automate energy, heating and cooling, security, and related items using computerized building automation systems.

25. Contract out expensive, undesirable, or hazardous operations.
26. Use the most modern maintenance techniques available.

4.4. Conducting a Facility Survey

When a plant engineer assumes responsibility for an existing facility, it is advisable to conduct a facility assessment to determine the condition and appropriateness of the major facility systems and components. The objective is to develop a plan for correcting, upgrading, or retrofitting these systems. The survey requires preparation, observation, analysis, planning, and action.

4.4.1. How to Conduct a Facility Survey (Piper 1988a)

1. Obtain drawings of facility and find location of critical components.
2. Peruse records of all systems, components, and equipment—repair history, material, specifications, purchase date, age of component.

Facility Component	Condition	Action	Location
Facility Site			
Roads, parking lots, walk ways			
Curbs, gutters, storm drains			
Grass and trees			
Flower beds and trees			
Building Structure and Envelope			
Trusses			
Columns			
Decking			
Exterior walls			
Footers			
Foundation			
Floors			
Roofs, flashing			
Roof drains			
Windows, frames			
Interior, Finishes			
Interior doors			
Panic hardware			
Wall coverings			
Ceilings and windows coverings			
Restrooms			
Interior lighting			
Mechanical Equipment			
Boilers, pumps, economizer			
Boiler chemical system			
Blowdown system			
Gas lines, meters, regulators			
Oil tanks, lines , pumps			
Chillers			
Cooling towers			
Water heaters			
Gas distribution systems			
Air compressors, dryer, tanks controls			
Air conditioning, handling units			
Units heaters, Unit ventilators			
Exhaust fans			
Dust collectors, fans, ducts			
Air makeup units			
Control systems			
Electrical			
Primary service			
Transformers			
Switchgear			
Distribution system, duct			
Breaker panels			
Motors			
Lighting			
Building automation system			
Battery chargers			
Uninterruptible power supply			
Meters			
Energy controller			
Electronic Infrastructure			
Telecommunications center			
Telecommunications system			
Satellite communication system			
In=Plant radio, pager, voice system			
Computer data busway, LAN			
CNC download network			
Facsimile systems			

Facility Component	Condition	Action	Location
Service Systems			
Elevators, escalators			
Dock lifters			
Bridge cranes, jib cranes			
Waste handling systems			
Trash compactor			
Waste incinerator			
Recycling baler			
Wastewater, sewer system			
Lunch room, cafeteria			
Nurse station, first aid			
Security, Fire Protection			
Perimeter fences			
Security gates			
Guard house			
Security lights			
Security/key card readers			
Motion detectors			
Video cameras and monitors			
Doors, locks			
Manual/automatic alarms			
Sprinkler pipe, valves pump, tanks			
Hoses, nozzles, hose enclosures			
Extinguishing systems			

Condition/Action/Location Codes

Condition Codes
A. Deteriorated
B. Bad structure
C. Broken
D. Rotting
E. Inoperative
F. Obsolete
G. Malfunction
H. Leaking
I. Inefficient
J. Unsafe
K. Corroded
L. Dirty
M. Clogged
N. Energy loss
O. Environmental risk

Action Codes:
1. Repair now
2. Repair routine
3. Test more often
4. Upgrade/replace
5. Cleanup/cleanout
6. Repaint/redecorate
7. Improved efficiency
8. Improve safety
9. Improve environment
10. Retrain operators
11. Adjust controls
12. Reassign operator

Location Options:
Building #
Grid or Column #
Department/Section #
Machine #

Figure 5 Facility Survey and Action Form. (Adapted from *Building Operation Management*)

3. Cite potential trouble spots.
4. Assemble a team of specialists to survey the facility.
5. Prepare an itinerary and schedule for touring the facility.
6. Develop or use a prepared checklist to avoid missing key items.
7. Take a tour or a series of tours, focusing on one or more components during each tour, noting observed conditions.
8. Review corporate strategy to ascertain future use of the facility.
9. Discuss condition of the facility with other engineering and operations personnel, building occupants, or anyone who can provide insight into the condition of the facility or equipment.
10. Generate a report with lists of problems and deficiencies plus recommended corrective actions.
11. Prioritize the lists by classifying problems as critical, serious, routine, or minor.
12. Make cost estimates of required repairs as a part of the report.
13. Issue work orders to have critical and serious problems corrected immediately or within a short time.
14. Schedule other repairs or problem correction as funds and manpower become available.
15. Repeat the survey every three to six months to determine further deterioration or level of correction from previous survey; take further corrective action as required.

An assessment survey would include a thorough review of the facility systems and components shown in Figure 5. Using the above approach, the new plant or facilities engineer can gain control of assigned responsibilities and develop a plan for resolving identified problems as soon as possible after assuming the new duties.

5. OPERATIONAL ISSUES FOR PLANT AND FACILITIES ENGINEERS

5.1. Plant and Facility Design and Construction

A plant or facilities engineer responsible for design, construction, and startup of new facilities or operations manages the project by maintaining liaison among architects, consulting engineers, contractors, and suppliers to ensure the project is on schedule, within budget, according to specifications, and completed according to the terms of the contract.

5.1.1. Design Using CAD/Computerized Layout Techniques

The plant engineer may be called upon to design a new facility or the flow and layout of an existing facility. With the use of CAD and computerized layout techniques such as CORELAP, multiple options can be evaluated qualitatively and quantitatively to select the optimum solution. Performance of the selected solution can be evaluated further using techniques of simulation and optimization discussed in Chapters 93–102.

5.1.2. Building Codes Compliance and Use of Standards

Building codes are detailed listings of design and performance criteria that must be observed before building occupancy is approved. Codes generally describe types of construction, building limitations, environmental requirements, safety systems, repair and alteration procedures, permits, and fee structures and penalties. Codes can be both an asset and liability. While they may add cost to a building, codes compliance generally ensures a safe building. If an inspector makes unreasonable demands, the code can be used to refute these demands. Enforcement and approval procedures vary depending on the jurisdiction in which the facility is located.

Plant engineers must know which code applies to facilities in each locality. The best-known codes publishing organizations are Building Officials and Codes Administrators International (BOCA), International Conference of Building Officials (ICBO), and Southern Building Code Congress International (SBCC). Further information can be obtained from the Internet.

There are also many published standards for various parts of the building or equipment available from such agencies as the American National Standards Institute (ANSI), the American Society for Testing Materials (ASTM), the American Society of Mechanical Engineers (ASME), the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the National Fire Protection Association (NFPA), Underwriters Laboratories (UL), Factory Mutual Engineering Corporation (FMEC), and the Occupational Safety and Health Administration (OSHA). The use of standards in planning and constructing a new or revised facility ensures that safety considerations as well as other building conventions are observed (Steiner 1988).

Standards cover almost every conceivable component of buildings and equipment and are normally followed by architects when the original structure is built. The plant engineer making revisions should be especially careful to follow standards to maintain the integrity of the building, its processes, or components.

The building permitting and approval process contains the following procedural steps:

1. Determine the type of structure needed.
2. Select the site.
3. Determine zoning of site/apply for variances to zoning board.
4. Submit architectural and engineering plans to building codes administrator (BCA) for approval.
5. Obtain a temporary building permit.
6. Apply for permanent permit, obtain full permit.
7. Select contractor(s).
8. Obtain environmental permits.
9. Begin construction.
10. Cooperate during periodic inspections by BCA.
11. Complete building.
12. Pass final inspection or make revision to comply with codes.

5.2. Plant and Facility Maintenance

Whether the plant or facilities engineer is directly in charge of maintenance, this activity is of paramount importance. Throughout this chapter are noted a number of maintenance issues, and the relationship between maintenance and plant engineering is explained in Section 2.3.1. The key issue relating to maintenance for plant engineer is to ensure that all facilities and services are available for production or operations depending of the type of facility involved. In some cases maintenance reports to the plant engineer, while in other cases maintenance is a separate department or is integrated into operations. Details of maintenance are described in Chapter 59 of this Handbook. See also sections throughout this chapter relating to maintenance.

5.3. FACILITY MANAGEMENT/BUILDING AUTOMATION SYSTEMS

Both manufacturing and service facilities can benefit from the installation of building automation systems that monitor energy consumption and automatically adjust heating and air conditioning systems. These computer-based systems may also permit real-time monitoring and management of security, video surveillance, fire detection, utilities, transportation equipment, elevators, room occupancy, equipment operation, lighting or other facility management-related functions. Newer systems have user-friendly software that can be learned by inexperienced personnel in a relatively short time. Some systems use voice synthesizers for communicating with security, fire, management, or maintenance people. An emerging technology known as computer-assisted facility management not only includes the above-mentioned features but also has the ability to do maintenance planning, facility design, space planning, and property management. CAFM, coupled with computerized maintenance management systems, gives the plant or facilities engineer the resources to manage the facility effectively. To make best use of building automation systems, the plant engineers should audit facility performance by collecting and analyzing data collected from the system. Building automation systems are also capable of managing multiple facilities and controlling processes. Data management has become fully integrated with direct digital control of functions and interconnected systems directed by building specific protocols (Tatum 1990; Katzel 1998).

In addition to saving labor, these systems reduce energy consumption, avoid security breaches, reduce fire damage, and provide other intangible benefits that make justification for automated building systems feasible. In selecting a building automation system, it is essential to design the system properly, select systems to meet organizational needs, purchase quality equipment with user-friendly software and system flexibility, and obtain long-term customer service from a reliable vendor (Piper 1999).

5.4. Buildings and Grounds

As part of their duties, plant engineers are typically in charge of the buildings and grounds department that employs the janitorial staff and groundskeepers. While this may seem far afield from engineering, many opportunities for making the functions efficient are available. The key goal is to maintain an orderly workplace both inside and outside of the facility that positively impacts productivity in the operation. While everyone needs to be involved in keeping order and cleanliness throughout the facility, buildings and grounds employees facilitate and support other workers in maintaining a clean and orderly workplace.

The janitorial workforce is typically involved in cleaning the the plant or facility, handling refuse, and performing sanitation duties. In some instances, power sweepers, scrubbers, and powered handling devices are operated by the janitorial staff.

Some of the more common functions in groundskeeping are caring for flowers, trees, or shrubs, mowing grass and weeds, cutting out fence rows, patching holes in roads or parking areas, opening drainage ditches or culverts, and in winter removing snow from parking lots, sidewalks, or shrubbery, to name a few. In performing these functions, equipment used ranges from rakes and shovels to pruning shears, power mowers, chain saws, tractors, backhoes, front-end loaders, snow plows, and trucks. The equipment used depends on the size of the facility and the assignment of duties by management.

The plant engineer can make significant cost savings by ensuring that buildings and grounds services are provided efficiently by taking the following actions:

1. Recognize the value of employees who perform buildings and grounds work.
2. Set a budget to cover the grounds maintenance needs of the organization.
3. Train people in use of equipment and certify operators of larger equipment, especially in safe use of lawnmowers, chain saws, tractors, and other dangerous machinery.
4. Issue safety shoes, goggles, hard hats, ear muffs, gloves, back supports, and other safety equipment and ensure that equipment is used to protect employees.
5. Simplify tasks by providing adequate equipment for all assigned tasks. (See also Section 6.2 on waste handling.)
6. Apply work measurement to find time for janitor and groundskeeper work, measure efficiency, and determine the correct number of people assigned to the size and type of facility being served (Use work sampling, time study, and published standard data.)
7. Provide adequate supervision to plan and schedule the job to ensure that all necessary work is done on the correct frequency and within time available.
8. Periodically inspect quality of work being performed, reward work well done, and make corrections if work is unsatisfactory.
9. Conduct work sampling studies to identify potential problems and solve problems as they are recognized.
10. Institute teams to reduce reliance on supervision.
11. Keep equipment maintained properly and practice preventive maintenance with reporting/documentation that PM has been performed.
12. Consider outsourcing all or portions of the buildings and grounds functions to contractors whose qualifications, credit ratings, and performance records have been thoroughly screened.

Proactively creating a well-organized buildings and grounds staff can greatly improve productivity and quality of life in the facility and minimize problems associated with this function (Ross 1996).

5.5. Safety and Loss Control

5.5.1. Safety Management

Plant engineers often manage the safety program in plants or other facilities. Although industrial engineers receive a course in industrial safety, they may need to fill knowledge gaps by further study and experience. A comprehensive and effective safety program should include the following process steps, none of which may be omitted:

1. Well-defined management strategy, policy, and commitment to safety
2. Goal for safety improvement set and resources allocated
3. Designated responsibility/authority/accountability for safety
4. Formal rules and procedures for safety
5. Engineering of safety into every process and product
6. Safety training and special awareness programs
7. Supervision committed to and competent in safety
8. Effective safety communication and promotion
9. Positive safety attitudes through motivation and rewards
10. Safety inspections using committees
11. Immediate correction of unsafe acts and conditions

12. Disciplinary action administered for willful unsafe acts
13. Well-equipped, trained, and staffed first aid function
14. Thorough accident investigation with effective remedial action
15. Meaningful safety performance measures with critical analysis
16. Effective preventive and corrective maintenance programs
17. Continual assessment of the safety program
18. An iterative program of continuous safety improvement

The results of an effective safety program not only can be measured in injuries prevented and lives saved but also may have a distinct bottom-line impact on the corporation or entity. Companies that do not have effective safety programs often pay the equivalent cost in terms of workers' compensation and lost productivity. The inference can be made that a safe workplace is a productive workplace (McElroy 1964).

Because an effective safety program in the plant or facility must include training, the ultimate objective of training is to influence the attitudes of employees around the clock. Off-the-job accidents cost industry many times more than on-the-job injuries. Although workers' compensation is not involved, absenteeism from off-the-job injuries results in productivity losses and insurance cost increases. Employees injured off the job may, with the assistance of unscrupulous lawyers, sometimes claim the injury occurred during work time. Such fraud can be combatted by effective record keeping and supervisory vigilance.

A plant engineer charged with the responsibility for safety is obligated to comply with OSHA regulations, but must as a professional obligation administer an effective safety program beyond OSHA regulations that concentrate on conditions. Accidents are caused by people, and a well-trained, safe worker can avoid unsafe conditions and attendant accidents. (See also Chapter 43.)

5.5.2. Loss-Control Programs

Administration of the plant loss-control program may fall to the plant engineer or may be handled jointly with the personnel manager. Loss control includes the insurance program plus fire, security, and safety. The objective of loss control is to provide uninterrupted operations and minimize losses of life and property from fire, theft, accidents, and other such occurrences. Safety and security are addressed elsewhere in this chapter, and a brief treatise on fire protection follows.

Many organizations have regular visits by insurance inspectors who identify potential fire hazards. Although some inspectors may go to extremes (such as sprinklers under desks), it is advisable to follow recommendations by insurance inspectors where feasible. If inspections do not occur, the plant engineer should conduct a fire risk survey to identify fuels, ignition sources, fire propagation routes, fire detection and extinguishing systems, and life-saving measures. The adequacy of fire-detection and extinguishment systems should also be assessed and corrective measures taken immediately.

Sprinklers should be tested regularly to ensure that all systems are ready should a fire strike. If a booster pump is in place, it should also be tested. Because as booster pumps are high horsepower, the testing alone can add to electrical demand charges. Having the pump on a safe circuit and testing during off-peak loads can save some of the demand charges.

A well-trained fire brigade composed of plant employees can respond to a fire within 1–4 minutes in most facilities, compared with 5–15 minutes for a municipal fire department. Most fires can be controlled in the first 5 minutes if a rapid response occurs. Fire brigade members should be recruited from maintenance or operations ranks dispersed throughout the facility. Training should consist of first aid, evacuation procedures, and the location and use of fire extinguishers, hoses, sprinkler valves, and other equipment. Municipal fire departments should also be acquainted with the plant layout, fire-fighting equipment, and special hazards.

5.6. Plant and Facilities Security

The security function usually includes fire prevention and reporting, crime prevention and detection, risk management, and administration of security personnel. A security survey should be taken to determine the scope of the security function, the condition of this service, and the steps necessary to bring security up to standard. Outside guards may be necessary to prevent unauthorized entry to critical manufacturing areas, laboratories, computer rooms, and other sensitive areas. The level of security depends on the sensitivity and confidentiality of the work, the labor situation, the local crime situation, and the proximity of fire and police protection (Piper 1988b).

Special protection should be given to computer records. Not only should access to computer areas be denied to unauthorized persons, but codes and passwords should be carefully restricted. Computer rooms should be fire resistant, with special halon extinguishing systems for protection of electronic circuitry and magnetic media, the loss of which could be catastrophic for the business.

By using the checklist that follows, the plant or facilities engineer can cite deficiencies in the security system and take action to correct deficiencies (Piper 1988b; Pearlman and Cana 1999):

Is a security plan currently in effect?

Is a key control system rigidly enforced?

Are penalties for unauthorized entry or use of keys enforced?

Are safe combinations, computer access codes, and other sensitive information closely controlled?

Have security personnel been thoroughly screened and trained?

Are security patrol schedules revised regularly to avoid established patterns?

Are employees carefully screened for past criminal behavior?

Are security personnel trained in sprinkler system operation and cutoff? In fire extinguisher use?

Are computer operating and records rooms, laboratories, and other sensitive areas secured by modern personnel identification systems (card access, hand print, eye retina)?

Is the perimeter of the plant or facility protected to limit access?

Are gates kept closed when employee access is minimal?

Are fences maintained and inspected regularly?

Are electronic fire, movement, and detection monitoring devices (ultrasonic, seismic, infrared, contact) installed and operational?

Does the electronic building control system automatically notify fire and police as well as plant security personnel of incidents?

Are video monitors/CCTV and intrusion-detection monitors used for constant surveillance of critical areas?

Are positive identification systems for personnel installed at plant entrances?

If contract guards are used, does the guard service have a blemishless record for guard selection and training, service and reliability?

Does a disaster plan and organization exist with delegated responsibilities? Do security personnel know names of all managers, employees, agencies, and emergency services to be contacted in a disaster?

Does a public relations plan exist and is a spokesperson designated to provide information about the disaster to the press and public?

6. WASTE-MANAGEMENT CONCERNS FOR PLANT ENGINEERS

6.1. Management and Legal Issues on Waste Management

Waste management, environmental law, and other environmental issues must be addressed by plant and facility engineers. The information that follows should guide a new plant engineer with an industrial engineering background in gaining control of the waste management and environmental program as quickly as possible.

Industrial engineers by definition eliminate waste, and they can apply industrial engineering methodology to waste reduction. Waste was paid for as part of a purchased item.

Although many managers take a nonchalant attitude toward waste management, management must realize that effective waste management can improve profitability. To prevent waste, management at all levels must learn to think of the *total system or process* and include waste management in all decisions. They should understand that the beginning of the waste stream is not at the trash dock, but in product design, purchasing, engineering, or even top management. It should never be assumed that any waste item cannot be eliminated, utilized more effectively, or recovered.

6.1.1. Legal Issues on Waste Management

Too often, management makes decisions about waste management based solely on avoidance of fines resulting from many environmental laws in and court decisions instead of making rational decisions based on good management practice. It behooves the plant and facilities engineer to become intimately familiar with all applicable environmental laws and regulations. Space in this chapter does not permit a review of laws, but some assistance can be found in Chapter 19 of this Handbook.

6.1.2. Waste Management as a Productivity or Resource-Utilization Issue

Industrial engineering by definition maximizes the utilization of resources including capital, machines, material, people, data, energy, and technology by devising innovative systems for production or service. The objective of productivity improvement is to maximize the utilization of these resources.

Waste avoidance or reduction maximizes the material resource and reduces labor and equipment requirements as a result of less handling and disposal effort.

6.1.3. Environmental and Waste-Management Productivity and Benchmarking Measures

The effectiveness of the waste-management and environmental program can be measured by applying productivity measures internally to the organization or externally as benchmarking measures to compare performance with similar organizations. Measures include:

Labor productivity (output/man hour)
Handling equipment productivity
Operations productivity
Energy productivity (output/M BTU)
Labor content of waste management activities
Cost of waste handling and disposal
Value of waste handled and discarded
Volume of waste handled
Weight of waste handled
Production downtime incurred (or avoided)
Complaints from EPA, OSHA (or avoided)
EPA fines assessed (or avoided)
Operating costs reduced
Material losses (or losses avoided)
Energy saved or converted
Defects avoided
Quantity or value of waste sold or exchanged

6.1.4. Economic Considerations on Waste Management

Industrial engineers learn to weigh alternative proposals using engineering economy principles. Business school graduates are often taught that there must be a short-term, bottom-line impact for an expenditure to be made. Solutions to waste-management problems may be evaluated using life-cycle costing principles with data supplied by activity-based costing. Applying waste-management and disposal costs to the justification process improves the justification dramatically. While waste disposal is a non-value-added activity, finding ways to eliminate or reduce waste at the source can produce savings through one or more of the following:

Lower labor cost
Less material waste
Less expensive raw materials
Reduced material-handling cost
Lower energy costs
Improved product quality
Reduced maintenance costs
Profit through waste exchange
Reduced long-term liability for improper disposal, spills, and accidents
Avoidance of fines for environmental noncompliance
Reduced transportation, tipping fees, and disposal costs

6.2. Waste Streams and Waste Handling

6.2.1. Solid and Hazardous Waste Streams

Industrial waste streams contain nonhazardous materials such as paper, wood, metals, plastics, fibers, and food waste. Paints, some plastics, and metals may be hazardous or nonhazardous depending on their composition. Many chemicals are considered hazardous and require special disposal methods under stringently controlled conditions.

6.2.2. Solid Waste Handling

The typical solid waste stream consists of nonhazardous packaging material, cafeteria and restroom trash, office waste paper, floor sweepings, and waste materials from processing operations. When possible, material should be sent to a recycling area, with nonrecyclables going to a disposal area.

Engineers often give detailed consideration to material handling of product and raw material but often ignore handling of waste material within a plant. Consequently, default material-handling methods for waste material remain primitive and labor intensive. While every effort should be made continually to eliminate waste material, an IE-oriented plant or facilities engineers should devise cost-effective or innovative methods for handling waste material that has not yet been eliminated.

Waste handling should be viewed as a non-value-added but necessary process. All waste-handling activities should be documented or mapped to determine who is spending time to handle waste and how much this activity is costing at each step by applying work measurement. From these cost data, more cost-effective methods of handling and disposal can be developed.

Simply designing a route for waste handlers to follow and monitoring their methods can improve efficiency in waste handling. Savings opportunities exist if the study finds that production people are spending time handling or disposing of waste materials while the production operation remains at a standstill. Lift trucks from production areas are sometimes used for transfering trash to disposal area, but this practice interferes with production when they are needed to deliver or remove palettes from production operations. A lift truck should be assigned to waste handling to avoid this situation, especially if distances to the disposal area is long.

Depending on the type of operation, such handling devices as dumping hoppers, tilt carts, four-wheeled carts, trailer trains, rolling waste cans, scrap conveyors, chutes, and pallets are used to move waste material for recycling or disposal. At the disposal area, waste material is sometimes placed on an open trailer or dumped into a trash compactor. A skid steer loader may also be used to load a trainer or compactor. Mechanization is desirable to reduce costs to the extent possible if waste-reduction efforts have not fully eliminated waste.

If a contractor is engaged to handle waste in the plant, the handling equipment may be owned by the contractor, who may work on a fixed-fee basis either by tonnage or hours expended. While this approach may reduce equipment investment, the contractor should indemnify against liabilities for contractor personnel and ensure that the company is compensated for damage to equipment or interruptions to production caused by the contractor.

6.3. The Industrial Engineering/Environmental Methodology

The industrial engineering-based environmental methodology outlined below is the systems approach to waste management through which industrial and plant engineers can solve environmental problems in a cost-effective and productive manner. The methodology is based on the premise that waste begins at the top management decision-making process. When top management realizes where the value stream containing waste begins, commitment to waste reduction and elimination of non-value-added activity may occur. The revised IE environmental methodology is as follows (Ross 1989, 1999):

1. Help top management understand where the waste stream begins and get support for waste-reduction and environmental-improvement programs.
2. Outline clear objectives and scope for the environmental program.
3. Get everyone involved at all levels of the organization.
4. Handle the legal issues of environment as a top priority as follows:
   Become familiar with all applicable laws.
   Take an environmental audit to find problems before regulators arrive.
   Be sure all paperwork is submitted on time to avoid fines.
   Implement effective environmental controls to keep the organization in the lowest possible environmental risk category.
   If an inspector arrives at your facility, be cooperative and don't try to hide anything (if you're caught, it will cost you dearly).
   Implement changes punctually.
   Protest unfair citations or excessive fines.
5. Organize and train teams to address waste-reduction issues.
6. Make a process map of all activities performed in all processes.
7. Identify, quantify, and prioritize waste streams at any point in each process.
8. Implement effective waste-management tactics, including the following, which appear in descending order of value:
   Eliminate or reduce waste streams at the source.

Redesign the product to reduce waste—use value analysis.
Change processes, conditions, and procedures to reduce waste.
Reevaluate reality of quality requirements that may produce waste.
Purchase good-quality, nonpolluting materials.
Insist on returnable containers—set up a container or pallet pool.
Exchange waste with other companies.
Find another product to use waste productively.
Segregate waste and reduce each type.
Recover resources from waste.
Reclaim, reuse, recycle wastes even if they only break even.
Find secondary outlets for waste.
Improve material handling of waste; avoid makeshift handling methods.
Improve maintenance procedures on equipment to reduce waste
Mix wastes into compost for landscaping and ground cover.
Cogenerate waste material to make electricity and reduce waste volume.
Incinerate waste material for process, water, or comfort heating.
Dispose of waste that cannot be reclaimed to a landfill as a lost resort.

9. Take a long-range perspective; don't look for a quick fix.
10. Do justifications based on activity-based and life-cycle costing, including environmental and social costs.
11. Train people in the organization to reduce waste and reward people for exceptional effort in the environmental area.
12. Benchmark with similar organizations and emulate best waste practices.
13. Seek outside assistance such as universities and trade associations.
14. Develop or recognize economic incentives for waste reduction.
15. Make the process of waste reduction iterative and repeatedly review processes to make further waste reductions.
16. Evaluate results and make changes in the program as necessary.

By using the methodology outlined above and keeping cognizant of the many industrial engineering-related resource conservation issues, plant engineers can improve the environment, resource productivity, organizational profitability, and quality for all stakeholders.

7. TECHNOLOGICAL CONCEPTS FOR PLANT ENGINEERING

Throughout this chapter, reference has been made to many electronic and computer applications with which plant and facilities engineers need to be familiar. Notable among these is the computerized maintenance management system (CMMS), which is often used by plant engineers to schedule and control maintenance and operations in plant engineering areas. This system is described in some detail in Section 3.4.

The second electronic system under the control of plant engineers is the facility management or building automation system, which usually includes an energy controller. These systems are described in Section 5.3.

Depending on the type of operation, process-control computer systems interconnected with manufacturing, engineering, and administration are often needed. Key to interconnectivity is the installation of a fieldbus through which data are transmitted among users. Manufacturing execution systems operate on a distributed control network ring (Kamal Zafar 1998).

Another group of electronic systems used by plant engineers pertains to preventive and predictive maintenance. A description of these systems appears briefly in Section 3.4 and is described more fully in Chapter 59, which pertains specifically to maintenance.

The importance of understanding new technologies has been emphasized in this chapter by outlining the knowledge and skills that a successful plant and facilities engineer needs upon assuming that position. Because the above-mentioned systems are highly varied and extremely complex, it is not within the scope of this chapter to describe these technologies in detail. By being aware of the many possibilities for improvement through technological concepts, the plant engineer can take steps to become competent in the use of electronic equipment and/or to be able to manage persons who are familiar with the details.

8. MANAGING ENERGY

8.1. Why Energy Is an Important Resource

Until 1973, when the oil embargo occurred, energy was regarded as an uncontrollable overhead item, but rapid escalation in energy costs changed this perception and elevated energy to the status of a key resource to be productively utilized. Since energy has become plentiful, many enterprises have simply adjusted their budgets to higher prices and have forgotten the easily implemented opportunities for energy conservation and cost reduction.

This section offers an integrated approach for finding, evaluating, prioritizing, and implementing energy conservation opportunities and energy and utility system improvements. Plant or facilities engineers or other managers should devote a significant amount of time to energy management. If techniques described here are applied, significant energy-saving opportunities should be found.

8.1.1. Why Engineers Should Be Concerned about Energy

Engineers should be aware of and take action to overcome these conditions:

Failure to recognize energy as one of the five key resources to be managed
Missed conservation opportunities sapping profits
Emphasis by engineers on other resources (labor, machines)
Lack of concern about energy in capital decisions
Ignoring that energy price increases continue to occur
A lack of understanding of the total cost of energy
Ignoring that energy savings drop directly to the bottom line
Poor administrative controls of energy costs
Poor maintenance of energy equipment and systems

8.1.2. What Are Enterprise Resources?

Resources are needed to activate any enterprise. Most enterprises have the following resources at their disposal:

Labor/manpower
Material
Machines
Technology/data
Energy

How and in what proportion resources are consumed depends on the type of activity or operation in which the enterprise is engaged. Although energy may be a small portion of running a garment factory or manual assembly plant, a metal fabricating shop with large punch presses or a heavy chemical plant may have a large proportion of its budget in energy. Energy is sometimes an essential part of the process (melting, heat treating, welding, chemical processing), while at other times it may facilitate the operation (heating, comfort, driving machines).

8.1.3. Energy Productivity

As a key enterprise resource, energy productivity can be computed. By definition, productivity measures the output vs. the input, and the index is found by applying formulas similar to the following:

$$\text{Energy productivity index} = \frac{\text{\$ value of plant outputs}}{\text{kWh}} \text{ or } \frac{\text{\$ value added by plant pperations}}{\text{\$ energy cost}}$$

Other combinations may reveal trends in particular situations. Productivity measures plotted over time can show trends in utilization of the energy resource relative to a baseline that can signal problems or show progress in energy reduction.

8.1.4. Energy Myths

To begin an energy conservation program, engineers must overcome myths that inhibit consideration of many opportunities that if implemented would produce sizeable savings for this valuable resource. Some myths are:

Energy costs are a small part of the budget.
We have no big energy consumers.
We've already minimized energy consumption.
Its not in the budget.
We don't have time to reduce energy.

Its cheaper to let machines run.

Energy is plentiful.

8.2. Energy and Utility Concerns for Plant Engineers

8.2.1. The Energy Process

The entire effort to obtain and maintain an adequate, dependable, and cost-effective supply of energy is a process that is more extensive than most people realize. The process should be conceptualized in terms of a business process in which all steps from conception to termination are considered. Although the energy process may vary with the type of enterprise, some typical steps in the energy process include:

1. Planning the process
2. Determining energy needs for process, building heat, and other uses
3. Selecting of energy form
4. Negotiating rates with utilities
5. Designing the optimum system installation
6. Anticipating future needs
7. Detailing maintenance requirements of the system (periodic, preventive, predictive)
8. Conducting daily operation of the system
9. Accommodating environmental concerns
10. Using waste heat or material for energy
11. Conducting energy-related waste disposal
12. Administering the energy effort (invoice processing, etc.)
13. Taking regular energy assessments for continuous improvement in energy conservation
14. Justifying and replacing equipment
15. Replacing energy sources with more efficient or lower-cost sources
16. Iteratively reassessing and reengineering the process

8.2.2. The Energy System

The energy system includes not only the equipment in the plant or facility, but utilities that supply energy (gas, electric, water) to the plant. The system also includes secondary energy supplies such as steam and compressed air. The distribution system, the protective devices, and all equipment needed to supply energy to the process or operation of the facility, equipment, or operations are parts of the energy system. Aside from maintaining good relationships with utility companies, the main concern of a plant engineer or plant manager is to keep the in-plant system functioning effectively at all times.

While this chapter focuses predominately on energy conservation and cost reduction, the importance of system operation and maintenance cannot be overemphasized. We tend to take energy for granted, but continual vigilance is needed to ensure that energy is available for the process to run, the building to be heated, and paychecks to be printed on time. Some action items on energy system operation and maintenance are included in the energy-assessment procedure in Sections 8.6–8.8.

8.2.3. Managing Utility and Service Systems

The effective management of utilities and services is a primary responsibility of most plant and facilities engineers. The scope of utility and service systems includes:

Electric, gas, and water supplied by outside utility systems

Piping systems

Steam generation and distribution systems

Chiller systems, cooling towers

Heating, ventilation, refrigeration, and air conditioning systems

Building instrumentation and control systems

Pollution-control systems, dust-collection systems

Telephone and communication systems

Compressed air systems

To be able to manage these complex systems, the plant engineer should (Rospond 1999):

1. Become familiar with all utility and service equipment
2. Establish contact with all utilities; gain their cooperation
3. Conduct an audit of each system to determine current condition and needed corrective measures
4. Determine availability of installed spares, spare components and replacement parts, and backup systems
5. Ascertain ownership of utility equipment such as substations, transformers, and lift pumps
6. Develop effective preventive and corrective maintenance programs
7. Implement continuous improvement of utility and service operations
8. Upgrade training of employees responsible for these systems
9. Justify and install state-of-the-art equipment where possible
10. Monitor power quality, upgrade system for digital computer systems
11. Improve transformer efficiency

See the Appendix for specific improvement possibilities.

8.2.4. Demand and Power Factor

Demand and power factor are often major invisible electric costs. Many electric utilities do not show data on these items on electric bills, and it is incumbent upon the energy manager to obtain these data. Electric utilities base demand charges on an integrated peak demand in kilowatts over the highest 30 minutes during any 1-, 6- or 12-month period, depending on the utility's policy. Power factor charges occur when inductive or capacitive loads get out of phase with current supplied, as shown in Figure 6.

Power factor is the difference between current used in kilowatts (kW) and current supplied in kilovolt amperes (kVA) as shown in this example.

A small factory has a monthly demand of 237 kW and 324 kVA as measured by utility meters.

$$\text{Power factor} = \frac{\text{kW demand}}{\text{kVA metered}} = \frac{237}{324} \times 100 = 73\%$$

If the utility requires 85% power factor to avoid penalty,

$$0.85 \times 324 \text{ kVA} = 275 \text{ kW billing demand}$$

$$\begin{aligned} \text{Billing demand} &= 275 \text{ KW} \\ \text{Actual demand} &= \underline{-237 \text{ kW}} \\ \text{Excess demand} &= 38 \text{ kW} \end{aligned}$$

Excess demand is charged at utility demand charges of \$4.00–10.00 per kW depending on rate structures. Even at \$4.00 the cost of 38 kW/month would be \$152.00, or \$1824.00/year.

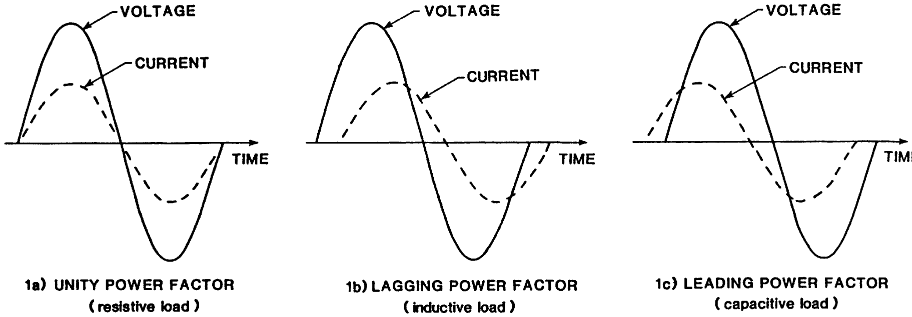

Figure 6 Graph of Reactive/Out of Phase Current.

When capacitors are installed, power factor increases to 93% (well above the 85% level), thus avoiding the penalty. The payback is as follows:

$$\frac{\$1200 \text{ capacitor cost}}{\$1824 \text{ power cost saving}} \times 12 \text{ months/year} = 8 \text{ months}$$

Adding capacitors means the circuit capacity is thus increased to allow adding more load. Note: Demand and power factor calculations in each utility area differ, hence the above example would have to be revised to meet local conditions.

Demand and power factor charges are often a major percentage of the total power cost and to a large extent are controllable. Demand can be controlled by shedding loads when peak demands are approached, either manually or through the use of a programmable energy controller. Power factor can be eliminated by replacing inefficient motors or installing capacitors that limit reactive current to levels acceptable to the utility. Controlling demand and minimizing reactive current makes significant reductions in power costs obtainable. Solutions to reducing costs of these items are included in Sections 8.6–8.8

8.3. Financial Considerations about Energy Management

8.3.1. Assessing the Cost of Energy

The real cost of energy is not just the price per gallon, Mcf or kWh but in executing the process that provides energy to run the business. Because energy is an essential resource for almost any manufacturing or processing operation, massive effort must be expended to keep the supply of energy available in the proper quantity and quality at the minimum cost consistent with keeping the enterprise in effective operation.

The most costly aspect of energy is unavailability. When energy becomes unavailable, costs soar and adverse consequences result:

Production interruptions
Missed schedules
Lost customers
Penalties for shutting down customers production lines
Spoiled work, rework, non-value-added activity
Costly cleanout of ruined product from processing equipment

Likewise, the benefits of effective energy management can be measured in terms of lost production avoided, productivity improvement, continued customer satisfaction, and profitability increases. The real cost of energy is in executing the process that provides the energy supply to run the business.

By having the cost of energy failures highlighted through the use of activity-based costing, the engineering manager can determine the cost–benefit ratio of operating the system to avoid future failures.

Another caveat in determining the real costs and benefits of effective energy management is where to focus effort. Prevalent philosophies today include ‘‘pick the low-hanging fruit’’ and ‘‘don’t sweat the small stuff.’’ Often these philosophies lead to missing the really big winners. While there may be some merit to each of these philosophies, the real savings in energy systems may be from finding less obvious, high-return savings that will provide long-term solutions to complex problems.

8.3.2. Justifying Energy-Conservation Opportunities Using Activity-Based Costing

While energy costs are typically considered overheads, costs can be traceable to specific activities within the operation. Applying activity based costing, life-cycle costing, or other systems that provide accurate data on energy use allows opportunities for conservation and system upgrade to be identified and justified.

Too often, worthwhile energy projects are killed by the one-year payback syndrome. In addition to being too strict, the one-year payback concept ignores the time value of money, a fundamental of engineering economy. In many energy and environmental projects, the payback is nowhere close to a one-year undiscounted payback.

To get top management’s attention, the project author must get outside of the narrow confines of labor or utility savings and include the benefits of a dependable, cost-effective energy process to justify energy related projects. Management reacts best to $$$$ and ####, so it is essential that you speak their language. The basis, for these savings is in keeping records using activity-based costing. If energy problems cause lost production, customer dissatisfaction, or excessive costs, ABC cost data that quantify these problems should get top management project approval.

Especially useful in justifying energy improvements is rework, reinspection, repackaging, or any other re-word that connotes non-value activity caused by energy failures or inadequacies.

8.3.3. Using Life-Cycle Costing to Assess Return on Energy Projects

Life-cycle costing is also useful in justifying energy projects because all benefits and costs throughout the expected life of the project or equipment are predicted, and disposal costs at the end of the project are included. Placing a value on environmental conservation, energy availability, and system dependability in a LCC calculation can further assist in justifying energy projects.

Data from ABC can also be used to substantiate life-cycle costing. The use of activities as the basis for cost justification gives a true representation of what actually happens in the organization, and can demonstrate interdependencies of energy with other activities in the organization. See Chapters 88–92 for more detail on costing.

8.3.4. Impact of Utility Deregulation

Until recently, utility companies had monopolies in certain areas of the country, but as a result of deregulation, it is now possible to purchase gas or electric from other utility companies and have it delivered through systems of the former utility company. The impact on energy users is that opportunities for significant savings now exist as a result of deregulation. Energy managers should investigate the possibilities for accessing savings from deregulated utilities to improve profitability of the company.

8.4. Relationship between Energy and Environment

8.4.1. Pollution from Energy Production and Waste Heat Recovery

Energy and environment are inextricably intertwined issues. Energy production is one of the chief causes of air pollution, and conversely, energy production can be a major solution to environmental problems. Acid rain caused by burning fossil fuels and discharging pollutants such as nitrous oxide and sulfur dioxide results in harm to aquatic life, animals, vegetation, and humans.

Some solutions for both energy and environmental problems lie in burning trash or other waste material after all recyclables have been removed. While this approach reduces waste streams by over 90%, so-called environmentalists raise a loud cry about burning anything, even though benefits far outweigh costs. The ultimate solution to energy-related pollution is conservation.

8.4.2. Cogeneration

The concept of cogeneration is both environmentally friendly and energy cost effective. Definitions of cogeneration include topping and bottoming systems. A topping system primarily generates electricity, and an alternative use is found for the exhaust steam. The bottoming system produces heat to facilitate a process, and the excess is captured for electric power generation or other uses as a byproduct.

Typical cogeneration methods include use of waste process gases to drive gas turbines for electric generation, recapture of low-pressure steam for electric generation or driving machinery, and use of waste steam or heat for electric generation and peak shaving. Incineration of waste materials as fuel for steam generation, process heat, district heating or air conditioning, or electric generation is a growing cogeneration option.

8.5. Establishing Strategies for an Effective Energy-Management Program

8.5.1. Strategies and Tactics for Major Energy Improvements

1. Convince your management of the value of energy conservation and systems improvement.
2. Get energy improvement into the budget.
3. Develop a strategic objective to have the best installed energy systems and make the most efficient use of energy possible.
4. Develop and implement a specific plan for taking energy assessments.
5. Identify every energy-consuming device in the facility.
6. Conduct a comprehensive analysis of all energy equipment.
7. Develop a plan to upgrade technology of all energy equipment.
8. Review energy bills and find demand power factor and contract rates.
9. Negotiate with utilities to get lower rates and better breaks on charges.
10. Audit past bills, and get adjustments where possible.
11. Find real costs of energy deficiencies and unavailability.

12. Justify new technologies and permanent solutions to energy problems.
13. Reengineer the energy process, and stop doing business as usual.
14. Make energy an iterative process that is under frequent review.
15. Use steps in the detailed procedure that follows.

8.5.2. Starting an Energy-Management Program

Central to an energy-improvement effort is an energy assessment. Whether techniques of energy improvement are called surveys, audits, or assessments depends on objectives and individual preferences. An audit focuses on the quantitative aspects of energy consumption and finds savings opportunities by analysis of current energy use patterns and consumption data. A survey usually focuses on qualitative opportunities that produce easily implemented improvements. An assessment usually follows a structured approach to identify, evaluate, and implement energy saving projects or system improvements. Often the terms are interchangeable, and all approaches yield good results. In the remainder of this chapter the term *assessment* will be used most frequently Managers or engineers finding ways to reduce energy requirements should not be concerned with terminology as much as results.

The methodology shown in the Appendix provides a step-by-step approach to energy conservation and cost reduction. It includes practical solutions, many of which can be implemented at little or no cost. Examples will be discussed along with application of the methodology. By following the steps in the methodology, the energy-analyst should find numerous energy-saving opportunities.

Generally, an energy assessment will include finding energy-saving and system-improvement opportunities. The procedure in the Appendix shows the detailed steps to assess energy opportunities. Before the assessment starts, one person and/or a multidisciplinary team should be assigned to conduct the assessment, and each member should be trained in their specific roles. The composition of the team depends on skills available in the organization. Normally a combination of engineers, supervisors, operators, and human resource people have sufficient diversity of background to generate creative ideas for energy improvements.

8.6. Steps in an Energy Assessment

Prepare for the assessment:
- Make a commitment to energy improvement.
- Select an individual or a team to improve energy.
- Collect data for energy bill analysis.
- Identify operations and components of the energy system to include in the assessment.
- Obtain instrumentation to do a credible technical assessment.
- Determine who controls those operations or components.
- Obtain agreement from operations chiefs to proceed with the assessment.
- Get a computerized energy analysis program if available.

Collect data on energy consumption, practices:
- Review energy bills for past two years.
- Record demand and power factor data.
  - Get utility to show power factor and demand on monthly bills.
  - Find criteria for power factor and demand charges.
- Input to computer spreadsheet and make charts and graphs, convert to BTU/caloric equivalent.

Take plant tours to identify energy opportunities:
- Observe present/potential energy waste and system problems.
- Record nameplate data, load rating, etc.
- Review the energy system.
- Find all energy system equipment, including invisible.
- Fill out energy data sheets.
- Compute theoretical load, compare with billed load.
- Make inferences about discrepancies.

Analyze data from steps 1 and 2.
- Correlate data with production or activity level.
- Find the big energy consumers.
- Apply activity-based costing to find energy-related delays.

Develop and evaluate energy conservation solutions.
- Revise team assignment to develop solutions.
- Use teams to get ownership of improvements.
- Use checklists to find energy savings.
- Follow energy-improvement opportunities (see Section 8.7).
- Apply analytical techniques:
  - What, where, when, who and why?
  - Eliminate, combine, resequence, and simplify operations.
- Apply systematic creative thinking, brainstorming.

Evaluate solutions, select best alternatives:
- Conduct economic evaluation.
- Use ABC and LCC.
- Consider people aspects.
- Assess feasibility.

Quantify and prioritize energy-improvement opportunities.
- Avoid the one-year payback syndrome.
- Show costs of energy unavailability.

Present findings to management:
- Develop each recommendation fully.
- Prepare a coherent report.
- Show why management should accept your recommendations.
- Express recommendations in management's language ($$$$ and ####).
- Rehearse the presentation, and present the report succinctly.
- Gracefully accept management's decision.

Implement improvements and monitor results:
- Assign responsibility for implementation.
- Establish measures of specific improvements.
- Verify savings.
- Chart energy productivity.
- Modify improvements if required.
- Avoid false savings due to external changes.

8.7. Energy-Improvement Possibilities

Facility
- Install enough insulation, weather stripping.
- Seal off leakage through windows, cracks.
- Evaluate refenestration (window replacement).
- Install vestibules at doors.
- Seal around dock doors/use flap doors to seal out cold air.
- Reduce solar gain (insolation) to reduce cooling load.
- Close all doors and other openings in winter.

Energy infrastructure in the plant
- Give the energy infrastructure and other energy delivery systems constant attention.
- Make someone responsible for operating and maintaining energy systems in the facility.
- Check ownership of interface devices with the utility supplier.
- Set up a preventive maintenance program for every part of the system, including:
  - Contacts, insulation, dust and dirt on equipment, heat buildup in ducts and switches.
- Note failure points and correct the root problem immediately.
- Reengineer the system to bring it to state of the art.

Electrical

Upgrade electrical distribution systems.
Control peak load demand, shed loads using prioritized controller.
Run equipment off peak where possible.
Retrofit for higher voltages.
Correct power factor by using energy-efficient motors or capacitors.
Turn off equipment when not needed.
Monitor and upgrade power quality for digital equipment.

Natural Gas

Check for leaks and explosion hazards.
Check piping for corrosion.
Check for improper installations.

Utility deregulation

Become familiar with new regulations and procedures.
Contact potential energy suppliers for quotes, interview alternate suppliers.
Beware of bogus suppliers offering unrealistic deliverables.
Carefully evaluate economics of all offers; determine the *real cost*.
Negotiate rate reductions.
Take full advantage of deregulation.

Lighting

Reduce number of fixtures.
Avoid electrician's dream (excessive lighting).
Install more efficient lighting fixtures, electronic ballasts, and long-life bulbs.
Use task lighting, reduce lighting in nonproduction areas.
Turn off lights when not in use.
Balance lighting heat load with air conditioning.
Install occupancy sensors or more switches to turn off unneeded lights.
Utilize photocell and/or timers on lighting, especially outdoors.
Tie lighting into building control systems.

Process

Run process equipment only when needed.
Avoid short runs on process equipment.
Consider energy in scheduling production.
Make energy a prime consideration in replacing process equipment.
Schedule operations/production around energy considerations.
Reduce run times of equipment to bare minimums.
Use waste heat to run the process or supplement primary energy sources.

Heating, ventilation

Select heating equipment carefully for maximum efficiency.
Install programmable thermostats, energy controllers.
Control heating using computer building controllers.
Avoid pulling out heat, make up air loss with waste heat.
Burn waste material for building heat.
Don't heat seldom used space.
Use radiant heat in isolated spots.
Install ceiling fans to bring heated air to the floor level.
Change to cheaper energy sources.
Keep filters, coils, and ductwork clean.

Expand comfort zone in summer and winter.
Use passive/low-energy cooling where possible.

Air conditioning systems (see also heating and air ventilation ideas)
Use outside air to cool building before using ACU.
Clean ACU filters.
Use timers to control HVAC.
Install energy-management systems to control HVAC.
Replace refrigerant compressors or chillers with more efficient units.
Redesign system for best efficiency and maximum output/kwh.
Evaluate gas cooling as an alternative to electric cooling.
Conduct vigorous preventive/predictive maintenance on system.
Insulate ductwork and piping in AC system.

Indoor air quality
Eliminate pollutants (smoke, dust, vapors)
Introduce properly filtered fresh air
Do more frequent changes of the air in the building
Change controls, improve dampers, use variable speed blowers
Rebalance system to accommodate varying demands

Boilers, steam, hot water
Check fuel air ratio, NOX
Check flame pattern
Check stack temperature
Check CO content in stack
Insulate pipes
Preheat makeup water with waste heat
Heat air using heat exchangers.
Return steam condensate and keep it warm.
Repair hot spots in fire box.
Correct steam leaks and repair traps.
Install automatic controlled blowdown.
Implement effective boiler water treatment.
Consider cogeneration or alternate fuels.

Compressed air system
Repair air leaks.
Run at lowest possible pressure.
Reclaim waste heat for winter heating or heating restroom water.
Install refrigerant air dryers and maintain effectively.
Install cooling towers for water-cooled compressors.
Discontinue running cooling water down the sewer.
Replace energy-inefficient motors and compressors.
Keep maintenance records to justify new equipment.
Automate compressor system controls to minimize energy use.
Evaluate load/unload against intermittent stop/start cycle.
Avoid improper use of compressed air (blowing chips).
Obtain high-quality intake air using filters and coolest possible air.
Practice effective preventive maintenance.
Consider alternative energy to power compressors.
Install remote monitoring of air compressors with diagnostics.

Motors/drives

Replace old motors with energy-efficient motors.

Install capacitors on poor power factor motors.

Turn off motors when not needed (unless startup demand negates savings).

Install variable-speed drives where possible.

9. SUMMARY: CREATING EXCELLENCE IN PLANT AND FACILITIES ENGINEERING

A key goal of this chapter has been to motivate industrial engineers assigned to plant and facilities engineering duties to strive for excellence. By keeping mindful of organizational strategy and applying effective industrial engineering and management techniques, including those described in this chapter, the industrial engineer can function as a plant or facilities engineer to create continuous improvement in productivity and quality for the benefit of the organization.

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