Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 1
What is Industrial Engineering?

The following examples illustrate what industrial engineers do.

- A manufacturer of corporate jets opened a new facility to manufacture tail sections. An industrial engineer (IE) laid out the new facility, including deciding where material would be delivered, where each machine used in the manufacturing process would be located, how work would flow through the facility, and where finished sections would be shipped from the facility.
- A large air chiller has a compressor that is housed in a steel cylinder. The cylinder was being made by bending and welding two pieces of steel. An IE redesigned the cylinder and the manufacturing process so that the cylinder is now made by bending and welding one piece of steel. The manufacturing process takes less time and the cylinder is stronger.
- An IE at a hospital worked with a team to redesign the process for cleaning an operating room and preparing it for the next operation. The time between scheduled operations was reduced from 45 to 20 minutes. More operations can be scheduled in each operating room each day.
- A plant that assembles lawnmowers found that bolt holes on parts were not always lining up properly. An IE gathered and analyzed data to determine the source of the problem. The IE found that parts from a particular supplier were not meeting the tolerances that had been specified. The IE worked with the supplier to improve their production process so that the tolerances were met in the future.
- An IE found that the number of back injuries in an automobile assembly plant was increasing. The IE analyzed the safety reports on such injuries from the last year and found that the increase was occurring in the engine assembly area; further investigation showed that a redesign of the engine had made the engine assembly awkward. The IE worked with the assembly workers to redesign the assembly task, including the purchase of a new hoist. The IE monitored the safety reports over the next three months and found that the rate of back injuries had declined.

These examples illustrate different features of this definition of industrial engineering:

> The **design** or **improvement** of a **system** of **people**, **machines**, **information**, and **money** to achieve some **goal** with **efficiency**, **quality**, and **safety**.

Certain words are show in **bold face** in the definition:

- **Design** - Some industrial engineering tasks involve the creation of a *new* facility, process, or system.
- **Improvement** - Most industrial engineering tasks involve the improvement of an *existing* facility, process, or system.

- **System** - Most engineers design physical objects, but most IEs design systems. Systems include physical components, but also include processes, rules, and people. Components of a system have to work together. Material and information flow between the components of a system. A change to one part of system may affect other parts of the system.
- **People** - Among all types of engineers, IEs think the most about people.
- **Machines** - An IE must select the appropriate machines - including computers.
- **Information** - Data can be used for immediate decision making but ca also be analyzed to make improvements to the system.
- **Money** - An IE must weigh costs and savings now against costs and savings in the future.
- **Goal** - Every designed system exists for some purpose. The IE must think about different ways to accomplish that goal and select the best way.
- **Efficiency** - Whatever the goal of the system, the IE usually seeks to have the system achieve that goal quickly and with the least use of resources.
- **Quality** - The IE's organization always has a customer and the organization must deliver goods and services to the customer with the quality that the customer wants.
- **Safety** - IEs have to make sure that the system is designed so that people can and will work safely.

IEs are sometimes called efficiency engineers, but some think that effectiveness engineer is more accurate. What is the difference between being efficient and being effective?

- An efficient process doesn't waste any time or resources.
- An effective process produces a desired effect or contributes to a desired goal.

Two words in our definition of industrial engineering (efficiency and goal) relate to these two aspects of an IE's job. A process can be effective but not efficient if the process could be done as effectively but in less time or with fewer resources; for example, the time to produce a product might be reduced without any loss of customer satisfaction with the product. A process can be efficient but not effective; for example, a department that efficiently produces reports that no one uses is not effective.

The words in bold face in the definition also indicate areas that an IE must learn about. An IE must know how to answer questions like these:

- **Design and improvement** - Where should a facility be located? How should all the components be laid out physically? What operating procedures should be used?
- **System** - How should the tasks be allocated among different parts of the system? How should material and information flow among the different components of a system?
- **People** - What are people good at? What types of tasks should not be assigned to people? How can jobs be designed so that people can do their jobs quickly, safely, and well?
- **Machines** - What types of machines are available to do different tasks, including the movement and storage of material and information?
- **Information** - How can data be used to determine how well the system is functioning?

- **Money** - How can we trade off costs and savings that occur at different times, maybe over a number of years?
- **Goal** - What is the goal of this system? What are the different ways a system could achieve that goal?
- **Efficiency** - How can we produce products and services with the least amount of time and resources?
- **Quality** - How can we make sure that the system is consistently producing goods and services that meet customer needs?
- **Safety** - How can we keep people from making mistakes? How can we protect people from hazards in the work place?

After you have read this book, you should have:

- An understanding of the types of work IEs do in different types of organizations.
- The ability to explain to others what IEs do,
- The ability to market yourself as an IE,
- An overview of the topics in a BSIE curriculum,
- An understanding of the context in which IEs work, including global and societal issues,
- A commitment to professional and ethical behavior now and in the future, and
- Improved professional skills, especially oral and written communication skills and teamwork skills.

This course will not turn you into an IE since you can't learn all the knowledge and skills that an IE needs in just one semester, but it will start you on your way to becoming an IE. You will have the Big Picture of industrial engineering, so that the ideas you learn in later courses fit together.

This book has three major sections:

- Preliminaries. This chapter, Chapter 1, begins to get you thinking about what IEs do. Chapter 2 introduces you to the big ideas you will hear throughout the book. In Chapter 3, we will spend a little time thinking about teaching and learning so that you and I have some idea about how each of us learns best.
- IE Tasks. Chapter 4 discusses organizations, the roles of the people who work in organizations, and the role of an IE in organizations. Chapter 5 describes some frameworks and processes that IEs use (1) to design or improve a physical production system and (2) to design or to improve the procedures used in the operation of that production system. Chapter 6 gives more specifics about the IE tasks in designing or improving the production system and Chapter 7 gives more specifics about the IE task in the operation of the production system. By the end of Chapter 7 you will know a lot about what IEs do. In Chapter 8, you'll think about your career as an IE and learn about career issues such as lifelong learning and engineering ethics.
- IE Tools. IEs use certain tools and a body of knowledge about people (Chapter 9), mathematical methods (Chapter 10), and business (Chapter 11).

Finally the book has a chapter about the history and future of industrial engineering (Chapter 12) and a reference list (Chapter 13).

I am only pretending that industrial engineering can be broken into topics and chapters. Every topic in this book relates to every other topic, but it would be too confusing if we tried to discuss everything at once. I have divided the material into chapters in a way that I think will help you learn about industrial engineering. However, themes and threads tie all the chapters together. The next chapter describes those threads.

Welcome to industrial engineering

Being an IE is very satisfying because you can create an efficient and safe workplace where people are proud of the high quality products and services they produce. IEs improve efficiency, which means that we help bring prosperity. IEs improve quality, which means that we help provide good products and services. And IEs improve safety, which means that we help protect people. You should be very proud that you plan to become an IE. According to the bumper sticker version of industrial engineering, IEs make things better.

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Chapter 2
Big ideas you will hear frequently

At times while reading this book, you may wonder exactly what you are learning and you may not be able to point to specific new skills and knowledge you have, but I guarantee that you will have new ideas and new ways of thinking by the time you complete this book. By the time you finish reading this book, you will have begun to think like an IE. How does an IE think?

One example of how an IE thinks is that when something goes wrong - a customer got the wrong shipment, a worker was injured, a plant did not produce the quantity of product that was planned for that day - an IE blames the system, not the people. An IE keeps asking "why?" until the root cause is identified for a problem:

- Why did the customer receive the wrong shipment?
  - Because the wrong shipping label was put on the customer's shipment.
- Why was the wrong shipping label put on the customer's shipment?
  - Because some shipments were removed from the shipping department.
- Why were the shipments removed?
  - Because the customer had made some last minute changes to the order.
- Why did the customer make some last minute changes?
  - And so forth.

The IE in this example could end up identifying problems in how customer orders are tracked, in how the sales people identify appropriate products for customers, or in when and how shipping labels are printed and applied to shipments. The IE will probably end up making changes to the physical system (including the information system) and to the procedures used. Perhaps the shipping label should not be printed until the order is actually being shipped.

The big idea from this example is that an IE blames the system, not the people. Now, that idea may not always be true; yes, sometimes people simply make mistakes, but the IE should always think first, second, and often about how systems can be improved so people don't make mistakes. *An IE tries to set up systems so people do tasks right the first time every time.*

Here is a list of ideas that you will read about throughout this book and that we will bring up repeatedly in our discussions:

- If a problem occurs, blame the system, not the people.
- Design the system so people do tasks right the first time every time.
- Design the system so people can do their work efficiently, well, and safely.
- Reduce the variation in a system, so tasks are done consistently.
- IEs are always unhappy because they are always thinking "this could be done better."
- If it ain't broke, it can still be improved.

- Small incremental improvements of a process add up, but more radical reengineering may sometimes be needed.
- A system should help ordinary people do extraordinary work.
- Some workers hate IEs because industrial engineering can be viewed as a tool of management to get more work out of the workers.
- How a person does a job is important in achieving efficiency, quality, and safety.
- The process for doing a task makes a big difference in how efficiently, well, and safely the task is done.
- Achieve quality in goods and services by having good processes, not by inspecting goods and services to fix problems after they have occurred.
- While most engineers design physical objects, industrial engineers design systems. A system includes physical objects, but also includes rules and procedures that aren't physical.
- The ideas of IE have been around for decades, but the ideas get repackaged and resold periodically: some examples are TQM, CQI, re-engineering, the Toyota system, lean manufacturing, and Six Sigma.
- IEs can work for any organization because IEs improve processes and systems.
- Every organization must scan the environment for change and must think about its place in the global economy.
- The customer is not always right, but the customer comes first.
- All products and services involve both products and services.
- A team of people using good team processes will produce better work than any one of the individuals could have.
- Happy workers are good workers.
- Decisions should be based on facts, logic, and analysis, not on hunches.
- People can usually grasp information better, especially data, if it is displayed visually.
- Document what you do.
- Don’t use information technology to computerize an inefficient process; make the process more efficient first.
- An IE must engage in lifelong learning. You must keep up with new technologies, new software, and new ideas.

None of the above statements is true all the time. You don’t want to stick blindly to any one of these statements all the time. But most of the time, the above ideas are good ways for an IE to think.

It is about you

One big, final idea that you will see throughout this book is that industrial engineering is about you, in two ways. First, the ideas of industrial engineering can be applied to your own life, and second, you need to make sure that you use good processes for doing industrial engineering. As an IE you work on improving the system of the organization for which you work; as an individual, you work on improving the system that is you.
Many students have read and have recommended very strongly *The Seven Habits of Highly Effective People*, by Stephen Covey. Those seven habits are:

1. Be proactive.

2. Begin with the end in mind.
3. Put first things first.
4. Think win/win.
5. Seek first to understand, then to be understood.
6. Synergize.
7. Sharpen the saw.

In Chapter 8 (IE Careers), I'll give you more details on each of these points. Together, the seven habits help you apply IE ideas to make yourself an effective person.
As an IE, you do your work in a context: the people you work with closely, the organization that employs you, the area where the organization is located, the state where you live, the country where you live, and, of course, the world. The systems approach, which I'll explain in Chapter 5, urges you to think about putting the process you are studying into a larger context so you won't make a change that improves the process but that does damage to the larger system. I like the phrase "think globally, act locally."

IEs, more than other engineers, think about the people in the system. Engineering ethics, which I'll present in Chapter 8, starts with the rule "Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties." Throughout this book, I'll urge you to consider your own behavior and your effect on systems at different levels and especially your effect on people.

For example, as a woman in a male dominated field, I have decided to use inclusive language; I avoid using the word "he" for an engineer. I don't want my language behavior to cause any student to have doubts about becoming an engineer.

You'll have many issues to think about throughout this book. One of the biggest issues involves your choices about who you are.

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Chapter 3
Learning and teaching

A small child brags to her friend, "I taught my dog to whistle."
"Wow, says the other, "Let's hear!"
"Oh, he can't whistle," replies the first.
"Why not? I thought you said you taught him!"
"I did! He just didn't learn it."

Source: Assessment Matters, August 18, 2004, Volume 2, Issue 1, ASU West Campus Academic Affairs.

All BSIE programs provide you with the knowledge and skills you need to begin your career. However, you will probably use only about one-third of what you learn in the program, at most. That one-third will be different for each of you, depending on the type of job you take and the type of organization for which you work. BSIE programs try to include the knowledge and skills that apply to most jobs and most organizations.

During your career, you will need to apply knowledge and skills that you won't have learned in the university because 1) we can't cover everything and 2) new knowledge and new skills are always being created. Thus, engineers must engage in lifelong learning.

This chapter is about learning and teaching. Learning is the goal; the primary way you learn is through your active engagement with ideas. If you are doing your job as student well and if I am doing my job as professor well, you will read, talk, write, and do problems that help you interact with new ideas and help you make those ideas yours. You won't, I hope, be thinking about how I am teaching, and you may not be thinking a lot about how you are learning, but you will have changed by the end of this course.

However, I think we will benefit from spending some time now thinking and talking about learning and teaching especially so you can plan how you will keep learning throughout your life. This chapter is a brief review of ideas on learning and teaching, with the following sections addressing the following questions.

3.1 Seven Principles for Good Practice in Undergraduate Education.
What are these principles? How will we apply them in this class? How can you apply them in classes that don't use these principles?

3.2 Your style of learning. Researchers have developed various categorizations that describe how people learn and various questionnaires to help you determine which categories best describe your style.

- What is your personal learning style?
- How can you build on the strengths of your style?
- How can you compensate for the weaknesses of your style?

3.3 Theories of learning. Researchers have developed theories about how people learn.

- What are those theories?
- What can they tell us about effective learning?

3.4 Lifelong learning. You will need to continue to learn for as long as you live.

- How can reading books help you stay current as an IE?

3.5 Some tools for students.

- What tools and processes do effective learners use?

3.1 Seven Principles for Good Practice in Undergraduate Education.

Chickering and Gamson present seven principles of good practice in undergraduate education. Teachers and students should work to apply these principles, but you and I both know that not all professors do so. As a student, you can try to apply these principles, even if your professor isn't practicing all of them.

1. *"Good practice in undergraduate education encourages contact between students and faculty."* I implement this principle by having lots of class discussion, by coming early and staying late for classes, by posting and keeping my office hours, by answering email as soon as I can, and by trying to accommodate students who come outside office hours. In any class, ask the professor for his or her preferred method for you to contact them with questions and to have discussion outside of class.
2. *"Good practice in undergraduate education develops reciprocity and cooperation among students."* I implement this principle by having lots of class discussion, by having student work in teams, and by not grading on a curve. In any class, set up a study group with other students. You can ask others to explain your points of confusion to you, but also explaining a point to someone else really helps you understand that point better.
3. *"Good practice in undergraduate education encourages active learning."* Learning is not a spectator sport. I implement this principle by assigning reading, homework, and other activities. In any class, do the reading, participate in discussion, do the homework, and you will find that you are engaged with the material in a way that makes learning natural.
4. *"Good practice in undergraduate education gives prompt feedback."* I implement this practice by encouraging class discussion so you can receive feedback on your ideas, by grading and returning homework promptly, and by responding to email as quickly as I can. This principle is hard for a student to implement. If the professor isn't returning homework quickly, or isn't giving comments on written work, you may not receive the feedback you need to improve your learning.
5. *"Good practice in undergraduate education emphasizes time on task."* I implement this principle by making assignments early and encouraging students to start the homework and reading early. I also allow students to redo all homework assignments, because revising assignments encourages you to spend more time and thus to achieve more learning. This principle relies on your for complete implementation. Set up your weekly schedule to allow you to spend time on each course.
6. *"Good practice in undergraduate education communicates high expectations."* I implement this principle by expecting each assignment to be perfect. Essays should be well written and contain no spelling or grammatical errors. Mathematical assignments should be correct and clear. Treat each assignment as an example of your professional work. Because student work is not always perfect, revision of the work helps you achieve that professional quality.
7. *"Good practice in undergraduate education respects diverse talents and ways of learning."* I implement this principle by asking each student to name an organization that we will use when we discuss each aspect of IE. I believe that each of you already has knowledge that will be relevant to our discussions and I hope that you will feel

comfortable volunteering that knowledge in class. In this chapter you will be able to learn more about your own style of learning and about how to build on your strengths and compensate for your weaknesses. You can use that knowledge in any class that you take. Differences also include disabilities, such as hearing loss, vision problems, or learning disorders. If you suspect you have such a problem, get professional diagnosis and advice. Correcting your hearing or vision or learning how to compensate for a learning disorder can remove barriers to learning.

3.2 Your style of learning

Researchers have developed various categorizations that describe how people learn and various questionnaires to help you determine which categories best describe your style. *You can learn how to use your strong points and how to compensate for your weak points.* Neil Fleming has a short questionnaire (16 questions) that will classify your preferred learning style as

- visual,
- auditory,
- read/write, or
- kinesthetic.

These labels indicate your preferred way to take in and give out information. The web page also gives advice on good ways to study using your preferred style.

Richard M. Felder and Barbara A. Soloman of North Carolina State University have developed a questionnaire called the Index of Learning Styles to assess preferences on four dimensions (active/reflective, sensing/intuitive, visual/verbal, and sequential/global). The learning style model was formulated by Richard M. Felder and Linda K. Silverman. You can take the questionnaire and then read advice on the best strategies for different styles.

The most important point about your preferred style of learning is that you should learn how to build on your strengths and how to compensate for your weaknesses. For example, if you prefer aural learning, then you may need to "Speak your answers aloud or inside your head" when you take a test. As you become aware of your preferences, you will also be able to notice and adapt to the preferences of others that you work with. If you know that someone prefers aural input, then that person might prefer a voice mail message instead of an email message.

While people clearly prefer certain styles for transmitting and receiving email, some researchers (Pashler *et al*., 2008) point out that no research study has shown that adapting a teaching style to a student's learning style results in improved learning. They agree that teaching methods should adapt to the student, and also to the content being taught, but that more research is needed to identify the correct categories for classifying students and for selecting appropriate teaching methods.

3.3 Theories of learning.

Researchers have developed theories about how people learn. Educational research has established two important facts:

1. Students already have considerable knowledge, some of which is correct, and some of which is not. Students are not empty slates on which professors write. Students are not empty buckets into which professors pour knowledge.
2. Learning is not a spectator sport. Active learning is better than passive learning, if the latter actually exists.

I will discuss each of these points and then describe the theory of andragogy, or adult learning.

Students already have considerable knowledge, some of which is correct, and some of which is not. People naturally search for explanations and theories to explain their own experiences. Wankat and Oreovicz wrote:

> For example, many engineering students start freshmen physics with the belief that a constant force must be applied to keep an object moving at constant speed. This belief results from years of pushing wagons, riding bikes, and driving cars. For those puposes this 'knowledge' is adequate. In first-year physics, Newton's laws and friction are introduced, and the knowledge structure has [to] be reconstructed. (page 284)

They also describe the theory of constructivism, which involves showing students experiments (for example, a dry ice puck) that challenge preconceived beliefs. Once the students have discarded old models, then the new, correct model can be introduced. Everyone has ideas to contribute, most of which are correct, but some of which are wrong. We all have experience with systems, especially the experience we have gained from working for various organizations. We all search for explanations and theories to explain our experiences with systems.

One way in which our knowledge is sometimes wrong is that we can misinterpret our own experience. For example, a person may take the blame for a bad experience working for a fast food restaurant, but by discussing that experience, reading about how fast food restaurants organize work, and thinking more, the person may begin to understand how a system constrains how a person can act. Your personal experiences with employers are valuable information, but you should strive to understand how these examples fit into the concepts and ideas of industrial engineering. Your existing theories about how systems work and about how work is organized will probably need some adjusting as you learn about concepts from industrial engineering. My job includes challenging some of your beliefs. I will be surprised if you aren't uncomfortable at least once as you read this book.

Learning is not a spectator sport. Active learning is better than passive learning, if the latter actually exists. Research has clearly shown that people have an attention span for listening well to a lecture that is, at most, 20 minutes. The traditional one-hour lecture, however brilliant, is likely to lose people's attention.

More sophisticated models exist (for example, the Kolb learning cycle), but I believe learning occurs through activity and reflection. Activity can be:

- participating in class discussion,
- writing a short essay,
- doing a problem,

- talking with your colleagues in the class,
- reading a book, or
- listening to a lecture (a short one).

Reflection is harder to describe because it is internal and silent. As you read this book, you will be exposed to new ideas and you may have some of your existing ideas challenged; you need to take the time to think about the new ideas, make them your own, and perhaps replace some of your old ideas. After each section, ask yourself: what did I learn from that? Some professors promote such reflection by using a one-minute paper at the conclusion of each class, with questions such as: What idea did you learn today that you found interesting? What concept or idea still confuses you? Other professors have students keep learning journals, where students record their reactions to and thoughts about the activities involved in the class. You could argue that such reflection is still very active, but the activity is primarily inside your head.

You may find that these moments of reflection come naturally. I find that I do a lot of reflection while I drive (I have had only one small accident in my life, and that accident was not my fault, so my reflection doesn't seem to impair my driving). Most people find that reflection works best when they are in a place where they are unlikely to be interrupted.

Literally, the word "pedagogy" means education of children. The word "andragogy" refers to the education of adults. Stephen Brookfield lists the four assumptions of andragogy, based on the work of Malcolm S. Knowles:

> 1. Adults both desire and enact a tendency toward self-directedness as they mature, though they may be dependent in certain situations.
> 2. Adults' experiences are a rich resource for learning. Adults learn more effectively through experiential techniques of education such as discussion or problem-solving.
> 3. Adults are aware of specific learning needs generated by real life tasks or problems. ...
> 4. Adults are competency based learners in that they wish to apply newly acquired skills or knowledge to their immediate circumstances. ... (page 92)

Brookfield describes "self-directed, empowered adults" as adults who

> see themselves as proactive, initiating individuals engaged in a continuous re-creation of their personal relationships, work worlds, and social circumstances rather than as reactive individuals, buffeted by uncontrollable forces of circumstance. (page 11)

Again, citing Knowles, Brookfield says that self-directed learning

> is defined as a process in which individuals take the initiative in designing learning experiences, diagnosing needs, locating resources, and evaluating learning. (40)
> At the heart of self-directedness is the adult's assumption of control over setting educational goals and generating personally meaningful evaluative criteria. (19)

The learner's assumption of control clearly conflicts with having goals and evaluation that are determined by the professor. However, Brookfield acknowledges that learners can't know what should be learned until they have learned it. The professor's job includes motivating the learner by demonstrating the importance of the concepts being learned.

One implication of the fact that people already have concepts, the fact that active learning is better, and the assumption that adults are self-directed, is that a concept will not be accepted by adults just because the professor says the concept is correct. We can't go into depth in all the topics in this course because it is an introduction to industrial engineering, but we should seek to understand *why* a concept is accepted and used by IEs.

3.4 Lifelong learning

You will need to continue to learn for as long as you live.

I will have more to say about lifelong learning in Chapter 8. Here I emphasize the need to read books as one way to engage in lifelong learning. Why read books?

- By reading biographies of successful people, you can learn how they achieved what they did.
- Business classics, like *My Years with General Motors* (1964), by Alfred P. Sloan, still have a lot to teach us.
- New books about business often repackage ideas from industrial engineering as new fads. We need to retain our solid IE skills while keeping up with the new packaging and new phrases.
- Books on new ideas and research in science and engineering can help us. Some believe that biology (for example, new research on the human genome) will be the wave of the future. As IEs we may become involved in production systems that involve some of these new products and services so we should stay up-to-date.

The following list gives examples of books, recent and old, that support your IE education.

- Bossidy, Larry, Ram Charan, and Charles Burck. *Execution: The Discipline of Getting Things Done.* Crown Publishing Group, 2002.
- Brinkley, Douglas. *Wheels for the World. Henry Ford, His Company, and a Century of Progress.* Viking Penguin, 2003.
- Chiles, James R. *Inviting Disaster. Lessons from the Edge of Technology.* HarperCollins Publishers, Inc., 2002.
- Collins, Jim. *Good to Great.* HarperBusiness, 2001.
- Covey, Stephen. *The Seven Habits of Highly Effective People.* Simon & Schuster Adult Publishing Group, 2004.
- Covey, Stephen. *The 8th Habit: From Effectiveness to Greatness.* The Free Press, 2004.
- Crosby, Philip B. *Completeness: Quality for the 21st Century.* Penguin Group, 1992.
- Crosby, Philip B. *Quality is Free.* The McGraw-Hill Companies, 1979.
- Crosby, Philip B. *Quality without Tears.* The McGraw-Hill Companies, 1984.
- The Dalai Lama and Howard C. Cutler. *The Art of Happiness at Work.* Penguin Group, 2003.
- Ehrenreich, Barbara. *Nickeled and Dimed: On (Not) Getting Rich in America.* Henry Holt & Company, Inc., 2001.
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- George, Michael L. *Lean Six Sigma: Combining Six Sigma Quality with Lean Production Speed.* The McGraw-Hill Companies, 2002.
- Gilbreth, Frank B., Jr., and Ernestine Gilbreth Carey. *Cheaper by the Dozen* and *Belles on their Toes.* Originally published in 1948 and 1952, these two books tell the true

story of Frank and Lillian Gilbreth, who used efficiency methods on their 12 children, and helped develop many of the ideas of IE.

- Goldratt, Eliyahu M., and Jeff Cox. *The Goal*. North River Press, second edition, 1992.
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- Peterson, Donald E., and John Hillkirk. *A Better Idea. Redefining the Way Americans Work.* Houghton Mifflin, 1991.
- Pirsig, Robert M. *Zen and the Art of Motorcycle Maintenance.* Bantam New Age, 1991.
- Rifkin, Jeremy. *The End of Work.* G. P. Putnam's Sons, 1995.
- Ritzer, George. *The McDonaldization of Society.* Pine Forge Press, 2000.
- Robitaille, Denise. *Root Cause Analysis.* Paton Press, 2004.
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3.5 Some tools for students.

The basics work. Come to class for every meeting, do the reading before class, start the homework as soon as it is assigned, and participate in class discussion. If you do these basics, you will do well. I guarantee it.

Eat right, exercise, and get enough sleep. Yes, I sound like your mother. Many college students believe they don't need much sleep. If you think that, you are probably wrong. According to The Better Sleep Council "If you sleep longer on the weekends than during the week, you probably aren't getting the sleep you need every night."

Start practicing your IE skills by keeping the material for this class organized. Be aware of the due dates for homework and the date of the midterm. Track your progress on revising each homework assignment. Talk with your colleagues in the class. If you explain a concept to someone else, you benefit a lot from having to organize and present your thoughts. Beyond the basics, I'll describe one tool for learning that may be new to you.

Concept map. A concept map shows the relationships among concepts, especially how they are related to one central concept. This web page gives a good explanation of how to create a concept map, including an example with Saint Nicholas as the central concept. I find that creating my own concept map is a very good exercise to help me reinforce and organize my knowledge; looking at someone else's concept map doesn't usually help me much. This web page has good advice on how to use a concept map to review reading, to review for an exam, or to organize your thoughts to write an essay.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 4
Organizations

This chapter will help us answer an important question: What is the mission of an IE, in other words, why does an IE exist? We will answer that question by considering the following questions:

- 4.1 What is an organization? Why does an organization exist?
  The purpose of an organization is called its mission. An organization should have a clear mission, a clear vision, and strong values.
- 4.2 What do people do in an organization?
  An organization has directors, managers, workers, and support staff.
- 4.3 Who does an organization serve?
  An organization serves its customers.
- 4.4 Who does the work in an organization?
  The workers do the actual work.
- 4.5 What role does an IE play in an organization?
  The IE designs or improves a system of people, machines, information, and money to achieve some goal with efficiency, quality, and safety. The IE is usually a manager or a member of the support staff.

4.1 What is an organization?

Covey says "Begin with the end in mind" and all organizations should do that. An organization should have a *mission* statement, that is, a clear, succinct statement of why it exists.

Collins and Porras suggest this approach to defining mission, or what they call purpose: An effective way to get at purpose is to pose the question "Why not just shut this organization down, cash out, and sell off the assets?" and to push for an answer that would be equally valid both now and one hundred years into the future. (page 78)

Consider these examples:

- "The mission of the Environmental Protection Agency is to protect human health and the environment." (Source)
- "Building healthier lives, free of cardiovascular diseases and stroke." (Source)
- "The FTC's Bureau of Competition enforces the nation's antitrust laws, which form the foundation of our free market economy. The antitrust laws promote the interests of consumers; they support unfettered markets and result in lower prices and more choices." (Source)
- "NFI's mission is to improve the well-being of children by increasing the proportion of children growing up with involved, responsible, and committed fathers." (National Fatherhood Initiative, Source)
- "The mission of the Office of the United Nations High Commissioner for Human Rights (OHCHR) is to work for the protection of all human rights for all people; to

help empower people to realize their rights; and to assist those responsible for upholding such rights in ensuring that they are implemented." (Source)

- "The mission of the [Illinois] Department of Corrections is to protect the public from criminal offenders through a system of incarceration and supervision which securely segregates offenders from society, assures offenders of their constitutional rights and maintains programs to enhance the success of offenders' reentry into society." (Source)
- "Google's mission is to organize the world's information and make it universally accessible and useful." (Source)
- "I work to help plastic surgery patients become bold in their quest, informed in their choices, and responsible in their decisions." (Susan Gail Enterprises, Inc., Source)
- "EVRAZ North America is a leading steel manufacturer that produces flat, long and tubular products." (Source)
- "The mission of Parkview is to provide quality healthcare services and education to improve the health of the people we serve." (Source)
- "To develop, manufacture and supply scanning components, spindles, optics and Electro Optic modules, while maintaining high quality standards with exceptional customer service." (Lincoln Laser, Source)
- "LDM sells, manufactures and develops copper alloy rods and billets. It is our aim to achieve worldwide success in our specific niche markets. The organisation distinguishes itself through a high customer-orientation and service level, and drive for continuous improvement." (Source)

The following list gives attributes of a good mission statement:

1. It should state the purpose for which the organization exists.
2. It should have a narrow focus.
3. It should be clear.
4. It should get to the point.
5. It should be realistic, feasible, and achievable.
6. It should be a succinct one sentence with few adjectives and adverbs.
7. It should provide guidance for leadership and employees.
8. It should let prospective employees know what the company is like.
9. It should be unique to that organization.

Consider again the examples given above. Most of these are well written. Some are a little wordy, some are more than one sentence, and some incorporate elements of vision and values statements, which we will discuss in the next sections. However, each provides a clear statement about why the organization exists and they all provide guidance to members of the organization about what types of activities it should undertake.

For example, if a prospective client approached LDM to ask if the company can provide lead free copper billets, the company would respond "we can." But if a prospective client approached them to ask for copper pipes, company would say "we don't do that." In fact, companies often refer clients to other companies and often receive referrals back in turn. A group of companies, in a geographical area or in an industry, often know the missions of each company and refer clients to the appropriate company.

Now consider these examples of mission statements, which don't make clear what the organization does:

- “The mission of Southwest Airlines is dedication to the highest quality of Customer Service delivered with a sense of warmth, friendliness, individual pride, and company spirit.” (Source)
- “Henderson Manufacturing Company is dedicated to providing high quality, competitively priced products, on time with personalized service. Additionally, we strive to provide a safe and rewarding work environment that recognizes individual achievement and promotes the skills of teamwork and communication.” (Source)
- “Empower every person and every organization on the planet to achieve more.” (Microsoft, Source)
- “The Specialty Mfg. Co. is committed to providing quality, custom solutions which meet our customers’ unique needs. We provide a highly valued experience for our customers and employees by making all our business partnerships enjoyable, professional and profitable.” (Source)

If you didn't know already what these organizations do, these statements don't help much.

An organization should also have a *vision* statement, that is, a statement of how the organization would like to be perceived by its customers. A mission statement gives the reason the organization exists. The vision statement describes what the organization wants to be. What is the destination for this organization?

Consider these examples:

- “Our vision is to be the world's most dynamic science company, creating sustainable solutions essential to a better, safer and healthier life for people everywhere.” (DuPont Science, Source)
- “To build the largest and most complete Amateur Radio community site on the Internet.” (eHam.net, Source)
- “Clemson [University] will be one of the nation's top-20 public universities.” (Source)

The Alliance for NonProfit Management provides good advice on creating a vision statement:

> A vision statement should be realistic and credible, well articulated and easily understood, appropriate, ambitious, and responsive to change. It should orient the group's energies and serve as a guide to action. It should be consistent with the organization's values. In short, a vision should challenge and inspire the group to achieve its mission.

Profitguide.com quotes Ron Robinson, president of ABARIS Consulting Inc., as saying that a vision statement should paint “a picture of the ideal organization in the future.” It should not look only a few years into the future.

The following list gives attributes of a good vision statement:

1. It should state what the organization aims to be in the future.
2. It should allow for growth and development.

3. It should be inspiring to the employees. Now you can use the adjectives and adverbs that didn't belong in them mission statement.
4. It should be clear.

Finally, many organizations have a *values* statement. Carter McNamara says

> Values represent the core priorities in the organization's culture, including what drives members' priorities and how they truly act in the organization, etc.

Consider these examples:

- "Toastmasters Internationals Values
  - Integrity,
  - Respect
  - Service
  - Excellence." (Source)
- "IBMers value:
  - Dedication to every client's success
  - Innovation that matters, for our company and for the world
  - Trust and personal responsibility in all relationships" (Source)
- A2Z Computing Services Value Statement:
  We are responsible to the communities that we represent. To provide them a service that will enhance their online community with a professional, informative and entertaining website.
  We are responsible to the residents of the communities. To provide them a source of information pertaining to all aspects of their community that are inkeeping with the community's values and morals.
  We are responsible to the businesses that advertise on and sponsor our pages. To do our best to ensure the success of their advertising campaign with fair pricing and quality design work.
  We are responsible to the nonprofit and community organizations. To provide them a method to market and support their missions via our community websites.
  We are responsible to our employees. To provide them a safe work environment, fair wages, opportunity for advancement, and equal opportunity regardless of sex, race or religion.
  We are responsible to our subcontractors. To provide them agreeable and timely payment for services and adequate information for completion of the work ordered.
  We are responsible to our suppliers. To provide them timely payment for products or services and to demand not the impossible but to request the reasonable.
  We are responsible to the banks and creditors who have loaned us money. To submit payments timely and accurately.
  We are responsible to our investors. To ensure their investment returns a reasonable profit.
  (Source)

The following list gives attributes of a good values statement:

1. It should set priorities for the organization by stating what is important.

2. It should describe how members of the organization interact with each other and with others outside the organization.
3. It should provide guidance about trade-offs.

Collins and Porras found that visionary companies have strong values.

> In a visionary company, the core values need no rational or external justification. Nor do they sway with the trends and fads of the day. Nor even do they shift in response to changing market conditions. (page 75)

Now let's put mission, vision, and values all together. Collins and Porras found that mission, vision, and values (or what they call ideology) was very important to their visionary companies.

> A detailed pair-by-pair analysis showed that the visionary companies have generally been more ideologically driven and less purely profit-driven than the comparison companies in seventeen out of eighteen pairs. ... This is one of the clearest differences we found between the visionary and comparison companies. (page 55)

But they also noted:

> The visionary companies attained their stature not so much because they made visionary pronouncements (although they often did make such pronouncements). Nor did they rise to greatness because they wrote one of the vision, values, purpose, mission, or aspiration statements that have become popular in management today (although they wrote such statements more frequently than the comparison companies and decades before it became fashionable). Creating a statement can be a helpful step in building a visionary company, but it is only one of thousands of steps in a never-ending process of expressing the fundamental characteristics we identified across the visionary companies. (pages 10-11)

Peters argues that a leader should live the vision and preach it with intensity and emotion (*Thriving on Chaos*, pages 406-407). Hayes and Wheelwright found that the successful manufacturing companies had strong philosophies. Jim Collins says the statements don't matter as much as the alignment of the organization with the mission, vision, and values:

> Studying and working closely with some of the world's most visionary organizations has made it clear that they concentrate primarily on the process of alignment, not on crafting the perfect "statement." Not that it is a waste of time to think through fundamental questions like, "What are our core values? What is our fundamental reason for existence? What do we aspire to achieve and become?" Indeed, these are very important questions-questions that get at the "vision" of the organization.

Organizations that have mission, vision, and values statements may not call them that and may not separate out the three parts. They often put these statements together on one web page. Consider these examples.

[[insert examples]]

As we have seen, some mission statements just aren't very good. Also, some organizations make the creation of mission, vision, and statements into a ponderous exercise, without much purpose. I have spent time on mission, vision, and values statements for three reasons.

1. As Covey says, "begin with the end in mind." Collins and Porras found that the visionary companies were more likely to focus on an ideology than were the less successful companies.
2. The IE working for an organization needs guidance – exactly what does this organization do and with what values? What is the goal that this organization's system is trying to reach? If the organization's mission isn't clear the IE will have a hard time knowing what effectiveness means for that organization.
3. As I will discuss more in Chapter 8 IE Careers, you will be happier if you work for an organization that is compatible with your mission and vision, and especially with your values.

For some humor on the subject of mission and vision statements, try this link: Mission statement generator.

4.2 People in an organization

An organization is created to accomplish some mission. The people in that organization also have a vision of what they want the organization to be. Values govern how the people in the organization will get to that vision. Who are the people who do all that?

Consider these examples:

- General Motors Corporation (GMC) has a Board of Directors with 12 members, including the company's Chief Executive Officer. None of the other Directors are employees of GMC. In addition to the CEO, the company has 23 other Corporate Officers. GMC employees about 212,000 people worldwide.
- Colorado State University-Pueblo is part of the Colorado State University System which has a 10 member Board of Governors. CSU-Pueblo has a president, a chief academic officer (provost), four academic Deans, Dean of the Library, a VP of Finance and Administration, a Dean of Student Life and Development, a Director of Intercollegiate Athletics, 17 Department chairs, about 150 faculty members, and about 300 other staff employees.
- Krage Manufacturing, in Pueblo, CO, was founded by Sam Krage, who is the owner and president. Krage Manufacturing employs about 25 people in manufacturing operations and about 3 people in support (material ordering, customer service, and programming).

These examples show that all organizations contain the following four groups of people:

1. The founder, directors, president, chief executive officer, or entrepreneur. These people determine the mission of the organization and broadly define the types of processes and values the organization will use in achieving that mission.
2. Managers. These people set up and monitor the processes that will be used to achieve the organization's mission.
3. Workers. These people actually do the work of the organization. They make the products and they deliver the services to customers. They are sometimes called line workers.

4. Support. These people provide the goods and services the workers need that are not part of the mission of the organization, for example, information technology, accounting, and the cafeteria. They are sometimes called staff workers.

Even an organization with one person has these four roles. As I wrote this book, I was acting as the director of my one person organization when I decided to take on the mission of writing an introduction to industrial engineering and to apply for a sabbatical to do so. I was acting as a manager when I decided to write the book on my home computer and when I laid out my schedule, chapter by chapter. I spent most of my time acting as the worker, writing the book. Finally, I was support staff for myself when I set up my computer, my book cases, and my work space so that I could actually focus on the writing.

4.3 Who does an organization serve?

Any organization needs an ongoing source of revenue in order to continue to exist. The people who provide those revenues are sometimes called:

- customers - the people who pay for and receive a product or service.
- clients - the people who pay for and receive a service, for example, clients of a bank, insurance company, or lawyer.
- stakeholders - the people who provide the revenue even if they don't directly receive the product or service, for example, the parents of some university students.

I'll use the word "customer" to cover all these situations even though the word can cause problems. For example, you can't say to me "the customer is always right" when you get a problem wrong on homework. Even in a traditional selling environment, the customer is not always right, but the customer comes first.

Not all organizations provide goods and services directly to consumers. A manufacturer of overhead cranes sells its products to other manufacturers who use the cranes in plants that make consumer goods. Because a clothing manufacturer sells its product through a large department store chain, the manufacturer must consider the ultimate consumer as a customer, but also should think about the department store chain as a customer.

Some people in an organization have internal customers:

> [E]verything you do inside a company, whether it's typing a letter, running an engineering analysis, or attaching a bolt, affects other employees, who are really your internal customer. The people who receive your work depend on you. If your work is bad, they can't do an excellent job either. ... So within any organization you have to keep two customers in mind: the internal customer, or everyone who will be affected by your work, and the external customer, the person who buys the final product or service. (Petersen, pages 158-9).

Identifying the customer can sometimes be difficult. In health care, the patient receives the service and may also be paying for it, but often payment comes from a health insurer who may, in turn, receive money from the patient's employer. In the university, the student or the students' parents pay for a portion of the cost of educating a student; all colleges and universities also receive revenues from other sources, such as state government, federal government, donors, alumni, and foundations. In such situations, the word "stakeholders" indicates that several groups have a stake, or an interest, in what the organization does.

The organization has to focus on meeting the needs of each of these groups in order to keep revenues flowing to the organization over the long run.

Most products also have service components that are important to customers. For example, Bodine Electric Company provides CAD files for its products, through CAD Register, where many other companies also provide such files. An engineer considering specifying the purchase of a Bodine product will appreciate the convenience of being able to integrate the CAD file into the larger file of the product being designed.

The customer comes first because customers provide the long term revenue for the organization. Various authors have put this point in different ways.

- W. Edwards Deming said in *Out of the Crisis*: "Profit in business comes from repeat customers, customers that boast about your product and service, and that bring friends with them." (page 141).
- Feigenbaum said in *Total Quality Control* that an effective quality system "provides for continuously measuring and monitoring actual customer quality satisfaction with the product in use ..." (page 107).
- Tom Peters said in *Thriving on Chaos*: "Only those who become attached to their customers, figuratively and literally, and who move aggressively to create some new markets -- for fast growing and mature products alike -- will survive." (page 48)
- Denove and Powers in their book *Satisfaction* say: "listening to the needs of your customers and creating advocates by striving to deliver upon those needs are paramount to long-term profitability." (page 22*)

Quality

A key idea in attracting and keeping customers is to provide a product or service that has high quality. The word "quality" is used for two concepts that we must distinguish:

- a set of characteristics of a product or service that customers want to purchase. For example, people want to buy fast food because they want to buy food at a convenient location, at a reasonable price, and in a short period of time. People want to buy fine dining because they want a menu with a range of choices, well prepared good, and attentive service.
- the consistent production of a product or service with a specified set of characteristics.

An organization can lose customers by either:

- producing a product or service with a set of characteristics that consumers don't want, for example an expensive restaurant with a wide range of choices but where the service is rushed and customers are not allowed to linger.
- producing a product or service with a set of characteristics that customers do want but where the actual occurrence of those characteristics is inconsistent, for example, a restaurant where service is sometimes good and sometimes not.

Either of these above situations can be called a "lack of quality." The first concept has many names:

- grade
- requirements
- specifications

- quality of design

This first concept of quality lets us say that a Masserati is of higher quality than a VW. Juran points out that this concept is from the view of the customer.

The second concept also has several names:

- quality of conformance
- conformance to specifications
- quality of production.

We can talk about whether a particular VW is of high quality. Does the paint finish have any defects? Do the doors open and close well? Juran points out that this concept is the concern of the producer.

As an IE, especially in the first part of your career, you will be more involved with the second meaning of quality. This book has lots about how to create a process that consistently produces a product or service to meet requirements.

As you move up in an organization you will become more involved in the first meaning of quality and more involved in helping the organization select a set of requirements for a product or service that will attract and retain customers. This section focuses on the first meaning of quality, especially the issues involved in designing a product or service to satisfy customers.

Attracting and keeping customers

How does an organization find out what customers want? How does an organization create goods and services that will satisfy customers into the future? The most important way to know what the customer wants is to ask, by asking the customer directly and by collecting and analyzing data.

The 1982 book *In Search of Excellence* by Peters and Waterman has some out-of-date examples, but its chapter "Close to the Customer" talks about the way in which top companies are *obsessed* with customer service, quality, and reliability. For example, they report on their conversations with IBM's marketing vice president:

> He says he wants salesmen to "act as if they were on the customer's payroll," and he talks of putting "*all IBM* resources at the customer's disposal." (page 161)

Customer focused companies are also obsessed with measuring customer satisfaction.

> To make sure it is in touch, IBM measures internal and external customer satisfaction on a monthly basis. ... Employee attitude surveys are taken every ninety days, and a check is kept on employee perceptions of the way customer service is being maintained. (page 161)

"Obsession" seems the correct work to describe some of the stories Peters and Waterman tell.

> [Frito-Lay] will spend several hundred dollars sending a truck to restock a store with a couple of $30 cartons of potato chips. You don't make money that way, it would seem. But the institution is filled with tales of salesmen braving extraordinary weather to deliver a box of potato chips or to help a store clean up after a hurricane or accident. Letters about such acts pour into the Dallas

> headquarters. There are magic and symbolism about the service call that cannot be quantified. ...[I]t is a cost analyst's dream target. You can always make a case for saving money by cutting back a percentage point or two. But Frito management, looking at market shares and margins, won't tamper with the zeal of the sales force (pages 164-165).
>
> Freddy Heineken says bluntly, "I consider a bad bottle of Heineken to be a personal insult to me." (page 181)
>
> Caterpillar offers customers forty-eight-hour guaranteed parts delivery service anywhere in the world; if it can't fulfill that promise, the customer gets the part free. That's how sure Cat is, in the first place, that its machines work. Once again, we are looking at a degree of overachievement that in narrow economic terms would be viewed as a mild form of lunacy; lunacy, that is, until you look at Caterpillar's financial results. (page 171)

In fact, Peters and Waterman conclude:

> [A]ccording to rational analysis, *almost every one of our service-oriented institutions does "overspend" on service, quality, and reliability.* As David Ogilvy reminds us: "In the best institutions, promises are kept no matter what the cost in agony and overtime." (page 170)

But listening to the customer is not enough because the customer cannot always know the best choice and cannot always know what the customer will want in the future. The organization has to educate a customer and may even create features of a product or service that the customer didn't know to ask for.

> Average customers don't know what is possible if they haven't seen or heard of it (page 157, Petersen).

For example, customers now expect the ability to track a shipment (by UPS, FedEx, or others) but most customers would not have known to ask for that service before it became available. Innovation is still needed; a customer may not know of a need until seeing what can be done.

Quality Function Deployment is a planning tool that involves identifying customer needs in a product or service and then ensuring that each of those needs is met. Kenneth A. Crow gives a detailed explanation of how a set of matrices are used. For example, in the product planning matrix, a row is a customer need and a column is a feature of the product or service. Entries show the contribution of each feature to each customer need. Value engineering is a similar system in which functions of a product or service are identified. Then the value to the customer of each function is compared to the cost of providing the function.

Another tool, Kano analysis, classifies features as:

- "must have" - if the feature is not present, the customer is dissatisfied.
- "more is better" -more of that feature always produces more satisfaction.

- “delight” - a feature that the customer didn't expect and which increases satisfaction.

This article by Kathy Parker gives more information on this appraoch.

Peters and Waterman also found that their excellent companies

> are superb at dividing their customer base into numerous segments so they can provide tailored products and services. (page 182)

New techniques are enabling organizations to customize products and service for different customers. An organization may focus more on certain customers because often a small percentage of customers provide a large percentage of revenues. For example, business travelers are a small percentage of all the customers of an airline, but because they travel frequently, often paying full fare, they account for a large percentage of the airline’s revenues. Some organizations may choose to focus on a particular type of customer and even to reject some potential customers, but they can make such choices only if they have good data about their types of customers.

A challenge is to provide high quality service and customized products to a large number of customers. “Mass customization” refers to the production of highly personalized products and services with the efficiency of mass production. Information technology is usually key to accomplishing this production process. For example, Dell allows customers to customize any computer. The Ritz Carlton Hotels record the preferences of their customers so that returning customers have their wants met automatically.

Software and databases allow organizations to track customers and to customize the service or product for each customer. Customer Relationship Management (CRM) means learning more about the organization's customers in order to provide goods and services that better meet customer needs. An organization may think it knows who its customers are and what their needs are, but collecting data may lead to some surprises. The organization may discover a market segment it didn't realize existed and thus be able to market to those customers. It may discover that some customers are using the organization's goods or services in a way that the organization had not anticipated. Linking a CRM database to a GIS (Geographical Information Systems) system can map the locations of customers and help determine where to site a new customer service location. The approach has been applied most in organizations that market directly to consumers, but it is applicable to all organizations. Also, CRM can increase customer loyalty and lead to higher sales. For example, online book sellers that track a customer's purchases can use its CRM database to suggest books that this customer might like.

CRM software (such as Microsoft Dynamics CRM, Infor CRM, SAP, Salesforce.com, NetSuite CRM+,) has been developed to track all customer interactions, including marketing, sales, support, account management. The software is used to log and analyze every contact that a customer or potential customer has with the organization. Such a database can help provide service; for example, if a customer calls with a new order, the database would prompt the employee to ask if a previous problem has been resolved satisfactorily. The frequent shopper cards now common at grocery stores enable the company to learn about its customers in great detail. A CRM can make the company more efficient in handling customers and thus lead to better provision of customer service.

Why is product quality and customer service so bad?

Any discussion of "the customer comes first" has to recognize that the principle may be more honored as a principle than as truth. I am sure that you have had experiences with organizations where it is clear that the customer did not come first. Why do organizations claim the customer comes first, but we, as consumers, have many complaints about products and services? I have found these possible explanations.

- We are spoiled. In fact, the goods and services we receive are very good.
- Quality is getting better but our expectations are getting higher at a faster rate. Denove and Power make this argument in their book *Satisfaction*:

  > We measure quality across a myriad of industries and we can state unequivocally that product quality is on the rise. (page 89)
  >
  > Products from washing machines to desktop computers are being built to last longer than ever. Improved electronics, tighter manufacturing tolerances, and new materials such as titanium and carbon fiber all have contributed to a longer product life cycle. Quality and defect-reducing programs such as TQM (total quality management) and Six Sigma have set new standards for products leaving the factory. (page 89)
  >
  > What does this mean for current and future generations of customers? Without a doubt, the answer is higher expectations. Consumers don't care about *why* things last longer; they just want the product to work properly and efficiently right out of the box and keep working that way for years to come. (page 90)

- Goods are getting better, but service isn't. Denove and Powers argue that different forces drive product and service quality.

  > Raising product quality is a function of innovation and technological breakthroughs. But improving customer service is often more a matter of what a company is *willing* to do, as opposed to product innovations that are limited by what a company is *able* to do. (page 91)

  Also, they point out that new service initiatives can be copied by competitors. These authors argue that organizations should invest in improved service only where it will make a noticeable difference in customer loyalty. For example, they describe how Washington Mutual was the first bank to offer free checking; the increase in market share, the slowness of the competition to follow, the half-hearted efforts of competitors (somewhat free checking), and WaMu's other programs in customer service gave WaMu a permanent advantage.
- You get what you pay for. If you pay fast food prices, then you can't expect the type of service you would get in a restaurant.
- Because customers are sometimes rude, service representatives are also rude. Perhaps we are caught in a downward spiral.
- Organizations indulge in rhetoric, but don't provide the resources and training required to produce high quality products and services. No matter how much an

employee cares, the production of high quality requires training and support. Yes, it is annoying to be asked for one's account number again, but the employee representative can't be blamed if the account number wasn't transferred with the call.

- Organizations compete on price, not quality. Organizations are so concentrated on cutting costs, that the quality of product and services has to decline.
- Quality projects are often focused on reducing costs and those savings are not passed on to customers.
- Customer representatives are not authorized to do what it takes to make a customer happy. John di Frances makes this argument:

  > If employees are not first educated to empathize with the "why" that drives their customers' desires, and second, if they are not empowered to instantly take the necessary action to effect the circumstances to exceed their customers' expectations, then there's little hope for improved service.
- Employees don't care. We'll talk more about that explanation when we discuss motivation in Chapter 8. Of course the real issue is why they don't care.
- Employees have to meet a work quota of producing a certain number of items or servicing a certain number of callers. Such quotas prevent them from concentrating on quality. The organization may say that quality matters, but the workers know that the schedule and the quotas matter more.
- Employees in many service positions are paid at the minimum wage and turnover is frequent. Why should such employees care about doing a good job? Denove and Powers tell the story of Mission Hills Bowl, a bowling center in Southern California, which pays its employees at twice the market rate and hires people with personality. The result is stellar customer service, loyal customers, the ability to charge customers more, and good profits. (pages 150-153)
-

4.4 The customer comes second.

Think about where you work. Does anyone ever ask you how things could be improved? Does your supervisor say he's listening to your ideas, but he really isn't? Are you encouraged one day, then criticized the next? In far too many cases, the supervisor behaves differently depending on the circumstances and how he feels that day. Much of the time he's friendly and considerate, perhaps even outwardly cooperative. Then suddenly he turns on you, criticizing you and undermining your confidence. In an uncertain environment like that, where people never know what to expect, they quickly learn to quit sticking their necks out and retreat back into their shells. (page 4, *A Better Idea*, by Donald E. Petersen and John Hillkirk).

Employees are turned off to the company through the normal operating practices of the organization. The thoughtless, irritating, unconcerned way they are dealt with is what does it. They feel they are pawns in the hands of uncaring functional operations. (page 15, *Quality without Tears*, Philip B. Crosby).

Companies must put their people first. Yes, even before their customers. There. Now, I've said it. I know it's controversial. It makes most people nervous just to hear it, but it works. (Rosenbluth and Peters, *The Customer Comes Second*, page 9)

In the previous section I argued that the customer comes first, but now I say "the customer comes second." These two statements don't really conflict because the first one means that employees must put the customer first, but the second one means that employees can only put customers first *if the company puts the employees first*.

I borrowed this phrase "the customer comes second" from the book by that name by Hal Rosenbluth and Diane McFerrin Peters, which describes the policies at Rosenbluth Travel, a travel agency that focuses on corporate accounts. Rosenbluth Travel has a long, rigorous hiring process to be sure they are hiring the right people, emphasizes finding nice people who will provide excellent service, extensively trains new associates, listens to and reacts to what associates say makes them unhappy, helps associates continue to learn, gives associates the support and the freedom to provide exceptional service, and lays off workers only as a very last resort. They summarize the approach as follows:

> Every company operates on a hierarchy of concerns. Ours is the following: people, service, profits. In that order. The company's focus is on its people. Our people then focus on serving our clients. Profits are the end result. (page 25)

Measuring up: Benchmarking your workplace practices quotes a Purdue study that concluded that

> organizations with high levels of employee satisfaction are more likely to have high levels of customer satisfaction.

Hire well

Rosenbluth emphasizes the importance of hiring well. Pyramid Machine, in Somerset, Kentucky, hires people with an attitude of humility, as described in "Humility, Inc." from MMS Online.

> Compared to this humility, says Mr. Daniels [general manager of Pyramid], any lack of prior machining experience is not an important consideration at all.

Collins talks about how Nucor emphasizes hiring the right people. Nucor located its steel making factories in farming communities because of the work ethic of such people. They pay well and use team bonuses.

> The Nucor system did not aim to turn lazy people into hard workers, but to create an environment where hardworking people would thrive and lazy workers would either jump or get thrown right off the bus. (page 81)

Tom Peters, in *Thriving on Chaos*, also emphasizes recruiting people who share the values of the company. The line people, he argues, are best able to determine who those hires should be (pages 315-320).

Increasingly, organizations ask applicants to demonstrate their abilities in the work situation. For example, the Pueblo Area Boys and Girls Clubs observe applicants

> implementing a hands-on activity with youth in a program as a key part of the interview and screening process. Final candidates are each given a program activity to implement while being observed by senior staff. Sometimes youth involved in the activity are asked their opinion of how the activity was run and what they thought of the individual candidates. The comments are recorded and used to assist in making a final decision about employing the candidate. This process gives the organization a

> better idea of how the candidate will perform on the job, as well as giving the candidate more information about job expectations. Also, staff and youth gain a sense of involvement and connection with the organization by participating in the process.

Denove and Powers focus on customer satisfaction, so they studied what organizations do in order to provide good customer service. The successful companies use hiring policies "founded on the following key tenets:"

- They focus on personality rather than the technical skills of the potential employee with whom their customers will spend most of their time.
- When necessary, they will pay above market average -- sometimes well above -- to attract the absolute best candidates from which to choose.
- They attract career-minded individuals who will care about the long-term satisfaction of their customers by making it widely known that they are a company that believes in promotng from within.
- They search out creative employee benefits that create a more desirable working environment. (pages 154-155)

Train well

Training of new workers is crucial. Peters says that training - and retraining - should be an obsession, but isn't. He cites Federal Express and Disney as having strong training programs.

> The training Federal Express gives its customer service people in Memphis and Disney's training of a 17-year-old would-be jungle boat drive far surpass the training many technical firms give their machinists. (*Thriving on Chaos*, page 325).

He says that Nissan spent $30,000 per worker on training before opening its plant in Smyrna, Tennessee. Peters lists these elements of a good training program: (pages 326-328)

1. "Extensive entry-level training that focuses on exactly the skills in which you wish to be distinctive."
2. "All employees are treated as potential career employees."
3. "Regular retraining is required."
4. "Both time and money are generously expended."
5. "On-the-job training counts too."
6. "There are no limits to the skills that can profitably be taught to everyone." Even complicated topics like statistical process control can be taught to everyone, if the course is taught well.
7. "Training is used to herald a commitment to a new strategic thrust."
8. "Training is emphasized at a time of crisis." In response to new technology or competitive challenges, training helps the organization respond.
9. "All training is line-driven." The line workers help develop the training.
10. "Training is used to teach the organization's vision and values."

Will people take the training and leave? Perhaps, but why would they leave an organization that treats them so well?

Support workers

Rosenbluth gives associates the support and the freedom to provide exceptional service. According to Denove and Powers (page 135), Nordstrom department store has two rules for employees:

1. Use your good judgment in all situations.
2. There will be no additional rules.

This freedom is not an invitation to chaos because the supervisor's job is to help the salesperson learn what good judgment is. Without detailed rules, Peters says (page 348), workers concentrate on helping customers, not on trying to get around the rules about toilet breaks.

Some organizations practice open books. According to the case for open-book management Companies that practice open-book management teach employees how to read a balance sheet and share critical financial information. In short, they get their front-line people to think like owners.

Open book management gives workers the data to help them understand how their work affects the company. Also, opening the books clearly conveys trust.

Lay off only as a last resort

Rosenbluth lays off workers only as a last resort and Peters argues for employment guarantees.

> Most trace the idea of employment security back to 1806 and the cotton mill owned by Robert Owen in New Lanark, Scotland. Faced with an abrupt reduction in the supply of raw materials (an American embargo), almost all millers shut down and fired their workers. Owen stopped the machines, but kept paying full wages and turned people to maintenance tasks during the four-month crisis.
>
> Owen reaped the reward that is, today, the heart of the matter. His workforce was subsequently much more amenable to managerial, organizational, and technological changes. Constant innovation, supported by workers, led to extraordinary long-term profitability relative to competitors. (Peters)

Peters argues that such guarantees will work only with these 3 tactics:

1. "Careful hiring (understaffing) and extensive use of overtime/temporaries/subcontractors." Basically, the permanent work force can handle only demand that is less than normal.
2. "Redeployment and retraining." Idle workers are moved to other jobs, are used to perform maintenance, or are loaned to the community for service projects. Redeployment to sales helps bring the company out of the slump and provides workers with valuable knowledge about customer wants.
3. "Work sharing and short work weeks."

Such guarantees can't always continue, but how the company handles the layoff may affect its ability to recover.

4.5 The IE's role in an organization.

Recall the four groups of people found in any organization:

1. Directors,
2. Managers,
3. Workers, and
4. Support.

Where does the IE fit in?

An IE can be in any of the four groups. An IE can start a company or be among the directors of a company, although in such a role the IE probably isn't doing much industrial engineering but may be using IE skills to be a good CEO.. An IE is often a manager or supervisor of workers. IEs are only rarely group 3, the workers. The only way an IE can be a worker, that is, the person who does the work described in the mission of the organization, is if the mission of the organization is to do industrial engineering. Consulting companies, such as Accenture, St. Onge, etc., hire a lot of IEs, but many more jobs are available as CEO, manager, or staff. So most IEs are managers or support staff. I'll talk more about what types of jobs IEs can have in different types of organizations when we get to Chapter 8 IE Careers.

IEs are, first, engineers. All engineers, including IEs, design, but most engineers design physical products or physical structures, objects that you can see, while IEs design systems and you can't really see a system.

All engineers, even those designing an object (for example, a computer chip, a car, or a bridge), have to think about the system in which that object will function and have to think about the system that will make that object. Every engineer should think about DfX, which is short hand for

- Design for Manufacturability,
- Design for Usability,
- Design for Maintainability
- Design for Reliability
- Design for Repairability
- Design for Recylclability
- Design for Maintainability

Thus, all engineers are concerned with systems, but IEs always think about systems.
But what exactly does an IE do? Recall the definition of industrial engineering that I gave in Chapter 1:

> The design or improvement of a **system** of people, machines, information, and money to achieve some goal with efficiency, quality, and safety.

An IE designs and works continually to improve a production system, that is, a system that produces a product or service. Although we often talk about the fact that engineers solve problems, when an IE solves a problem, the IE also makes a change to the system so that problem never occurs again. If an IE is solving problems all the time (for example, the order for a particular client is late and the IE expedites the order), something is wrong. The IE should be working on the system, not putting out fires.

The next chapter will give you much more specific information on how an IE designs and improves a production system.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 5
The IE Approach

How does an IE improve efficiency, quality, and safety?

In this chapter I'll explain PDCA and DMAIC, two acronyms that explain the steps an IE uses, and the tools used in these steps. I'll also explain five frameworks that will give you a larger view: systems thinking, lean operations, Deming's 14 points, Six Sigma, and sustainability. These five frameworks will help you understand how to do the steps of PDCA or DMAIC within an organization. They help us think about

1. the organization as a system,
2. the goals of the organization,
3. the people in the organization,
4. the essential goal of reducing variability, and
5. the organization's ongoing viability.

Finally, I'll talk about fads. The tasks and frameworks for IE get repackaged and resold very regularly. Should we care? Should we do something about this situation?

This chapter has the following sections:

- 5.1 PDCA or DMAIC
- 5.2 Systems thinking
- 5.3 Lean operations
- 5.4 Deming's 14 points
- 5.5 Six Sigma
- 5.6 Sustainability
- 5.7 Fads
- 5.8 The two parts of a production system

For each of the approaches in sections 5.1 through 5.6, I will also explain the tools an IE uses in that approach.

5.1 PDCA or DMAIC

How does an IE create a process to reliably produce a product or service with specified requirements? While the definition of industrial engineering says "the design or improvement" of a system, most IEs are involved mostly in improvement. The IE approach is to continually improve the system.

Collins and Porras found a focus on continuous improvement in the companies they studied:

> Visionary companies focus primarily on beating themselves. Success and beating competitors comes to the visionary companies not so much as the end goal, but as a residual result of relentlessly asking the question 'How can we improve ourselves to do better tomorrow than we did today?' And they have asked this question day in and day out – as a disciplined way of life – in some cases for over 150 years. No

> matter how much they achieve – no matter how far in front of their competitors they pull – they never think they've done 'good enough.' (page 10)

Improving the whole system at once is hard, so the IE focuses on a particular process in the production system. Harrington (page 9) provides a good definition of process:

> Any activity or group of activities that takes an input, adds value to it, and provides an output to an internal or external customer.

Plan-Do-Check-Act (PDCA) and Define-Measure-Analyze-Improve-Control (DMAIC) are two acronyms indicating the steps an IE does to improve a process in a production system.

PDCA

PDCA stands for Plan, Do, Check, and Act. The steps were developed by Shewhart and popularized by Deming; they are sometimes called the Shewhart Cycle.

- Plan - Ask and answer the following questions. What data do we have to help us plan improvements? What part of the organization should we work on next? Where do we have the biggest problems? Where do we think we can make the biggest improvement? What improvements could we make? What experiments could we do to get us data to evaluate proposed improvements? How would we analyze those data?
- Do - Carry out the planned experiments to test the various proposed improvements.
- Check - Observe the effects of the experiments. Analyze the data from the experiments. Decide which improvements, if any, should be implemented.
- Act - Reflect on what was learned. Implement the improvements that have been shown to be effective, or repeat the cycle focusing on specific improvements that show promise but need more refinement.

When you are done with PDCA, you do it again. Or, in other words, you are never done because you must practice continuous quality improvements. This web page has a good summary of the steps.

DMAIC

DMAIC stands for Define, Measure, Analyze, Improve, and Control.

- Define - Select a process for improvement. The project champion assigns a project team and give them a project charter. Develop a preliminary process map. Use the Voice of the Customer to determine real requirements.
- Measure - Determine the current status of the process. Determine performance measures. Identify the gap between current status and desired status. Identify the critical process inputs (the Xs) and critical process outputs (the Ys). Develop a detailed process map. Determine possible root causes for the problems.
- Analyze - Evaluate the contributions of various possible root causes. The emphasis is on rigorous analysis of data.
- Improve - Test possible improvements through designed experiments. Develop an implementation plan for the ones that are shown to best meet the project objectives.
- Control - The project champion carries out the implementation plan. Sustain the improvement by training workers and by implementing control charts. As with PDCA, when you are done DMAIC, you do it again.

Process Redesign to Reduce Cycle Time, by D. Bandyopadhyay, describes an example.

PCDA, DMAIC, and other versions all have in common these important features:

- Make sure you are solving an important problem.
- Use a team to generate ideas because a group of people can generate more ideas than any one individual.
- Use facts, experiments, and data for decision making.
- Continuously improve quality.

PDCA and DMAIC are very similar, but have some differences. Since it is sometimes called the Shewhart *Cycle*, PDCA emphasizes more the need to repeat the steps, while DMAIC adds the Control step lacking in PDCA.

In some ways, PDCA and DMAIC are organized common sense, but the fact that the steps enforce organization is good. Others have developed similar steps. For example, Juran's "Universal Sequence for Breakthrough" (page 16-2) is similar to PDCA and DMAIC but is more explicit about how a quality improvement project must fit into an organization:

- Prove the need for a program,
- Identify the major projects using a Pareto diagram,
- Secure management approval,
- Organize for improvement by designating those who will steer the investigation (including generating theories to be tested, giving authority to perform analysis and tests, and acting on the new knowledge) and those who will conduct the detailed analysis to discover the cause of defects,
- Diagnose to discover causes and remedies,
- Overcome cultural resistance to technological change,
- Make remedies effective, and
- Provide controls to hold the gains.

The tools for PDCA and DMAIC

Both PDCA and DMAIC use these tools:

- Teams
- Documentation
- Process flow diagram or flowchart
- Documentation
- Check sheet
- Histogram
- Pareto chart
- Brainstorming and Nominal Group Technique
- Defect concentration chart
- Cause and effect diagram or fishbone diagram
- The five whys and root cause analysis
- Box plots
- Scatter diagram
- Regression analysis
- Design of experiments and analysis of variance
- Control charts

I have listed the tools in roughly the order in which an IE is likely to use them. I'll give an example and explain each now.

Teams. Continuous improvement of a process requires the involvement of everyone who works on that process. A team is usually created to focus on a particular problem or a particular process, but may include people who work in the processes that provide input or receive the output from the process being studied. For example, a team to improve the process of moving patients from the Emergency Department to a hospital room should include people who move the patients, but should also include people who work in the Emergency Department as well as people who work in the hospital. Team members may need training in some of the tools described below and support from staff people for data analysis.

Documentation. According to Robitaille (page 65):

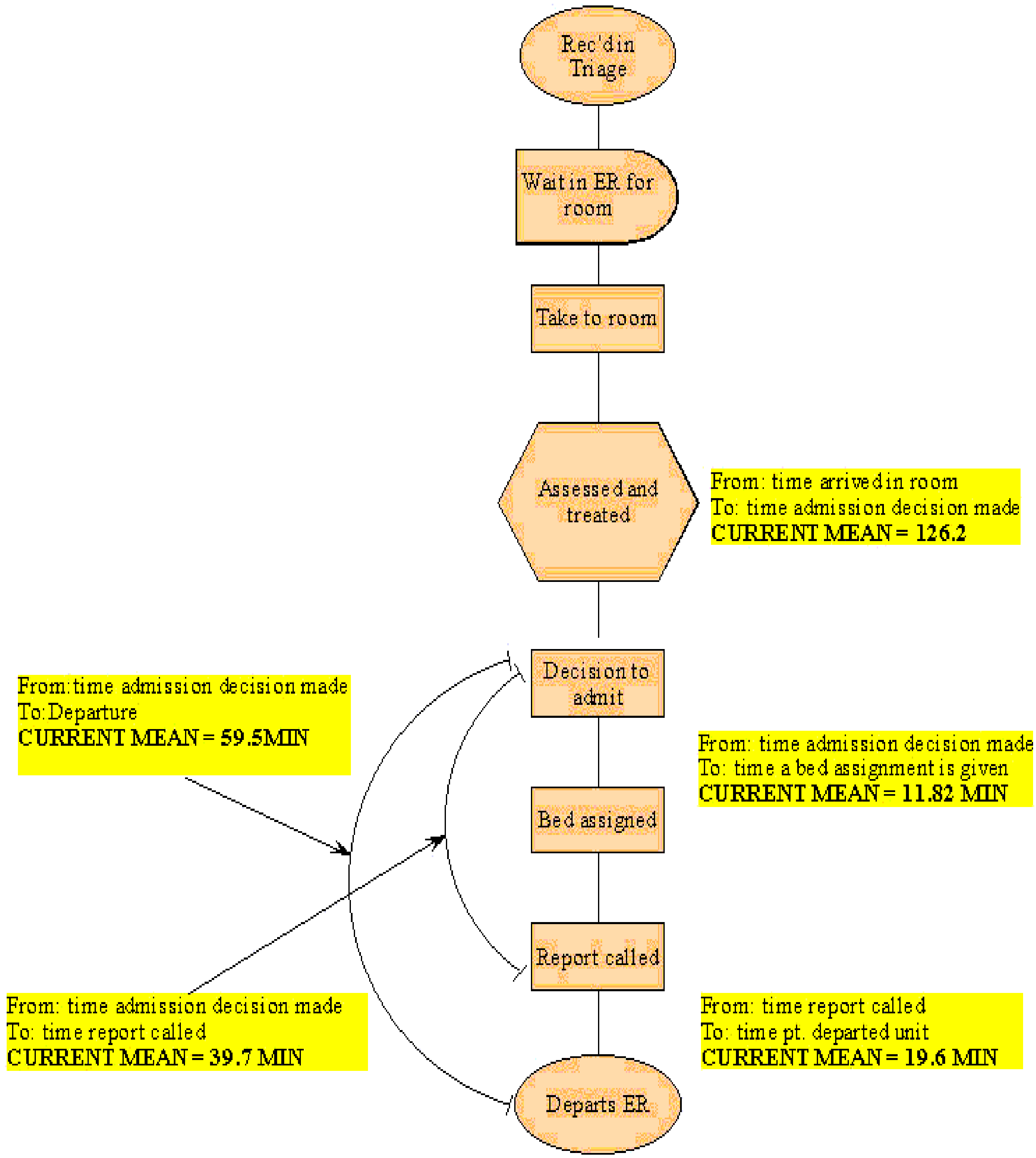
> "If the documents aren't correct, the system will always have problems."

One of the first steps of a team in analyzing a problem should be to determine whether a process is actually being implemented the way the documentation says it should be. Differences may require adjusting the process or the documentation. The team should also document its work, including data collection and analysis, and conclusions reached. Finally, when the team completes its work, it should be sure that the recommended changes are reflected in the documentation of the process, materials used for training new workers, and so forth. Documents form the long lasting memory for the organization.

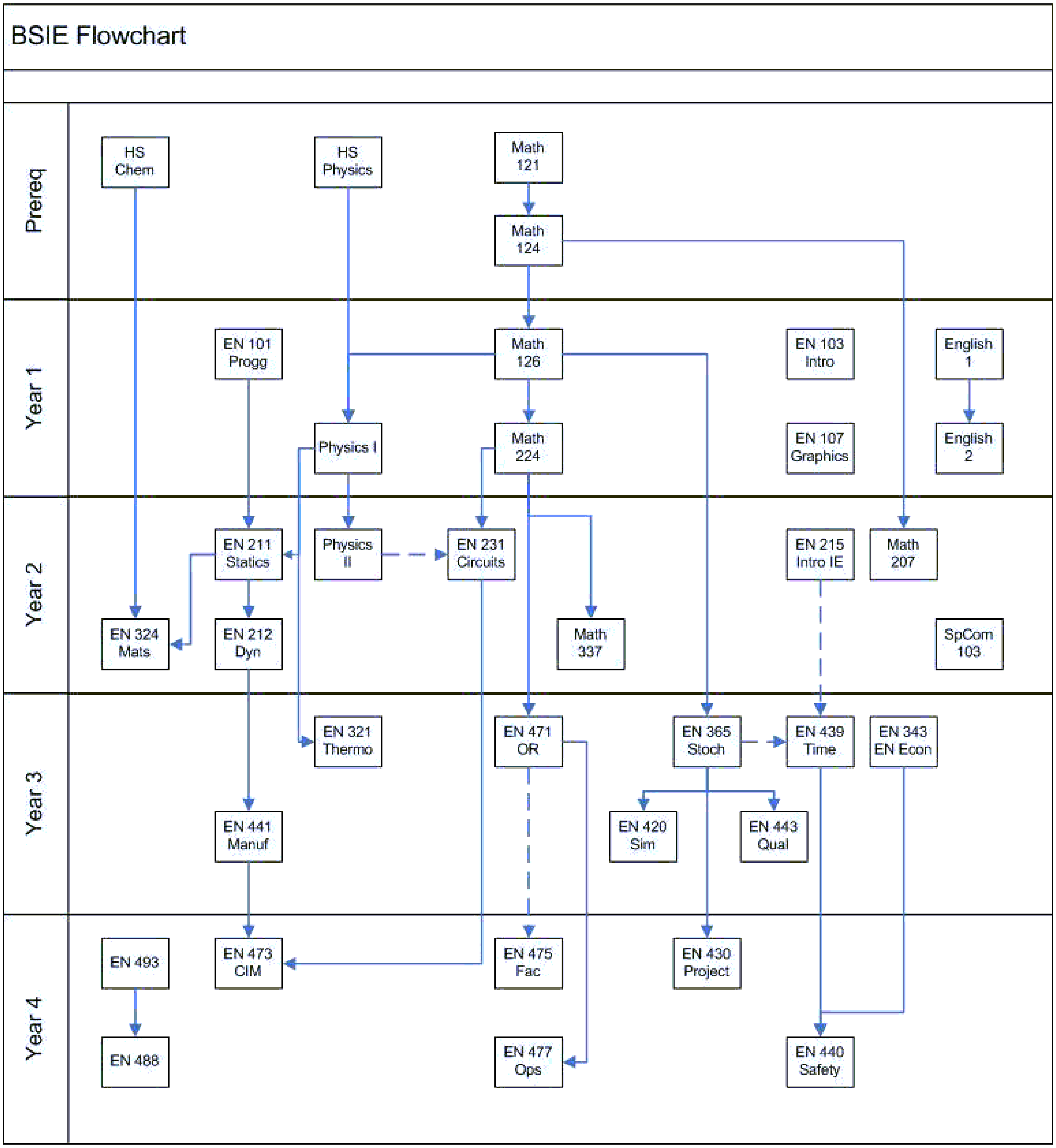
Process flow diagram or flowchart. A flowchart is a visual representation of the steps involved in the process being studied. If a product is being manufactured, the flowchart shows the operations done by different workers on that product. If a service is being produced, the flowchart shows the steps performed by different workers for that customer. Usually a flowchart should follow the product or the customer. One acronym to help you include all the relevant parts of each process on a flowchart is SIPOC: for each process, make sure you include the suppliers, the inputs, the process, the outputs, and the customers.

The flow chart below, from Parkview Hospital, shows the flow of patients from the Emergency Department to the Hospital. The chart was used to study the components of the time to transfer patients, so the chart also includes information about the average time patients spend at each step.

ER TIMES FOR PTS. ADMITTED TO THE NURSING UNITS



The flow chart below shows the courses in the BSIE program; it was created using the program Visio.



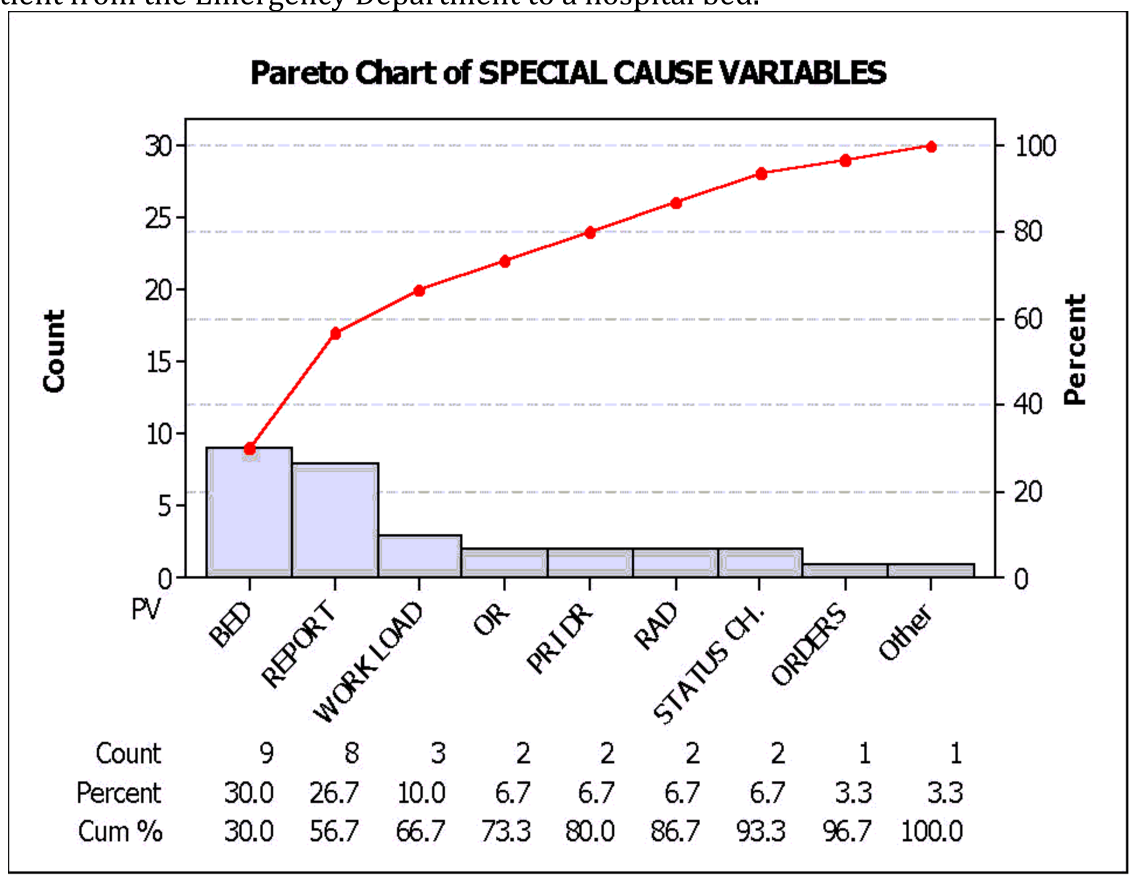
Other General Education courses not shown:
2 courses in the Humanities
2 courses in the Social Sciences
1 course in History

Check sheet. An important type of documentation is to routinely record all exceptions and problems. Each instance of a problem may seem to be isolated, but analysis of such data may turn up problems that should be studied and fixed. A check sheet is a simple chart allowing workers to put a check mark next to the type of problem that has occurred, or to record by hand a problem that does not fit into the types listed. An example of a checksheet used to record the reason for telephone interruptions is shown here. The Quality Training Portal has another example at the web page Tally Sheet.

Histogram. Categorical data such as data recorded in a check sheet can be displayed in a histogram. The relative number of different types of problems is easier to see in such a visual display. The following histogram shows the reasons why a patient was not able to moved from the Emergency Department to a hospital bed. The Quality Training Portal has example at the web page Histograms.

Pareto chart. A Pareto chart is a special type of histogram in which the categories are listed from most frequent to less frequent. The following Pareto chart shows the data from the previous histogram. The Quality Training Portal has another example at the web page Pareto Analysis.

The following Pareto chart from Parkview Hospital shows the causes for a delay in moving a patient from the Emergency Department to a hospital bed.



Putting the items in order by frequency means that the biggest cause is listed first; that cause is usually the one that should be focused on first. If you can fix the biggest causes, then you will have eliminated a large proportion of the defects.

The Pareto principle (named after economist Vilfredo Pareto, but generalized by J. M. Juran) is also sometimes called the 80-20 principle. Juran wrote (page 2-16):

> Managers are well aware that the numerous situations and problems they face are unequal in importance. In marketing, 20% of the customers (the 'key' customers) account for over 80% of the sales. In purchasing, a few percent of the purchase orders account for the bulk of the dollars of purchase. In personnel relations, a few percent of the employees account for most of the absenteeism. in inventory control, a few percent of the catalog items account for most of the dollar inventory. In cost analysis, roughly 20% of the parts contain 80% of the factory costs; the basic function of a product accounts for 80% of the cost, while the secondary functions account for only 20% of the cost. In quality control, the bulk of the field failures, downtime, shop scrap, rework, sorting, and other quality costs are traceable to a vital few field failure modes, shop defects, products, components, proceses, vendors, designs, etc.

The Parkview chart had 9 causes; 20% of 9 is 1.8 or about 2. The largest 2 causes (Bed and Report) account for only 56.7% of the problems, so we can see that the Pareto rule doesn't always hold. It is, however, often a useful guideline.

Juran points out that quality improvement projects should be selected by the use of Pareto analysis, that is, the IE should focus first on the most frequent errors.

> It is these projects which contain the bulk of the opportunity for improvement in failure rates, quality costs, downtime, process yields, *etc*. (Juran, page 2-17)

Defect concentration chart. Sometimes defects or other problems can be recorded or displayed according to location. For example, breakdowns of machines can be displayed on a map of a factory to determine if the breakdowns are occurring in a particular area. Defects in welds on a product can be displayed on a diagram of the product to see if the weld defects are concentrated in a particular part of the product. The Quality Training Portal has an example at the web page Concentration Diagrams. As I'll discuss in Chapter 10, visual displays of data often help people reach conclusions more quickly.

Brainstorming and Nominal Group Technique. Usually everyone on the team has ideas about why the problem is occurring. However, a good process should be used to develop a list of possible causes to avoid the team from focusing too early on just a few causes. Team brainstorming usually works best with these steps:

1. Clear statement of the problem or issue for which ideas are being generated. For example, generate possible causes why customers sometimes receive shipments that are missing items.
2. Silent generation of ideas by each individual, writing on paper.
3. Round robin collection of ideas, recorded on a board or flip chart visible to all. Each person gives one idea during each round, and can "pass" during any round. During this step, ideas are not evaluated. The more ideas and the more different the ideas, the better. After a round in which all pass, some time should be allowed for all to think a bit more. The facilitator should be sure to encourage everyone to volunteer all the items generated during the silent generation. Sometimes people are hesitant to volunteer ideas that differ from what others have said, but one of the values of working in a team is the generation of different types of ideas.

4. Clarification and combination of ideas. Often some ideas are similar in concept, but different in wording. The team works together to clarify and combine ideas. Ideas should not be overly combined; if the person who volunteered an idea wants to keep an idea separate, the team should usually defer to that person.
5. Prioritization among the ideas. This step is not always appropriate. If the team is brainstorming causes for a problem, data, not voting, should usually be used to determine which causes are more important. If the team is brainstorming ideas for next steps for the improvement, prioritization is needed. If there are 10 or few items, each team member can rank order the items (from 10 for the highest priority to 1 for the lowest) and the sum is used to prioritize. If there are more items, voting can be used to first reduce the list. For example, each person is given a number of votes equal to half the number of items. Each person allocates votes; votes can be allocated all to one item (expressing a strong preference), or allocated among items. Sometimes colored dots or colored pens are used, so the team's preferences are visible and can be discussed.

Cause and effect diagram or fishbone diagram. Often causes can be grouped into overall categories such as people, equipment, methods, and materials. The figure below includes those labels on what are called the major bones of the fishbone, with more specific ideas categorized under those labels. Smaller lines can be included as needed.

The five whys and root cause analysis. According to Robitaille (page 1).

> Root cause analysis (RCA) is an in-depth investigation into the cause or causes of an identified problem, a customer complaint, a nonconformance, the nonfulfillment of a requirement, or an undesirable condition.

The goals are

1. to determine why the situation occurred, tracing back in time through previous steps in the process, and
2. to prevent the situation from occurring again.

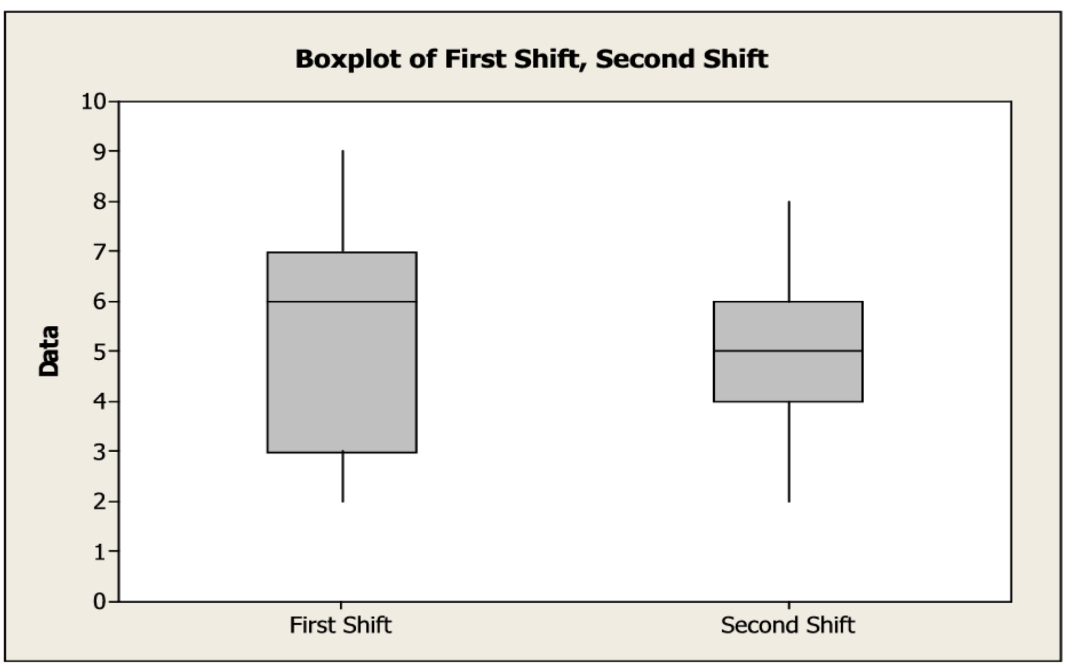
The goal is not to blame a person, but to fix the system. One approach is to continue to ask "why" at least five times, as we did in chapter 2 in the example about an incorrect shipping label. That situation could be solved superficially by telling the workers "don't put the wrong shipping label on a customer's shipment," and that solution may last an hour, a day, or a week, but unless the reasons for the wrong labels are identified and fixed, wrong labels will happen again.

Box plots. Box plots are useful for the visual display of variability in data. For example, data were collected on the number of damaged shipments for first and second shift for 3 weeks (15 data points for each shift).

First shift	Second shift
8	6
6	5
5	5

8	5
6	4
7	5
3	6
5	6
5	3
3	6
7	2
3	6
6	8
2	4
9	4

Comparing the average number of defects, we might conclude that because the first shift has a higher average number of damaged packages (5.53 versus 5.00 for the second shift), the workers on that shift are doing something to cause more damage; the analyst might focus on determining what is different between how those shift works. However, that conclusion would not be correct, as shown by the diagram below, with a box plot for each shift.



The top edge of each box is the 75th percentile of the data for that shift (75% of the time the number of defects for that shift was below that number), the middle is the median (50% of the time the number of defects for that shift was below that number), and the bottom is the 25th percentile (25% of the time the number of defects for that shift was below that number). The lines extend out to the largest and smallest value for each shift. This box plot shows that while the medians differ (as did the averages), the data have considerable overlap and the difference in shifts probably do not account for the damages. Thus, the analyst would know that defects are probably being caused by some reason that occurs on both shifts. This plot used only two box plots for the two shifts, but more box plots can be compared in one chart.

Scatter diagram. A scatter diagram (or X-Y plot) shows how one variable affects another. Perhaps heavier boxes are receiving more damage. The plot below shows the damage rate (that is the fraction of packages that are damaged) as a function of weight (to the nearest half pound). This plot gives some support to the argument that the damage is related to weight.

Regression analysis. A scatter diagram shows the effect of only one variable on the variable we are studying. More sophisticated analysis allows for more independent or explanatory variables. With more variables, plots cannot be used, but the mathematical techniques of regression analysis can indicate which variables are most important in explaining the variation in the dependent variable, that is, the variable being studied.

Design of experiments and analysis of variance. After careful analysis of data, a team may have some good ideas about why the problem is occurring and may have some good ideas about how to fix the problem. A carefully designed experiment can test these ideas. The analysis of variance (ANOVA) is a mathematical technique (like regression analysis) for determining which variables have the most effect on the variable being studie.

Control charts. Key measurements of a process should be monitored to make sure that the process is functioning within the required limits. The design and use of control charts requires mathematical analysis to distinguish natural variation in the system from clear indications that the process has changed. I'll show you more about control charts in Chapter 10.

5.2 Systems thinking

The educational system in the US has these parts:

- Preschool and kindergarten,
- Elementary schools - grades 1-6,
- Middle schools - grades 7-8,
- High schools - grades 9-12, and
- Higher education, including 2-year community colleges, and 4-year colleges and universities.

We call this list of parts a “system” because the parts interact with each other to achieve overall goals, such as an educated population. The parts may interact through cause and effect or through the exchange of information or material. We can think of the input and output of the overall system, and we can also think about the input and output of each part; for example, some of the students who graduate from middle school (an output) go on to high school (an input). We can also think of the parts as being processes in the educational system.

Feigenbaum defines a system as:

> "a group or work pattern of interacting human and machine activities, directed by information, which operate on and/or direct material, information, energy, and/or humans to achieve a common specific purpose or objective." (page 92)

Clearly this definition relates closely to industrial engineering and explains why some industrial engineering departments are called industrial and systems engineering. However, systems engineering is also used sometimes in a more limited meaning, to refer to designing a computer and information system.

When we define a system we implicitly draw a line around some parts to include those parts and to exclude others. For example, the educational system includes the schools, but not the roads students travel on to get to school or the organizations that employ students after they graduate. Generally, looking at a larger system is more accurate but harder. We can understand some aspects of the educational system without considering these other parts, but some aspects require looking at the larger system. We can still examine the educational system if we remember to include in our study its interactions with its environment, such as the transportation system and the employment system.

For the IE, the systems approach is important because it reminds us to consider the environment surrounding the system we are studying and to move the boundaries outward as much as possible so that we consider a problem in its larger context.

Some systems have feedback. A thermostat is an example of a system in which negative feedback helps the system maintain a set temperature; the feedback is called "negative" because an increase in temperature leads to a decrease in heating. The educational system doesn't tend to have a lot of feedback and that may hamper improvement of the system. Have you ever been asked by your high school to give feedback on how well your education prepared you for college or for work?

The operation of a system that has evolved without conscious design or a system that has been designed piece by piece almost always can be improved. Analysis means to take a system apart in order to understand how the parts work; systems thinking stresses synthesis, that is, understanding how the parts work together and how the system works as a whole. Understanding how each part of the educational system works is not enough for a good understanding and certainly not enough for making recommendations for improving the educational system; better recommendations would come from understanding how the parts of the system work together also.

A system has the property that a change to one part can have effects, sometimes surprising effects, on other parts. A state might require that students entering state-funded four year universities meet certain standards (for example, knowledge of a foreign language). The effects of such a change might be good for the universities, but the effects on the high schools must also be considered; they might, for example, have to provide more language classes. Improving one part of system may have good or bad consequences on another part of the system. Using antibiotics to cure diseases has had the consequence of creating bacteria that are immune to some antibiotics; within the system of individual patient and doctor, having the patient take antibiotics makes sense, but in the larger system, we might want to be more cautious about their use.

A system may have emergent properties, that is, properties of the whole that are not the property of any part. For example, living systems are alive, but one can't isolate that property in any part of the system; it is a property of the entire system.
Turner *et al.* (page 38) classify systems these ways:

- Natural (for example, a river) or man-made (for example, a bridge),
- Static (for example, a bridge) or dynamic (for example, the U.S. economy),
- Physical (for example, a factory) or abstract (for example, the architect's drawing of the factory), and
- Open (interacting with its environment) or closed (interacting very little with its environment)

Certain types of systems with feedback occur frequently in organizations and in society. If you learn to recognize them, you can learn what actions to take. William Braun describes 10 system archetypes:

- Limits to Growth (aka Limits to Success)
- Shifting the Burden
- Eroding Goals
- Escalation
- Success to the Successful
- Tragedy of the Commons
- Fixes that Fail
- Growth and Underinvestment
- Accidental Adversaries
- Attractiveness Principle

This web page has a summary of the above models.

In this book *The Fifth Discipline*, Peter Senge argues that organizations must become learning organizations by building knowledge of four disciplines: personal mastery, mental models, shared vision, and team learning. The "fifth discipline" is systems thinking, and he gives these laws of complex systems:

1. "Today's problems comes from yesterday's 'solutions.'" Solutions can have unintended and undesired effects.
2. "The harder you push, the harder the system pushed back." "Compensating feedback" may keep a system in the state it started.
3. "Behavior grows better before it grows worse." Actions that make short term improvement may cause long term disaster.
4. "The easy way out usually leads back in." Easy and obvious solutions would have been done already if they would have worked. Hard work is needed to find the real solution.

5. "The cure can be worse than the disease." Some easy solutions become addictive.
6. "Faster is slower." Any organization has an optimal rate of growth.
7. "Cause and effect are not closely related in time and space."
8. "Small changes can produce big results - but the areas of highest leverage are often the least obvious."
9. "You *can* have your cake and eat it too - but not at once." For example, an improvement in quality pays off *eventually* in improved profits.
10. "Dividing an elephant in half does not produce two small elephants." Some problems must be solved by improving the whole system.
11. "There is no blame." "You and the cause of your problems are part of a single system."

While most engineers design physical objects (cars, bridges, and so forth), IEs design and improve production systems. A production system is a system that produces goods or services for customers. IEs have to think about how a production system works *as a system* by using the types of ideas I've just described.

The history of engineering often emphasizes the design of objects, but Thomas P. Hughes argues that the important inventors in the 20th century were actually builders of systems, not just inventors of objects. Hughes wrote:

> "To associate modern technology with individual machines and devices is to overlook deeper currents of modern technology that gathered strength and direction during the half-century after Thomas Edison established his invention factory at Menlo Park. ... Large systems -- energy, production, communication, and transportation -- compose the essence of modern technology." (pages 184-185)'

Hughes argues that Edison was concerned with the electric system not just the lightbulb. Hughes gives this quote from Edison's papers:

> It was not only necessary that the lamps should give light and the dynamos generate current, but the lamps must be adapted to the current of the dynamos, and the dynamos must be constructed to give the character of current required by the lamps, and likewise all parts of the system must be constructed with reference to all other parts, since, in one sense, all the parts form one machine, and the connections between the parts being electrical instead of mechanical. Like any other machine the failure of one part to cooperate properly with the other part disorganizes the whole and renders it inoperative for the purpose intended.
>
> The problem then that I undertook to solve was stated generally, the production of the multifarious apparatus, methods, and devices, each adapted for use with every other, and all forming a comprehensive system. (Hughes page 73)

Hughes argues that, like Edison, Ford was a system builder, a builder of a production system:

> [From 1910 to 1913] Ford and a few like-visioned mechanics and self-educated engineers created at his Highland Park plant a system of mass production unlike any the world had even seen. They established a finely directed, controlled, and steady flow of energy and materials on a scale then unprecedented. (Hughes, page 203).

5.3 Lean operations

The word "lean" means skinny or having no fat. Lean operations have no waste.
Taiichi Ohno described seven types of muda, or waste: (Womack and Jones, 309-310)

- "overproduction ahead of demand" - products that are produced before they are needed to meet consumer demand have to be stored (storage costs money) and represent the investment of money that could have been used elsewhere.
- "waiting for the next processing step" - products that complete a process and then have to wait to be processed again require storage and represent invested money.
- "unnecessary transport of materials" - the movement of products into and out of storage, or the movement of products over long distances in a plant because the layout is poor wastes time and wastes money in transport and in the purchase of transporting devices.
- "overprocessing of parts due to poor tool and product design," including any processing that does not add value from the customer's point of view.
- "inventories more than the absolute minimum" - excess inventory represents money that could be invested elsewhere and thus represents waste.
- "unnecessary movement by employees during the course of their work" - a poor layout wastes time.
- "production of defective parts." - defective products or defectives services will have to be reworked or redone and may lose customers who will go elsewhere.

Gnanam cites Alukul for another waste: "not fully using people's mental and creative skills."

The framework of lean operations focuses on the concepts of value, value stream, flow, pull, and perfection (Womack and Jones, page 8) in order to reduce all of these types of waste. *Value* is defined by the customer. An organization must have a clear definition of value as perceived by the customer. Time and money spent on features of a product or a service that the customer does not perceive have value are wasted time and money. Knowing what the customer values requires becoming close to the customer and constantly solicitly feedback. In lean operations, a process flow diagram (which I discussed earlier) is called a value stream map. The diagram is similar, but the reason for creating the diagram is to identify

- activities that "create value as perceived by the customer,"
- activities that "create no value but are currently required by the product development, order filling, or production systems ... and so can't be eliminated just yet," and
- activities "which don't create value as perceived by the customer ... and so can be eliminated immediately" (Womack and Jones, page 38).

After those last activities are eliminated, the IE focuses on reducing the non value adding steps. The value stream mapping also identifies the time actually spent in adding value and time the product spends in storage or transport. Time in storage or transport is waste and should be eliminated.

Picture-Perfect Manufacturing, from MMS Online, describes how Stremel Manufacturing, in Minneapolis, Minnesota, used current state maps and future state maps to make sure that waste-reduction initiatives "improve the overall flow rather than merely optimize individual steps."

In continuous *flow*, a product never waits but flows continuously through the manufacturing system, thus eliminating time in storage and in transport. Batches and queues should be eliminated. If products move through the production systems in batches, then the first item in a batch must wait until the last item in a batch is completed before it moves to the next processing time; batches mean product spends time waiting, and that time is waste. The presence of queues mean that a product was completed at a previous processing step before the next step was ready for more input. Since the final step of the production process is shipping the product to customers, product should be produced at the rate that meets the market demand. The principle can be applied in the production of services also.

One barrier to flow and one reason for using batches is the time necessary to switch the production facility from producing one kind of product to producing another. Setup Reduction: At the Heart of Lean Manufacturing, from MMS Online, describes how Richards Industries, a manufacturer of specialty valves in Cincinnati, Ohio, reduced its setup times from an average of 50 minutes to 27 minutes. This reduction enabled them to reduce the typical batch size from 200 to about 20 to 30.

Flow can be improved by eliminating bottlenecks as shown by the following example from World War II.

> An operations research worker during his first day of assignment to a new field command noticed that there was considerable delay caused by the soldiers having to wait in line to wash and rinse their mess kits after eating. There were four tubs, two for washing and two for rinsing. The operations research worker noticed that on the average it took three times as long for the soldier to wash his kit as it did for him to rinse it. He suggested that, instead of there being two tubs for washing and two for rinsing, there should be three tubs for washing and one for rinsing. This change was made, and the line of waiting soldiers did not merely diminish in size; on most days no waiting line ever formed. (page 3, Morse and Kimball)

A bottleneck is the narrowest part of a bottle and limits the flow in or out of the bottle. In the original situation with only two tubs for washing, the lines in front of those tubs would have been long, indicating that the wash tubs were the bottleneck, that is, the place in the production process with the least capacity. If washing took three minutes and rinsing took one minute, two wash tubs can serve 40 soldiers per hour while two rinse tubs can serve 120 soldiers per hour. With the new configuration, three wash tubs can serve 60 soldiers per hour, the same service rate as one rinse tub.

Bottlenecks can be identified by looking for places where WIP (Work in Progress) piles up and create queues. The processing rate at a bottleneck can be increased by reducing the time to process one item or by adding more processing capability. As a bottleneck's rate is improved, WIP in front of the bottleneck will disappear, but another bottleneck may now appear.

Pull. In a lean system, no product or service is produced until a customer asks for it, that is, product is pulled not pushed through the system. Some product must be maintained in sales places to meet immediate demand, but reduction in lead time through improvements such as daily deliveries reduces the amount of stock kept on hand and allows more variety in stock.

Lean systems constantly seek *perfection*. An organization should not compete against its competitors. If benchmarking shows the company is doing better than its competitors, it should not relax. "To hell with your competitors; compete against perfection by identifying all activities that are muda and eliminating them" (Womack and Jones, page 40).

Lean operations use the following tools, in addition to the tools listed earlier:

- *The five Ss* - sort, set in order, shine, standardize, and sustain. Sort and throw out tools that are not being used. Rearrange the work place so it is orderly. Keep everything clean. Establish standard policies. Maintain these activities. This Shop Really Shines ... And Sorts, Simplifies, Standardizes and Sustains, from MMS Online describes the application of 5S at Merritt Toll Company, in Kilgore, Texas. The company found that the implementation of 5S was a "lean enabler" because the visual aspect of 5S allowed them to see the next steps to take, literally and figuratively. The "visual workplace" is a phrase that captures the benefits of 5S: workers can use visual cues to do their work. For example, Parkview's Emergency Department uses color codes as visual clues. A Tracker Board keeps everyone up-to-date on the status of each patient. The ED has three zones and each is color coded. Also, in the trauma room, supplies for head, chest, and abdomen are color coded. The Braslow tape is a measuring stick that can be laid next to a child to make a quick estimate of the dosage based on the child's height; each region of the stick has a color code corresponding to the drawer with appropriate dosages of each commonly used drug. The Quality Training Portal has a lot more information about the 5Ss at the web page What You Need to Know About 5S's.
- *Kaizen* - the Japanese word meaning continuous improvement. Make small and continuous improvements because they add up to large improvement.
- *SMED* - single minute exchange of die. In order to reduce batch sizes, the manufacturing system must be able to switch quickly from making one product to making another.
- *TPM* - total preventative maintenance or total productive maintenance. Workers should be involved in maintaining all equipment at peak performance throughout the lifetime of the equipment. I'll say more about TPM in Chapter 6.
- *Poka yoke* - mistake proofing. The workplace should be designed so workers cannot make mistakes. For example, a three-pronged electric plug cannot be inserted incorrectly. John R. Grout of Berry College has listed many examples of mistake proofing here.
  The Quality Training Portal has a lot more information about error proofing at the web page What You Need to Know About Mistake-Proofing (Poka Yoke). Harrington (page 150) gives some examples applicable to office work:
  - use a phone that does not have a disconnect button so you cannot mistakenly disconnect a phone call;
  - mail letters in envelopes with plastic windows so the address does not have to be retyped, perhaps introducing errors, and so that the correct letter goes to the recipient;

- *Takt time.* The time to produce a product should be based on the demand from that product and then the whole flow should be designed around that time. Takt time sets the pace that is needed to meet customer demand.
- *Kanban*. A card or other visual signal is used to trigger production in the pull system.

Steelcase: Learning How to Implement Customer-Focused, Enterprise Wide Lean describes the improvements made in one company.

The Quality Training Portal has a lot more information about lean manufacturing at the web page What You Need to Know About Lean Manufacturing.

5.4 Deming's 14 points,

W. Edwards Deming (1900-1993) applied statistical process control during World War II to help the US mobilize its war time production. After the war, Deming tried to get US companies to continue to use these ideas, but he found little response. US Manufacturers were facing soaring demand from consumers after the war, and felt little need to think about efficiency and quality. In 1950 JUSE (the Union of Japanese Scientists and Engineers), on the other hand, invited Deming to Japan to help apply the Japanese apply these ideas in the rebuilding of Japanese production.

Japan credits Deming for playing a major role in the success of Japanese manufacturing products, especially in Japanese improvements in quality and efficiency. The most prestigious award for quality improvement awarded in Japan (by JUSE) is called the Deming Prize.

Several anecdotes illustrate what Deming was like.

- He composed an easily sung version of the Star Spangled Banner .
- When asked how he wanted to be remembered, he said "I probably won't even be remembered," but added "Well, maybe ... as someone who tried to keep America from committing suicide."
- Deming's first lectures in Japan in 1950 were transcribed and made into a book by JUSE. He donated the royalties to JUSE.

In 1980, NBC aired a documentary titled "If Japan Can ... Why Can't We?" that described Japanese progress in efficiency and quality in the automobile and electronics industries, and that also explained why the Japanese credited Deming with much of their success. As Deming said, his phone rang off the hook. I'll talk more about the history of Japan, Deming, and US companies in Chapter 12.

What did Deming teach the Japanese? In his book *Out of the Crisis*, published in 1986: Deming summarized his teaching in the following 14 points,

1. Create constancy of purpose towards improvement of product and service, with the aim to become competitive, stay in business, and to provide jobs.
2. Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for a change.

3. Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place.
4. End the practice of awarding business on the basis of price tag. Instead minimize total cost. Move toward a single supplier for any one item, on a long-term relationship of loyalty and trust.
5. Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.
6. Institute training on the job.
7. Institute leadership. The aim of supervision should be to help people and machines and gadgets to do a better job. Supervision of management is in need of overhaul, as well as supervision of production workers.
8. Drive out fear, so that everyone may work effectively for the company.
9. Break down barriers between departments. People in research, design, sales, and production must work as a team, to foresee problems of production and in that may be encountered with the product or service.
10. Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity. Such exhortations only create adversarial relationships, as the bulk of the causes of low quality and low productivity belong to the system and thus lie beyond the power of the work force.
11. a. Eliminate works standards (quotas) on the factory floor. Substitute leadership.
    b. Eliminate management by objective. Eliminate management by numbers, numerical goals. Substitute leadership.
12. a. Remove barriers that rob the hourly worker of his right to pride of workmanship the responsibility of supervisors must be changed from sheer numbers to quality.
    b. Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means, inter alia, abolishment of the annual or merit rating and of management by objective.
13. Institute a vigorous program of education and self-improvement.
14. Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

Deming often lamented that some managers liked some of his points, but rejected others. Deming said his 14 points were not a menu from which a manager could choose.

More than the other frameworks in this chapter, Deming's principles are about people. Regarding "drive out fear," Deming elaborated:

> No one can put his best performance unless he feels secure. Se comes from the Latin, meaning without, cure means fear or care. Secure means without fear, not afraid to express ideas, not afraid to ask questions. Fear takes on many faces. A common denominator of fear in any form, anywhere, is loss from impaired performance and padded figures. (*Out of the Crisis*, page 59)

In point 10, Deming says that the primary cause of poor work is not lack of effort by workers.

> Eliminate targets, slogans, exhortations, posters, for the work force that urge them to increase productivity. 'Your work is your self-portrait. Would you sign it?' No – not when you give me defective canvas to work with, paint not suited to the job,

> brushes worn out, so that I can not call it my work. Posters and slogans like these never helped anyone to do a better job. (*Out of the Crisis*, page 65)

Deming was famous for insisting on measurements, but he also thought numbers should not be used to judge workers.

> Goals are necessary for you and for me, but numerical goals set for other people, without a road map to reach the goal, have effects opposite to the effects sought. (*Out of the Crisis*, page 69)

Deming emphasized repeatedly the need to remove barriers that prevent good work.

> Give the work force a chance to work with pride, and the 3 per cent that apparently don't care will erode itself by peer pressure. (*Out of the Crisis*, page 85)

He said that the annual rating of individuals should be eliminated.

> The day is here when anyone deprived of a raise or of any privilege through misuse of figures for performance (as by ranking the people in a group) may with justice file a grievance. (*Out of the Crisis*, page 118)

Deming is often quoted as saying "Measure, measure, measure," but he stressed using that feedback to improve the process, not to judge the performance of employees. Denove and Power describe the work of J.D. Power and Associates in performing customer satisfaction surveys for many companies. Denove and Power stress that companies that listen to the voice of the customer from these surveys (and other input) are more profitable, but they lament that some companies use the surveys to judge particular stores, particularly to incentivize the managers of stores by making their salaries dependent on the customer satisfaction score. They point out the natural effect of such a strategy: employees in the stores will seek to manipulate the customer satisfaction ratings, even to the extent of begging customers to give good reviews.

> By focusing corporate attention on customer satifaction scores, did we somehow let a very powerful genie out of the bottle? As we've said many times throughout this book, our goals is to emphasize some crucial truths: listening to the needs of your customers and creating advocates by striving to deliver upon those needs are paramount to long-term profitability. We never meant for companies to take their eyes off these basic truths by focusing their attention exclusively on the scorecard. (page 228)

The lesson here is that no single quantitative measure, or even a group of such measures, can replace good judgment.

Fundamentally, Deming believed in people.

> People require in their careers, more than money, ever-broadening opportunities to add something to society, materially and otherwise. (*Out of the Crisis*, page 85)
>
> People stay home or look around for another job when they can not take pride in their work. Absenteeism and mobility are largely creations of poor supervision and poor management. (page 121)

While I have focused on Deming's 14 points, other quality gurus have made similar points. For example, in *Quality without Tears*, Philip B. Crosby lists 21 points under five headings that make up the Crosby Quality Vaccine: Integrity, Systems, Communications, Operations, and Policies. These features must be present to have a quality organization. Point C under Communications is:

> Each person in the company can, with very little effort, identify error, waste, opportunity, or any other concern to top management quickly -- and receive an immediate answer. (pages 7-8).

Like Deming, Crosby blames management for a lack of quality; he cites as the most important symptom of a troubled organization:

> Management denies that it is the cause of the problem. (page 5)

Feigenbaum points out the high costs of poor quality, which he breaks into costs of prevention (management, training, etc.), costs of appraisal (incoming inspection, calibration, maintenance, testing), costs of internal failure (scrap and rework), and costs of external failure (warranty expenses and customer services) (page 115). He also says (page 77)

> Quality must be designed and built into a product; it can not be exhorted or inspected into it.

According to Feigenbaum, a Total Quality System is achieved by considering

> both how well each person, each machine, and each organization component works individually and how they all work together. (page 85)

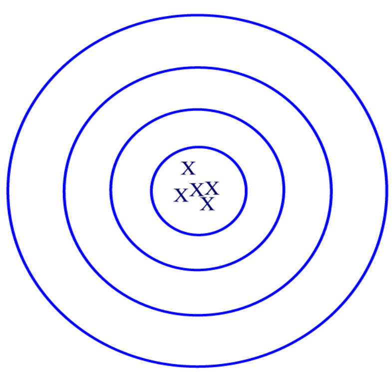
Feigenbaum lists 12 points that describe an effective quality system (pages 107-108). Point 7 says that the system

> makes quality motivation a continuous process of quality goals, quality measurements, and an attitude of quality-mindedness beginning with general management.

5.5 Six Sigma

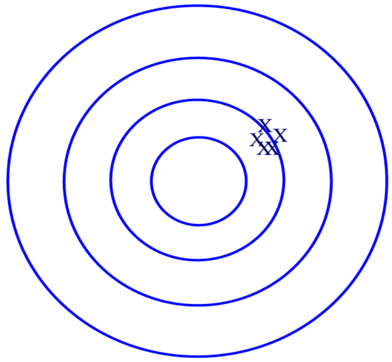
Consider the following three targets, showing where arrows hit a target when shot by three different archers.

Target 1



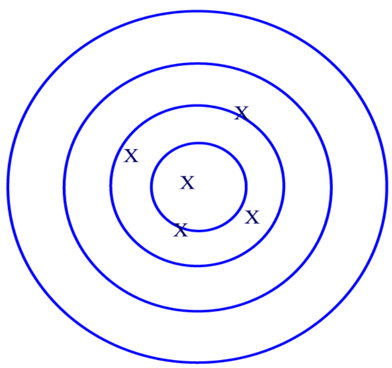
In Target 1, all the holes are in the center, showing that the first archer has consistently put the arrows where they should be.

Target 2



Target 2 shows a tight cluster of arrow holes, but that cluster is not in the center. The second archer is being consistent, but the archer's aim is off.

Target 3



On Target 3, the holes are scattered around the center, but with a large amount of dispersion. The third archer must be using different methods each time.

Target 1 represents desired performance. How can we get the second and third archers to achieve that desired performance? The second archer needs only to readjust the aim and the tight cluster of arrow holes will be in the desired location. However, what can we tell the third archer to do? The third archer needs to focus first on being consistent. That archer must be shooting the arrow differently each time. Achieving consistency will be hard work requiring looking at every part of the process the archer is using.

Six Sigma emphasizes using data and quantitative analysis to reduce variability. If the variability in a process can be reduced, then the process can be centered to produce items with the required specifications.

Six Sigma aims to achieve a six sigma performance target (only 3.4 defects out of a million opportunities) for product and service characteristics that are critical to quality, that is, the characteristics that matter most to customers (Harry and Schroeder, page 13).

A six sigma level of defects is a dramatic improvement over the defect rate of the average company, which is 3.5 to 4 sigma. Harry and Schroeder point out that 1500 square feet of wall-to-wall carpet cleaned to a three sigma level would still have about four square feet of uncleaned carpet, while a six sigma level would mean the uncleaned area would be the size of a pinhead (Harry and Schroeder, pages 14-15). The resulting quality saves money for the company by reducing the need for rework. As a customer, you are likely to call back the three sigma carpet cleaners and make them redo the work correctly (at their cost), but you won't call back the six sigma cleaners. The six sigma organization has dramatically reduced the cost for rework.

Production processes need to be consistent in efficiency, quality and safety. Six Sigma seeks to reduce the variability in the time and resources used to perform a task, the measurements concerning a product or service that indicate value for the customer, and the processes that ensure safety. Every task is done right the first time. Because defects are reduced, costs are reduced: costs for rework, repair, handling customer complaints, and warranties. In fact, Phil Crosby argues that quality is free because increased quality decreases costs so much.

How does Six Sigma achieve this increase in consistency? The DMAIC steps that you have already read about came from Six Sigma. Six Sigma really is another version of industrial engineering, involving the same steps to achieve continuous improvement.

Six Sigma uses the following tools, in addition to the tools listed earlier:

- *Benchmarking.* An organization should use data to determine where its products and processes stand in relation to competitors and to amount of improvement in specific areas that is necessary to have the organization outperform its competitors. (Harry and Schroeder, page 61).
- *Process capability analysis.* Recall the picture below, showing the targets shot at by three archers. Let's assume that all the holes created by the first archer lie within a circle of diameter of 18 mm and that the center of the target is a circle of diameter 20 mm. If this archer aims in the center, his process is capable of shooting all the arrows into the target's center. The same is true for the second archer. However, the holes from the arrows shot by the third archer lie within a larger circle; let's say it is a circle of diameter 66 mm. The fact that 66 mm is greater than 20 mm indicates that the process used by the third archer is not capable of putting all the arrows in the center of the target, even when the archer's aim is at the center. Process capability analysis involves determining the variability in a measurement produced by a process and comparing that variability to the range allowed in that measurement. If the actual variability is greater than the allowed variability, the process is not capable of producing the measurement desired and the process needs improvement, that is, the variability in the process must be reduced.

- *PFMEA* - Potential Failure Mode Effect Analysis. In PFMEA, a part of the production system is analyzed to consider all the possible ways in which failure can occur. Each possible mode of failure is rated for the seriousness of the effect on the production system, the frequency of occurrence, and the ability to detect and repair the failure. You can see scales for each of these at The Quality Training Portal (Generic Severity Rating Scale, Generic Occurrence Rating Scale, and Generic Detection Ranking Scale). Each potential failure is then assigned a Risk Priority Number (RPN), calculated as severity rating x occurrence rating x detection rating, and the failures with highest RPM values are targeted for reduction. The FEMA Info Centre has a lot more information. A fault tree analysis is similar, but uses a visual display of the sequence of events that can be caused by a failure. The Quality Training Portal has an example of a fault tree at the web page Fault-Tree Analysis.

5.6 Sustainability

The Brundtland Commission (also called the World Commission on Environment and Development) defined sustainable development as

> development that meets the needs of the present, without compromising the ability of future generations to meet their own needs.

Recycling is an important part of sustainability. For example, consumers can buy carpet made from nylon fiber recycled from old carpet. When the consumer wants to dispose of carpet made from Nylon 6, manufacturers will take back the old carpet and recycle it into new carpet. But the collection, analysis, and reuse of old carpet has presented challenges. For example, the old carpet must be analyzed in order to determine its content and to plan its reuse. The carpet industry and government are working together through Carpet America Recovery Efforts (CARE) to prevent used carpet from being sent to landfills. Initiatives include designing ways to economically collect used carpet, developing new products, and finding markets for the new products.

The benefits of recycling have been long known, but the reverse logistics of collecting items for remanufacturing is daunting. In 1981 Brown wrote (page 191):

> The energy required to recycle aluminum is only 4 percent of that required to produce it from bauxite, the original raw material, while the energy to recycle copper is only a tenth that used to produce the original material. For steel produced entirely from scrap, the saving amounts to some 47 percent. Recycling newsprint saves 23 percent of the energy embodied in the product and also reduces the pressure on forests: a ton of recycled newsprint saves a ton of wood, a dozen trees. Recycling glass containers saves 8 percent, but returnable glass containers, of course, save far more energy.

The EPA gave the following recycling rates for 2013 for the US.

- Lead-acid batteries: 99.0 percent,
- Steel cans, 79.6 percent,
- Newspapers/mechanical papers: 67.0 percent,
- Yard trimmings: 60.2 percent,
- Aluminum beer and soda cans: 55.1 percent,

- Tires: 40.5 percent,
- Selected consumer electronics, 40.4 percent,
- Glass containers: 34.0 percent,
- PET bottles and jars: 31.3 percent, and
- HDPE natural (white translucent) bottles: 28.2 percent.

"Mechanical papers include directories, newspaper inserts, and some advertisement and direct mail printing."

Electronic waste (computers, cell phones, and so forth) is an increasing problem because of the toxic chemicals in such equipment: fire retardant, cadmium, mercury, and lead. Recycling is difficult because of the need to collect waste from consumers (at curbside or at drop off centers), the need to sort waste (for example, sorting glass containers by color and removing contaminants such as metal caps), and the need for companies to have a steady source of supply of high quality waste material.

The same supply chain that delivers a company's product to consumers can, to some extent, be used to return that product. The phrase "reverse logistics" refers to the return of goods for refund, repair, and recycling. UPS, for example, offers to help companies with Asset Recovery and Recycling Management. Reverse Logistics Provides Green Benefits describes how Coors, Dell, and other companies are recovering and reusing material from consumers.

Sustainability involves more than recycling. Hawken (page 12) states that production processes that use nonrenewable resources, that require excessive amount of energy, or that generate waste are not sustainable.

All engineers have a role to play in achieving sustainability. Some aspects of sustainability relate more to civil engineering - building design - or mechanical engineering - product design. IEs have a large role to play in designing sustainable practices because we focus on the reduction of waste and because we recognize that optimizing a part of system may cause suboptimization of the entire system. The concepts of life cycle analysis and systems analysis that underlie sustainability clearly relate to industrial engineering and industrial engineers should be leading in this new field.

In "Life" is Our Ultimate Customer: From Lean to Sustainability, Gary Langenwalter points out that

> Only six percent of materials actually end up in products

and that

> Short-term financial returns always trump longer-term issues such as caring for the environment and social well being until the long term suddenly becomes short term - like Hurricane Katrina.

Langenwalter discusses the reasons to aim for sustainability and the way that lean manufacturing methods apply. The green@work magazine reports on efforts by companies to move toward sustainability. Companies work together through the United States Business Council for Sustainable Development. CERES "is a national network of investment funds, environmental organizations and other public interest groups working to advance environmental stewardship on the part of businesses." Its "mission is to move businesses, capital, and markets to advance lasting prosperity by valuing the health of the planet and its people."

Some engineering societies have added sustainability to their codes of ethics. In November 1996, the ASCE (American Society for Civil Engineering) amended the first Fundamental Canon of its code of ethics to read:

> Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.

The ASCE gave this definition of sustainable development:

> "Sustainable development" is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development.

The code of the NSPE (National Society of Professional Engineers) includes the statement

> Engineers are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations.

The Institute of Engineers in India, The Institution of Professional Engineers New Zealand, The World Federation of Engineering Organisations, and The Japan Society of Civil Engineers, among others, have statements about sustainability in their codes of ethics. The code of ethics of the Institute of Industrial Engineers does not include any statement about sustainability.

Some universities have created centers on topics related to sustainability.

- Carnegie Mellon's Center for Sustainable Excellence seeks to teach engineering students about concepts that support sustainability, such as life-cycle assessment and industrial ecology. They are developing a database of educational material.
- Michigan Tech's Sustainable Futures Institute offers a 15-credit Graduate certificate in Sustainability.
- The University of Michigan's Center for Sustainable Systems has research projects in modeling of energy flows, life cycle design, building design, renewable energy, and renewable materials. The Center offers a 15-credit Graduate Certificate Program in Industrial Ecology.
- The Engineering Design Institute at Philadelphia University "is an interdisciplinary research center focusing on green materials, sustainable design and community outreach."
- Colorado State University-Pueblo offers a minor in sustainability; the minor is housed in the Department of Engineering.

This list is just a small sample of the education and research opportunities in sustainability in engineering. The Board of Directors of the ASEE (American Society for Engineering Education) adopted a statement in 1999 including this sentence:

> ASEE believes that engineering graduates must be prepared by their education to use sustainable engineering techniques in the practice of their profession and to take leadership roles in facilitating sustainable development in their communities.

In 2012, Pueblo government developed a sustainability plan, which is being implemented.

Increasingly, sustainability is part of how engineers work.

5.7 Fads

Since the mid 1980s, the phrase *Total Quality Management (TQM)* has been used to describe the application of Deming's ideas for improving quality, especially including managerial commitment to quality, empowered teams, and statistical methods. The phrase *Continuous Quality Improvement (CQI)* describes the same concepts but the term allows the application of the ideas where the word "management" might meet resistance, for example, in education. The term CQI is also widely used in healthcare.

A *flexible manufacturing system* can easily change from making one mix of products to a different mix of products. An FMS allows quick response to changes in the market. Such systems usually involve small batch sizes, extensive use of automation, a centralized computer controlling all work flow, and ease in reconfiguring and adding machines. The concept was popular from the mid 1980s through the mid 1990s.

Agile manufacturing stresses that manufacturers cannot control the market place and must be able to move quickly to respond to changes. Companies must be able to develop and produce products quickly and each product may have a very short life cycle. The concepts were first developed in the early 1990s at the Iacocca Institute and Lehigh University. Key concepts include rapid prototyping, a loose conglomeration of many small companies that reform into new alliances for new products, and the use of information technology to share information.

The 1993 book *Reengineering the Corporation* by Michael Hammer and James Champy describes methods for

> the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed. (page 32).

The approach, called *Business Process Improvement*, involves the use of teams to improve processes, a focus on the customer's perception of the process, empowering workers to make decisions that keep customers happy, and placing the steps in a process in a natural order.

World Class Manufacturing involves being the best manufacturer of a product as compared to any organization anywhere in the world. This goal is achieved by using ideas from lean manfuacturing, Japanese methods for improving quality, and benchmarking to identify and adopt the best practices from other companies.

This description of management labels could go on for more pages, but you probably feel like you are reading the same ideas over and over again. This list illustrates the fact that industrial engineering ideas get regularly repackaged and resold under a new name. Certainly there are differences among these concepts. For example, some focus more on manufacturing, while some are applicable to any organization producing goods or services.

Some ideas have stronger roots in engineering and others have stronger roots in business. The emphasis in each new repackaging is slightly different and old concepts and methods are given new names, but you can often clearly see the good IE concepts under all the new packaging.

For example, can you guess which approach is being described by this quote?

> It is a business process that allows companies to drastically improve their bottom line by designing and monitoring everyday business activities in ways that minimize waste and resources while increasing customer satisfaction. (Harry and Schroeder, page vii)

They are describing Six Sigma, although I am sure some practitioners of lean operations would claim this description as well. Indeed, another fad is Lean Six Sigma.

The list of concepts I have focused on in this chapter includes some new packaging that may not survive much longer (lean operations and Six Sigma), although I believe that systems thinking and Deming's 14 points have already shown that they have lasting power. I also believe that sustainability will not fade.

Should we care that our ideas are repackaged (often by business school professors) and resold? We should, of course, recognize that the new packaging usually means a new book which usually contains a not thinly veiled advertisement for the consulting services of the authors.

> To date, every company that has implemented Six Sigma under our guidance has seen profit margins grow ... Companies ranging from AlliedSignal to DuPont Chemical have come to us because despite improvements they made in quality, their profit margins were stagnating, if not shrinking. (Harry and Schroeder, page 1)

Books selling new fads almost always tell you that you need professional help to adopt the new approach.

We might be annoyed by the rhetoric and even more annoyed by the jobs that go to adherents of the latest fad rather than to industrial engineers, but I think we should, overall, be pleased by the new fads because every new fad brings more people in contact with the fundamental ideas of IE. Different organizations are still using language left over from different fads, and as an IE you may need to adapt how you sell IE within your organization depending on which fad they have embraced, but you can still sell and use the fundamental concepts and approaches of IE, whatever they are called.

5.8 The two parts of a production system

Every production system has two parts:

1. Long lasting, physical assets, including facilities, production equipment, information technology, and equipment for material handling and storage.
2. Procedures to train workers, schedule work, to do work, to perform maintenance, to order inventory, and to track work.

Here are some examples.

A steel plant has:

1. Furnaces, ladles, molds, and equipment for chemical analysis.

2. Procedures to follow in making steel, including how much scrap steel and other material, what temperatures, and what molds are to be used for each job that is done.

A hospital has:

1. X-ray and other diagnostic machines, rooms for patients, operating rooms, and information systems.
2. Procedures for checking patients in and out, for scheduling operations, and for tracking patient information.

A fast food restaurant has

1. A building, equipment used to make the meals, and places for people to eat.
2. A menu, opening hours, and procedures workers follow to greet customers, to take orders, and to prepare and deliver meals to customers.

One way to understand the distinction between the two parts is to imagine that you visit an organization when no one is working. You can observe the first part, the physical assets, but you cannot observe the second part, the procedures for how the work is done. Analogously, in a computer system, the first part is the hardware and the second part is the software.

The distinction between these two parts of the production system is not perfect, but it is useful and it is a traditional way to describe the tasks of an industrial engineer. Changing the first part of a production system, the physical assets, usually takes a lot of time. When we build a building, we generally intend to use the building for a long time. We can remodel the inside of the building at some cost, but altering the size or shape of a building is a major project.

Changes to the second part of a production system, the procedures, can usually be done more quickly. Changing job responsibilities of workers or making a change to training procedures requires thought, work, and time, but can be done much more quickly than changing a building.

Industrial engineering education is often broken into courses that study these two parts of the production system. Most programs include a course focused on facility location and layout and a course focused on operations planning and control. I have followed that approach. The next two chapters describe the tasks industrial engineers do regarding these two parts of the production system. Chapter 5 focuses on the physical assets of an organization and Chapter 6 focuses on the procedures for using those assets.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 6
Design or improve a production system

This chapter describes what an industrial engineer does to help an organization design and improve the part of its production system that is made up of long lasting physical assets, including facilities, production equipment, information technology, and equipment for material handling and storage.

The IE must make four interrelated sets of decisions about these assets.

- 6.1 What type of physical assets does the organization need?
- 6.2 Where will the organization put these assets? This question must be answered on two levels:
    - Where in the world will the organization put the buildings to house these assets?
    - Where, within the organization's buildings, will the organization put each asset?
- 6.3 How will the organization move and store physical items?
- 6.4 How will the organization move and store information?
- 6.5 How will the organization maintain its physical assets?

Again, I am pretending that these topics can be broken apart and considered separately, but they really can't be. All of these questions have important connections to each other.

6.1 How many of what type of physical assets does the organization need?

Depending on the type of steel the company will make in a plant, a steel company chooses what type of equipment it needs: a furnace, ladles, molds, gates and other devices to control the flow of the molten steel, and so forth. The American Steel and Iron Institute has a good explanation of how steel is made and the types of equipment used.

Depending on the type of care the hospital will provide at a particular location, the hospital chooses what type of equipment it needs: beds, stretchers, and other equipment for patients; diagnostic equipment such as ultrasound machines, X-ray machines, and blood testing equipment; computer technology to store data on patients; and so forth.
Every industry has suppliers of equipment who are eager to help you, the IE, decide to select their equipment. For example, the Association for Iron and Steel Technology (AIST) has a Buyer's Guide. Hospital Technology "is designed to help healthcare professionals find manufacturers and suppliers of medical equipment and companies in the forefront of modern hospital technology."

In selecting what equipment to purchase use, an IE should consider the following types of factors:

- Design features of the product or service,
- Production forecast,
- Costs and other services offered by different suppliers, and

- The availability and the cost of suppliers of parts compared to the cost of making the part.

The design of a product or service leads to requirements for certain types of equipment. For example, one of the important choices made during design of a product is the tolerance on a dimension. The required dimension on a part for that product is specified by the design engineer, who also specifies the tolerance required on that dimension. For example, the design engineer might specify that the length of a rod should be 10.215 cm plus or minus .001 cm. The production process must reliably produce rods with lengths between 10.215-.001 = 10.214 cm and 10.215+.001 = 10.216 cm. Generally, a tighter tolerance requires a more expensive machine. The article "Think You Can't Afford New CNC Multi Technology?" from *Production Machining* describes why a manufacturing company purchased sophisticated CNC (Computer Numerical Control) machines in order to be able to consistently meet the tight tolerances being specified by their customers.

Because achieving tight tolerances is expensive, design engineers should be very careful that their specified tolerances are truly justified and the IE should look at the design and perhaps question some of the design decisions made by the design engineer. The best situation is when the IE is involved in the design, so the design engineer designs for manufacturability. This example shows that design decisions affect the choice of production method.

The volume of production will also affect the equipment purchased. For example, office equipment (such as copiers, faxes, and shredders) often have rated capacities. The first question an office supplier asks if you want to purchase a copier is how many copies the office makes per month. Similarly, a manufacturing environment running three shifts, six days a week, requires different machines than a shop that occasionally uses a particular machine.

Selecting a good supplier for equipment can be crucial and cannot be based only on the initial cost. The magazine Foundry Management & Technology recommends considering five criteria in selecting a supplier for equipment and services for a foundry: environmental awareness, reliability, product alignment, innovation, and value.

> Selecting a supplier with a history of innovation is important to a lasting partnership that targets future growth. Innovation is shown by how effectively the supplier adapts to changes in the industry, often leading the market with technological advances.

For some parts that go into a product, the IE may need to consider whether to make the part in house or buy the part from a supplier who specializes in that part. For example, most manufacturers purchase fasteners (bolts, screws, etc.) rather than making them in house because fasteners can be made more cheaply with higher quality by a company that specializes in making fasteners.

In order to make decisions about the purchase of capital assets for production, the IE will have to know something about the industry. For example if you go to work for a steel mill, you will need to learn about the equipment used to make steel. If you go to work for a company that makes integrated circuits, you will need to learn about those manufacturing processes and the equipment used. We can't possibly teach you all the different types of manufacturing processes used in different industries; it would take too long, and you would end up using only a small fraction of what you learned. All IE programs select what they think are the most widely used and most important processes.

In a manufacturing processes class in an IE program, you will learn about the following types of materials:

- Metals,
- Ceramics,
- Polymers, and
- Composite materials.

You will learn about the following types of manufacturing processes.

- Solidification processes such as casting, extrusion, and injection molding,
- Manufacturing using the pressing and sintering of powders,
- Metal forming including forging and rolling,
- Material removal processes including turning, drilling, milling, and grinding,
- Heat treatment to affect hardness and toughness,
- Surface processes including surface hardening, chemical cleaning, plating, and coating,
- Joining processes including welding and soldering, and
- Assembly processes including the use of mechanical fasteners.

This document has descriptions of different types of casting and forging processes.

6.2 Where in the world should the organization put these assets?

During the 1921 flood in Pueblo, Colorado, the Arkansas River overflowed its banks and prevented people on the north side of the River from reaching the only hospital, located on the south side of the River. It is estimated that 1500 people died in the flood. In 1923, six doctors founded Parkview Hospital so residents north of the River would have access to a hospital.

In 1881, Colorado Fuel and Iron built a steel mill in Pueblo to be close to the sources of iron ore and to be close to its customers, the companies that were building new rail lines in the Western United States. Transporting ore over large distances is very costly, so the mill located near the sources. Transporting the final product is still costly, but the tonnage to be transported has been reduced by the manufacturing process. For this reason, most plants that process some type of ore or mineral are located near the source, not near the customers.

In 2006, Nissan moved its North American headquarters from Gardena, California, (in the Los Angeles area) to Franklin, Tennessee (south of Nashville). According to a Bloomberg article, the state of Tennessee provided incentives worth up to $197 million, while California countered with a package worth only $25 million.

An organization should consider three types of factors in locating a new production facility:

1. The location of customers who will buy the product or service,

2. The costs to manufacture the product or provide the service in that location, and
3. The cost to move raw material to the production location and the cost to move the product or service to the customers.

Sometimes one of these factors greatly dominates the other two. For example, in locating a restaurant, factor 1, locating near desired customers, is the dominant consideration. J.C. Melaniphy lists Principles of Restaurant Site Selection, which includes this statement:

> One of the tricks in the food business is to locate your units within the existing travel patterns of a majority of people in an area. This will permit you to intercept consumers without requiring them to change their patterns.

Similarly, locating a retail store near competitors can be good, for example, in a shopping mall, since each organization benefits from customers attracted by the ability to shop efficiently.

Factor two, the cost to manufacture the product or to produce the service in a given location, includes:

- the cost to buy land and build a building, the cost to buy an existing
- building, or the cost to rent space,
- taxes of various kinds
- utilities including water, electricity, and heating and cooling,
- availability of employees with the needed training or education, and community amenities that help attract and keep employees.

Global outsourcing of service is occurring because companies are focusing on the second factor; for example, the cost of providing a computer service call center is much lower in India than in the United States. Since calls from customers can be transferred from any location around the world at low cost (cost factor three), the location of demand (cost factor one) almost doesn't matter. The issue being raised by some is whether the service provided is of the quality that customers demand.

"An Analytical Approach to the Outsourcing Decision," by Korn available from MMS Online, argues that

> there can be damaging consequences for companies that focus too intently on the cost of labor. When outsourcing work, manufacturers run the risk of losing proprietary information, receiving parts that don't meet quality requirements and waiting for delayed shipments.

The article describes how Innovative Turbo Systems, a manufacturer of after-market auto turbochargers in Simi Valley, California, competes on the basis of innovative design and that "the key is to keep that intellectual property within the company." A relentless focus on making its in house processes efficient has reduced its methods below the cost of outsourcing.

Global outsourcing of manufacturing occurs because in some countries the cost of raw materials and wages are so low that they compensate for added costs in moving the goods to final markets. Some analysts argue that some costs are often neglected in that calculation. Also, security concerns are causing some companies to reconsider their overseas manufacturing locations. C-TPAT (Customs-Trade Partnership Against Terrorism) is a voluntary US program in which companies certify that they can account for the security of goods at all time from manufacture to entry into the US.

> The partnership establishes clear supply chain security criteria for members to meet and in return provides incentives and benefits like expedited processing

Rosenbaum argues that C-TPAT is the price of offshoring.

> It is the price of the risk a comp assume when you go out into an increasingly hostile and insecure world to harvest all those cheap materials and all that cheap labor. It is a hidden cost but no less real for that.

Some companies create long term relationships with suppliers so the suppliers will locate a manufacturing facility nearby and provide supplies on a JIT basis. Factor three, the cost to move product to the supplier, dominates here, but also the ability to easily provide Just In Time deliveries.

An organization that makes many products might choose to have one location for the production of all its products, allowing smoothing of production and allowing other economics, but at the cost of having to transport products further to reach all markets. Alternatively, the organization could have several small production facilities located closer to markets with each producing the entire range of products. Or the organization could have plants that specialize in certain types of products or in certain components or assemblies that go into various products. When the organization chooses a site, it should consider its plans to handle growth.

The location of public facilities is a special case that often attract attention, for example, the location of a new firehouse. Community colleges are usually located close to where the students are since students at community colleges often have strong ties to their community through family and employment that prevent them from moving to obtain education.

In getting products to consumers many retail store chains use distribution centers. Suppliers deliver products to the distribution center where the shipments are broken apart and re-aggregated for shipment to retail stores. Distribution centers are usually located so they are close to manufacturers and to stores and have good access to transportation systems such as air, rail, and highways. Target operates 37 distribution centers including one located in Pueblo.

While the distribution of goods from manufacturers to retail locations often use distribution centers, recycling requires the location of sorting centers. European legislation, based on the concept of extended producer responsibility, requires companies to take back certain products from consumers. Sorting centers for batteries must be located close to consumer collection sites but also close to sites that use or dispose of the batteries.

Sometimes an organization's mission defines where the organization is located, in fact, the organization was created to serve that area. For example, the Boys and Girls Clubs of Pueblo County serves youth in Pueblo and Otero Counties. However, even an organization with a mission to serve a particular area has to decide where to locate facilities within their service area.

Siting multiple service locations can be a very difficult problem and IEs who are specialists in operations research (the subject of Chapter 10 of this book) have developed sophisticated mathematical methods to solve such problems. For example, this article explains how devices were located for Schlumberger RMS to provide a service to remotely read electrical meters and transmit the information to a central database. Receivers are placed on poles owned by the electric company. The goal is to minimize the number of receivers used to be able to read all the meters. The company found that solving by hand even a small problem (4,208 meters to be read and 2,393 possible poles for the location of receivers) took almost 4 weeks and could not be easily redone if errors in the data were found. Also, the solution process did not incorporate limits on receiver capability. Operations research techniques were used to efficiently allocate receivers for an electric company in Illinois; the problem involved 116,600 meters and 20,636 poles. This method saved the time of planners and also generated an improved solution over what would have been achieved by manual methods.

In 2002 UPS "averaged more than 1.1 million package deliveries a night" in its next day delivery service. Packages received at ground centers are delivered by trucks to airports. Planes fly the packages to a UPS hub airport (perhaps making an intermediate stop to pick up more packages). After sorting the packages, the process is reversed with the same planes delivering packages back to airports, perhaps taking a different return routes. Packages are then delivered by truck. Since late in 2000, UPS has used a large computer program called VOLCANO to help its planners develop a network of aircraft routes and to select aircraft to assign to each route in order to meet forecasted flow of packages. The program has helped UPS reduce its operating costs by using aircraft more efficiently and has helped UPS reduce its need to purchase more very expensive planes.

After locations are chosen for manufacturing products or providing services, an organization must then lay out each facility, that is, decisions must be made about where to locate each function, each department, and each machine within the facility.

Generally, four types of layouts can be considered:

- Product layout (also called flow line, assembly line, or production line). The facility is laid out in a single line following the steps in making the product or providing the service. The layout is developed by considering the steps in making the product. An exploded diagram of the product or considering how to disassemble the product can help the IE decide what layout is appropriate. A sample exploded diagram for a bicycle is here. For service locations, the layout would follow the flow of the person. For example, a blood donation center is laid out so the person donating blood moves from reception, to interview, to donation, to recovery in a single path. A product layout allows for a clear visual understanding of how products move. This example shows how a company that makes forged parts laid out the flow of products through the plant. The Die Shop lies off the flow line because it does not handle the product, but rather provides dies for the forging process.

- Process layout. The facility is laid out by department with each department performing one kind of task. The product may not follow a straight line as it moves from department to department, and may even move back to a previous department. This layout is usually appropriate for a job shop, where each job is unique. Lean From The Get-Go from MMS Online describes how Ron Malone, president of R&D Manufacturing Industries, Inc., laid out a job shop to highlight visualization.

  > An employee should be able to walk through a work area one time and come away with 90 percent of the information about that area after that first tour.
- Fixed layout. The product being manufactured or person receiving the service stays in one place and workers and tools come to it. Examples include manufacturing a large aircraft, performing an operation on a patient in a hospital, or building a house. The Next Generation of Operating Rooms discusses the layout of an operating room.

  > A typical response to equipment-crowded ORs is a request for increasingly larger ORs. However, experience has shown that the most valuable space in an OR is the space immediately surrounding the patient table. The prime space around a patient should be as free of carts as possible to provide work area for staff. Utilization of ceiling-supported utilities and equipment booms allows ergonomic organization of equipment around the patient.
- Cell layout. A product layout is usually best when the production facility makes only a few products. A process layout is usually used when the production facility makes a variety of products. In a cell layout, a group (or family) of products that require similar steps in a similar sequence is manufactured in one cell. Since the goal of any layout is flow, the cell layout tries to get the benefit of flow that can be achieved in a product layout in an environment that would usually use a process layout. A U-shaped cell allows easy communication among workers in different parts of the production process. Lean Manufacturing Shapes A Cell at MMS Online describes a cell to machine flight control surfaces for airplane wings, made from aluminum castings.

A restaurant for sit down dining tends to have a kitchen with a process layout, with stations for grilling, baking, frying, etc. Different products (meals) require the cook to move from station to station. However, a fast food restaurant kitchen tends to have a product layout, with a dedicated area for each product, for example one area includes equipment to make fries and then to place them into serving containers. A fast food restaurant makes fewer different products than a sit down restaurant, so it should use a product layout.

In Chapter 4 we read the article Setup Reduction: At the Heart of Lean Manufacturing from MMS Online, which describes how Richards Industries, a manufacturer of specialty valves, reduced its setup times and batch sizes. The first step in achieving those reductions was to group the machines into four cells for production of the four very distinct product lines. “In this arrangement, machines [in a cell] could share common setup areas, tool storage and fixturing items.” Boeing Auburn Machine Fabrication made a similar change from a process layout to a layout based on cells for each product.

A Radically Different Production Plant from MMS Online describes the process layout used for a machining center at C&A Tool in Churubusco, Indiana: "this 110,000 square foot factory is full of unexpected features -- self-contained areas dedicated to milling, turning, grinding and automatic machining; a central service corridor; a strategically located material handling area; a centralized metrology lab."

I listed four types of layouts above, using the terms product layout, process layout, fixed layout, and cell layout, but other analysts use other categorizations and other labels. For example, NetMBA describes these layouts:

- Project - Example: building construction
- Job shop - Example: print shop
- Batch process - Example: bakery
- Assembly line - Example: automobile production line
- Continuous flow - Example: oil refinery

Creating a good layout involves considering how material moves through the facility. For small layout problems, you may be able to find a good solution by hand. Try it with this example of a process layout. You can move the locations of the 6 departments (Paper Storage, Design, Binding & Handwork, Printing, Customer Service, and Packaging & Shipping) to minimize the Total Distance traveled. Use the Trips Matrix to guide your thinking.

Larger problems require the sophisticated methods of operations research. Systematic Layout Planning (SLP, developed by Richard Muther) is a systematic method for creating an appropriate layout. It has three steps:

1. Relationships. Collect, organize, and display information on the flow of material and relationships between functions.
2. Space. Collect, organize, and display information on the space needed by each function and on the space available.
3. Adjustment. Create a preliminary layout and then adjust it. Continue to evaluate and adjust layouts until a satisfactory solution is reached.

Software is available to help the IE find a good layout. For example, "FactoryFLOW is a graphical material handling system that allows industrial engineers to optimize a factory layout based on material flow distances, frequency and cost." (Source)

Designing a new layout is a difficult task, but redesigning an existing layout can be even more difficult and very frustrating. The existing layout may have grown up by pieces and may have obvious flaws, but the cost and time involved in stopping production to redo the layout often means that the organization just lives with the existing layout, makes small improvements in the layout, or makes improvements in layouts only within a department.

6.3 Material handling and inventory equipment

The design of a layout must also include the selection of appropriate material handling and storage equipment, including equipment to move incoming supplies, to move product between work stations, to move finished goods to shipping, and to store supplies, WIP

(Work in Progress), and completed products. Material handling is a large part of the cost of a product.

Material handling and storage uses a wide range of equipment, such has

- Cranes and hoists
- Automated Storage and Retrieval Systems
- Fork lift trucks, hand trucks,
- Conveyors,
- Pallets, containers, bins, shelves, and racks

Browse in the web pages at the Material Handling Exchange to see the range of material handling equipment. Browse in the web pages at Concept Storage Solutions to see the range of storage equipment.

The Material Handling Industry of America (MHIA) lists these 10 principles of material handling:

1. Planning. The material handling system should be planned, and not just allowed to evolve.
2. Standardization. Where possible, use standard equipment, containers, and racks so they can be reused. Methods and software should also be standardized.
3. Work. Movement and storage of supplies, WIP, and finished product should be minimized.
4. Ergonomic. Consider the ergonomic implications for workers, especially concerning lifting.
5. Unit Load. Use as large a unit load as possible when transporting material so the human and equipment make as few trips as possible.
6. Space Utilization. Make effective use of all space. For example, shelves should be placed so that vertical space is not wasted.
7. System. Plan the entire material handling system to include receiving, storage, retrieval, and shipping to customers.
8. Automation. Use mechanized processes where appropriate.
9. Environment. Energy use and harmful environmental effects should be minimized. Hazardous material should be handled appropriately.
10. Life Cycle Cost. Equipment should be evaluated based on the cost over the entire life cycle.

The Conveyor Center of FloStor lists The Twenty Principles of Material Handling which include other ideas as well, such as:

13. Utilize gravity to move material wherever possible, while respecting limitations concerning safety, product damage and loss.

They also recommend making sure that data flows with inventory, and that a maintenance plan be developed for material handling equipment.

Some of these principles conflict with other ideas of industrial engineering. For example, maintaining flow requires that products move in small batches (in fact, a batch size of 1, where possible) rather than in large unit loads.

Robot Rx is a good example of an integrated system of receiving, storage, dispensing, and tracking.

> ROBOT-Rx is a stationary robotic system that automates the drug dispensing process using bar code technology. Located in the central pharmacy at Gwinnett Medical Center, ROBOT-Rx automates the following bar coded medication areas:
>
> - Storage
> - Dispensing
> - Returning
> - Restocking and crediting.

6.4 Movement and storage of information

Data are being created in every organization. Such data include faults or breakdowns in the system (a machine tool just broke in cell 3, or Mike in purchasing has gone home sick) as well the details of every transaction (machining part X32 on machine 3 started at 9:30 am on 26 January 2006 and took 2 minutes and 3 seconds; checking patient 3789 into the hospital started at 9:30 am on 26 January 2006 and took 12 minutes and 36 seconds). All data have the potential to be used for immediate decision making (dispatch Mary to replace the tool in cell 3; reroute Mike's calls to Stan for the rest of the day) and for long term decision making (the times to machine small parts is less on machine 3 than on machine 4; let's consider putting together a team of machinists to determine why this difference is occurring and to see if we can cut the machining times on machine 4). Automation For Information from MMS Online talks about the importance of capturing and using information at all steps of the manufacturing process, often with an increase in profits at little cost.

> Instead of purchasing new capacity or new machinery, the plant realizes a potentially larger amount of capacity that formerly was going to waste.

In Feedback From A CNC In Real Time Is...A "Significant Event" At Cessna from MMS Online Mark Albert describes how an investment in retrofitting two CNC machines with standard PC hardware and Windows based software, linked to the company's intranet, allowed information to be gathered and used in real time and in long term decision making.

In the Emergency Department at Parkview Hospital, physician orders are entered into the computer; such entry captures the order more accurately than paper entry, avoiding problems of legibility as well as reducing errors due to drugs with words that look like or sound like another drug. Because physician orders (for drugs and for tests) are captured electronically, they are displayed immediately to the relevant staff; the filling of the order doesn't have to wait for a paper order to be moved to the correct department.

When considering the use of information technology, IEs should consider the following principles:

- Don't automate an inefficient process. First make the process more efficient.
- Collect information as it occurs.
- Add value for the customer.
- Interoperability of computer technology has improved, but still must be a concern

- Allow for the cost of maintaining information technology.

Computer technology should not be purchased without thinking first about whether the processes the technology will support are really necessary. Focus first on eliminating unnecessary steps and on improving the efficiency of a process; then think about using information technology. Computer technology and software to support electronic routing of approvals for purchase orders might make sense, but first examine the process for approval of such orders; perhaps all the approvals are not needed. The improved process might not need computer technology.

Investments in hardware that allow the automatic collection of information can reduce the need for humans to enter data, allowing for more accuracy in databases. Point of Sale terminals capture sales data as the sales occur, enabling tracking of inventory and sales. In its manufacturing process, Fujifilm replaced a step requiring workers to enter a tracking number with a scan of a barcode, reducing movement by workers and increasing accuracy. In 2004 the Food and Drug Administration gave the hospital industry two years to meet a requirement that all drugs administered to a patient in a hospital be confirmed by scanning the patient's barcode ID and the barcode for the drug. Copeland Corporation uses bar codes to ensure that the correct products are shipped to a customer.

Barcodes continue in use, but the newer technology of Radio Frequency Identification (RFID) means that an object can be located from a distance, without the need for a line of sight to the object. In an article in Directions magazine, David Williams explains what an RFID tag is:

> An RFID tag consists of a microchip and an antenna, often in the form of a tiny ribbon that can in turn be packaged into many forms, such as a label, or imbedded in between the cardboard layers in a carton. On the microchip is stored information about the product that the tag is affixed to, which can then be "read" when the tag passes within proximity of an RFID "reader," with that information being relayed back to a computer system that updates the location status of the associated product.

The railroad industry was a leader in the use of barcodes to track the location of rolling stock, and now they are leading in the use of RFID tags. RFID tags can be used for automatic toll collection. Edinburgh, Scotland, uses RFID tags on buses to control traffic lights and reduce traffic congestion.

A product that is manufactured with an embedded RFID tag can be tracked through the manufacturing process, through the supply chain, through the sales channel, and even to the final customer. In 2004, Walmart announced that by the end of 2006 all suppliers would have to put an RFID tag on shipping crates and pallets. This article explains the challenges faced by a small manufacturer in meeting the Walmart mandate, but also the way the manufacturer will use the RFID tags to improve the packing and shipping process. RFID tags cost more than barcodes, but the overall savings from RFID tags may be more than barcodes. Some companies are now moving toward placing RFID tags on individual items (called item level tagging), but consumers have privacy concerns.

When humans do have to enter data, technology can make data entry easy through touch screens, stylus entry systems, and wireless PDAs. Customers enter their own data when making purchase on the web.

Be sure that the computer technology you recommend actually adds value for the customer. What is the contribution to efficiency, quality, or safety, and what, thus, is the contribution to customer satisfaction?

Interoperability is an issue for both hardware and software; computer technology and computer software from different manufacturers and from different suppliers may not work well together. Standards are supposed to reduce this problem, but a cynical saying is: "standards are great; everyone has one." Many engineering devices now have computer technology and software built in. This article talks about the movement of Coordinate Measurement Machines from inspection to in-line monitoring of quality. Because the goal is to compare the design with the actual part, users have to be careful that their CAD system and CMM system will talk with each other. The Evraz rail mill in Pueblo uses "in-line ultrasonic inspection using linear and phased array ultrasonic technology—looks for internal defects without compromising product" (http://www.evrazna.com/LocationsFacilities/RockyMountainSteelMills/RMSMRailMill/tabid/72/Default.asp).

Finally, when you are computing the cost of purchasing computer technology, include the cost of maintaining the system and of purchasing upgrades and replacements.

6.5 How will the organization maintain its physical assets at peak performance?

The goal of maintenance is that all required equipment performs flawlessly during all planned production time. Here are some examples:

- During working hours in an office, the office machines, including computers and copiers, always work; planned maintenance is done out of normal working hours.
- During planned production time in a manufacturing plant, no machine even breaks down.
- No delivery vehicle every breaks down, including having a flat tire.
- During business hours in a retail store, the terminals for check out are always operating correctly.

Total Productive Maintenance (TPM) aims for three zeros:

1. "Zero unplanned equipment downtime,
2. Zero equipment-caused defects, [and]
3. Zero loss of equipment speed."
   (IE Handbook 16.65)

Another important goal is zero equipment related injuries.

Unplanned or unscheduled downtime occurs when a machine breaks down or works poorly enough that production is halted for repair or adjustment, called remedial or emergency maintenance. Unplanned downtime, unless balanced by overtime production, usually leads to lost production time, idle workers, and failure to meet promised delivery dates to customers. An organization wants to avoid unplanned downtime and planned or scheduled maintenance helps keep equipment operating properly. It can also prolong the life of the machine and reduce the life cycle cost of the equipment. For example, regular oil changes greatly enhance the performance of a car and greatly increase the life of the engine.

When purchasing equipment the IE should consider maintainability as one criterion.
- How often are various types of maintenance recommended by the manufacturer?
- How easily can maintenance tasks be performed?
- How easily can problems be diagnosed?
- How expensive are replacement parts?
- How quickly can replacement parts be obtained?
- Does the manufacturer provide training and support for maintenance personnel?
- How much time to maintenance and repairs take?

In the article These U.S. Shops Are Ready For the "Internet of Things" from MMS Online, Mark Albert describes how the open source protocol MTConnect allows the integration of data from various machines:

> In a nutshell, MTConnect translates the proprietary computer language of each machine into a common, simple, Internet-based language that can be used by a growing field of data acquisition and machine monitoring software applications.

The companies are now able to collect data, for immediate action and for long term improvement.

The IE has to make a number of decisions in creating a planned maintenance or preventive maintenance program:
- the frequency and schedule for each type of maintenance on each machine, from cleaning and lubrication through replacement of consumables to overhaul and eventual replacement.
- the personnel, in house or contract, who will perform each type of maintenance. Routine maintenance will usually be performed by the operator, often on a daily basis.
- the inventory of spare parts to be maintained.

Predictive maintenance is a step beyond preventive maintenance. Historical data on a machine and data from sensors or analysis of machine use can help schedule maintenance better. For example, the number of copies made on a copier can be used to schedule types of maintenance. On other machines, sensors can product tool failure and lab analysis of lubricants can detect metal wear. The noise or vibration from a machine and temperature measurements can also indicate its condition.

Total Productive Maintenance (TPM) carries these ideas further, in three phases. First, each machine is brought up to its highest level of performance and availability by identifying and remedying any problems. Improvement may be needed in changing a machine from product to product since such time is lost to production. Second, each machine is maintained at that level through a carefully designed preventive maintenance schedule, perhaps involving predictive maintenance. Regular cleaning by the production worker can be used to uncover problems before they affect production. Third, through the analysis of data collected in earlier phases, consideration can be given to purchasing new equipment that will reduce the life cycle cost of providing the function needed.

TPM involves all workers in maintaining the equipment. This article describes how a manufacturing plant trained workers to do first line maintenance.

> Jobs that had traditionally been done by skilled technicians were routinely being done by machine operators. These included tasks such as lubrication, basic machine programming, machine set up and change-over. One of the major benefits we derived came from the fact that machines were being attended to on the majority of occasions straight away rather than having to wait for the next available maintenance technician to address the problem.

The T in TPM stands for Total and indicates a total focus on maintaining equipment at its highest level in performance and availability. All an IE's skills and knowledge can be applied here to gain improvements in equipment availability but also to reduce defects, to produce at desired rates, and to improve safety.

TPM uses Overall Equipment Effectiveness (OEE) as one measure:

OEE = availability x performance efficiency x rate of quality.

where

- availability is the ratio of up time to total planned work time,
- performance efficiency is the ratio of actual output to theoretical output, and
- rate of quality is the ratio of good output to actual output.

Monitoring these three components can lead to better understanding of where productivity is being lost, as explained in this article.

This chapter has described what an IE does in locating, laying out, and designing the production system. The next chapter turns to the IE's role in operation of the production system.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 7
Operate a production system

Recall that the previous chapter was about selection and organization of the physical assets of the organization. Now that the production system has been set up, we need to discuss how to operate it. This chapter is about the operating rules for the production system. One difference between the previous chapter and this one is in the amount of time that a decision affects the organization. Building a new facility (an example of a decision discussed in Chapter 6) usually affects the company for years and takes money and time to change that decision. In this chapter, I'll describe decisions that usually affect the company for less time, and that take less time to change, but even among these decisions, the time varies. Consider these decisions:

- Select and commit to working with a supplier.
- Hire enough workers to run the operation for two shifts.
- Allocate planned production over the next month and schedule workers for different shifts.
- Decide which particular jobs will be done on this week's shifts.
- Begin work on a particular job on a particular machine by a particular team.

These decisions are all part of "operations management" and they have impact over a shorter time period than the decisions in Chapter 5, but they still vary in how long they affect the company.

This chapter is organized into the following sections. (This organization follows closely that used by Turner *et al.*)

- 7.1 Forecasting
  In chapter 6, we already discussed the issue of deciding on the size of an operation. How big a steel plant? How big a hospital? How many fast food restaurants in one area? How big a chip manufacturing plant? The answer to those questions puts an upper limit on how much steel can be made, how many chips can be made, how many patients can be served, and how many customers can be served, but the organization still needs to forecast demand and make adjustments to the work force, the resources ordered, and so forth.
- 7.2 Aggregate planning
  With a forecast of overall demand, the organization now plans how it will meet that demand, perhaps through building inventory during certain periods or by adding temporary workers.
- 7.3 Operations planning
  Now the organization gets more specific. Given the aggregate plan, how much of which resources will be needed? Which supplier will deliver them? How will work be allocated in the manufacturing process?
- 7.4 Supply chain and inventory management
  When and where will incoming resources be received? How will finished product be stored? Will subassemblies be made and used as orders are received?

- 7.5 Operations policies
  Which order will be started at what time on which production equipment by whom? Many other decisions about scheduling and other policies are needed before operations can begin.
- 7.6 Operations
  Once operations are underway, the IE still has some questions to answer. How is the work proceeding? Is the schedule still working? How can we handle any difficulties that arise? What information should we collect on the actual operations?

7.1 Forecasting.

In a completely flexible production system where supplies, labor, and capacity can adjust immediately to demand and where goods and services are produced only when a customer is ready to buy, a production forecast wouldn't be needed. Agility, lean manufacturing, and pull systems all tell the IE to work toward that ideal, but as long as the lead time on any input to production is greater than zero, some planning and thus some forecast are needed. The goal of forecasting is a prediction of aggregate demand (that is, demand for all products in a broad grouping) over a forecast horizon.

Operations management would be much easier if the level of demand for an organization's products or services never changed. Then the forecast for today would be the "same as yesterday." If customers have been purchasing the products or services of an organization, what causes the level of demand to change? Why doesn't the demand stay the same?

- *Seasonality.* Most consumers buy Valentines in February, Halloween costumes in October, and more of almost everything for gift giving in December. An organization that produces a seasonal product or service will have such regular -- and somewhat predictable -- changes in demand. For example, during its busiest period from Thanksgiving through December, UPS adds leased aircraft to the fleet of planes it owns.
- *Long term trends.* Over a time period of years or even decades, consumers tastes have changed. Consumers tend now to buy larger houses, more prepared foods, and more casual clothing than in the past. Demographics, such as the aging of the baby boomer generation, can affect demand. The demand for school buildings has gone up and down with changes in the number of children of school age.
- *Economic cycles.* When the whole economy shrinks or grows, demands for all products are affected to a greater or lesser degree. Demand for some products and services tend to be immune to economic cycles (for example, luxury yachts), some tend to be demanded more when the economy is doing well (for example, air travel and automobiles), and others are counter cyclical, that is, the demand increases when the economy is not doing well (for example, products related to do-it-yourself and home repair and applications to graduate school). Based on historical data on the economy and on demand for its products and services, an organization can use economic forecasts to help forecast demand.
- *Product life cycle.* Most products have a life cycle involving stages of introduction, growth, maturity, and decline. This web page shows some examples of life cycles for products that are still used (although more current data would probably show a decline in the VCR). Fashion items and fads have very short life cycles -- do you

remember pet rocks? An organization can watch the demand for its product and services and gain some knowledge of where each product or service is in its life cycle.

- *Marketing.* An organization spends money on marketing in order to increase demand, so forecasts should reflect the predicted effects of marketing campaigns.
- *Change in pricing.* A planned temporary or permanent change in prices will affect demand and should be reflected in the forecast. Temporary discounts may not increase demand, but only shift it over time, and thus can be used to smooth a seasonal demand pattern.
- *Product innovations.* As the saying goes, build a better mousetrap and the world will beat a path to your door. When they do, your production system will have to adjust to the new demand.

Reread the above list again, and notice that some of the factors are more under the control of the organization than are others. For example, an organization can decide on a marketing plan or pricing structure, but it can't move the date of Valentine's Day or Halloween. However, an organization can insulate itself from some of the factors by choosing its mix of products and services. For example, Current Catalog sells paper products related to: New Year's, Valentine's Day, St. Patrick's Day, Easter, Mother's Day, Father's Day, Graduation, the Fourth of July, Thanksgiving, Halloween, Christmas, and Hannakuh, as well as other nonseasonal items (for example for birthdays and anniversaries). They always have some products for the current season, whatever the time of year. An organization can strive to have a mix of products and services where the demand for each goes up or down, but the overall level of demand is fairly level.

Most advice about how to maintain an organization's demand for its goods and services over the long run focuses on innovation. Even some of the oldest companies do not make the identical products and services they did even five years ago. For example, Coca Cola was founded in 1886 and now sells over 400 brands worldwide. In 2015 Coca Cola is moving to smaller bottles and cans.

"New and improved" is a common phrase in marketing, but even the best companies make mistakes. Coca Cola introduced a new formula for Coke (New Coke) on April 23, 1985, and returned to the old formula on July 11, 1985, after consumers protested very loudly.

An organization's competitors are also developing new products and their actions, especially their innovations, will affect the demand of all organizations producing similar products and services. Many say: innovate or die. All our previous discussion about the need to have a focus on the customer applies here.

By considering all its product lines, the place of each in the life cycle, and plans for new products and services, an organization can use an aggregated (or bottom up) approach to create a forecast for the overall level of demand for the products and services of the organization. Good forecasts build on quantitative analysis and on judgment.

While the above discussion assumes that we make only one forecast, a more sophisticated approach involves the use of scenarios and probability to make forecasts and plans.

7.2 Aggregate planning.

The goal of aggregate planning is to use the aggregate forecast to determine aggregate production during each future time period in the planning horizon. The forecast may say the demand will be 1000, 1500, and 2000 units in the next 3 months. We could make exactly that much each month or, for example, we could smooth the production by making 1500 each month, at the cost of having to store 500 units from the first to the third month. Typically the forecast extends further into the future than the planning horizon and the aggregate plan should change as new forecasts become available, creating a rolling plan. For example, if the 4 month forecast is 1000, 1500, 2000, and 2500 we might still plan forward 3 months, but we might make a different plan than if we know the forecast is 1000, 1500, 2000, and *1500* for the next 4 months.

An aggregate plan may include smoothing production by building up inventory, planning for back ordering, or using discounts to shift demands in time. The plan may include changes in the size of the workforce, subcontracting work to other producers, or scheduling overtime. Different aggregate plans can meet the same forecasted demands, at different cost.

7.3 Operations planning

Two different philosophies can be used for operations planning, although most organizations fall somewhere between these two extremes. The two philosophies are called Materials Requirements Planning (or push production) and Just in Time (or pull production).

MRP or push. After a forecast has been turned into an aggregate plan, more detailed production plans are made, based on knowledge of the components needed for each part and the lead time to receive supplies from suppliers and to produce and assemble products. Materials Requirements Planning works backward in time using knowledge of the required production schedule and the product structure to determine how many of which parts have to be ready by what time, and works backward in time from the knowledge of lead times from suppliers to determine when orders should be placed.

For example, an organization that wants to produce 200 bicycles by the end of a specified week plans backward in time for the manufacture of 200 frames and the assembly of 200 bicycles, and plans backward in time for the delivery of 400 wheels and other parts from suppliers or from other parts of the production system. If the supplier of wheels needs one week notice, then the order must be placed at least one week before they will be needed. A restaurant that plans to offer a prime rib special will need to place an order with its supplier of meats in order to meet the planned demand. The chef will also need to plan for the side dishes that customers are likely to eat with prime rib. Perhaps some items can be made ahead of time and frozen for later use.

MRP is a very simple concept, but all the required planning can be very complicated. The production schedule interacts with the choice of lot size, that is, the number of a particular type of component, say, a type of bicycle frame, that are manufactured before the production process is switched over to another type of frame. MRP must also adjust to the capacity constraints on the plant and to the need for rework or scrapping of defective parts. Material Requirements Planning (MRP) can also be extended as Manufacturing Resource Planning (MRP II) where the Master Production Schedule produced by MRP is also used to plan marketing. The MRP plans must be adjusted as new forecasts become available. Very accurate and sophisticated information systems are needed to trace inventory and production.

MRP has a very serious problem, which is indicated by its other name: push production. The production process is planned around a forecast, which will not, of course, be exactly correct. No forecast is perfect. The bicycle company may find that it has produced 200 bicycles of a type that is decreasing in popularity. Automobile manufacturing in the US was notoriously a push system and car lots at sales places might be littered with models that customers didn't want while there would be shortages of more popular models. MRP pretends that we have a planned economy, but we don't. MRP ignores the uncertainty about what customers will actually buy.

JIT or pull. If the production process can be made lean, especially if lead times on production and lead times for delivery from suppliers can be reduced, the need for forecasts is reduced and the production process can be made more responsive to current customer demand. At the extreme version, no supplies are ordered and no products are made until a customer has placed an order. In a less extreme version, customization for the particular customer (for example, a customer who has ordered a car with a specific color scheme and other features) is postponed until late in the production process, so the final product already has a buyer who wants exactly those features.

Pull production requires a different kind of precision and discipline than MRP, as is implied by the other name for pull production: JIT, or Just In Time. Lean manufacturing requires reduction in WIP (Work in Progress), which means that each production step produces the amount needed for the next step at exactly the point in time when that next step is ready for more input. Suppliers make frequent small deliveries just when the supplies will be needed. Lot sizes are smaller and the production system can be changed quickly from one model to another.

A kanban system can be used to control the production. A physical card or ticket (Kanban is the Japanese word for card) is attached to an item as it completes one step in the manufacturing process; when the item has moved through the next processing step, the kanban is returned to the previous production step to trigger production of another item. Kanban systems can be designed in several ways and a crucial decision is how many kanbans should be used in each part of the system. The kanban system emphasizes the importance of the flow of information in a production system. While a card system is simple and easy to implement, a computer based system allows for faster flow of information back up the production line to trigger more production. This feature is why JIT is also called "pull" production: demand pulls production through the process.

JIT also requires that disruptions to the production process be fixed immediately. The production process has little WIP so the breakdown of a machine crucial to one step can quickly bring the entire production process to a stop. Organizations implementing JIT production must also look at the lead time necessary to repair machines or to receive replacement parts. Preventive maintenance becomes absolutely crucial so that breakdowns can be avoided.

A major advantage of JIT or pull production is the reduction in WIP and the increase in the ability of the production system to respond to a change in demand. With less WIP, a change in customer preferences leads to fewer items having been produced based on an incorrect forecast.

Some lean production can be described as mass customization, where the production process takes advantage of the efficiencies of mass production, but information technology and the ability to switch models quickly allows almost infinite variations in the actual product.

7.4 Supply chain and inventory management

The two philosophies (push and pull production) explained in the previous section have implications for an organization's interactions with its suppliers, interactions with its customers, and the amount of inventory the organization maintains. Supply chain management and logistics refer to all the aspects of maintaining flow of product from suppliers through the production process to customers. In either push or pull the goal is to maintain the flow and reduce inventories. Many strategies can be used to accomplish that goal.

In contrast to Just In Time, some people refer humorously to a Just In Case philosophy, where an organization stockpiles supplies and product in case of any disruption in the supply chain and breakdown in the production process. Holding inventory has benefits, but it also has costs: the cost to provide space and storage facilities for inventory, the cost to move the product into storage and then out of storage to the place it is needed, and the cost due to the fact that money has been spent on the inventory and the money is not available for more productive uses.

A crucial concept that underlies many of the strategies I will describe below is the idea of reducing variability by standardization. Here is an example. A manufacturer uses 10 different kinds of bolts in its products. It uses from 100 to 1500 on average of each kind of bolt each day. Because the product mix varies from day to day and because products use different types of bolts, the demand for each type of bolt varies greatly from day to day. The organization maintains an inventory of 5 days' supply of each type to ensure that production is not disrupted when the plant switches to another type of product. It also has storage places for each kind of bolt, information systems to track the inventory of each, and labels to ensure that the correct type of bolt is delivered to each place in the production process that requires the use of that type of bolt.

Now assume the manufacturer redesigns its products with a focus on reducing the number of different bolts used in the products and it is able to reduce the number of different types of bolts from 10 to 3. Its overall average use of bolts per day will be the same, but it will probably have reduced the variation in how many bolts per day it is using. If the mix of products being made changes from day to day, the variability in demand for different types of bolts will have been reduced because all products are using only 3 types of bolts now. The demand for bolts is more predictable and it may need to maintain only 3 days' supply of each type, it needs less storage space and fewer distinct storage spaces, it has fewer types of bolts to track, and fewer worries about the wrong type of bolt ending up at a production point.

The pooling of the demand for bolts into larger numbers for a fewer types of bolts reduces variability in the demand for any one kind of bolt. At the extreme, if all products the same number of one type of bolt, the demand for bolts would be smooth no matter what mix of products is being made. The more that inventory can be standardized, the more that variability can be reduced.

Standardization brings benefits and these ideas can be applied not just to the standardization of bolts, but of other components of products, of storage bins and pallets, and of shippers and suppliers.

Strategies
An organization that picks and works closely with a few suppliers may choose to share forecasts and even information systems with those suppliers. A kanban system (usually computerized) might extend from the organization to its suppliers. With only a few suppliers, the organization can communicate more closely, get to know those suppliers well, and work together so both the suppliers and the organization can be successful. An organization that has a large customer can ask to work closely with it, again including the sharing of information to the benefit of both.

Supply chains and customer chains that rely on transportation over long distances introduce delays due to time in transit and the chance of disruption. Items in transit should be viewed as inventory, to be reduced. Supply chains can be shortened by having suppliers that are located nearby. Reliable shippers should be used. More frequent smaller shipments allow more responsiveness to demand. If the organization uses a few suppliers for all its items, each shipment may have only a few of each item, but may still be a large shipment that is efficient to transport.

Information technology, including bar cards and RFID tags can be used to maintain accurate knowledge of all inventory. Surprise stock outs can be eliminated. Information technology can be used to track customer demand closely and to change production plans quickly. Information technology can be used to have customers enter customized orders, for example, as Dell does for its computers.

An ABC analysis classifies inventory into the A items that account for the highest amount of total purchasing costs in a year, the B items which are the next level, and the C items which may be numerous but are not costly. The A items should be managed most closely, but close management of C items may not be cost effective. One must be careful, however, to consider other factors. D items as those that have not been needed for over a year. One must be careful, however, not to assume that D items can be dropped from inventory. Parkview Hospital, in Pueblo, for example, stocks rattlesnake antivenin, no matter how infrequently it is needed.

Parts, inventory storage, and shipping containers should be standardized. Having one type of pallet rather than three will be more efficient. The law of large numbers tells us that the overall variability in the number of pallets used will go down.

Subassemblies should be standardized. While the final products may differ, they may all be composed of similar parts or similar subassemblies. Subassemblies can be made and only customized into final products later in the production process.

Supplies are often ordered in bulk because of quantity discounts and because of the cost of placing an order. A supplier might be willing to give the quantity discount in exchange for a long term commitment. The cost of placing an order can be reduced by the use of information technology within the organization and with suppliers.

Tools are often neglected in the design of an inventory system. The article Company Reduces Inventory And Costs With New Software from MMS Online, describes how the Aerospace Group of Parker Hannifin Corporation used software for tool management to decrease its stock of tools and reduce its cost in buying tools.

A storage facility can be laid out so that frequently requested items can be retrieved with little travel. However, the layout should also take into account items that are often requested in the same order (e.g. bolts and nuts) and locate them near each other.

Partners

A well run supply chain requires working with partners, usually the organization's suppliers. Other companies will provide supply chain logistics support to your organization. For example, UPS (which used to be named United Parcel Service) does a lot more than deliver parcels. UPS Supply Chain Solutions will design a supply chain system, including transportation, compliance with regulations on shipping, and management of returns. For example, in this paper, UPS discusses the cost of logistics for hospitals.

Like UPS, Penske Logistics, DHL, and Agility also offer logistics support.

7.5 Operations policies

Many more detailed questions still need to be answered:

- What plane arriving at an airport should be scheduled to land on which runway?
- In what order should the driver of a delivery truck make deliveries?
- Which patient waiting in an emergency room should be seen next by which medical professional?
- How should a log be cut into lumber at a lumber mill?

- In what order and using which hand should each operation be done in assembling a door handle and lock?

This section builds on two major concepts: the process matters and the IE sets policies.

First, the process by which work is done matters. The details of how workers do their jobs have small but cumulative effects that have big impacts on efficiency, quality, and safety. An air traffic control system that consistently maintains required separations will be safer, even if each small lapse in maintaining required distances only slightly decreases safety. A delivery schedule that reduces travel time by just a few percent allows more deliveries in a day. A good method for sorting patients in an emergency room (such a method is called triage) can make sure that time is spent on the patients most in need of attention, thus improving quality of care. Cutting each log into a better combination of lumber of different dimensions can improve the company's profit from each log. A well designed and tested process for assembling locks can reduce time, increase quality and reduce repetitive strain injuries. The process matters.

The second important concept is that the IE is involved in setting policies for how these decisions are made, not in actually making the decisions. Those policies are taught as Standard Operating Procedures and are incorporated into computer packages that support decision making. An IE can analyze different policies for choosing which plane should land next and determine which policies serve well in the long run. The policies can be encoded in a computer program that analyzes data on incoming planes, gate availability, and connecting flights and can display information visually and even recommend decisions to support decision making by the air traffic controller.

An IE can do the same for the delivery truck by creating a policy (perhaps a computer program) for laying out daily delivery routes. An IE can test the effectiveness of different rules for triage and implement the best rules as the ER policy. The IE can develop a combination of hardware and software to measure an incoming log and to compute the most profitable cutting pattern, given current market prices for different types of lumber. An IE can use various methods to devise the best assembly process, test the process in practice, and implement the process through training of workers. The IE devises the policies for how work is done.

IEs are in a very delicate position regarding workers. If you had 10 years of experience assembling locks, how would you feel if an IE just out of college told you how to do your job? IEs have to balance the fact that experienced workers often know how to do their jobs well with the fact that new ideas, new products, new equipment, or a bigger view of the system may mean that the IE just out of college *does* know a better way.

A new IE or an IE working with a new group moves slowly and builds credibility. Sometimes experienced workers are frustrated that their suggestions for improvement have been ignored. The experienced workers, if involved in a process improvement project from the start, may have ideas and interest in improving the process. Some companies have methods for involving workers in process improvement.

For example, quality circles, an idea borrowed from the Japanese, involve working groups of line workers who meet regularly to improve the production process in the area where they work. Sometimes such groups are called Kaizen teams, using the Japanese work for "change for improvement."

IEs can also reduce conflicts with workers by remembering that IEs don't do the work. IEs set policies for the processes and then get out of the way. If the IE is engaged in doing the work, in repairing poorly done work, or in expediting work that has fallen behind, the IE should step back and figure out how to improve the process. If you ever find yourself reaching out to do some work that a worker should be doing, put your hands behind your back. Remember that the IE works on the system and the worker works in the system. Constant improvement in the policies for operations can add up over time to considerable improvement in efficiency, quality, and safety. You may, as we have discussed already, be stuck with a poor layout, but you can still make a lot of improvements within that layout.

This focus on operations has risks. First, optimizing a small part of system may result in suboptimization for the larger system. Certain policies for landing planes may lead airline companies to change their schedules in ways that harm the overall functioning of the airport of or the air system as a whole. Second, you can focus so closely on small issues that you miss the big issues; as the saying goes, you can't see the forest for the trees. Perhaps the layout really is so inefficient, as compared to competitors, that the company will continue to lose money until the layout is redone. Optimizing small parts of a system while ignoring big problems that can destroy the system is sometimes described as rearranging the deck chairs on the Titanic.

The area of operations research (research on operations, called, more grammatically, operational research in Britain) has many fascinating ways to improve the efficiency, quality, and safety of operations, with primary emphasis on efficiency. Visual displays, analysis of data, and computer programs can help. The field of operations research solves many interesting operations problems. I will now describe some of the problems and approaches used in scheduling and in routing.

Scheduling

Even a simple scheduling problem can be difficult, but a Gantt chart can help you visually evaluate schedules.

In this example, assume two jobs are waiting to be processed at two machines, A and B. Each job must be processed first on A and then on B. We want to minimize the total time to complete both jobs. This table show the processing time of each job on each machine in minutes.

	A	**B**
Job 1	30	50
Job 2	50	30

The Gantt chart below shows that the total completion time is 110 minutes if we start with job 1.

Minutes	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130
Machine A	1	1	1	2	2	2	2	2					
Machine B				1	1	1	1	1	2	2	2		

This second Gantt chart below shows that the total completion time is 130 minutes if we start with job 2. Since we wanted to complete both jobs as quickly as possible, we should start with job 1. The total time to complete both jobs (called the makespan) will be 110 minutes.

Minutes	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130
Machine A	2	2	2	2	2	1	1	1					
Machine B						2	2	2	1	1	1	1	1

In this case, the best decision wasn't hard to find and perhaps you can see that we did job 1 first because it required less time on machine A than did Job 2. That decision policy is called Shortest Processing Time or SPT. Is it always a good policy? It works well for 2 jobs on 2 machines, but not when we have more jobs, as this example shows.

	A	**B**
Job 1	30	10
Job 2	50	40
Job 3	60	60

If we use SPT to select which job to run on machine A whenever we have a choice, we would do the jobs in the sequence 1, 2, 3, and this Gantt chart shows that this sequence gives a makespan of 200 minutes.

Minutes	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	181-190	191-200
Machine A	1	1	1	2	2	2	2	2	3	3	3	3	3	3						
Machine B				1					2	2	2	2			3	3	3	3	3	3

However, this Gantt chart shows that the sequence 3, 2, 1 gives a makespan of 170. The sequence 3,2,1 is, in fact, the best, as you could confirm by checking all 6 possible sequences.

Minutes	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	181-190	191-200

Machine A	3	3	3	3	3	3	2	2	2	2	2	1	1	1						
Machine B							3	3	3	3	3	3	2	2	2	2	1			

If you are scheduling n jobs on 2 machines, there are n! possible sequences (you have n choices for the first job, n-1 for the 2nd job, n-2 for the third job, and so forth). Checking all those sequences would take quite a while if n is large. Johnson's algorithm is guaranteed to give us the best sequence of n jobs on 2 machines:

1. Select the smallest processing time for all jobs on both machines.
2. a. If the time selected is for Job j on machine A, schedule job j next on machine A. Cross out Job j.
   b. If the time selected is for Job j on machine b, schedule job j next on machine b, working backward in time. Cross out Job j.
3. Repeat 1 and 2 until all jobs have been crossed out.

Try this algorithm on the three-job data above and confirm that you get the sequence 3, 2, 1.

This discussion leads again to our important results: local optimization (for example, schedule next on this machine the job with the smallest processing time) may not lead to the best overall system performance. Therefore, someone has to set policies for scheduling across the whole system.

If scheduling three jobs on two machines can be tricky, imagine how complicated bigger scheduling problems can be? Johnson's algorithm gives us the best sequence for *n* jobs on two machines and a similar algorithm works in some circumstances for sequencing n jobs on three machines, but then we don't have algorithms that work in general. You also can't examine all possible sequences to find the best one, so you may need to be satisfied with a good sequence, even if it is not the best. Operations research analysts have found some generally good approaches, depending on your goal:

- SPT, or Shortest Processing Time. At each machine, select from all the jobs waiting for processing the job with the Shortest Processing Time on that machine. SPT scheduling on a single machine minimizes the average time all jobs spend in the system.
- FCFS, or first come first served. At each machine, select from all the jobs waiting for processing the job that arrived first.
- EDD, or earliest due date. At each machine, select from all the jobs waiting for processing the job that has the earlier due date, that is, the date that it is due with the customer.
- Critical ratio. For each job waiting for processing at a machine, compute the ratio of (total processing time left on that job)/(time left until the job is due) and select the job with the largest critical ratio.
- Lowest possible slack. For each job waiting for processing at a machine, compute the slack, that is, the time until the job is due minus the total processing time left on the job, and select the job with the smallest slack.

Each of these approaches has strengths and weaknesses and much research has been done on which approach to use in which circumstances.

Another possible approach to scheduling focuses on bottlenecks. Recall that a bottleneck is the resource with the smallest capacity. The flow rate through the bottleneck limits the flow rate through the entire system, so the goal of scheduling should be to keep the bottleneck busy all the time. Time wasted at the bottleneck is time wasted for the entire system. Staffing should be arranged so the bottleneck resource is running during breaks and lunches. A new job is scheduled into an available time slot on the bottleneck machine and then is scheduled backward and forward in time to the other machines.

Eliyahu Goldratt generalized this focus on bottlenecks into the Theory of Constraints (TOC). An organization's performance is limited by its weakest link, so identify that link and increase its performance; the result will be an increase in performance for the entire organization. Repeat. The book *The Goal* by Eliyahu M. Goldratt and Jeff Cox, is a novel that introduces Goldratt's ideas.

Actual scheduling problems can be very complicated. Hsu *et al.* describe the requirements for scheduling road test on vehicles each day at the General Motors Development Center in Kapuskasing, in northern Ontario. Vehicles must cool off between tests, must be road tested in groups, and must have a minimum number of escort vehicles since the tests are done on public roads. Also, drivers have a maximum number of hours they can work and have required breaks.

Since such situations have unique requirements which may change over time, an IE usually tries to devise clever heuristics; a heuristic for solving a problem is a solution method that gives a good, if not optimal, solution. Clever heuristics can be developed that take advantage of the structure of the problem in that situation. A heuristic can be implemented in a computer program that asks the human user to input data, constraints, and weights on different objectives, and that then suggests a solution for the human to adjust. Often a "what if" capability lets the human try out and compare different solutions.

The General Motors authors tried using a standard optimization package (CPLEX) but the resulting problem was too big to be solved in a reasonable amount of time. They devised a heuristic to develop a number of feasible schedules and pick the best among them. The results were a reduction in time to make a schedule from nearly four hours to a few minutes, an increase of more than double in the average daily throughput, a reduction in corporate warranty costs in the millions of dollars due to the ability to perform more tests, and an improvement in employee satisfaction because of the improved quality of schedules.

Scheduling problems also arise with scheduling workers. In the airline industry, among others, workers submit requests for schedules and the company would like to satisfy as many requests as possible. In addition, safety rules may place constraints on lengths of shifts and time between shifts.

Gordon and Erkut describe a spreadsheet they designed to devise a schedule for volunteers at the Edmonton Folk Festival in 2003. Even scheduling a team with only 32 members became very complicated in an attempt to satisfy as many preferences by volunteers as possible. Edmonton hosts many festivals each summer and the competition for volunteers is fierce. The Edmonton project was on a small scale and took two months to implement.

Continental Airlines uses an optimization program to construct schedules for pilot training.

> A dedicated team of operations research and software professionals, including specialists in large-scale optimization, databases, C++, Visual Basic, and quality assurance from Navitaire as well as manpower planners, training schedulers, managers, and information technology professionals from Continental Airlines, worked together on this project for over two years.

The project has paid off

> "Overall, Continental has estimated savings in excess of $10 million annually from using the system to create training plans. " (Yu *et al.*, page 260)

Routing

The driver who has to deliver packages wants to pick the best route, that is, the sequence in which to deliver packages. Consider this problem, an example of what is called the Traveling Salesman Problem, where the driver has to make loop starting at A and visiting B, C, and D before returning to A. The table gives the distances between each site that must be visited.

	A	B	C	D
A	-	5	4	3
B	5	-	6	8
C	4	6	-	4
D	5	8	4	-

In this case, the distances and the matrix are symmetric. In this small problem, you can try all the different orders and find the smallest (it has length 18), but a large problem can be very difficult and we may need to settle for a sequence that is good even if we can't show that it is the best sequence.

A very clever approach to the Traveling Salesman Problem that can be easily applied is the Meals On Wheels algorithm, which uses space filling curves, as explained here

.

Blakeley *et al.* created a decision support system to help supervisors in over 250 offices of the Schindler Elevator Corporation, Inc., schedule and create routes for maintenance visits. The project took approximately $1 million to implement, but reduced the route building process from several weeks in each office to a few hours. The total savings are estimated to be over $1 million annually.

Warehouses and distribution centers use workers to retrieve items based on customer orders. While much research has been done on how to create optimal routes for order picking, Dekker *et al.* describe a warehouse in the Netherlands that had unique features (for example, two floors) and unique requirements (for example, breakable items must be picked last). By analyzing various heuristics for generating routes and by analyzing data on the popularity of products (10% of products account for 70% of the total picks), the authors reallocated storage locations to improve the routes selected by the heuristics. However, since travel time accounted for only about 13% of the time to pick an order, the total time was reduced by only 4%. Other changes were used to reduce the picking time (for example, using scanners with a quicker response time). All the changes enabled a reduction in the number of pickers from 20 people to 12 to 15 people, depending on the level of demand.

These examples show just a few of the ways operations research can be applied to improve operations.

7.6 Operations

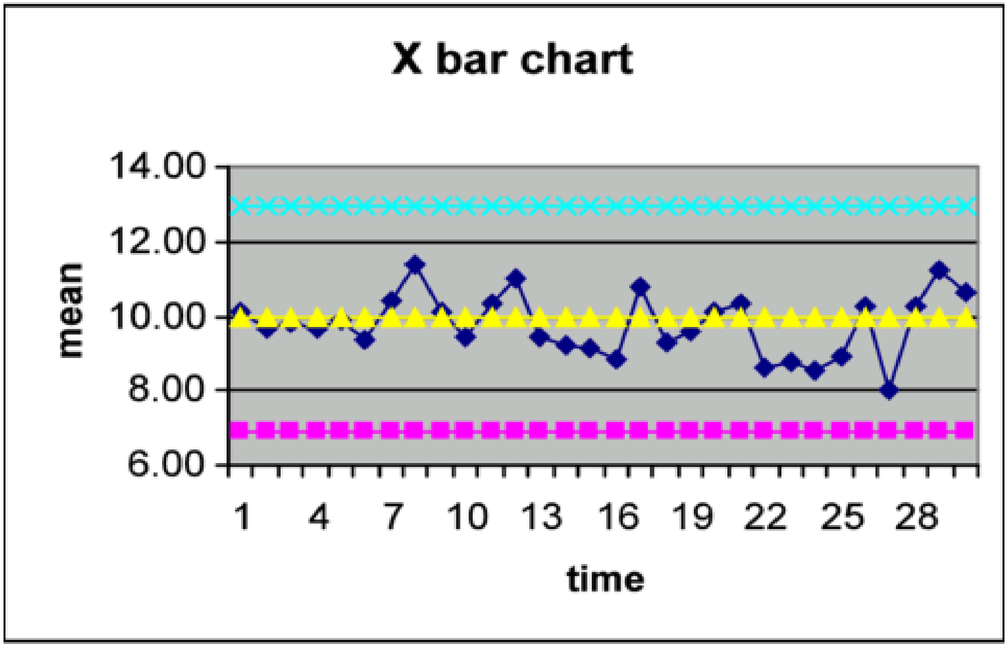
Finally (!), the workers actually do the work. They make steel, they make computer chips, they take and fill orders for food, and they take care of patients. Since the IE doesn't do this work, what is the IE doing?

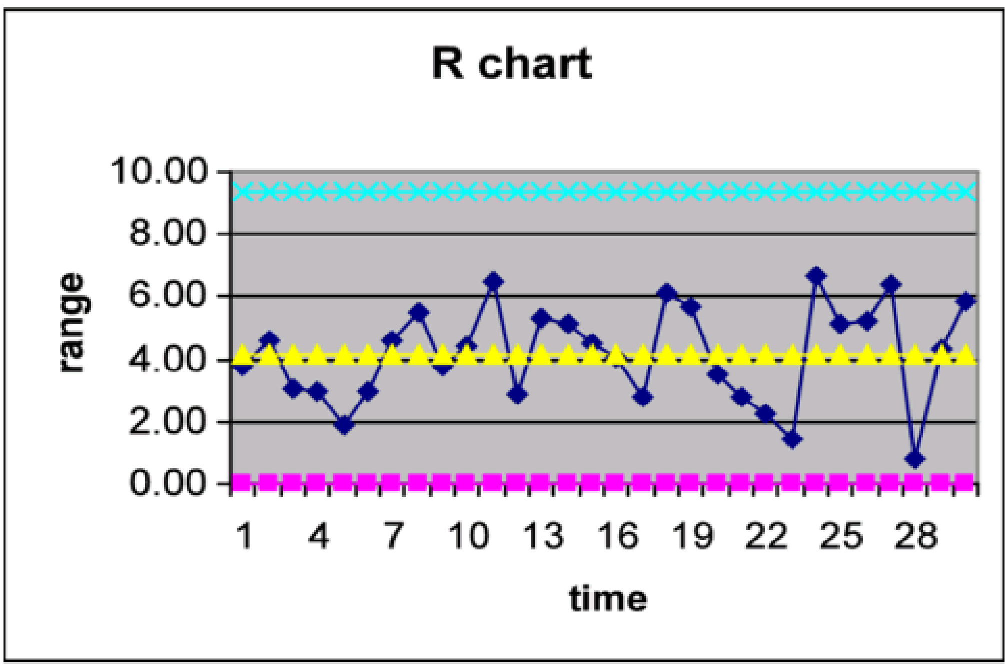
The goal of the IE is a perfect system, humming along, producing goods or services for satisfied customers. Two issues make that vision not quite accurate. First, problems can occur. The IE has to make sure the system is collecting data that will enable the detection and correction of problems. Second, the IE is never happy: "if it ain't broke, it can still be improved." The system needs to be monitored and data need to be collected.

Monitoring to detect problems

Recall the three targets from section 5.5. After we have helped the second and third archers achieve the tight cluster of arrows in the bullseye that the first archer had, we need to continue to monitor the system to detect if the archer's performance wavers. A production system that is reliably producing products or services within specifications might slip (1) in its mean or (2) in its variance. In the first case, the archer still has a tight cluster, but is not aimed at the center; in the second case, the archer is still aimed at the center, but the cluster has spread out.

Control charts are designed to detect either kind of slippage in the production system. A control chart is a plot of the performance of the system over time. Typically two charts are created, one showing the average (are the arrows aimed at the center of the target?) and the other showing the variability (are the arrows still tightly clustered?).





The two charts above show a process that is in control. The upper chart, called the X bar chart, shows the average measurement from several recent parts. Notice that the average in this chart is always between the lines, called the Upper Control Limit and the Lower Control Limit. The lower chart, called the R chart, shows the range from several recent parts. The range is computed as the difference between the largest and smallest part. Notice that the range in this chart is also always between its limits.

Monitoring to integrate operations

The article "Real-Time Data Collection for Real-Time Customer Response," from MMS Online describes how KVK Precision Specialities, in Shenandoah, Virginia, uses the collection of data to integrate sales, production scheduling, and tracking.

> Bar code scanners throughout the shop facilitate automated data collection, which enables the software to keep track of every job in real time as it moves through the shop.
>
> …
>
> All of the software's capabilities, which include order entry, scheduling, resource planning, real-time tracking, inventory of more than 4,000 component parts and imaging capabilities are utilized. The software tracks a job from the time a purchase order is received until the product is shipped to the customer.

Such systems are often also used to allow customers to track their own orders and thus to plan their operations better.

Monitoring to enable trace back

The International Organization for Standardization (ISO, from the Greek work for equal) has developed many international standards, but the two that IEs should be aware of are 9000 and 14000.

ISO9000 is a set of standards for the tracking of business processes. Put colloquially, the standards require that you say what you will do and that you actually do what you said you would do. The organization must have documents that say what procedures are followed for each step in the production process and the organization must be able to show that these steps actually were followed. Companies can have their operations certified by registrars, that is, certified that the operations follow the ISO standards. Especially in international markets, many large customers require that their suppliers be ISO9000 certified.

ISO describes the 9000 and 14000 standards as follows:

> The ISO 9000 family is primarily concerned with "quality management". This means what the organization does to fulfil:
>
> - the customer's quality requirements, and
> - applicable regulatory requirements, while aiming to
> - enhance customer satisfaction, and
> - achieve continual improvement of its performance in pursuit of these objectives.
>
> The ISO 14000 family is primarily concerned with "environmental management". This means what the organization does to:
>
> - minimize harmful effects on the environment caused by its activities, and to
> - achieve continual improvement of its environmental performance.

Note that ISO9000 deals with "quality management" not with "quality," and ISO14000 deals with "environmental management" not with "clean environment." An organization that is ISO certified is not guaranteed to be producing products and services with high quality or guaranteed to be minimizing its harm to the environment, but the organization is guaranteed to have consistency in their processes for quality management and environmental management. Since reducing variability and achieving consistency are required for quality, the ISO standards are certainly related to quality.

This web page has a good short description of the actual requirements of ISO 9000. An example requirement is:

> The products shall be identified and traceable by item, batch or lot during all stages of production, delivery and installation.

This requirement and others mandate the collection of significant information during the manufacturing process so that if a customer has a problem, the organization can trace that problem back through the system, determine the cause of the problem, and prevent the problem from occurring again.

The ISO standards are strongly rooted in IE principles, as shown by this list of quality principles on which the most recent ISO9000 standards are based.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 8
IE Careers

This chapter has these sections:

- 8.1 Employment Ask yourself:
    - In what type of industry do I want to work?
    - For what type of organization do I want to work?
    - Where do I want to work?
      What type of IE job do I want?
    - Should I start my own business?
- 8.2 Education and lifelong learning Ask yourself:
    - Should I become a Professional Engineer?
    - Should I pursue higher education?
    - Should I seek certifications?
    - What professional organizations should I join?
    - How will I keep up to date with new ideas in IE?
- 8.3 Ethics Ask yourself:
    - What situation might arise in my professional career that would have ethical aspects?
    - How will I recognize such situations?
    - How will I know what to do in such situations?

8.1 Employment

The following people are all graduates of CSU-Pueblo with a BSIE degree.

- When Jorgen Salo graduated with his BS, he went to work for DeBourgh Manufacturing Company in La Junta, Colorado, a manufacturer of school lockers. He is now president of the company.
- Megan New is an Environmental, Health and Safety Manager with Vestas.
- Joey Talbott works in Pueblo as a water quality engineer for the State of Colorado.
- Veronica Garcia is an Industrial Engineering Manager with Nestlé.
- Eric Samora is a Supply Chain Manager at Fiberguide Industries.

These job titles illustrate the different career paths that graduates with a BSIE degree can take. Many university students have already made important professional and personal decisions, but you will probably need to make other important decisions when you finish your degree.

All career advice always urges you to plan: ask yourself questions about your goals, think hard about the answers, and then plan your career so you can achieve your goals. Such advice is excellent (I will give you such advice in more detail in this section) and many people follow such advice - to some degree. However, many happy and successful people will readily tell you that chance and luck played a large role. I like the word "serendipity" which means a happy and unexpected find that occurs when you are looking for something else.

When I graduated with a BA in math I decided to go for my Master's degree to have a more readily marketable degree and because my professors said I should. I looked at math programs, but decided I wanted to apply my math. I was accepted into the Department of Industrial Engineering and Operations Research at the University of California at Berkeley - and they actually offered to pay me to go to graduate school - so I accepted. I also liked to idea of moving from New Jersey to California. I got my Master's degree in one year and started my PhD program, again because my professors seemed to think I was good, but I kept telling myself I really didn't intend to finish the program. But I did finish it, and when I did, I had one made one clear career decision: I did not want to be a professor.

Because I was part of a two-career couple I ended up at Purdue University, in West Lafayette, Indiana, but because I didn't want to be a professor, I took a research job at the university. After a while the Department of Industrial Engineering asked me to teach a course, so I did, and I was good at teaching and loved it. In 1980, I ended up as a professor, and I moved to Ohio State in 1986 and then to Colorado State University - Pueblo in 1998. I love being a professor.

One lesson I would like you to get from that story is for you to be prepared for serendipity. If another path to your career goals or to your career happiness appears, be sure that you have your eyes open enough to see it and your mind open enough to consider it. Another lesson is for you to accept and seek out mentors who will offer you good opportunities. My first department chair (Ferdinand Leimkuhler at Purdue) suggested I teach a course in engineering economy and then later a course in decision analysis. I had never had a course in either but ended up making those areas my specialty areas for teaching and research For me, the most important part of my career happiness has been to be in an organization where the professional contributions I wanted to make match the organization's mission. For example, my move in 1998 to CSU-Pueblo was motivated by my desire to be at a university where teaching is primary, research is expected, and service is valued.

My story is not unique. A former colleague of mine told me once about having been ill when in graduate school. He was told that he had not long to live, a pronouncement that turned out to be wrong. He said this experience had changed his attitude and after that he viewed every event as a wonderful bonus. His career, like mine, involved taking advantage of opportunities that arrived by serendipity.

However, taking advantage of serendipity doesn't mean you just take what comes. Consider the usual advice that I cited earlier: ask yourself questions about your goals, think hard about the answers, and then plan your career so you can achieve your goals. I add to that advice: be prepared to take advantage of the good opportunities that arrive by serendipity. As some have put it, when opportunity knocks, make sure you that answer the door.

Consider these questions:

- In what type of industry do I want to work?
- For what type of organization do I want to work?
- Where do I want to work?
- What type of IE job do I want?

- How much travel do I want to do?
- How much does money matter to me?
- How much does work matter to me as compared to family and leisure activities?

You may want to consider these questions in a different order. For example, you may want to decide where to live first and then consider the other questions. However, deciding, for example, to work in Pueblo obviously limits your choices about for what organization you will work. Also, you may want to consider the answers of your partner to these questions. Locating two good jobs in one area is called the "two body problem" and may require sacrifices by both partners. Sometimes the members of a couple alternate the sacrifices. One may, for example, provide primary support while the other attends graduate school, and then they reverse roles.

Your answers to these questions will certainly change over time. Many people find travel exciting when they are early in their careers, but then want to travel less if they have children.

Most IEs work in manufacturing, but you should consider other fields. The NAICS system is used to classify establishments according to their primary industrial activity. We can use these codes to consider how industrial engineering can be used in many fields.

At the highest level of aggregation, NAICS lists these type of establishments:

- Agriculture, Forestry, Fishing and Hunting
- Mining
- Utilities
- Construction
- Manufacturing
- Wholesale Trade
- Retail Trade
- Transportation and Warehousing
- Information
- Finance and Insurance
- Real Estate and Rental and Leasing
- Professional, Scientific, and Technical Services
- Management of Companies and Enterprises
- Administrative and Support and Waste Management and Remediation Services
- Educational Services
- Health Care and Social Assistance
- Arts, Entertainment, and Recreation
- Accommodation and Food Services
- Other Services (except Public Administration)
- Public Administration

This web page from the US Census Bureau has a complete listing and I suggest you spend some time looking at that list. Did you ever think about working for an organization in Doll, Toy, and Game Manufacturing or a Limousine Service or Motion Picture and Video Industries? Think big and think broadly before you make decisions.

You also should give some thought to the type of organization you might work for.

- Publicly held corporation,
- Privately held corporation,
- Federal, state, or local government agency,
- Not for profit organization, or
- Charitable organization.

Most IEs work for publicly traded for profit corporations. Almost all the big companies you can think of fall into this category: for example, IBM, Ford, Intel, and Dell. "Publicly traded" means anyone can buy a share of the ownership of the company on a stock exchange. Some large companies are privately owned (or closely held); they do not have shares available for purchase by the public. Every year Forbes magazine compiles a list of the largest privately held companies. The list includes Bechtel, Enterprise Rent-A-Car, Toys "R" Us, Hallmark Cards, and Mervyns.

Some companies are family owned; even if they may be publicly traded, members of one family own a great deal of the shares. This list of the world's largest family businesses shows. Sam Walton's descendants own 50.9% of the shares of Wal-Mart. Ford family members own about 40% of the voting stock of Ford Motor Company. Other family owned businesses are not publicly traded: Cargill, Koch Industries, and Mars are examples. If you work for a family owned business, especially a small one, you must consider the question of how high you can rise in the firm if you are not a family member. The Asplundh Tree Service was founded in 1928; in 2010 third generation family member Scott Asplundh became the company's CEO.

Some companies have some workers who are unionized while others do not. According to the US Bureau of Labor Statistics, in 2014, 11.1% of wage and salary workers were members of unions, but the percent unionized varies by type of employment. In local government, 41.9 % of workers are unionized, a category that includes teachers, fire fighters, and police officers. In transportation and utilities, 19.6% of workers are unionized, but finance has only 1.3 % unionized.

Some companies are big, as measured by revenues or number of employees. IBM has almost $100 billion in annual revenue and employs close to 380,000 people, Hewlett Packard has revenue of over $57 billion (about 65% of it generated outside the US) with about 302,000 employees, and Proctor and Gamble has over $83 billion in annual revenue and employs about 118,000 people.

Most businesses are small. According to the Small Business Administration, small businesses (that is, businesses with fewer than 500 employees)

- Represent 99.7 percent of all employer firms.
- Employ about half of all private sector employees.
- Pay 43 percent of total U.S. private payroll.
- Have generated 65 percent of net new jobs annually over the past 17 years.
- Create more than half of nonfarm private gross domestic product (GDP)
- Hire 43 percent of high tech workers (scientists, engineers, computer programmers, and others).

- Are 52 percent home-based and 2 percent franchises.
- Made up 97.5 percent of all identified exporters and produced 31 percent of export value in FY 2008.
- Produce 16.5 times more patents per employee than large patenting firms

A large company may have many IEs, and therefore any one IE can probably specialize more. In a small company, the IE will be called on to do many aspects of industrial engineering; in fact, the IE may find that he or she is an engineer first and an industrial engineer as time allows.

Some establishments are subsidiaries or divisions of larger companies. The Schlage plant in Colorado Springs, which manufactures lock sets, is a subsidiary of IRCO (formerly Ingersoll Rand). IRCO also makes golf cars, refrigeration equipment, construction equipment, and other products. Trane is also owned by IRCO. The former Goodrich plant in Pueblo is now owned by UTC Aerospace Systems.

Many businesses have international connections. For example, General Motors, with headquarters in Detroit, Michigan, manufactures cars in 33 countries, including China, where it has seven joint ventures and two wholly owned enterprises, and employs more than 20,000 people. Bosch, headquartered in Germany, employs 290,000 people most of them outside Germany. "The Bosch Group comprises Robert Bosch GmbH and its roughly 440 subsidiary and regional companies in some 60 countries. Including its sales and service partners,"

The CSU-Pueblo Library has a helpful list of sources for business research and many of these sources will help you determine important facts about an organization you are considering working for.

You might want to start your own business, if not now, maybe eventually. The Small Business Administration has information on starting, financing, and managing a new business. In Pueblo, the Small Business Development Center provides individual help, as well as seminars and workshops. VentureWell, formerly the National Collegiate Inventors and Innovators Alliance (NCIIA), states "We believe it is no longer enough for engineers to leave school with a purely technical education."

You should find out all that you can about the mission, vision, and values of an organization before you join it. Read the organization's written material, but also ask those who work there what values drive the company. Collins and Porras argue that visionary companies have especially strong cultures, and you better fit in with that culture:

> Only those who 'fit' extremely well with the core ideology and demanding standards of a visionary company will find it a great place to work. If you go to work at a visionary company, you will either fit and flourish – probably couldn't be happier – or you will likely be expunged like a virus. It's binary. There's no middle ground. It's almost cult-like. Visionary companies are so clear about what they stand for and what they're trying to achieve that they simply don't have room for those unwilling or unable to fit their exacting standards. (page 8).

Explaining IE
The good news is that almost whatever your answers to these questions about where you would like to work, you, as an IE, will have knowledge and skills that can be applied in that type of job. The bad news is that you may need to sell your IE skills and knowledge and you may even need to create your own job.

Even if you want to find a job in a well established field where industrial engineering clearly applies, say in medical care in a hospital, many providers in that field may not be familiar with industrial engineering. Industrial engineering is simply less well known than other types of engineering. Everyone knows, or thinks they know, what an electrical engineer does. Everyone knows that a mechanical engineer designs objects like cars, machines, and tools - designing objects is what everyone thinks all engineers do. Chemical engineering and civil engineering are also well known. Many engineering fields have names that are very descriptive of what they do; examples are environmental engineering, agricultural engineering, and aeronautical engineering.

Industrial engineering, on the other hand, isn't very well known, and the phrase "industrial engineering" isn't very descriptive of what we do, since IEs can work in organization that wouldn't be called "industry."

This lack of name recognition leads to two tasks for you.

1. You need to be able to explain what IE is - to your family, to acquaintances, but especially to prospective employers.
2. You need to know how to find good IE jobs that aren't labeled IE.

You need to have a short explanation of IE that you can give quickly, easily and persuasively. That explanation may be more or less detailed and more or less technical depending on who you are talking with and how interested they actually are. Remember that most people grasp concepts better if you give an example. The example could be about your job as an IE or about how an IE might help with some household task, such as making dinner.

The Institute of Industrial Engineers (IIE) gives the following definition of IE:

> Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of people, material, information, equipment, and energy. It draws upon specialized knowledge and skills in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems.

IIE also held a competition for the best bumper sticker explanation of IE and the winner was "Industrial Engineers make things better."

Those definitions are good but you didn't create any of them. You probably won't be able to deliver someone else's definition reliably and persuasively, so you should create your own definition. Think about examples and analogies you might use and try them out on people. Some ways to start include:

- "Industrial engineers think hard about a task before doing the task. For example, …"

- “Industrial engineers design the work place so people can do their jobs well. For example, …”
- "An industrial engineer designs a system so people and machines can accomplish some goal. For example …”

Notice that each of the above definitions gets to an example very quickly. You can even turn that around and start your explanation with an example:

- "Here’s an example. A team at a hospital looked at the task of cleaning up and preparing an operating room for the next operation and they found they could reduce the time and could schedule more operations in the room each day. This example shows that IEs help people be more efficient in their work.”

When I was explaining to a nursing home administrator what a graduate student and I proposed to do to help the nursing home improve its storage and inventory of supplies, she said "oh, you are like the closet organizers on the Home Channel." I thought that was a great comparison.

Selling IE

You also need to be able to explain to a company what you, as an IE, can do for them. Some companies know what IEs can do and hire industrial engineers, using that label. For example, this job ad from Jamak Fabrication was listed on monster.com:

Jamak is seeking an Industrial Engineer to work with our production departments.

> The Industrial Engineer works in the production departments of Jamak. In their role he/she will plan and oversee layout of equipment, conducts studies in operations to maximize work flow and spatial utilization, ensures facility efficiency and workplace safety, studies and records time, motion, methods, and speed to improve efficiency and establish a standard production rate in performance of maintenance, production, clerical and other worker operations. This position reports to the VP of Operations.

Specific Responsibilities:

- Complete work measurement analysis by identifying bottlenecks and idle resources to improve resource utilization.
- Identify sustainable Production improvements in quality, consistency, ergonomics, and costs of operations through the use of scientific tools.
- Interface with manufacturing and engineering to coordinate the implementation of new or improved manufacturing processes.
- Participate in cross-functional teams to eliminate non-value-added activities. Develop manufacturing process flows.
- Developing short and long term layout and workstation.
- Assist in preparing training guides and deployment documentation.

Minimum Qualifications:

- Bachelor of Science in Industrial Engineering (BSIE) required, with a focus in process improvement / lean manufacturing. MSIE preferred, but not required.
- 5 to 10 years industrial engineering experience required. Automotive/Heavy Industry experience is preferred.
- Demonstrated competency in the following areas: AutoCAD; System layout planning and development; Problem Solving; Ergonomics; Methods engineering

- Excellent written and verbal communications skills, strong analytical skills, and demonstrated ability in fostering teamwork and creating a positive, productive work environment.
- Must be able to work in a Team environment and have proven team leading skills.
- Experienced with disciplined problem solving techniques.
- Must be articulate and display a professional appearance
- Good communication skills and the ability to express ideas and concepts with confidence both verbally and in writing.
- Good working knowledge of Microsoft Office applications/databases including Access and Microsoft Project.
- Must be an experienced user of AutoCAD and statistical software such as SAS or MiniTab. Experience with simulation and optimization software products such as Arena, AutoMOD, and /or CPLEX will be beneficial.

This job ad perfectly describes an industrial engineer, by job title, by job responsibilities, and by qualifications. After gaining some work experience, you will be qualified to apply for jobs like this one.

Other companies hire industrial engineers, but under different labels, such as:

- Manufacturing engineer
- Quality engineer
- Reliability engineer
- Production engineer

This job, with GE, is not labeled as an Industrial Engineer, but asks for someone with an Industrial Engineering degree:

Global Supply Chain Planning Leader, with GE Healthcare, in Waukesha, WI.

A key position in the GE Healthcare Global Parts Asset Management team. Responsibilities include service parts supply chain planning with goals centered including inventory optimization and parts availability for $300M service inventory in 84 warehouses globally. Responsible for lean and efficient planning through strategic improvements in forecasting, procurement, and deployment. Must have strong problem solving and matrix management skills to lead and coordinate with regional planning leaders in other poles. Specific responsibilities include:

- Ensure effective service parts planning through state of the art planning system
- Lead projects delivering increased fill rates, optimized inventory, and enhanced planner productivity
- Drive solutions for supply chain planning issues by working cross-functionally throughout the organization
- Achieve global GPRS Parts Delivery and Inventory targets through optimized planning solutions
- Ownership of key planning metrics

Qualifications

- BS in Industrial Engineering, Operations Research or related field
- 3 to 5 years experience in Operations/Supply Chain Management
- Ability to interact with senior levels of management

- Global mindset, ability to work with global teams
- Strong quantitative and analytical skills
- Demonstrated cross-functional leadership skills
- Excellent communication skills

Desired

- MBA/MS
- Six Sigma Black Belt Certified
- Experience with Xelus planning tool
- Experience with Oracle order management

Flow International Corporation advertised on Monster.com for a Supplier Quality Engineer:

> The Supplier Quality Engineer will develop and maintain a supplier quality system to support the principles of an Advanced Lean Manufacturing system. This position will have an emphasis on external supply chain components that support internal manufacturing processes, including supplier performance, development, and monitoring. Responsibilities include establishing and managing teams for the implementation of the Advanced Lean Manufacturing system; developing the Supplier Quality program in support of Advanced Lean Manufacturing system; maintaining Quality system components for the Quality department that meets ISO 9001 requirements; ensuring that proper communication occurs within teams and among all associates, suppliers, and customers who are affected by each process; establishing key metrics and ensuring that all data preparation, collection and reporting of project progress occurs; establishing and managing schedules for project implementation; accomplish projects on time, on budget, on target (achieve expected results), and properly communicate throughout Flow.
>
> The ideal candidate will have a Bachelor degree in Engineering or related area with a minimum of (3) three years manufacturing and supervisory experience; extensive knowledge of ISO9001 supplier quality and components of the system; highly developed level of interpersonal skills to work effectively with others, solicit input, motivate associates, and elicit work output; ability to work independently on projects and with external suppliers; excellent verbal and written communication skills; ability for innovative/creative thinking; intermediate level experience with Windows, Word, Excel and Access and the ability to quickly develop a comprehensive knowledge of FLOW products. Previous project management experience a plus.

This job is not called Industrial Engineer and does not mention the words Industrial Engineering, but the description matches the knowledge base of the industrial engineer (lean manufacturing, supply chain management, and quality). After gaining some work experience, you will be qualified to apply for jobs like this one -- and you should apply for jobs like this even if the job isn't labeled as an industrial engineering job.

Unfortunately, other companies and even some industries just don’t know what IEs can do. The chemical industry tends to hire chemical engineers to do everything. For example, this job ad, posted on Monster.com by Air Products, asks for a Production Engineer, describes industrial engineering responsibilities, but requires a degree in Chemical Engineering

Air Products and Chemicals, Inc. (NYSE:APD), a Fortune 500 manufacturer of industrial gases and chemicals, has an immediate opening for an experienced Production Engineer at its facility in Dallas, TX.

The Production Engineer is responsible to:

- Participate in the implementation of comprehensive Process Control Systems including SPC/SQC program across multiple facilities.
- Lead and/or participate in activities associated with root cause investigation of out of control situations resulting from SPC/SQC systems.
- Work with suppliers as necessary to drive improvement efforts throughout the Value Chain.
- Lead Continuous Improvement events.
- Ensure best practice identification and transfer among various manufacturing facilities.

Qualifications:

- Bachelors degree in Chemical Engineering
- 3-5 years of Production or Quality experience in the chemical, electronics, or related industries
- Strong leadership and communication skills, ability to work within a team environment
- Must have the ability to work effectively with engineering, lab personnel, line personnel, and management
- Working knowledge of statistical techniques (SPC, SQC, DOE)
- Root Cause Investigation experience
- Working knowledge of the ISO 9001:2000 Standard
- Continuous improvement techniques a plus

While a chemical engineer might learn about SPC (Statistical Process Control), SQC (Statistical Quality Control), DOE (Design of Experiments), Root Cause Investigation, and ISO on the job, these topics would not have been covered in the education of that engineer. An Industrial Engineer would have learned about these as part of their education; I believe the company should be advertising for an Industrial Engineer. Should you apply for a job like this? I doubt it, since the job explicitly asks for a Bachelors degree in Chemical Engineering.

I believe a job ad like this one reflects the belief by some companies that the people who know the core function of the company (for example, chemistry at a chemical company) also know everything else about how to run the company. The industrial engineer would not know as much about the chemical processes as a chemical engineer, but would be much better prepared to take on the job described above.

8.2 Education and lifelong learning

As I mentioned in Chapter 2, many students have read and have recommended very strongly *The Seven Habits of Highly Effective People*, by Stephen Covey. Those seven habits are:

1. Be proactive.
2. Begin with the end in mind.
3. Put first things first.

4. Think win/win.
5. Seek first to understand, then to be understood.
6. Synergize.
7. Sharpen the saw.

"Sharpen the saw" reminds you to continually refresh and add to your knowledge and skills."

To practice as a physician in the United States, a person must earn an undergraduate degree, earn a graduate medical degree, pass the United States Medical Licensing Examination, and be approved by the state licensing board where the physician will practice. In most states and for most specialties, physicians are required to complete a minimum number of credits in continuing medical education each year to maintain a license. To practice as an attorney in the United States, a person must earn an undergraduate degree, earn a graduate law degree, pass a bar exam, and be licensed by the jurisdiction in which the lawyer will practice. In most states, attorneys are required to complete a minimum number of credits in continuing legal education each year to maintain a license.

Engineering, like medicine and the law, is considered a profession, but to practice as an engineer in the United States a person needs only to earn an undergraduate degree and need not be licensed. However, to be a principal in an engineering firm (for example, if you want to open your own firm as an engineer) or to approve engineering plans and drawings, you must be a licensed professional engineer (PE). Among all the types of engineering, licensure is most important for civil engineers, and probably least important for industrial engineers. As with physicians and attorneys, becoming licensed requires passing exams and being licensed by a state. Thirty states require continuing engineering education to remain licensed; Colorado does not. If you become a licensed PE in one state, most other states will have a process by which you can also be licensed in that state.

In Colorado, the Board of Licensure for Professional Engineers and Land Surveyors controls the licensure of engineers. In most states (including Colorado) the steps to becoming a licensed Professional Engineer are:

1. While a senior in an ABET accredited engineering program, pass the Fundamentals of Engineering (FE) exam. You are then an Engineer in Training (EIT).
2. Graduate from an ABET accredited engineering program.
3. Have 8 years of "progressive engineering experience of which education is a part."
4. Pass the Principles and Practice exam.

The FE and PE exams are administered by the National Council of Examiners for Engineering and Surveying (NCEES).

> The FE is a computer-based exam that is administered year-round in testing windows at NCEES-approved Pearson VUE test centers.
>
> The FE contains 110 multiple-choice questions. The exam appointment time is 6 hours long, which includes a nondisclosure agreement, tutorial (8 minutes), the exam (5 hours and 20 minutes), and a scheduled break (25 minutes).

The Industrial Engineering exam covers the following topics:

1. Mathematics 6–9 questions
   - A. Analytic geometry
   - B. Calculus
   - C. Matrix operations
   - D. Vector analysis
   - E. Linear algebra
2. Engineering Sciences 5–8
   - A. Work, energy, and power
   - B. Material properties and selection
   - C. Charge, energy, current, voltage, and power
3. Ethics and Professional Practice 5–8
   - A. Codes of ethics and licensure
   - B. Agreements and contracts
   - C. Professional, ethical, and legal responsibility
   - D. Public protection and regulatory issues
4. Engineering Economics 10–15
   - A. Discounted cash flows (PW, EAC, FW, IRR, amortization)
   - B. Types and breakdown of costs (e.g., fixed, variable, direct and indirect labor)
   - C. Cost analyses (e.g., benefit-cost, breakeven, minimum cost, overhead)
   - D. Accounting (financial statements and overhead cost allocation)
   - E. Cost estimation
   - F. Depreciation and taxes
   - G. Capital budgeting
5. Probability and Statistics 10–15
   - A. Combinatorics (e.g., combinations, permutations)
   - B. Probability distributions (e.g., normal, binomial, empirical)
   - C. Conditional probabilities
   - D. Sampling distributions, sample sizes, and statistics (e.g., central tendency, dispersion)
   - E. Estimation (e.g., point, confidence intervals)
   - F. Hypothesis testing
   - G. Regression (linear, multiple)
   - H. System reliability (e.g., single components, parallel and series systems)
   - I. Design of experiments (e.g., ANOVA, factorial designs)
6. Modeling and Computations 8–12
   - A. Algorithm and logic development (e.g., flow charts, pseudocode)
   - B. Databases (e.g., types, information content, relational)
   - C. Decision theory (e.g., uncertainty, risk, utility, decision trees)
   - D. Optimization modeling (e.g., decision variables, objective functions, and constraints)
   - E. Linear programming (e.g., formulation, primal, dual, graphical solutions)
   - F. Mathematical programming (e.g., network, integer, dynamic, transportation, assignment)
   - G. Stochastic models (e.g., queuing, Markov, reliability)
   - H. Simulation

7. Industrial Management 8–12
   - A. Principles (e.g., planning, organizing, motivational theory)
   - B. Tools of management (e.g., MBO, reengineering, organizational structure)
   - C. Project management (e.g., scheduling, PERT, CPM)
   - D. Productivity measures

8. Manufacturing, Production, and Service Systems 8–12
   - A. Manufacturing processes
   - B. Manufacturing systems (e.g., cellular, group technology, flexible)
   - C. Process design (e.g., resources, equipment selection, line balancing)
   - D. Inventory analysis (e.g., EOQ, safety stock)
   - E. Forecasting
   - F. Scheduling (e.g., sequencing, cycle time, material control)
   - G. Aggregate planning
   - H. Production planning (e.g., JIT, MRP, ERP)
   - I. Lean enterprises
   - J. Automation concepts (e.g., robotics, CIM)
   - K. Sustainable manufacturing (e.g., energy efficiency, waste reduction)
   - L. Value engineering

9. Facilities and Logistics 8–12
   - A. Flow measurements and analysis (e.g., from/to charts, flow planning)
   - B. Layouts (e.g., types, distance metrics, planning, evaluation)
   - C. Location analysis (e.g., single- and multiple-facility location, warehouses)
   - D. Process capacity analysis (e.g., number of machines and people, trade-offs)
   - E. Material handling capacity analysis
   - F. Supply chain management and design

10. Human Factors, Ergonomics, and Safety 8–12
   - A. Hazard identification and risk assessment
   - B. Environmental stress assessment (e.g., noise, vibrations, heat)
   - C. Industrial hygiene
   - D. Design for usability (e.g., tasks, tools, displays, controls, user interfaces)
   - E. Anthropometry
   - F. Biomechanics
   - G. Cumulative trauma disorders (e.g., low back injuries, carpal tunnel syndrome)
   - H. Systems safety
   - I. Cognitive engineering (e.g., information processing, situation awareness, human error, mental models)

11. Work Design 8–12
   - A. Methods analysis (e.g., charting, workstation design, motion economy)
   - B. Time study (e.g., time standards, allowances)
   - C. Predetermined time standard systems (e.g., MOST, MTM)
   - D. Work sampling
   - E. Learning curves

12. Quality 8–12
   - A. Six sigma
   - B. Management and planning tools (e.g., fishbone, Pareto, QFD, TQM)
   - C. Control charts

D. Process capability and specifications
E. Sampling plans
F. Design of experiments for quality improvement
G. Reliability engineering

13. Systems Engineering 8–12
A. Requirements analysis
B. System design
C. Human systems integration
D. Functional analysis and allocation
E. Configuration management
F. Risk management
G. Verification and assurance
H. System life-cycle engineering

The exam is hard because a great deal of material is covered and you have a limited time to answer a lot of questions. If you can answer more than half the questions correctly, you have a good chance of passing, so use your time wisely to focus first on the questions you *know* you can answer and then on the ones that you *think* you can answer; if you have extra time, then try the questions you *don't think* you can answer. The exam is closed book, but you are allowed to use the Supplied Reference Handbook. You should become familiar with this Handbook before the exam because you may be able to answer quite a few questions by knowing where to find the necessary formulas in the Handbook. In fact, the Handbook is a good summary for you to use while you take many engineering courses. A searchable online version of the Handbook is available while you take the test. You are allowed to bring into the room and use only a calculator from a limited list of calculators.

Some of our graduates have obtained jobs because they were able to list "Engineer in Training" on their resumes. Many employers respect the accomplishment represented by that label and want to hire people with the knowledge, drive, and concentration required to pass the FE.

The Principles and Practice Exam in Industrial Engineering is an all day exam, with two 4-hour sessions. The test is open book and the examinee is responsible for bringing any material that will be needed. There are 40 multiple choice sections in each half of the exam.

Joining and participating in professional organizations can help you stay current in industrial engineering. You can join these organizations as a student at a much reduced rate. For IEs, the following organizations are helpful:

- The Institute of Industrial Engineers (IIE). The dues are $37 for a student, $77 for your first year after graduation, and then $154 per year. You will receive the monthly magazine Industrial Engineer.
- The Society of Manufacturing Engineers (SME). Student membership is $20 per year and includes the monthly magazine Manufacturing Engineering. Professional membership is $138 per year.

- The American Society for Quality (ASQ). Student membership is $29 per year and includes online access to the monthly magazine Quality Progress. Full membership is $159.
- The National Society of Professional Engineers (NSPE). The free student membership is available to any full-time student in an ABET accredited program and includes eligibility to apply for scholarships. Due are $220 per year.

While the organizations listed above are open and helpful to students, our students and graduates often join and participate in the following organizations, which are open to all students and are *very* oriented to students:

- The Society of Mexican American Engineers and Scientists (MAES) "was founded in 1974 to increase the number of Mexican Americans and other Hispanics in the technical and scientific fields."
- The Society of Women Engineers (SWE) seeks to "Stimulate women to achieve full potential in careers as engineers and leaders, expand the image of the engineering profession as a positive force in improving the quality of life, [and] demonstrate the value of diversity." You receive the SWE Magazine.
- The National Society of Black Engineers (NSBE) was founded in 1975 "to increase the number of culturally responsible Black engineers who excel academically, succeed professionally and positively impact the community." You receive the NSBE Magazine.

Each of the organizations in these two lists has a useful web site, publishes a magazine or other publications, holds an annual conference, and has groups, based on interest or geography, where you can interact with other members.

8.3 Ethics

> Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties. (IIE code of ethics)
>
> Enslave yourself to the chart and compass – gain the freedom of the seas. Old sailor's proverb Source

On April 20, 1914, seventeen people including 10 children all under the age of 10 died in a fire in Ludlow, Colorado. They had been living in a tent city near a coal mining camp owned by Colorado Fuel & Iron (CF&I). Workers at the mines had been on strike since the previous September over low wages and poor working conditions and, when they were evicted from company housing, had moved with their families to land leased by the union. The strike was the culmination of two decades of effort to unionize Colorado miners; the UMWA (United Mine Workers of America) was determined that this strike would lead to recognition in Colorado and the mine owners were equally set against any union.

CF&I was not obeying state laws that required that miners not be paid in scrip (paper good only for purchases at the company owned store), that representatives of the workers could monitor the weighing process that determined their pay, and that miners be paid for "dead work" (work, such as installing roof braces, that did not directly produce coal).

The Colorado National Guard and private detectives hired by CF&I had been used by the company to attempt to break the strike, including the use of threats, harassment, and violence. The striking miners also engaged in violence against strike breakers.

On April 20, a gun battle erupted between the company men and workers in the tent city. "The question of who discharged the first bullet is now unanswerable" (McGovern and Guttridge, page 215), nor is it known how the fire started, but the National Guard's investigation concluded that

> men and soldiers swarmed into the colony and deliberately assisted the conflagration by spreading the fire from tent to tent ... . Beyond a doubt it was seen to, intentionally, that the fire should destroy the whole of the colony. (as quoted in McGovern and Guttridge, page 224).

Women and children hiding in a pit underneath a tent suffocated and died. (pages 235-236) The strike and the deaths were major national news. The union called the incident the "Ludlow Massacre" and used it as a rallying point to push for better working conditions. In 1989, the United Mine Workers of America (UMWA) erected a monument at the site and excavations are uncovering more details about the people who lived there.

The point of this story is that the conditions of work have been the subject of conflict between employers and workers for a long time; both sides have shown themselves to be willing to mistreat human beings, lie, kill, and die over these issues. The story of the Ludlow Massacre is very relevant to IEs because we design the work place and we are often responsible for the conditions under which people work.

The simple positions of employers and workers are clear: workers demand improvements in safety, pay, work hours, and other work conditions and some employers resist. The reality is, of course, much more complicated than that simplistic summary. The trend is clear: working conditions in this country have improved tremendously through the efforts of employers, workers, government, unions, and private organizations. But as I write these sentences in the first half of 2006, 31 coal miners have already died in accidents in the United States this year.

You are not, as an IE, going to face the ethical dilemma of whether to carry out an order to set fire to a tent city where adults and children live. You will, however, face other ethical dilemmas during your career and you should prepare yourself by considering:

1. the types of dilemmas you might face,
2. guidelines that others have developed to help engineers decide what is right and what is wrong in ethical dilemmas, and
3. what choices you will make and how you will behave if you face an ethical dilemma.

Some engineering disasters have received a great deal of attention and have lessons for engineers. While most of the following disasters relate better to civil and mechanical engineering, they hold lessons for IEs. The source is given for each summary.

- On November 7, 1940, a bridge across the Tacoma Narrows in Puget Sound collapsed. It had only been open to traffic since July of that year. Because the bridge, nicknamed Galloping Gertie, had been observed to twist in the wind even as construction was being completed, attempts had been made to stabilize it with additional tie-down wires. Plans for wind deflectors came too late. Only one life was lost in the collapse, a paralyzed black spaniel named Tubby, who bit the finger of an engineering professor attempting to rescue the dog from the car abandoned by its owner. The flexibility of the bridge design was innovative and its collapse caused engineers to rediscover forgotten knowledge about the role of wind in causing vertical movement of bridges, not just lateral deflection. A new bridge completed in 1950 still stands. Another, parallel bridge was completed in 2007 to reduce congestion.

- Early in the morning of March 28, 1979, a partial meltdown occurred in Unit 2 at the Three Mile Island nuclear electric generating plant near Harrisburg Pennsylvania. The unit had first generated electricity on December 31, 1978. The Nuclear Regulatory Commission's fact sheet on the incident states: "The accident was caused by a combination of personnel error, design deficiencies, and component failures." However, the instruments available to those monitoring the plant did not indicate directly the level of coolant in the core, which had gotten dangerously low. "Instead, the operators judged the level of water in the core by the level in the pressurizer, and since it was high, they assumed that the core was properly covered with coolant." No one was injured or died and "comprehensive investigations and assessments by several well-respected organizations have concluded that in spite of serious damage to the reactor, most of the radiation was contained and that the actual release had negligible effects on the physical health of individuals or the environment." (NRC fact sheet)
- On July 17, 1981, in the high-rise lobby of the one-year-old Hyatt Regency Hotel in Kansas City, Missouri, the connections of steel rods supporting lower skywalks to upper skywalks failed during a public event and 65 tons of skywalk and the people on them fell onto the crowds of people below. A total of 114 people died. An investigation determined that the original design, which suspended each level of skywalk from the ceiling of the lobby, had been changed during construction to a design which suspended the lower skywalks from the upper skywalks. The "result was that [the] fourth-level walkway had to bear weight of [the] second-level walkway suspended below" (page 305, Chiles). In November 1984 two engineers were found guilty of "gross negligence, misconduct and unprofessional conduct in the practice of engineering." Both lost their licenses to practice engineering in the state of Missouri (and later, Texas) but are still practicing engineering in other states. According to the TAMU website, "Official findings of the failure investigation conducted by the National Bureau of Standards, U.S. Department of Commerce [included the statement] 'Even if the now-notorious design shift in the hanger rod details had not been made, the entire design of all three walkways, including the one which did not collapse, was a significant violation of the Kansas City Building Code.'"
- On January 28, 1986, the space shuttle Challenger exploded about a minute after launch, killing all seven astronauts on board. O-rings, designed to seal the solid rocket boosters, failed and allowed hot combustion gases to leak and to ignite the external fuel tanks. "The failure of the O-ring was attributed to several factors, including faulty design of the solid rocket boosters, insufficient low temperature

testing of the O-ring material and the joints that the O-ring sealed, and lack of communication between different levels of NASA management" (Source)

- On February 1, 2003, the Columbia space shuttle burned up during re-entry into the earth's atmosphere, 16 minutes before the shuttle's scheduled landing. Seven astronauts were killed. Just over a minute after its launch on January 16, a piece of foam had broken loose from the Shuttle, striking and damaging the shuttle. The resulting gap allowed superheated air to enter during re-entry and cause damage leading to the shuttle's breakup. The official investigating board concluded: Cultural traits and organizational practices detrimental to safety were allowed to develop, including: reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements); organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of an informal chain of command and decision-making processes that operated outside the organization's rules. (Source)
- On September 11, 2001, two commercial airlines with almost fully loaded fuel tanks were piloted by hijackers into the twin World Trade Towers in New York City. The resulting fire consumed some fireproofing on the main structural steel supports and both Towers collapsed. According to a History.com time line, the North Tower stood for 102 minutes and the South for 56 minutes. Some engineers believe the towers, if designed and built correctly, should not have collapsed. A total of 2,826 lives were lost including those on the planes, those working in the Towers and unable to evacuate in time, and fire fighters and rescue workers who had entered the buildings to assist. (Source)
- In August 2005, New Orleans levees ruptured in the storm surges caused by Hurricane Katrina in August 2005. The disaster was blamed on poor design of the levees, poor construction of the levees, failure to require levees designed to withstand a storm surge of the magnitude that occurred, and long term destruction of wetlands that had, in the past, absorbed the energy of storm surges before they reached the city. The upgraded system is meant to withstand 100-year storm surge events.

These disasters, and others discussed in the book *Inviting Disaster* by James R. Chiles, generally involve the design of physical objects, both large objects designed by civil engineers and smaller objects designed by mechanical engineers. We can learn from these examples, but since IEs are not as involved in such design, they face different types of ethical dilemmas. In particular, IEs are more involved directly with effects on people.
IEs face four types of ethical dilemmas:

1. ethical dilemmas involving business practices,
2. ethical dilemmas involving conflicts between management and workers,
3. ethical dilemmas involving conflict between management and consumers, and
4. ethical dilemmas involving conflict between management and society as a whole.

The first type includes dilemmas that are not particular to engineering, but can be faced by an employee at any organization. Examples include:

- The company must engage in bribery to obtain a contract, perhaps in another country.
- You experience or observe prejudice such as racism and sexism in the work place.
- You observe a coworker behave unethically, perhaps stealing from the company.
- Your friend works for a competitor and you wonder what you are allowed to discuss.
- You wonder what type of email is appropriate using your work email account.
- You try to give credit to a co-worker, but that person refuses to allow you to do so.
- Your boss tells a lie in front of you.
- You believe that a supplier to your company has lied about their product.
- You have made a mistake and you are fearful that if you confess you will be fired.

Most of these situations will almost certainly be covered by policies, usually written policies, in your organization. Your initial employment briefing or documents should indicate to you, for example, what should and should not be included in email. If I have doubts about sending an email I am composing, I picture the email as the headline story in tomorrow's paper. If your organization does not provide you with such guidance, ask.
The second type of ethical dilemmas include conflicts between management and workers.

IEs are often in the middle of examples like these:

- The organization does not have appropriate safety rules or equipment to protect workers.
- The organization chooses a production process that poses a safety risk to workers.
- A worker deliberately slows down for a time study.
- Worker pay is low and turnover is causing problems with quality or safety.
- Your supervisor asks you to ignore a serious problem that you have uncovered and that you want to work on.
- Someone asks you to fire an employee who has complained about a problem that you think merits attention.
- The company seeks to cut pay or cut the workforce even thought you believe profits are high and the pay and size of the workforce are sustainable.
- Pressure to keep to a schedule in implementing a project is causing problems in quality or safety.

These are indeed difficult dilemmas since, in some of the examples, you may be trying to replace management judgment with your own. While not everyone would agree with your judgment that the management's decisions are unethical, you may decide that you don't want to be part of such an organization. The most important piece of advice I can give you about your future career is that you should have a healthy ready reserve of money (say 6 months salary) so you can walk away from a job. As I will discuss below, I don't advise that you make such decisions frequently or lightly, but you will feel much better if you know that your finances would allow you to walk away if the situation just gets unbearable.

Other ethical dilemmas involve a conflict between management and customers: Someone asks to you lie to a customer about the product's capabilities or the manufacturing process used to make it.

- A significant change affecting the quality of the product is made without telling customers.

Finally, some ethical dilemmas involve a conflict between the company and society at large.

- The organization makes a product that is profitable but is bad for people or the environment.
- The organization fails to dispose of industrial waste in a method that is appropriate.

Some of the above dilemmas may represent evidence that your values conflict with the values of your organization. Some of the examples relate to organizational justice. Employees' perception of how fairly the organization treats its employs has been shown to relate to job satisfaction and job performance.

Ethical guidelines

The most important fact to keep in mind when you face an ethical dilemma is that you are not alone.

- People, including engineers, have faced these dilemmas before and there are sources of advice for you. Use your professional guidelines and your professional organizations.
- Other employees in your organization, including other engineers, may share your concerns. Use your colleagues in your organization.
- Friends and family members may have faced similar situations. Use your personal support network.

The IIE Code of Ethics (indeed the code of ethics for every engineering profession) starts with the statement that is quoted at the head of this section: "Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties."

Roger Boisjoly, one of the engineers involved in the Challenger disaster made the following points:

- The data the engineers had on the O-rings didn't cover temperatures as low as what were forecast for the morning of the launch. Mr. Boisjoly's point is that extrapolating beyond the end of the data points is very different from interpolating between data points.
- Mr. Boisjoly's boss's boss said to Mr. Boisjoly's boss "Take off your engineering hat and put on your management hat." While the request is valid, once Mr. Boisjoly put on his management hat, he should not have made an engineering judgment. Mr. Boisjoly's point is that if you, an engineer, increasingly become a manager, you need to rely on your engineers for engineering judgment, not on your own engineering judgment.
- The immediate personal consequences to Mr. Boisjoly's health and his career were awful, but he would take the same actions today.
- "We were initially successful in stopping that launch." A group of colleagues standing together can have an effect.
- The engineers were usually required to prove it was safe to launch; in this case, the requirement was turned around. The engineers had to prove it was not safe to launch.
- Mr. Boisjoly's asks himself: would I allow my family members to use this product?

- He mentioned his mother as an influence.
- Mr. Boisjoly recommends picking your fights. Stay to fight another day.

The source for these points is a 1993 video distributed by Carnegie Mellon Center for the Advancement of Applied Ethics in the series Ethical Issues in Professional Life.

The Code of Ethics requires an engineer to "hold paramount the safety, health, and welfare of the public" but were the astronauts actually "the public"? The answer isn't clear but some observers believe the astronauts should have been involved more in the decision making process. However, teacher Christa McAuliffe certainly did not have the engineering expertise to evaluate the arguments.

Whether you are a licensed Professional Engineer or not, you are obligated by the professional code of ethics. The National Society of Professional Engineers (NSPE) publishes a model code of ethics and the Institute of Industrial Engineers (IIE) has adopted this version. The Code can help you think through ethical situations and the Rules of Practice (see NSPE version) provide more guidance. For example, the Rules of Practice include this statement:

> Engineers shall disclose all known or potential conflicts of interest that could influence or appear to influence their judgment or the quality of their services.

Because all engineers are bound by the Code, it can protect an engineer from pressure and allows engineers to stand together. "A code is a solution to a coordination problem" (Michael Davis, page 2), that is, it helps coordinate the actions of engineers in ethical dilemmas, without the engineers even have to talk with each other. It makes the engineering profession like a union, but a union to serve the public, not themselves (page 3). Thus, one engineer can count on the support of another engineer.

Students in this class have recommended these guidelines for ethical behavior for IEs:

- Don't accept bribes
- Don't be late.
- Don't tell lies
- Just because you can, doesn't mean you should.
- If you notice a problem, speak up.
- Focus on customers.
- As an employer, treat employees fairly, and, as an employee, treat your employer fairly.
- Do your job right the first time.
- Do your job promptly.
- Have money in the bank.
- Build professional trust with co-workers.
- Pick your fights.
- Consider how your action would look on the front page of the paper tomorrow.
- Consider what you would you do if your mother or father were watching.
- Drive out fear.

Goetsch (1999, page 525) suggests 5 guidelines, each phrased here as a question:

- The morning-after test: How would you feel about your decision tomorrow morning?
- The front-page test: How would you feel about seeing your decision on the front page of your hometown newspaper?
- The mirror test: How would you feel when looking yourself in the mirror after this decision?
- The role reversal test: How would you feel if you were the person affected by this decision?
- The common sense test: What do your common sense and your insticts tell you to do?

Harris *et al.* in their book *Engineering Ethics* recommend an approach based on paradigms and line drawing. For example, if faced with a situation that may or may not be bribery, the engineer should consider features that describe bribery (for example, a large gift, received before a decision it is meant to influence) as compared to features that are clearly not bribery (a very small gift, received after a decision). The engineer can decide, for each feature, where the current situation lies on the line between bribery and not bribery. A case with many features near the bribery end of the line is clearly wrong.

At Colorado State University-Pueblo, graduating engineers are invited to be inducted into The Order of the Engineer, at a ceremony using this pledge:

> I am an Engineer, in my profession I take deep pride. To it I owe solemn obligations.
>
> Since the Stone Age, human progress has been spurred by the engineering genius. Engineers have made usable Nature's vast resources of material and energy for Humanity's benefit. Engineers have vitalized and turned to practical use the principles of science and the means of technology. Were it not for this heritage of accumulated experience, my efforts would be feeble.
>
> As an Engineer, I pledge to practice integrity and fair dealing, tolerance and respect, and to uphold devotion to the standards and the dignity of my profession, conscious always that my skill carries with it the obligation to serve humanity by making the best use of Earth's precious wealth.
>
> As an Engineer I shall participate in none but honest enterprises. When needed, my skill and knowledge shall be given without reservation for the public good. In the performance of duty and in fidelity to my profession, I shall give the utmost.

According to their web page,

> The Order is not a membership organization; there are never any meetings to attend or dues to pay. Instead, the Order does foster a unity of purpose and the honoring of one's pledge lifelong.

Those who have been inducted into the Order wear a stainless steel ring on the fifth finger of the writing hand. Inductees are encouraged to wear the ring and to display the signed Obligation certificate as visible reminders of the publicly accepted Obligation as a contract with themselves.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 9
People

> "[M]ost of us -- including a good many people in industrial production itself -- fail to understand that modern production, and especially modern mass production, is not based on raw materials or gadgets but on principles of organization -- organization not of machines but of human beings, i.e., on social organization" (page 31, Peter F. Drucker, The Concept of the Corporation, 1983).

Among all the engineering specialties, industrial engineering focuses the most on people. Because we design and improve production systems involving people and machines, we need to think about what people and machines can and can't do quickly, well, and safely. On some tasks, people are clearly better than machines (for example, helping customers) while on other tasks, machines are clearly better than people (for example, lifting very heavy objects). Many production tasks require a combination of people and machines. The goal is to design a system of people and machines that can do the work with efficiency, quality, and safety.

This chapter is divided into five sections, but, as usual, the areas overlap.

- 9.1 Teamwork
- 9.2 Physical ergonomics
  The physical requirements of the work a person does, for example, lifting heavy objects, can affect efficiency, quality, and safety.
- 9.3 Safety and the work environment
  The physical environment in which the person works, for example, slippery floors or low lighting, can affect efficiency, quality, and safety.
- 9.4 Cognitive ergonomics
  The mental requirements of the work a person does, for example, remembering a complicated procedure, can affect efficiency, quality, and safety.
- 9.5 Work methods and standards
  The methods a person uses to perform a job, such as the order of doing each component of a task, can affect efficiency, quality, and safety.
- 9.6 Motivation
  The attitude of the person doing a job, as affected by the organization and by external influences, can affect efficiency, quality, and safety.

Poor conditions in any of these aspects can have harmful short term or long term effects on people such as:

- fatigue,
- acute injury such as a cut,
- chronic injury such as back pain,
- confusion,
- lack of attentiveness,

- wasted motions,
- poor customer service,
- poor quality of produced goods,
- absenteeism, and
- worker turnover.

Goetsch (page 145) defines ergonomics as "the science of conforming the workplace and all of its elements to the worker." Sections 9.1, 9.2, and 9.3 include topics in ergonomics or human factors. Some IE graduates choose to specialize in this area, often including graduate work.

9.1 Teamwork

Working in teams

All engineering work is done in teams because every project needs input and help from other people. You may be in charge of some projects and, at the same time, you may be supporting projects headed by others. You must learn to be a good leader and a good follower.

Team Charter and Team Guidelines

A Team Charter usually includes:

- Team name.
- A statement of the team's mission,
- A statement of the work the team will do,
- A list of members and contact information,
- The name of the team sponsor - who is the person in authority to whom the team will report?
- The resources the team will use, and
- The period during which the team will exist.

Team Guidelines list the rules for the operation of the team. Such rules might include:

- Listen. Seek clarification.
- No put-downs.
- Disagree with respect.
- Be on time.
- Be prepared.

The Team Charter and Team Guidelines should be short.
Read each of these pages; each has guidance on team charters and team guidelines:

- Team Charter by Kenneth Crow, DRM Associates.
- Team Groundrules by Kenneth Crow, DRM Associates.

Teamwork skills

Companies who hire engineers expect the people to hire to have the technical skills the company needs, but companies also want engineers who can work well with others. To function well on a team, you should be able to:

- Do the assigned work before the team meeting.
- Be physically and mentally present for team meetings.
- Stay on task; don't digress.
- Participate. Volunteer your knowledge and ideas.

- Give valid input on the topic or task.
- Recognize your own strengths and weaknesses; use your strengths, compensate for and try to reduce your weaknesses.
- Recognize and build on the strengths of your teammates.
- Identify shortcomings and help your team members strengthen their weak points.
- Recognize and adapt to cultural differences among team members and among teams.
- Accept and provide positive feedback.
- Accept and provide negative feedback in a constructive way.
- Communicate well, including listening well.
- Listen and check that you understand. Seek clarification.
- Don't dominate the discussion.
- Be quiet when appropriate, and speak when appropriate.
- Help team members become a team.
- Help your team develop team norms.
- Deal with problems in your team.
- Resolve conflicts within your team and between your team and others.
- Mediate a dispute.
- Avoid group think.
- Change your mind when appropriate and hold firm when appropriate.
- Follow the rules set forth in the team charter.
- Be respectful and professional to members of your team and to others.

Robitaille (page 31) says:
"The four most important elements of productive team building are:

- Respect
- Objectivity
- Creativity
- Open-mindedness."

She stresses the importance of language for establishing each of these."

How we say things is often as important as what we are saying.

Avoid groupthink
"Groupthink" (a term coined by Irving Janis in 1971) refers to the behavior of a group when individuals in the group overemphasize group cohesion and avoid raising information or opinions that differ from the group's. Read this brief description, including Remedies for Groupthink.

Being in a group is never an excuse for not doing your individual work. In your employment as an engineer, you will do a lot of work in groups, but you will also do a lot of work at your desk, thinking and working hard.

9.2 Physical ergonomics
People who perform repetitive hand tasks can experience pain, tingling, and numbness called Carpal Tunnel Syndrome (CTS). According to NIOSH

> Research conducted by the National Institute for Occupational Safety and Health (NIOSH) indicates that job tasks involving highly repetitive manual acts, or necessitating wrist bending or other stressful wrist postures, are connected with incidents of CTS or related problems. The use of vibrating tools also may contribute to CTS. Moreover, it is apparent that this hazard is not confined to a single industry or job but occurs in many occupations especially those in the manufacturing sector. Indeed, jobs involving cutting, small parts assembly, finishing, sewing, and cleaning seem predominantly associated with the syndrome. The factor common in these jobs is the repetitive use of small hand tools.

Methods to prevent CTS include designing tools so that the wrist is held correctly, designing the work layout so wrists are not stressed, scheduling work breaks for workers in jobs with potential hazard, and rotating such work among several workers. The Mayo Clinic provides advice to workers such as:

> Reduce your force and relax your grip. Most people use more force than needed to perform many tasks involving the hands. If your work involves a cash register, for instance, hit the keys softly. For prolonged handwriting, use a big pen with an oversized, soft grip adapter and free-flowing ink. This way you won't have to grip the pen tightly or press as hard on the paper.

CTS is an example of a Repetitive Stress Injury (RSI), meaning an injury not caused by one incident, but by a repetitive activity. Often the cause of such injuries is difficult to determine since workers may be involved in different types of activities. The even broader class of such injuries is called musculoskeletal disorders (MSDs). Even if conditions do not threaten workers with short-term or long term injury, conditions can reduce efficiency and quality through fatigue.

IEs must be aware of and prevent situations where work methods can cause harm to workers. Besides being the right thing to do, such prevention can save the organization money and can reduce the liability exposure of the organization. The Centers for Disease Control and Prevention lists many resources for various types of MSDs in various industries.

Researchers in physical ergonomics often rely on physics to understand the effects of work on human bodies. Specialists in this area often have to know anatomy and physiology. Lab studies of people doing a task may monitor the person's physiological condition (for example, heart rate and oxygen uptake) in order to determine the exact effects of different work on humans.

The IE may redesign jobs to reduce the need to stand, provide better chairs for workers, provide better hand tools for workers, and reduce the need for workers to lift heavy objects. Ergonomics stresses adapting the workplace to the worker. Such adaptions must be individual. Work stations that allow adjustments can help; for example, tables and chairs that can be raised or lowered, or a work station that accommodates left-handed and right-handed workers.

OSHA provides short case studies describing how job redesign has reduced ergonomic issues. Advanced Filtration Systems Inc. redesigned an inspection process to reduce the number of cases of CTS.

9.3 Safety and work environment

The workplace can be a dangerous location. According to the Bureau of Labor Statistics 4,585 workers died from work related causes in the US in 20013, as shown in the following table.

Event or exposure	Number of fatalities
Transportation incidents	1,865
Contact with objects and equipment	721
Falls, slips, trips	724
Violence and other injuries by persons or animals	773
Exposure to harmful substances or environments	335
Fires and explosions	149

The following table shows the occurrence in 2013 of nonfatal injuries involving days away from work:

Injury or illness	Number of cases
Sprains, strains, tears	426,950
Soreness, pain	202,620
Cuts, lacerations, punctures	98,680
Bruises, contusions	94,960
Multiple traumatic injuries	32,610
Heat (thermal) burns	15,890
Carpal tunnel syndrome	7,630
Amputations	6,480

The workplace can be a dangerous location, but the safety hazards can be reduced. The IE designs the workplace so that danger is reduced from the use of tools, machines, and materials in the production process.

For example, operation of a punch press often requires that two buttons, away from the punch location itself, be pressed simultaneously with the worker's left and right hands. If the worker's hands are pressing those buttons, the hands cannot be under the press, so cannot be injured.

Various tools that we have discussed already help an IE think systematically about what can go wrong: FMEA and fault tree analysis help the IE trace through how errors or faults can lead to accidents. Any accident in an organization should be carefully analyzed to determine the cause. The system should be changed to eliminate or reduce the change of that type of accident occurring.

An IE's instinct should be to design the system so that safety, efficiency, and quality occur naturally. If an injury occurs, an IE's first thought should be to blame the system. For example, lockout and tagout procedures are meant to protect maintenance and repair workers from the accidental start up of equipment. However, workers must obey such safety rules. The IE may be in charge of safety training programs for workers, which should include the reasons for certain rules. Many organizations have a one strike policy; any violation of a safety rule leads to immediate dismissal. While such a policy may seem extreme, it conveys clearly to workers the organization's dedication to safety.
Apart from the safety of the worker, the worker also exists in an environment and the IE must consider effects on the comfort of the worker of:

- vibration,
- heat and cold,
- humidity,
- noise,
- air quality, and
- lighting.

For example, this article describes the possible effects of prolonged exposure to vibration.

The web site of the Occupational Health and Safety Administration (OSHA) has information about different types of issues in safety. For example, this OSHA page points to resources relevant to hazards from cotton dust. The IE also has to know about the particular issues in the industry for which he or she works. For example, this OSHA page discusses safety and health issues for hospital workers.

Goetsch (1999) states that the field of occupational safety has expanded from concern with injury-causing conditions to include concern with disease-causing conditions. The safety manager is now the safety and health manager. For example, Goetsch mentions worker stress as a health concern, but also a potential safety concern if the stressed worker is less safety conscious (page 1). Similarly, NIOSH points to shift work and long work hours as safety and health potential issues:

> According to 2001 data from the Bureau of Labor Statistics, almost 15 million Americans work evening shift, night shift, rotating shifts, or other employer arranged irregular schedules. The International Labour Office in 2003 reports that working hours in the United States exceed Japan and most of western Europe. Both shift work and long work hours have been associated with health and safety risks.

Some companies have introduced programs to promote good health, for example, smoking cessation programs, safe driving programs, and exercise programs, at least partly to reduce health insurance premiums the company pays for workers. Some companies have gone as far as forbidding their workers to smoke off the job, but such programs have been controversial.

9.4 Cognitive engineering

At least some of the events at Three Mile Island (recall our discussion in Chapter 8) can be attributed to difficulties workers had in figuring out what was going on in the reactor. One problem is that the workers' normal job largely consists of monitoring a smoothly running reactor (yes, picture Homer Simpson). Such a job is boring and can quickly lead to lack of vigilance. When a problem occurs, the person is "out of the loop" because the computer controls have been running the plant. The workers must spend time figuring out what has happened. A second problem at Three Mile Island was that the design of the control room at that reactor did not convey crucial information to the workers, particularly the level of coolant in the reactor; they had to infer that level from other indicators.

Cognitive engineering builds on knowledge from psychology about human abilities in memory, perception, reasoning, and attention to design tasks that a human can do with efficiency, quality, and safety. Again, the focus is on adapting the workplace to the human. A human who must remember certain tasks in a specific order can be given a checklist. A human who has to perceive a change in an array of displays can be aided by a computer that detects the changes and alerts the human (for example, cockpit alarms for loss of altitude). A human who has to do a complicated set of reasoning can be supported by a computer system (for example, an immunohematologist who must interpret blood tests to identify antibodies in a patient's blood). A person who must pay attention to several sources of information can share the task with computers and with other humans.
A balance must be achieved between understimulating the human, leading to boredom, and overstimulating the human, leading to stress. Both can lead to losses in efficiency, quality, and safety. Generally, the human performs better when the worker clearly has control of the environment, including work pace. Shifting control to the computer can lead to boredom, stress, inattentiveness, and overreliance on the computer.

The design of controls, including computer hardware and software, to support human tasks requires careful analysis of usability, which is affected by screen layout, task sequence, and many other factors. NASA's Human Systems Integration Division

> advances human-centered design and operations of complex aerospace systems through analysis, experimentation, and modeling of human performance and human-automation interaction to make dramatic improvements in safety, efficiency, and mission success.

This FAA analysis of an airliner accident in 1993, in which 2 people were killed, shows the interplay of the design of the controls, the training of the pilot, and the behavior of passengers.

> Flight 583 was level at 33,000 feet when the leading edge slats deployed inadvertently. The autopilot disconnected and the captain was manually controlling the airplane when it progressed through several violent pitch oscillations and lost 5,000 feet. ...
> The National Transportation Safety Board determine that the probable cause of this accident was the inadequate design of the flap/slat actuation handle by the Douglas Aircraft Company that allowed the handle to be easily and inadvertently dislodged from the up/ret [retracted] position, thereby causing extension of the leading edge slats during cruise flight. The captain's attempt to recover from the slat extension,

> given the reduced longitudinal stability and the associated light control force characteristics of the MD-11 in cruise flight, led to several violent pitch oscillations. Contributing to the violence of the pitch oscillations was the lack of specific MD-11 pilot training in recovery from high altitude upsets, and the influence of the stall warning system on the captain's control responses. Contributing to the severity of the injuries was the lack of seat restraint usage by the occupants.

The root cause of that accident was identified as poor design of a handle.

Learning

Learning a task involves cognitive and physical improvement. Increased familiarly with the task and improved dexterity lead to a reduction in the time to do a job. Various learning curve equations are used to describe empirical relationships about what improvement can be expected from learning.

The Wright learning curve is described by a percent L such that a doubling of the cumulative number of units produced leads to a (100-L)% reduction in the cumulative average production time. For example, with an 80% Wright curve, if the first unit takes 100 minutes, then the first 2 units will take an average of 80 minutes, the first 4 units will take an average of 64 minutes, and so forth. It can be shown that the Wright curve must have an exponential equation, where a and b are constants.

$Y = aX^b$

Y = the cumulative average time (or cost) per unit.

The learning curve can be used to estimate production times for new parts, based on the planned production quantity.

9.5 Work methods and work standards

I have stressed that an organization is a system; an IE who looks at a part of the system must be sure to consider how that part fits into the overall system. The analysis and improvement of a work station and the methods used by an individual worker requires the IE to focus on a small part of the production system, but such analysis and improvement can provide tremendous gains in the efficiency, safety, and quality of the organization's output.

In this type of analysis, the IE looks at exactly how each individual worker handles work and performs the assigned tasks, including the worker's body movements and movements of each hand. The goal is to improve efficiency, quality, and safety by determining the best way to do the task.

When the IE focuses on one or a few work stations and on one or a few individuals, very sensitive issues arise. Some plants have a tradition of sending a new IE out to the shop floor with a stop watch. Many workers will see such an approach as a threat and the new IE may be faced with a near revolt. Also, experienced workers may not take kindly to a new college graduate's well meaning suggestions for improvement.

Deming stressed "measure, measure, measure" but he also stressed that measurement should be used to improve the system, not to evaluate an individual's performance. The IE can work with a team of production workers to measure differences among workers with the goal of identifying and spreading best practices. For example, Parkview Hospital measures the time that elapses from when a patient in the emergency room is assigned a bed in the hospital to when that patient is actually in the new room; this time is called the "move time." Analysis of the average move time for different nurses showed that two nurses were achieving significantly lower averages. Discussion among the nurses uncovered that the nurses with shorter average move time were anticipating which patients would be moved soon and initiating some of the required process before the start of the move time; they were efficiently overlapping tasks. The result is that the patient is settled into the hospital room more quickly. Allowing nurses to develop better practices and share them with each other can only occur in an atmosphere without competition.

Work sampling can be used to determine existing work methods. Observations are taken at fixed or random intervals. A small device that beeps is often used to prompt the worker or the observer to record the activity being done by the worker at that time. The resulting data can be used to determine the proportion of time being spent in each type of work. As described in this article about mine safety practices, work sampling can be used to determine if workers are following recommended practices. Video taping can also be used.

More sophisticated IE methods can uncover small inefficiencies in repetitive work and small improvements add up. The same type of visualization tools that helped map the entire production system can also be used to map tasks. For example, a worker assembling a lock will use both hands; a chart showing the actions of left and right hands may uncover times when one hand is idle and tasks could be redesigned. Such changes in the work procedure might also require a change in the layout of the work station.

While some latitude can be allowed in how workers do tasks, specified work methods are necessary for training new workers, for ensuring that products and services are of high quality, for enabling the identification of sources of problems when quality issues arise, and for ensuring safety.

IEs are often involved in setting work standards. A work standard is a statement of the how long a worker working at a reasonable pace over a work day should expect to take to complete a well defined job using a specified work method. Work standards are needed for several reasons:

- To support planning. Scheduling, staffing, line balancing, work flow analysis, and simulation models all rely on knowledge of how long different tasks take to perform.
- To estimate costs. Computation of the profit for each product or service requires adding up the time spent by each worker on each task to produce that product or service.
- To evaluate and improve productivity. The example involving the Parkview Hospital nurses show that measurement supports identification of best practices. It also supports the determination of whether changes to methods have led to improvements.
- To set worker pay. Some companies use work standards to devise incentive pay schemes.

Two methods can be used to determine work standards:

- Actual measurement of workers.
- Standard data.

Because the time for even an experienced worker to do the same task will vary from time to time, actual measurement involves measuring several workers several times. Such measurement usually also involves measuring the elements of the task, especially distinguishing portions of the task paced by the human and portions with time determined by a machine. An element should have an easily determined start and finish, should take an amount of time that can be conveniently measured, and should contain movements that make up a unified sequence. Sophisticated hand held devices can be used for such measurement, with data then being downloaded to a PC. For example, UmtPlus and WorkStudy3.0+ allow a laptop or other device to be used to collect data. Over time, the company may build up a database of the standard times for different tasks.

Actual measurement is time consuming, so some organizations use predetermined motion time systems. Again, the work is broken into elements, such as a grasp, movement, or placement. Depending on the details of the grasp (for example, the size of the item), the movement (for example, the distance the item is moved), and the placement (for example, how accurately must the item be placed), the IE can use a database to determine how long the element should take. The times for each element can be added up to determine the "normal time" for a job. A work standard must also include allowances for rest time, personal time, unavoidable delay, and so forth. This web page describes predetermined time systems in more detail and gives an example chart showing movements of left and right hands in a task.

This case study describes how Maynard worked with Cardinal Health Care Systems to determine the time savings that clients of Cardinal could expect from purchasing Cardinal's prepackaged kits of supplies needed for specific surgical procedures. These kits eliminate the need for the hospital staff to gather the supplies.

9.6 Motivation and leadership

> The second great lesson of the war [after mass production] was that it is really not true that the worker is happy and contented if he gets nothing out of his work except the pay check, or that he is not interested in his work and in his product. On the contrary, he yearns for a chance to know and to understand as much as possible about his work, his product, his plant, and his job. Plant management was forced to use its imagination to establish a relationship between the war worker and his product, not out of humanitarian reasons but for the sake of greater efficiency. The result of such attempts was everywhere an increase in efficiency and productivity, as well as in worker morale and satisfaction. (Drucker, page 157).

Achieving the goals of an organization is easier if each member of the organization wants to achieve and tries hard to achieve the goals of the organization. A similar statement can be made about each member of the organization trying hard to achieve efficiency, quality, and safety. The IE who works in a line position (as plant manager, for example) plays a large role in motivating workers. The IE who works in a staff position is less directly responsible for the motivation of workers, but still will need to consider how to motivate workers to do their best. Leadership is linked with motivation; leaders motivate others to strive to do their best.

The starting point for any discussion of motivation in organizations is the 1960 book *The Human Side of Work* by Douglas McGregor, who described two theories of motivation, Theory X and Theory Y. This web page has an excellent summary of the two theories. "Essentially, Theory X assumes that people work only for money and security" while Theory Y assumes that people work for "the higher-level needs of esteem and self-actualization." A typical Theory X approach to motivation is incentive pay, especially piecework rates in which an individual worker's pay is based on that worker's output. Inspection is used to ensure quality. A Theory X leader uses command and control. Deming's 14 points demonstrate a Theory Y approach to leadership. His point 12a states:

> Remove barriers that rob the hourly worker of his right to pride of workmanship

The Theory Y leader makes sure that workers have clear instructions, good tools, and the support they need to do their jobs well.

Theory X and Theory Y are convenient summaries, but no worker and no leader are probably completely described by either theory. Motivation is clearly a difficult subject. Some industrial engineering programs require students to take a course in psychology, at least partly to have better understanding of motivation.

Students in my class have sometimes summarized our discussions on motivation by saying "happy workers are good workers." Obviously, that summary is simplistic, but has some truth. Many organizations have found that treating workers well results in positive impact on profits.

For example, keeping wages low may seem to be an obvious way to keep costs low, but many companies do not realize that turnover caused by low pay or poor treatment of workers is very costly. Godfrey (Quality Digest, March 2004) described the findings of a group of his students who analyzed checkout times at a local grocery store.

> The root cause for long lines became obvious when the data were analyzed. Clerks new to the cash registers took far longer than those with more experience. Throughput could actually improve using fewer registers and clerks. However, the store’s high turnover of clerks meant that most registers were staffed with inexperienced employees. The reason for the high turnover was also easy to discover -- low wages. The math was simple: Increase wages, lower turnover, reduce staff and increase profits. It seem so obvious. But the store manager was unimpressed by the numbers. His supervisors were more concerned with keeping salaries low, so he was, too: improving profitability by raising wages wasn’t important to them.

Susan Heathfield cited the Wall Street Journal for this information:

> Gallup found 19 percent of 1,000 people interviewed "actively disengaged" at work. These workers complain that they don't have the tools they need to do their jobs. They don't know what is expected of them. Their bosses don't listen to them. Based on these interviews and survey data from its consulting practice, Gallup says

> actively disengaged workers cost employers $292 billion to $355 billion a year. Furthermore, Gallup concluded that disengaged workers miss more days of work and are less loyal to employers.

Widely accepted motivational programs may need to be carefully examined. McManus (Sept 2003) gives reasons not to use four traditional approaches to motivation: suggestion systems, employee of the month awards, performance appraisal systems, and sales commissions. Instead, he recommends a "well deployed annual planning process that involves all employees to some degree," regular recognition of "every employee who meets or exceeds performance standards," "personal development plans", and "profit sharing as a compensation approach."

Parkview Hospital in Pueblo was one of the first hospitals in the country to implement ideas from quality, especially Deming's 14 points. Deming's point 12b calls for abolishing the annual or merit review and Parkview has done that, replacing the annual review with the APOP, which stands for Annual Piece of Paper. I think that the crucial discussion point in that document is:

> Discuss barriers to effectiveness of work and with job satisfaction.

I believe that the fundamental facts of motivation are:

- Most people want to contribute to a successful organization.
- People work because they need money, but for most people, if pay levels are perceived as fair, money is not a motivator.
- Most people are motivated to do their best over the long run by internal motivation. External rewards work in the short term, but undermine long term commitment.
- Most people will feel that their contribution is valued, will feel that they are part of a team, and will feel that their hard work will be rewarded only if those statements are repeatedly demonstrated to be actually true.
- There are bad hires.

Motivation is clearly a difficult subject. I think you should, over your career, spend quite a bit of time thinking about your own motivation and the motivation of people who work with you.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 10
Operations research and other mathematical methods

Recall Deming's advice to "Measure, measure, measure." All engineers are fact based decision makers and often the facts we use involve numbers. How should engineers use numbers to make decisions?

- 10.1 Collecting data
- 10.2 Visual display of data
- 10.3 Models in general
- 10.4 Deterministic models
- 10.5 Stochastic models

10.1 Collecting data

While in graduate school, I worked part time for a large medical provider. On one project, I used data showing information on all the patients admitted to a particular hospital over a six month period. I first prepared summaries of the data in order to begin to understand patterns. During that process of getting to know the data, I noticed that the admissions included quite a few infants, just hours old. After puzzling over the high numbers, I mentioned the fact to my boss. He, too, was puzzled. We called the data source and learned that, of course, every new born child was an "admission" in order to enter the child into the hospital database. We didn't bother calling the data source when I discovered that the database included a pregnant male; that record clearly had an error.

That story has three lessons in it:

- Get to know your data.
- Know how the data were collected and coded.
- All data sets have errors.

Data are crucial to fact based decision making. In many organizations, conventional wisdom may not be true, and only data, carefully collected and analyzed, can help uncover truth. In many studies I have done, I have analyzed data already collected by other. Using existing data sets saves time, but has drawbacks. Since the data were collected for a different purpose, some important types of data may not have been collected. Also, as the above example illustrates, you have to understand how the data were collected and coded. For example, data on process times in a manufacturing plant may or may not include set up time.

Data that the IE collects for a particular study may be collected as part of the normal production process (for example, measure the weight of the first 4 bags of coffee produced each hour) or may be part of designed experiment. For example, to determine whether quality problems are due to differences in machine, worker, or supplier of input material, an IE may have each combination of machine, worker, and supplier produce a set number of products.

Because collecting data, either in the production process but especially in a designed experiment, takes time and resources, the IE must think first about how the data will be used. Data on the service time to serve each customer can be used for different purposes if data are also collected on the time of day, the employee who served the customer, and the type of service the customer needed.

10.2 Visual display of data

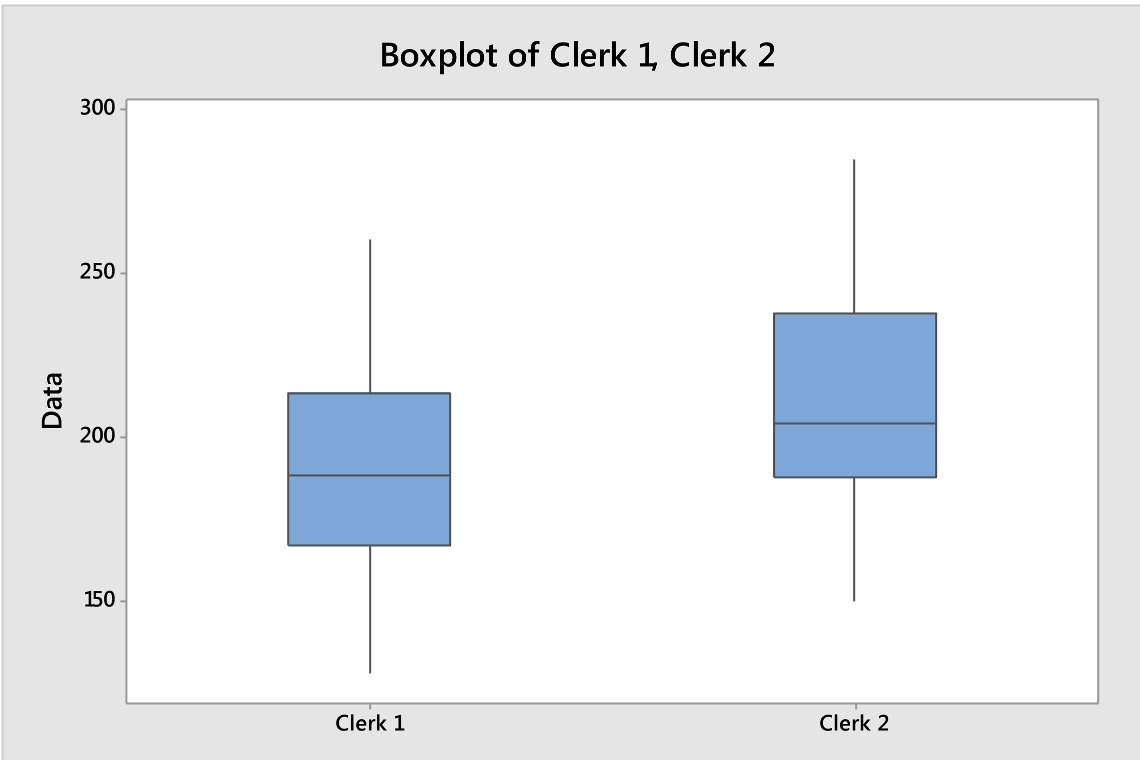
Consider the following example. An IE has looked at data on the elapsed time to serve customers for two clerks and has found that Clerk 1 has an average of 189 seconds, while Clerk 2's average is 211 seconds. Perhaps Clerk 1 is using a better process and Clerk 2 could learn from that process, or perhaps Clerk 2 tends to have customers with more items or more complicated orders. However, before you start thinking about reasons for the difference in averages, you should ask yourself first whether the averages really are different.

The table below shows the checkout times for Clerk 1 and Clerk 2 for the most recent 25 customers that each served. The first feature we might note about the data is that the times vary quite a bit about the averages.

Clerk 1	Clerk 2
163	285
261	184
209	202
235	150
179	204
149	191
170	188
128	211
221	180
179	201
144	260
218	252
164	186
192	223
184	271
188	269
194	224
207	260
172	211
236	202

191	188
161	223
225	193
174	216
188	182

This figure shows a boxplot of the data

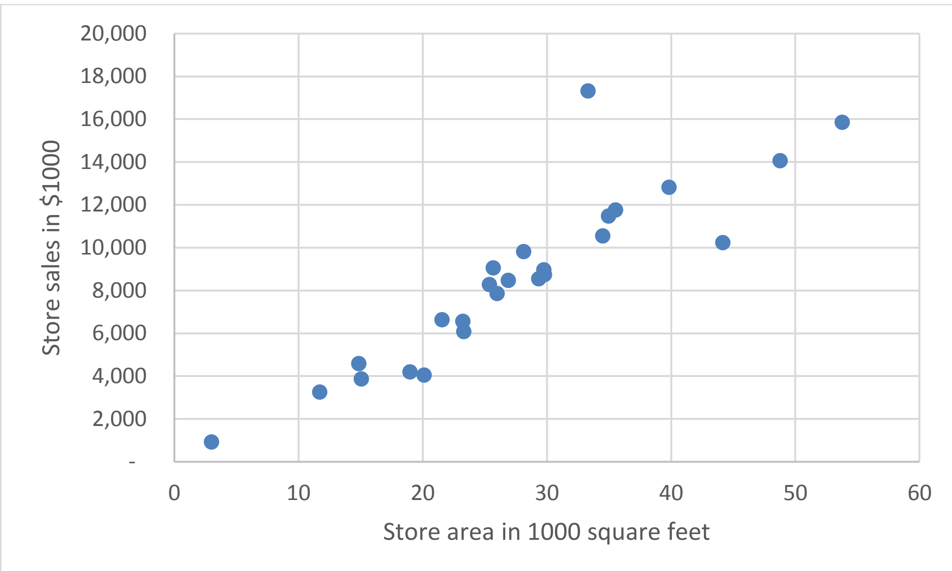


In a boxplot:

- The bottom line of the box is the first quartile, or 25th percentile; 25% of the data points lie below that value and 75% lie above it.
- The middle line of the box is the second quartile, or 50th percentile, also called the median; 50% of the data points lie below that value and 50% lie above it.
- The top line of the box is the third quartile, or 75th percentile, 75% of the data points lie below that value and 75% lie above it.
- Thus, the box covers 50% of the data.
- The top point is the largest value in the data.
- The bottom point is the smallest value in the data.

Now we can see that while the means are different, the variability within each clerk's data really overwhelms that difference. You might still want to talk to each to see whether they have ideas for how the clerks can serve customers quickly and you might still want to see if different features of customers affect the checkout time (and, if so, whether the process can adapt to those features), but you really don't need to focus on the difference in averages between the two clerks.

Statistical analysis can be done to check more analytically whether your conclusion of little difference is valid, but often a well designed display of information can help you reach quick conclusions, especially conclusions about where to focus your attention for improvement of a process. Human beings are good at detecting visual patterns. For example, this graph shows data on square footage of a company's retail stores (in 1000s of square feet) and annual dollar sales in each store. You can quickly detect that there is a generally upward trend, but you can also quickly see that one point doesn't fit that pattern well; there is one store with sales much higher than would be predicted by its square footage. Based on this graph, the analyst would want to find out what is different about that store.



You should use well designed visual displays of data. Any visual display of data (a graph, a boxplot, etc.) should also have a short description of the data, the source of the data, and the conclusion you draw from the graph.

Edward R. Tufte, a professor at Yale University, has written a great deal on how to design a good visual display of data - and how to avoid misleading and distracting visual displays. Tufte used this figure (created by Charles Joseph Minard in 1861) of the 1812 campaign of Napoleon's army to illustrate the use of several dimensions in a graphic.

The movement of the army is shown as a line on a two dimensional map, the number of men is shown by the width of the line, the progress to and retreat from Moscow are shown in two patterns, and the temperature (in degrees below zero) and dates of the retreat are shown on the graph at the bottom. Only a few moments with this graphic image makes clear the terrible fate of Napoleon's army. Tufte says "It may be the best statistical graphic every drawn" (*The Visual Display of Quantitative Information*, Edward R. Tufte, page 41). You won't create such a stunning image every time, but a carefully designed graphic can often convey your results much more persuasively than words.

The first graph on this web page nicely displays world population growth through history. Graphical images can be used to convey understanding, but they can also be used to mislead. The second graph on the same web page is misleading because of the truncated vertical axis. That graph projects the US population in 2050 and uses colors to indicate how much of the population would be Immigrants and Descendants since 1970 (colored red) and Growth from Descendants of 1870 Residents (colored green). By 2050 the size of the immigrant population (red) appears to be over 3 times the size of the 1970 resident population (green), but this impression is incorrect because the vertical axis does not start at 0 but at 203 million. In fact, the total population is about 390 million, the red population is about 132 million and the green population is about 248 million. The red population is less than half the total population. The use of red and green colors is another way the viewer is influenced. This web page discusses another graph with a truncated vertical axis.

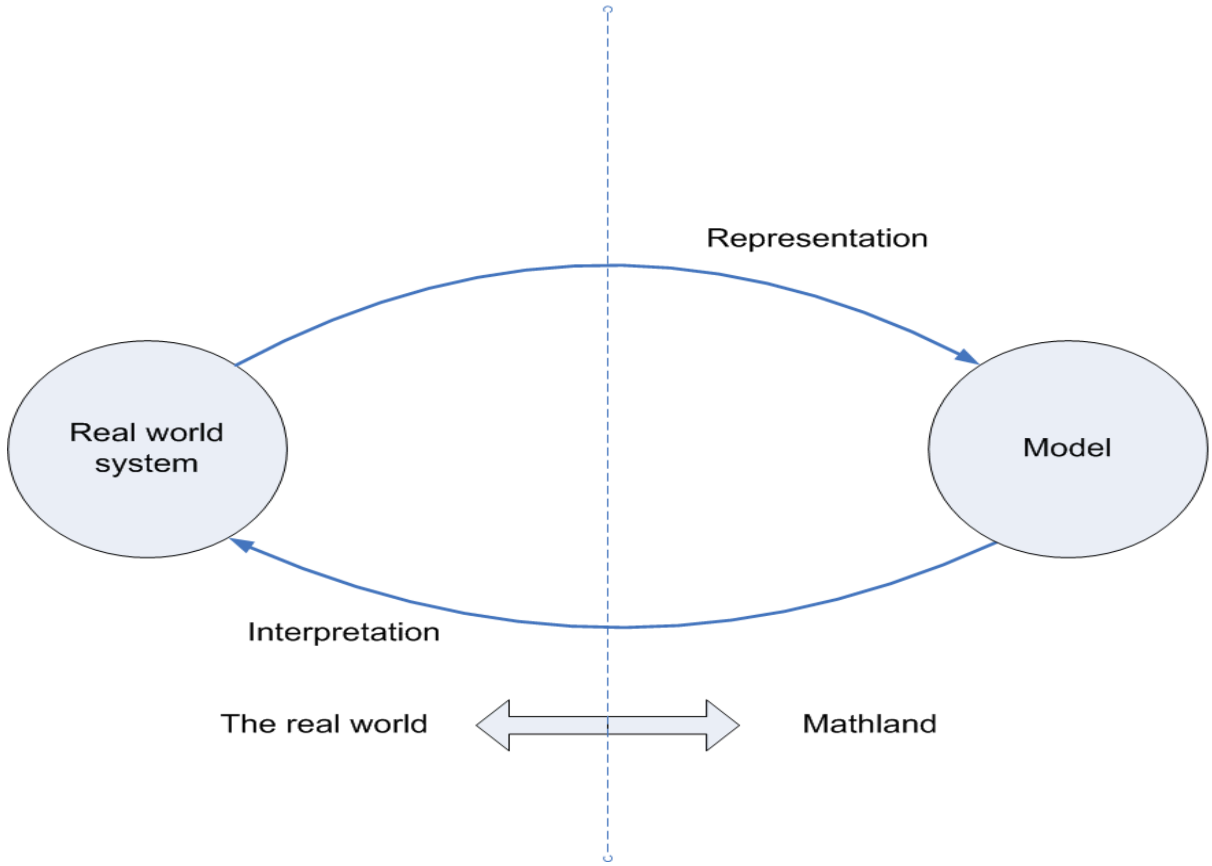
Tufte warns against the use of what he calls "chartjunk, " that is, ornamentation that attracts and diverts attention but does not add to understanding (*Envisioning Information*, Edward R. Tufte, page 33). He warns against the use of distracting patterns (see this example), three dimensional displays (see this example), and overly busy grids (see this example). Displaying areas can distort the viewer's perception of one-dimensional data (see the first graph, with cows, on this page). Tufte argues: "Cosmetic decoration, which frequently distorts the data, will never salvage an underlying lack of content" (page 34).

On the positive side, this web page has a collection of nice graphs on disease rates over time. Stephen Few shows some poor graphs and then the improved versions.
One of the most important types of graphs for an IE is a graph with time on the horizontal axis. Such a graph allows tracking and monitoring data such as the number of units produced each shift or the number of defects by type each week. The IE can quickly detect problems. For example, the figure below shows ... [use data that I'll use for QC chart in section 10.5]

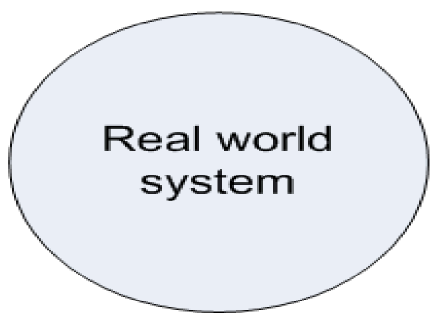
10.3 Models in general

IEs, and other engineers, often want to perform experiments on real systems, but such experimentation can be difficult. If an IE wants to try a new layout for a production system, moving equipment, furniture, and offices would be difficult and time consuming. Even trying a new procedure may disrupt the production system. Therefore, the IE would create a *model* of the system, usually a mathematical model.

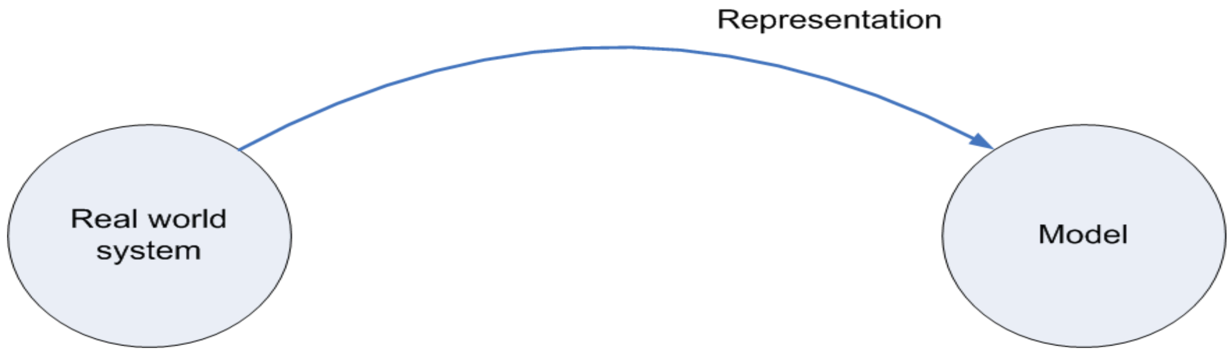
The following figure shows my favorite diagram.



I'll now build the diagram, explaining each piece. The first circle is labeled "real world system."



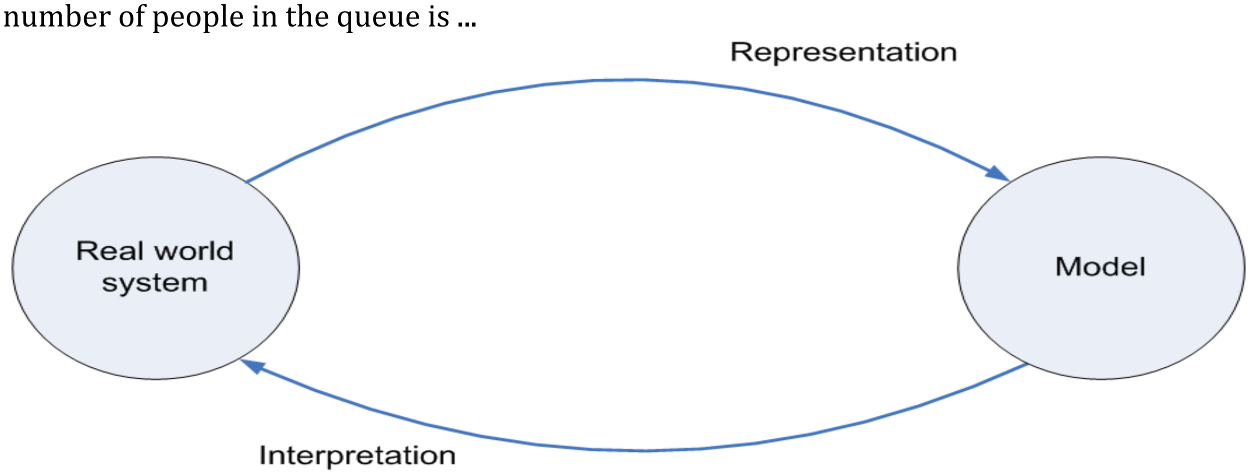
Drawing a line around some system involves deciding which parts are in your system and which are in the environment. For example, to study the arrival and service of customers at a bank, you would probably include the tellers, the drive up window, and the ATM, but not include the roads and traffic system that people use to get to the bank.



Now I've added the second circle, labeled "model." Some types of engineers use physical models. For example, a civil engineer might place a scale model of a building on a shaking table to predict how the building will respond to an earthquake. IEs tend to use mathematical models, expressed in equations or sometimes in computer code. For example, an IE might use the mathematics of queuing theory to create a model of the bank. The top arrow labeled "representation" reminds us that the model represents the real world system -- but only the relevant parts of the system. Our model of the bank must include information on the time between customer arrivals and the time to serve each customer (both of these times vary from customer to customer), but the model doesn't have to include descriptions of what color clothing customers wear. Depending on the purpose of our model it might include information on customer's disabilities so we can predict how many teller windows must be accessible to people in wheelchairs. The M/M/1 queuing model describes the time between arrivals as an exponential random variable with average $1/\lambda$ (say 6 minutes) and the time of service as an exponential random variable with average $1/\mu$ (say 4 minutes).

A model is never exactly correct; you should always remember the phrase "it's only a model." For example, the M/M/1 queuing model assumes that customers arrive at the average rate 1 every 6 minutes, or 10 customers per hour. Actually, the arrival rate probably varies over the day.

An IE creates a model in order to extract information; the loop from the model to itself is labeled "analysis." IEs use some models quite frequently and IEs can use mathematical results that others have proven. For example, for the M/M/1 queuing model, the average number of people in the queue is ...



The second line, labeled "interpretation," is where the IE interprets the mathematical results of the model back to the real world system. Now the IE must again remember "it's only a model" so the predictions may not be perfect. Since the M/M/1 queuing model assumes a constant average arrival rate, the results using $\lambda = 10$ customers per hour can only be applied to the period of the day with that arrival rate. A separate model might be needed for the lunch hour, which is probably busier.

10.4 Deterministic models

IEs are responsible for efficiency, including the efficient use of time and resources. You already know from calculus class how to find the maximum or minimum of a function and calculus is one tool that IEs use. However, IEs often need to maximize or minimize a linear function, which sounds easy, but finding the solution isn't easy when there are many variables and also some constraints. The following is an example of such a problem.

Dairy cattle have various nutrient requirements, such as protein, calcium, and potassium, that can be met by different types of feed, such as alfalfa, hominy, and corn cobs. The dairy farmer wants to mix a feed for the dairy cows that will meet the nutrient requirements at the minimum cost. I have created a very simplified version of the Diet Problem as applied to feeding dairy cattle. The following table gives the nutrient content (protein and potassium) of certain feeds (alfalfa, hominy, and corn cobs), as well as the nutrient requirement for protein and potassium (as a percent of the feed) and the cost of alfalfa, hominy, and corn cobs (in $/ton).

	Alfalfa	**Hominy**	**Corn cobs**	**Required**
Protein	28.0	11.9	3.0	15.0
Potassium	0.26	0.65	0.06	0.25
Cost	160	60	0	

For example, alfala is 28% protein, 0.26% potassium, and costs $160 per ton. Alfalfa is a good source of protein and a medium source of potassium, but it is expensive. Hominy is a medium source of protein and a good source of potassium, and it is cheaper than alfalfa. Corn cobs are not a good source of either protein or potassium, but since they are otherwise a waste product, they are free. With some thought, you can see that the optimal mix will probably need alfalfa to meet the protein requirement, hominy to meet the potassium requirement, and corn cobs to keep the cost down.

We want to determine how to mix the feed, that is, what fraction should be alfalfa (A), hominy (H), and corn cobs (C). We will use linear programming to solve this problem, by expressing the situation as minimizing a linear objective function (cost) subject to linear constraints (protein and potassium). We also know that A+H+C=1.

Here is the linear programming formulation:

$$\text{Minimize } 190\,A + 60\,H$$
$$\text{s.t. } 19.3\,A + 11.9\,H + 3\,C \geq 15$$
$$.28\,A + .65\,H + .06\,C \geq .25$$
$$A + H + C = 1$$

This model is an example of a linear programming model. We can solve it in Excel (although there are better tools for solving LP models). Because this model has only two decision variables (X1 and X2) we will first solve this one graphically. You won't usually solve an LP model graphically, but we will do it this time to help you understand LP models better.

Each LP model has an associated problem, called the dual problem, which gives us more useful information. First, let's add units or dimensions to all the quantities in the model.

We create the dual problem by transposing the matrix of coefficients in this set of inequalities; what was a row becomes a column and vice versa. We get this dual model; with each number I retained the units associated with it. I created a decision variable for each row in the original problem, Y1 through Y6.

If you look closely at the first inequality, you can figure out that Y1 must have units of $/protein and so forth. Here is the dual model with units added. [complementary slackness]

Now let's solve the original LP model with Excel, using the Solver Add-In.

I used Excel to solve this problem because no matter where you work, you will probably have Excel available. However, if you use LP a lot in your work, you will want to have your company buy a computer package that solves LPs.

Commercial packages are available to solve the nutrition problem for animals, for exampe, Feedsoft, SEIFormulator, and TailoredDiet.

This problem is an example of how industrial engineers use mathematics to promote efficiency. In this case, we helped the family use their resources and time efficiently to maximize their revenue from their crafts. This model is an example of an LP model, or, more broadly, an example of a deterministic optimization model. "Deterministic" means the model has no probabilities and "optimization" means we found the optimal, or best, solution.

An LP model is just one type of deterministic optimization model. Actually, we were lucky that we got an integer solution for this problem because the family really can't sell, for example, 1/2 of a puppet; an LP where the decision variables must be integers is called an integer programming model (IP).

Industrial engineers must be able to recognize situations where a deterministic model can be applied, create an appropriate model, and solve the model using an appropriate tool.

The following list describes situations where a deterministic optimization model might be useful:

- product mix - determine how much of each type of product to make subject to constraints on available resources. Our example was a product mix model. production scheduling - determine how much of each type of product to make in different time periods in order to meet specified production amounts by certain times.
- blending - determine the best blend of inputs to use to minimize the cost of producing a mixture. For example, different feeds can be blended to produce livestock feed. The objective function is to minimize cost and the constraints are to achieve minimum requirements on various nutrients.
- cutting stock - determine the best way to cut resource material to maximize profit. For example, a log can be cut into lumber of various dimensions which can be sold for different amounts.
- staffing - determine the best way to assign people to jobs to maximize their preference or to maximize the productivity, based on their abilities at different jobs.
- transportation - determine the best way to route resources through a transportation network to minimize the cost, while delivering the appropriate amount of resources to each location.
- assignment - determine the best way to assign resources to tasks.

- traveling salesman problem - determine the best route among a number of points that visits each point at least once.

Use Brazilian bulb article.

For any real world problem that you can't solve just by looking at it and thinking hard, you will need to use a computer package. Widely used computer packages for deterministic optimization include:

- Excel, with the Solver tool,
- GAMS,
- LINGO, and
- AMPL.

These computer packages are general purpose, that is, they will solve any linear programming problem and some deterministic optimization problems. If you develop a model that must be solved repeatedly with different data (for example, the daily production schedule), you will probably want to develop (with the help of skilled computer programmers) a specialized computer program adapted to efficiently solve exactly that type of problem. Such a specialized program will usually be faster, often much faster, because the program will take advantage of the structure of the problem.

Some deterministic optimization problems, however, are just so hard that even the best specialized program may take close to forever to find the best solution.

In section 10.4 we looked at a small routing problem, which was an example of the Traveling Salesman Problem (TSP). A driver who has to deliver packages wants to pick the best route, that is, the sequence in which to deliver packages. The driver has to make loop starting at A and visiting B, C, and D before returning to A. The table gives the distances between each site that must be visited.

	A	**B**	**C**	**D**
A	-	5	4	3
B	5	-	6	8
C	4	6	-	4
D	5	8	4	-

As I said in section 7.5, this small problem can be solved by looking at all the different orders to find the smallest (it has length 18). However, the number of possible solutions to a TSP with n nodes is n! and n! gets very large very fast. An algorithm for a particular type of problem is a method to find the optimal solution for that class of problems; it is guaranteed to find the optimal solution, but it may take a very long time to do that.

If you have a problem, like the TSP, that is really hard to solve, you may need to be satisfied with a good solution that you can't prove is the optimal solution. A heuristic for a particular type of problem is a method to find a good solution for that class of problems; it is not guaranteed to find the optimal solution. A good heuristic finds a good solution in a reasonable amount of time.

If you need to determine the route for a truck driver 6 A.M. based on data available at 6 P.M. the previous day, your computer program can't take more than 12 hours to solve the problem. Stephan Mertens has provided some interactive versions of well known heuristics such as the nearest neighbor heuristic and the insertion heuristic.

IEs can specialize in Operations Research, which involves the study of particular classes of problems, such as TSPs. Operations Research specialists devise better algorithms and heuristics for solving problems. They also try to find specific methods to solve problems that occur in special applications. As described in this article from InformationWeek, UPS uses operations research to optimize its delivery network.

10.5 Stochastic models

Consider the following problem:

Assume customers arrive at a bank randomly at rate 15 per hour. Also assume service times average 3 minutes and are modeled as a random variable with an exponential distribution. If we have one teller available, answer the following questions.

1. What proportion of time is the teller idle?
2. What is the expected number of people waiting for the teller?
3. What is the expected time spent a person waits for the teller?
4. What is the probability a person waits more than 10 minutes for a teller?

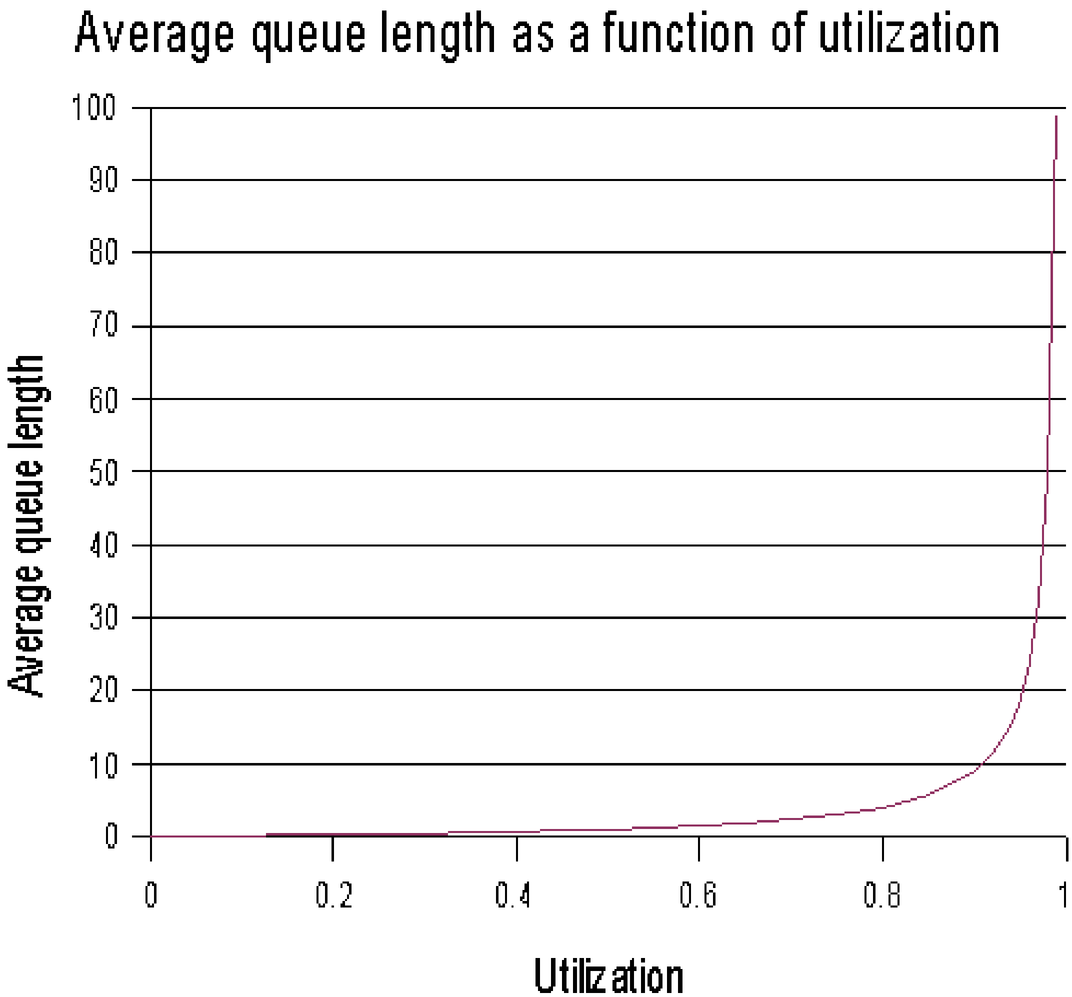
The arrival rate of customers is called λ and in this problem λ is 15 persons/hour. We can take the average service time (3 minutes) and compute the service rate of customers, called μ, as 20 persons/hour (60 minutes divided by 3 minutes per person).

1. The proportion of time the teller is busy can be computed as $(\lambda/\mu) = 15/20 = .75$, so the teller is idle 25% of the time.
2. The expected number of people in the queue is $\lambda^2/(\lambda - \mu) = 15^2/20(5) = 2.25$ people.
3. The average waiting time in line is $\lambda/\mu(\lambda - \mu) = 15/20(5) = .15$ hour = 9 minutes.
4. The probability that some one waits more than 10 minutes is

As an industrial engineer you can look at these answers and decide, for your organization, if these levels of service are sufficient. The teller is idle 25% of the time, so the teller can be doing other tasks during that time. The average number of people waiting is 2.25 and the average waiting time is 9 minutes. Finally the probability of waiting more than 10 minutes is xxx. Do we think we will lose customers with that amount of wait?

The industrial engineer might redo the analysis with two tellers. What will happen to each answer? The answer to question 1 will go up, while the answers to questions 2, 3, and 4 will go down. Again, the industrial engineer has to determine which solution is best for the organization.

Obviously, if the arrival rate, λ, is bigger than the service rate, μ, the queue will explode in length. The ratio of these numbers $\rho=\lambda/\mu$ is called the utilization and is a measure of how much the system is being utilized. When $\rho=0$, no customers are arriving and the queue length is zero. As ρ increases the average queue length will also increase. The following graph shows how the average queue length grows as utilization increases.



The average queue length stays below 5 people until ρ reaches about .84; the average queue length stays below 10 people until ρ reaches about .91. Above that point the average queue length grows quite rapidly as utilization increases. The problem is randomness: if the arrivals occurred at regularly intervals and if every service time were the same, the system could function well at high utilization. But sometimes customers arrive quickly and sometimes slowly; sometimes service takes a shorter time, but sometimes it takes longer. At high utilization, that randomly long service time has a big effect. Some managers don't account for the effect of randomness. They think that if an employee can handle, on average, 10 customers per hour, that only one employee is needed to serve an average arrival rate of 10 customers per hour, but this graph shows that randomness will make the queue grow unacceptably long.

This problem is an example of an M/M/1 queuing model. More generally it is a stochastic model. “Stochastic” means that probabilities are involved. In deterministic optimization we gave a mathematical formula for the objective function, but in most stochastic models, we have several goals (minimize the time the teller is idle, minimize the average number in the queue), so we want to compute the values of our various goals and then make trade offs. Where people are the items in the queue, the IE also has to consider the psychology of waiting lines. Watts describes Disneyland's mastery of making waiting in line seem acceptable.

"Disney planners came up with a unique system: first, a snakelike pattern masked the length of a line by running it back and forth in parallel lines; then a variety of visual and audio images kept those in line entertained; and finally, a cleverly engineered schedule kept visitors steadily embarking on the ride so the line would always appear to be moving forward." (page 389)

Some stochastic models allow for a sequence of choices that occur over time. A decision tree, with choices and chance events, can represent such situations.

Some real world situations are so complicated that we may not be able to write down formulas to calculate the measures we want to compare. For example, a sequence of queues can be used to represent the flow of products through a manufacturing system or the flow of customers through a service system. Such a system can be modeled in a computer simulation. The computer program actually simulates the operation of the production system, including randomness in the system. The simulation can be run many times so we can observe the average performance, and gather data to determine how often the system performs at different desired levels.

As we discussed in Section 5.5, Six Sigma seeks to reduce the variation in any production process. Once the variation in the system has been brought to an acceptable level (recall the analogy with keeping the arrows in a tight cluster), statistical quality control (SQC) is used to monitor the process to determine whether it is still under control.

[insert SQC example]

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 11
Business related skills

Industrial engineers are sometimes called industrial and systems engineers because IEs design or improvement a *system* of people, machines, information, and money. Of all types of engineers, IEs are the ones who think most about the people in the system and we also think most about money. Industrial engineering is the engineering discipline that has the closest ties to business issues. In this chapter we will look at some topics that are closely related to topics taught in business schools, but we will look at how they apply to industrial engineering.

- 11.1 Accounting
- 11.2 Engineering economics
- 11.3 Communication skills
- 11.4 Project management

11.1 Accounting

Consider a company that uses one production plant to make various models of several products, each sold at different prices. How can the company determine how much profit it makes on each model of each product? Consider a job shop that bids on jobs from customers. How can the company determine the amount of profit it will make at different bid levels? Consider a company that makes a certain part that goes into its product. How can the company determine how much it costs to make that part in order to compare that cost to the cost of buying the part from a supplier? Consider a company that is considering purchasing a new machine to reduce the time needed to manufacture a part. How can the company determine if the reduction in time is worth the cost of purchasing the machine? Cost accounting, and its newer variant Activity Based Costing, are ways to answer those types of questions. A lot of common sense goes into cost accounting. The cost for a company to make a product includes:

1. Direct material cost.
2. Direct labor cost.
3. Everything else.

Costs in the first two categories are relatively easy to compute. For example, in the first category, the product might need a certain amount of high grade steel, which the company purchases from a particular supplier. The IE can find out from the purchasing department how much the company pays for steel from that supplier. Scrap must be taken into account in computing the cost of the steel that goes into the product. In the second category, the labor cost can be computed for each worker who helps produce the product by using the hourly rate (including benefits and vacation time) and the time that worker spends on the part. That time would probably have been determined by the IE using methods we discussed in Section 9.4

The hard part is, of course, the third cateogry which includes all the costs that can't be directly allocated to any one product: machinery, office supplies, salaries for maintenance workers, salaries for management, and so forth.

Traditional accounting usually allocates these costs in proportion to direct labor costs or in proportion to machine hours used by each product. If manufacturing one type of product takes 2/3 of the direct labor costs of a plant, then traditional accounting allocates 2/3 of the overhead costs to that product. The goal is to use the allocation basis that best reflects what causes the cost.

Activity Based Costing extends the idea of linking costs with causes of costs. First the costs in category 3 (above) are allocated to activities (for example, purchasing, customer service, running the machine shop) and then those activity costs are allocated to specific products. For example, costs of paper might be allocated to activities based on the number of office workers assigned to each activity (having more office workers causes more use of paper); the costs of the customer service activity might be allocated among products based the number of customers or the number of customer orders for each product (having more customers or having more orders causes more need for the activity of customer service).

The article , from MMS Online, does a great job of explaining Activities Based Costing (ABC). In essence, ABC is a way to link costs with activities and link activities with the jobs or products that caused the activities. That way, all costs are divvied up and directed to the appropriate job or product, not just the costs that are obvious or easy to link. By linking activities with jobs or products, the cost of these activities can be more precisely allocated to the appropriate jobs or products." The article also points out that more accurate pricing helps the company bid more accurately and avoid situations of winning bids on which it actually loses money or losing bids on which a more accurate bid could have generated profit.

Because IEs think about money in the systems they design and improve, an IE has to know some basics about accounting. Some BSIE programs require students to take a course in Accounting. We don't require such a course, but we do allow it to count as a technical elective.

11.2 Engineering economics

IEs often have to evaluate alternatives:

- Which one of several available machines should be purchased to provide a needed function in the production system?
- Will investment in a new production process be worth the anticipated savings?

Methods for making such decisions are part of the area of industrial engineering called engineering economics or engineering economy. Despite its name, this area has more in common with finance than with micro or macroeconomics. The methods of engineering economics help the IE pick the most economic decision, that is, the decision that costs the least money, over the long run.

Consider the following example. An office manager is deciding which copier to purchase or lease. Two alternatives are:

- Copier A, which can be purchased for $10,000. Maintenance and repairs are estimated to be $600 per year and the copier will last 5 years.
- Copier B, which can be leased at $3000 per year, including all maintenance and repairs

More realistic engineering economic studies may involve comparisons that cannot be immediately expressed in dollars. To keep this example simple, I will assume that the copiers have similar features, that the same number of copies will be made on either copier, and that the supplies will cost the same.

More realistic engineering economic studies also look at the tax implications of each alternative. Large engineering investments may invovle tax investment credits, depreciation, and other tax considerations. To keep this example simple, I will ignore any tax effects.

The two alternatives can be displayed in cash flow diagrams:

The horizontal lines represent time, with now shown as time 0, and the 5 years into the future shown by the other numbers. The arrows represent the dollar amounts. In this example, all the arrows point downward, indicating that the dollar amounts are costs or outflows of money; revenues would be shown by upward pointing arrows.

In drawing these diagrams, I assumed that the $10,000 cost of Copier A would be paid now, and that the annual lease amounts for Copier B are due at the start of each year; five payments will pay for the five years of the lease. This diagram shows that we are correctly comparing 5 years of service from the two alternatives; more sophisticated analysis is needed if the life of the copier and the lease period don't match.

A simple, but incorrect, analysis would be to say that Copier A costs $10,000 plus 5 payments of $750, for a total of $13,750, while Copier B costs 5 payments of $3000, for a total of $15,000. Copier A costs less and should be chosen.

That simple analysis is wrong because it ignores the fact that the purchase of Copier A means that the company gives up any earnings it could have made by investing the $10,000. The company could have, for example, bought equipment to produce products and made money, it could have invested in equipment to save money, or it could just have put the $10,000 in the bank and earned interest on the money.

The correct analysis takes account of the time value of money, that is, the fact that $1 has the same value as $(1+i) one year from now, where i is the rate of return the company can earn on its money.

For example, if i=12%, $1 now has the same value as $1.12 one year from now, and has the same value as $$(1.12)^2$ or $1.25 two years from now, and so forth, using compound interest.

We can reverse the calculation and compute that $1 one year from now has the same value as $(1/1.12) = $0.89 now, $1 two years from now has the same value as $$(1/1.12^2)$ = $0.90 now, and so forth.

To keep the example simple, I am ignoring the effect of inflation.

Now we can compare the two alternatives by converting each dollar at future times to its equivalent value now, called its present value. The present value of Copier A turns out to be $12,703.58, and the present value of Copier B is $12,112.05. Since these present values represent costs, we want to pick the copier with the smaller present value, which is Copier B.

The choice between the copiers depends on the value of i, the interest rate. If I use i=6%, the present worth for Copier A is $13,159.27 and the present worth for Copier B is $13,395.32. We would choose Copier A with that interest rate.

I can plot the present worths of the two copiers as a function of i, the interest rate, as shown below.

The two lines on the graph cross at 7.59%. For a particular value of i, we want to pick the copier with the lower present value. For interest rates below 7.59%, Copier A is the better choice; for interest rates above that value, Copier B is the better value.

This simple example ignored many complications of more sophisticated engineering economics analysis, some of which I have mentioned above. In addition to the points I have already mentioned, this example assumed perfect certainty about future costs; more sophisticated analysis uses probability to express uncertainty about the future.

11.3 Communication skills

Every time I talk with people who hire engineering graduates, they mention the need for engineers to be able to communicate effectively. Communication skills include listening, as well as speaking and writing. They often mention the need for communication skills in small and large groups, with people at different levels of the organization, and in an international setting. By stressing those skills, in addition to quantitative and analytical engineering skills, employers are saying that you must be able to communicate your conclusions clearly.

I reviewed openings for IEs at Monster.com and found employers looking for the following qualifications:

- "Excellent verbal and written communication skills." (Watkins Motor Lines)
- "Exhibit problem solving expertise, excellent written and oral communications and foremost be a team player." (Custom Window Extrusions, Inc.)
- "Excellent written and verbal communications skills, strong analytical skills, and demonstrated ability in fostering teamwork and creating a positive, productive work environment." (Jamak Fabrication)
- "Solid oral and written communication skills." ("Fast-growing Plastics/Polymer products manufacturer in Southern California")
- "Excellent communication and presentation skills (oral and written)." (Cummins Inc., Fleetguard)
- "Excellent people skills with the capability to communicate effectively at all levels." (Maxim Integrated Products)
- "The candidate must have the ability to assess and discuss the development and implementation of engineered standards, and understand and use a variety of communication styles to facilitate the exchange of ideas and information between distribution, engineering, management, and associates." (Lowe's)
- "Team oriented and able to communicate effectively at all levels." (Sweet Street Desserts)

In this section I give some advice on how to write well and how to give a presentation.

How to write well

One important skill an engineering student must learn is how to present and defend a conclusion in written form.

This section is a guide for writing papers that have a high chance of meeting the standards I use for grading. To write a good paper, you must (1) have enough good content worth writing about, (2) organize that content into a thesis statement and a logical defense of the thesis, and (3) make sure that the details of every paragraph, sentence, and word are correct. In this paper, I will explain each of these components in more detail. I will also discuss the importance of giving credit to others.

Content

To write a paper, one must have something worthwhile to say.

Creating good content is hard work. I find that the most important tools I use are blank paper and pen (to brainstorm), and then scissors and tape (to organize). First, I brainstorm ideas, writing down all thoughts that come to my mind. I review the ideas that I have written down already to see if they lead to new thoughts. This brainstorming may take place over several days, even several weeks and involves a lot of thought. Second, I take these ideas and cut them into pieces of paper, one idea on each piece of paper. Finally, I use a large table to organize my pieces into a coherent whole. This organizational step may take some time and can be very hard work. After I have completed the organization, I tape the pieces of paper together in the order I will write about them, and then use them to compose a first draft.

Unfortunately, if I think your paper doesn't have enough content, I just can't say much. I sometimes write: “I think you can push these ideas further” and then I try to ask some specific questions to help you do more brainstorming.

Organization

The classic advice on how to organize a paper is: “Tell them what you’ll tell them; tell them; then tell them what you told them.” You will find that classic advice in this section.

The points I look for in organization include:

- The organization of the paper should be made clear to the reader.
  Give the reader a roadmap early in the paper and give frequent signposts throughout the paper.
- The paper should have a clearly stated thesis. The thesis is the statement that the paper defends.
- The entire paper should present a logical and organized argument in support of the thesis.

Very early in the paper (usually in the first or second paragraph), state your thesis and give a roadmap to the reader. You might say:

"In this paper I will argue that.... [state thesis]. To support this thesis, I will first argue that.... Then I.... and finally I...”

This paragraph can be almost a mini-version of the whole paper. More sophisticated approaches can still accomplish the purpose of giving a roadmap without following this rigid formula. Your initial paragraph shouldn't say only what topics the paper will address; it should state the conclusions and state the argument.

A technical paper should not be a mystery story. If I have finished the first paragraph of your paper and don't know what the thesis is, I am usually concerned that you do not have a clear thesis statement. Ask yourself: What conclusion am I defending in this paper?

Here are some examples of thesis statements:

- *Winnie the Pooh* by A.A. Milne is not just a children’s book about a bear. It has lessons for how to lead a good life, including how to be happy, how to get along with others, and how to compromise. [After this thesis statement, I would expect the paper to have three major sections, corresponding to the three parts of the second sentence.]
- People enjoy living in Pueblo because of the friendly people, the beautiful surroundings, and the favorable climate. Limited employment opportunities and schools that need improvement are drawbacks that Pueblo residents seek to ameliorate. [I would expect the paper to have five major sections, corresponding to the three benefits and two drawbacks listed.]
- Information technology is changing every part of Industrial Engineering, including how we create our solutions, how we convey those solutions to clients, and what those solutions involve. [I would expect the paper to have three major sections.]

- Higher education in the US is undergoing fundamental change, including a rebalancing among teaching, research, and service missions, a move to new teaching methods to respond to changing student needs, and a change in the mix of funding sources. [I would expect the paper to have three major sections.]

Sometimes you may find that you do not know what your thesis is until after you write a first draft of your paper. If you find yourself writing, often at the end of the paper, a sentence where you feel you have finally said what you are trying to say, then consider moving that sentence to the *start* of your paper as your thesis and reorganizing your paper so that it defends that thesis.

After stating your thesis, your paper should present a logical argument defending your thesis. Writing a logical defense of a thesis is like writing a proof of a theorem; one states the theorem first (the thesis) and then proceeds in a logical step-by-step fashion to prove the theorem.

The defense of your thesis can take many forms. You can present any evidence in support of your thesis including quotes from other sources and examples that illustrate your thesis.

The final paragraph of your paper should repeat the thesis of the paper. While it can also extend the argument, the final paragraph should be basically a summary of what was in the paper.

Details

Each paragraph, like your whole paper, should state and defend a thesis, actually a subthesis. The subthesis should, of course, be part of the overall argument that supports your thesis. I am deliberately not saying that your paragraph should have what is called a “topic sentence,” because the sentence should not just state the topic of the paragraph, but should state the subthesis that is being defended in this paragraph. Usually, this sentence should be the first one in the paragraph. (I think you will find that the first sentence of this paragraph is the subthesis sentence for this paragraph and that every sentence in the rest of this paragraph supports it.)

Connect sentences with words like “therefore” or “because” to show your argument in support of your thesis. A series of true statements is not a logical argument; such true statements require explicit logic to connect them into an argument. You may know that you mean that one sentence implies the next sentence, but your reader will follow your logic better if you state that logic.

Each paragraph should be about one concept. If I think you have put too many unrelated concepts in one paragraph, I will draw lines to indicate where I think the paragraph changed topic and suggest that separate paragraphs may be better or suggest that you indicate why all these ideas belong in one paragraph: what is the unifying idea?

Each paragraph should support the overall thesis. A paragraph can be well written and interesting, but should be deleted if it does not support the thesis of the paper.

A paper should have no spelling or grammatical errors. "Comments I often write on student papers" (gelow) shows some details of word usage and grammar. For each, I show an example of the error and how to fix the error. The book *The Elements of Style*, by William Strunk, Jr., and E.B. White (first published in 1935, and republished many times since), is an excellent handbook with other examples like the ones in "Comments I often write on student papers."

Getting all these details correct requires many rewrites of a paper. Word processors make it easy for us to check our spelling, check our grammar, move paragraphs and sentences around, and print new drafts. This paper, for example, has gone through a large number of drafts, easily over twenty. I find that I usually need to put aside a paper for a few days so I can come back to it with a fresh look. I also try to find someone to read and comment on my paper.

Giving credit

Always give credit to others for their ideas. If you quote a source directly, use quote marks and give the complete citation. If you do not quote the source directly, but still use ideas from the source, cite the source and make clear which ideas are from the source and which ideas are yours. Figures taken from a source should have the source shown in the figure legend. If you have obtained useful ideas in conversation with someone, cite, for example, "H. Carrasco, personal communication."

Using someone else's ideas without giving credit is plagiarism, which is academic misconduct as well as professional misconduct. While claiming credit for someone's ideas may give a person a temporary advantage, I believe that being generous in crediting others is a strategy that will pay off in the long run. Besides, giving credit to others is simply the right thing to do.

Conclusion

The ability to present a clear written argument in support of your conclusions will be very important to you in your career. A good paper requires attention to content, organization, and details. I have described the features I look for in a paper for my classes.

Comments I often write on student papers

1. The word "data" is plural.
   Example: Good data are important in making good decisions.
2. Make a list of items parallel; they should all be the same grammatical form.
   Example of error: My decision making process involves deciding I have a problem, define the problem, gather information, analyzing information, and decide.
   Example fixed: My decision making process involves deciding I have a problem, defining the problem, gathering information, analyzing information, and deciding.
3. Avoid indefinite referents.
   Example of error: I take a long time to make decisions. I do this because I am risk averse. ["this" is the indefinite referent in this sentence. This what?]
   Example fixed: I take a long time to make decisions. I take a long time because I am risk averse.
4. Connect your sentences to show your logic and to write more succinctly. Use few, but carefully selected words.
   Example of error: I take a long time to make decisions. I take a long time because I am risk averse.
   Example fixed: I take a long time to make decisions because I am risk averse.
5. Avoid the passive tense.
   Example of error: After I define the problem, information is gathered. [The passive tense leaves unclear who is doing the action, for example, who gathered the information.]
   Example fixed: After I define the problem, I gather information.
6. Pick a voice (for example, "I," "one," or "you") and use it consistently. If a student switches voice, I write in the margin: You have switched voices from "you" to "I."

Sometimes such changes in voice will work, but usually it is better to pick one voice and stick to it.

7. Avoid constructing sentences that start with "It is..." and avoid overly complicated sentence construction.
   Example of error: It is assumed that the decision to be made is one with serious consequences.
   Example fixed: I assume the decision to be made has serious consequences.
8. Don't use more words than you need.
   Example of error: Next, the decision-maker is faced with a difficult decision.
   Example fixed: Next, the decision-maker faces a difficult decision.
9. Avoid misplaced modifiers.
   Example of error: Questioning what to do next, my parents could provide some advice.
   Example fixed: Questioning what to do next, I turned to my parents for some advice.
10. Don't overuse quote marks. They should only be used when (1) you are referring to a word or (2) you are quoting someone.
    Example: The word "content" is ambiguous because it has several meanings.
    Example: As my mother often said: "if it sounds too good to be true, it probably is."
    Don't use quote marks because you haven't found quite the right word; search harder for a better word.
11. Pick a word and use it consistently. Unlike literary writing, technical writing does not improve with variation in words.
    Example of error: The decision had several possible consequences. Each possible outcome had several features. These attributes included the cost, the time spent, and the quality of product received.
    Example fixed: The decision had several possible consequences, each of which could be described by three features: cost, time spent, and quality of product received.
    The rest of the paper should use the words "decision," "consequences," and "features," consistently.
12. The word "thing" is usually too imprecise for technical writing.
    Example of error: I considered three things in making my decision.
    Example fixed: I considered three issues in making my decision.

How to give a good presentation

Giving a good presentation requires a lot of preparation.

- Know your audience. Adapt to their level of knowledge about the subject and their expectations for presentations.
- Pick a few major points and focus on them.
- Support your points with carefully chosen data. Don't dump all your data and charts into the presentation.
- Create a structure for your talk.
- Give a brief outline first.
- Rehearse.
- Enunciate clearly.
- Act as if you feel confident, even if you don't really feel that way.
- Make eye contact with everyone.
- Don't fidget with your hands.

- Stick to the time limit.
- Anticipate and be prepared to answer questions.
- Listen to questions carefully before you answer them.
- Ask for clarification if a question is unclear.
- Thank your audience for their attention.

Most professional presentations now use PowerPoint. You should also consider using a handout.

- A handout lets your audience follow better and take notes.
- Give a handout at the start of your talk, not at the end.
- Use only a few slides. Have one major idea per slide. Spend about 2 minutes on each slide.
- Use lots of white space, a large font size, and don't write in all upper case letters.
- Limit use of special effects and patterns.
- Practice zero defects - eliminate any typos.

"Death by PowerPoint" is a popular topic on the web. I believe these links have good advice:

- "Death by Powerpoint" by Angela R. Garber at SmallBusinessComputing.com. "Remember that the audience has come to see a speech, not a slide show."
- "Avoiding 'Death by PowerPoint'" by Corbin Ball at Corbin Ball Associates. "Let the audience know where you are going."
- "Death by PowerPoint" by Ann Miller at ClickZ Network. "Peter Drucker quite rightly said that communication takes place in the mind of the listener, not the speaker."
- "Death by PowerPoint" by Jesper Johansson at Jesper's Blog. "[R]ed text on a blue background is impossible to see for people who are color blind since it won't stop moving." A comment on Jesper's article points to this web page for good advice on the use of color.
- "Death by PowerPoint!" by Rob Waite at EZineArticles. "The projector warmed up, the presenter clicked on his computer, and I saw something that almost killed me on the spot – the little box in the lower left corner of the frame that read, "Slide 1 of 101". That's right, 101 slides!"

11.4 Project management

Most industrial engineering work gets done in projects. The Association for Project Management has a good glossary of project management terms. That glossary defines a project as a:

"unique set of co-ordinated activities, with definite starting and finishing points, undertaken by an individual or organisation to meet specific objectives within defined time, cost and performance parameters."

That definition means that a project involves people, money, time, and performance objectives.

A project usually has the following people:

- a sponsor, who assigns the project and to whom the project leader is accountable,
- a project leader, who is responsible for the successful completion of the project,
- team members, who do the work of the project with the leadership of the project leader, and

- stakeholders, who are other people not on the team who have a stake in the successful completion of the project or who have information and ideas that the team should consider.

Those descriptions sound very tidy, but often the real world is messier. The labels may differ in various organizations, and the responsibilities may not always be clear.

As an IE, you will often be the person who is responsible for a project. As your resume grows, you will list what you have accomplished in projects. Your success with your employer, your success in your career, and your success as an entrepreneur will depend to a large degree on your success as a project leader. Therefore, I have written this section as if you are the project leader.

For any project, you should always try to have a clear statement of the objectives of the project, who is responsible and to whom, the deadline, and the resources being made available. I have asked for these elements in your team charter. If the project sponsor doesn't provide these, you should put them in a document and get the sponsor's approval of that document.

I wish I could tell you that expectations always match the resources provided. A popular saying is "Good, cheap, or quick. Pick any two."

- If you want a project done well and fast, it will take a lot of money.
- If you want a project done fast and cheaply, it probably won't be done well.
- If you want a project done well and cheaply, it will take time.

However, many project sponsors wants all three: do it well, do it cheaply, and isn't it done yet?

Your skills as a student include managing your tasks for different classes, but students don't often manage teams of other people. Student activities are a great way to learn and practice project management skills; employers look for leadership roles in student groups because they recognize how much students learn through such activities.

As an IE, you will be responsible for multiple projects at one time. One of the worst statements you can make to a prospective employer is "I can work on only one project at a time." You may be the project leader on several projects, as well as a team member on other projects. Also, the people on your project teams certainly have other responsibilities; they may have tasks in the production system, they may be on other project teams, and they may be leading other projects. Most engineers don't have a secretary or administrative assistant; you will need to keep track of the papers, email, data, etc., for each of your projects.

Every project seems huge at first. Another popular saying is: "How do you eat an elephant? One piece at a time." Break a project into tasks, determine the order and relationships among the tasks, assign budget and people to each task, and then monitor the progress of each task. Planning may help you quickly uncover indications that the project will require more time, budget, or people. Either figure out how to get around those difficulties, or go back to the project sponsor.

Software can help you visualize and track the tasks in a project. Microsoft Project is the most well known such software. Activities can be tracked by time and money spent. Also, the critical path can be identified, that is, the sequence of tasks that will take the longest time to complete. If any task on the critical path takes longer than planned, the project will be behind schedule. Obviously, you want to monitor the progress of the tasks on the critical

path very closely. The Gantt chart (already discussed in section xx) is the most commonly used visual display for project management.
Communication is important.

- How much or how little does the project sponsor want to hear from you during the project? Some project sponsors will want you to get on with the job and not bother them; others may want to be kept informed of progress. Daily updates are almost always too much for anyone not on the project team. But don't let the project sponsor be blind sided by problems; bad news should come from you, not from someone else. However, whenever you talk to your boss about a problem, propose solutions; they may not be good solutions, and your boss may pick a different solution, but you are expected to propose solutions, not just raise problems.
- How will the team members share information? Email is helpful, but participants may spend too much time searching email for the bit of information needed now.
- How can you obtain the cooperation and information you need from stakeholders? The project sponsor should communicate that they are expected to provide what you need.
- How do you communicate your findings so your recommendations are implemented? Involving and especially listening to stakeholders help get buy in. Your verbal and written communication skills are critical here.

I have found some helpful resources on the web:

- I have already mentioned this helpful glossary from the Association of Project Managers.
- Michael Greer has a list of project management principles and a list of project management actions.

Introduction to Industrial Engineering
By Jane M. Fraser
Chapter 12
The past and the future

Jonathan Hughes defined industrialization as;
the permeation into most areas of economic life of techniques of specialization and division of labor based upon a core of scientific knowledge that utilizes systematic organization, mechanical, chemical, intellectual, and power-driven aids to production.
The history of industrial engineering is intertwined with the history of industrialization.

- 12.1 Interchangeable parts
- 12.2 New sources of power
- 12.3 Specialization of labor
- 12.4 The corporation
- 12.5 The factory and the manager
- 12.6 Analysis of work
- 12.7 The assembly line
- 12.8 Worker rights
- 12.9 Mobilization for World War II
- 12.10 Japan after World War II
- 12.11 Programmable controls, computers, and communication technology
- 12.12 The future

Where? 1924 first control chart, Shewhart 1931 textbook Economic Control of Quality of Manufactured Product. AIIE was founded in 1948 (in Columbus by an OSU professor). It become IIE in 1981. 1886 Henry Towne (1844-1924), co-founder of the Yale & Towne Manufacturing Co., published “The Engineer as Economist” in the Transactions of the American Society of Mechanical Engineers

12.1 Interchangeable parts

1800 - Eli Whitney, interchangeable parts in muskets.

12.2 New sources of power

Production requires power. The first sources of power were the human and then domesticated animals. Indeed power is often still measured in units called horsepower. Falling water was harnessed to provide power to mills, but required location near a stream. James Watt (1736-1819) made crucial improvements to earlier crude steam engines and patented his device in 1769. His new engine revolutionized the provision of power, as commemorated in the naming of the modern unit of power in physics: the watt. In a steam engine, wood, coal, or other product is burned to heat water. The pressure from the resulting steam is used to move mechanical parts.

The steam engine was a crucial development in the industrial revolution because power could be generated from any source of heat at any location and could be used to provide various types of movement. Cotton spinning and cotton weaving are an example of the revolution in work created by the steam engine. Steam engines were used to pump water from mines, allowing the extraction of ores previously unusable. Ships and trains were moved by steam power. Power tools and printing presses were driven by steam engines. The invention of this convenient source of power was useful also because of many other inventions that were powered by steam engines or that created other efficiencies. Edmund Cartwight developed the power loom, which was improved by John Horrocks (Hughes, page 58). Eli Whitney invented the cotton gin to replace hand harvesting of cotton. Dredging of rivers enabled steam powered ships to reach more cities.

12.3 Specialization

In 1776, Adam Smith published *An Inquiry Into the Nature and Causes of the Wealth of Nations* (available on line. Smith opened his book with a description of the specialization of labor, using a pin factory as an example. I quote this passage at length because it is a classic description, but also because it makes clear the increase in production that can be achieved.

> To take an example, therefore, from a very trifling manufacture; but one in which the division of labour has been very often taken notice of, the trade of the pin-maker; a workman not educated to this business (which the division of labour has rendered a distinct trade), nor acquainted with the use of the machinery employed in it (to the invention of which the same division of labour has probably given occasion), could scarce, perhaps, with his utmost industry, make one pin in a day, and certainly could not make twenty. But in the way in which this business is now carried on, not only the whole work is a peculiar trade, but it is divided into a number of branches, of which the greater part are likewise peculiar trades. One man draws out the wire, another straights it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head; to make the head requires two or three distinct operations; to put it on, is a peculiar business, to whiten the pins is another; it is even a trade by itself to put them into the paper; and the important business of making a pin is, in this manner, divided into about eighteen distinct operations, which, in some manufactories, are all performed by distinct hands, though in others the same man will sometimes perform two or three of them. I have seen a small

> manufactory of this kind where ten men only were employed, and where some of them consequently performed two or three distinct operations. But though they were very poor, and therefore but indifferently accommodated with the necessary machinery, they could, when they exerted themselves, make among them about twelve pounds of pins in a day. There are in a pound upwards of four thousand pins of a middling size. Those ten persons, therefore, could make among them upwards of forty-eight thousand pins in a day. Each person, therefore, making a tenth part of forty-eight thousand pins, might be considered as making four thousand eight hundred pins in a day. But if they had all wrought separately and independently, and without any of them having been educated to this peculiar business, they certainly could not each of them have made twenty, perhaps not one pin in a day; that is, certainly, not the two hundred and fortieth, perhaps not the four thousand eight hundredth part of what they are at present capable of performing, in consequence of a proper division and combination of their different operations.

As you read this passage, you should be struck by the idea that Smith is describing a system as it would be organized by an industrial engineer. Part of the job of the IE is to decide how to use specialization to organize the production of goods. Thus, the concept of specialization is central to industrial engineering; it is also central to questions about the economic organization of society.

Specialization, or division of labor, leads to enormous benefits for society.

> This enormous *division of labor* enhances our capacity a thousandfold, for it enables us to benefit from other people's skills as well as our own. (Heilbroner and Milbert, page 3)

As individuals, we don't need to know how to make a pin, fish, catch game, make bread, or fly a plane, but we can benefit from the skills of people who do know how to do those tasks. On the other hand,

> Our abundance is assured only insofar as the organized cooperation of huge armies of people is to be counted upon. Indeed, our continuing existence as a rich nation hinges on the tacit precondition that the mechanism of social organization will continue to function effectively. *We are rich, not as individuals, but as members of a rich society, and our easy assumption of material sufficiency is actually only as reliable as the bonds that forge us into a social whole.* (Heilbroner and Milbert, page 3)

Although specialization produces enormous wealth, individuals are no longer able to provide for themselves. A failure of the economic system, such as the Great Depression in the 1930s, can leave people unfed and unhoused. While the struggle for existence is often thought of as a struggle with nature, this economic failure was not caused by an act of nature.

> We are by no means the only nation that has, on occasion, failed to find work for large numbers of willing workers. In the very poorest nations, where production is most desperately needed, we frequently find that mass unemployment is a chronic condition. The streets of many Asian cities are thronged with people who cannot find work. But this, too, is not a condition imposed by the scarcity of nature. There is, after all, an endless amount of work to be done, if only in cleaning the filthy streets or patching up the homes of the poor, building roads or digging ditches. What is lacking is a social mechanism to mobilize human energy for production purposes. And this is the case just as much when the unemployed are only a small

> fraction of the work force as when they constitute a veritable army. (Heilbroner and Milbert, page 5)
> Economics is the study of how societies organize themselves to produce and to distribute goods. In a traditional society, before specialization of labor, each individual or family unit provides for itself. Even if labor becomes specialized, traditional societies solve the organizational issues by, for example, having sons take on the trades of their fathers. Rules of kinship, for example, might determine the distribution of the game from a hunt. Such traditions or customs, however, can support only a static economy, not economic progress (Heilbroner and Milbert, pages 7-9).

Besides tradition, the other ways society has organized to produce and distribute goods are, broadly described, *command* and *market*. In authoritarian economic organization, an individual or group commands people where to work. For example, the United States has used such methods during war time or during natural disasters.

> Even in America, we commonly declare martial law when an area has been devastated by a great natural disaster. On such occasions we may press people into service, requisition homes, impose curbs on the use of private property such as cars, or even limit the amount of goods a family may consume. (Heilbroner and Milbert, page 10)

Unlike tradition, which cannot support economic change, command, it can be argued, is an effective way to enforce economic progress, as seen in communist China or Russia (Heilbroner and Milbert, page 10).

We live, of course, in an economy that is primarily based on the market; that is, an economy based on individual choice. Specialization of labor means that individuals offer differ skills and work at different jobs.

Helibroner and Milbert's book *The Making of Economic Society* explains much more about how our economic system developed and how it worked; I highly recommend the book.

My short presentation here has one more point: notice the two meanings of the work economic or economy. The industrial engineer is concerned with finding the most economical way to perform a task in a production process; "economy" here means wise use of resources within the organization. The economist is concerned with understanding how the national economy works; "economy" here means the system for producing and distributing goods.

12.4 The factory and the manager

The changes discussed so far - interchangeable parts, new sources of power, specialization of labor, and the development of the corporation - all were involved in the development of factories, where workers, machines, power, and raw material were brought together in one site on a large scale, resulting in great increases in efficiency.

An agricultural society became an industrial and urban society. Work became centralized in cities, leading to a mass movement from rural areas to urban areas. In the United Kingdom, "urban areas (towns of 5,000 or more) contained about 13 percent of the population at mid-century [1750]; by the 1801 census they contained 25 percent." (Hughes, 62-63). London grew by about 170 percent from 1750 to 1831, but the county of Lancashire grew by about 400 percent during the same period (Hughes, page 61).

The factory changed the nature of work. Rural life may not always have been pleasant, but factory work was dirty, noisy, and often unsafe, involved long hours, and often paid poorly. The pace of work was set by others, not by the worker.

Legislation reduced some of the worst abuses. According to Hughes (page 65),

It came to be understood that the daily attachment of human beings to the ceaseless motions of machinery run by prime moves was destructive of human life.

Laws limited the working hours of children, regulated the use of women and girls in mines, and mandated some level of sanitation. Poor Laws created a system of poor relief.

While in the short run, many suffered, in the long run, the Industrial Revolution and the development of the factory, led to a great increase in the standard of living. The creation of the factory was accompanied by the growth of capital goods, that is, the "tools, equipment, machines, and buildings that society produces in order to expedite the production process" (Heilbroner and Milbert, page 70-71). Capital goods make human work more productive, meaning that more goods can be produced with the same amount of labor.

The workers no longer controlled the pace or other aspects of work, but the owner often did not take on that task either. The manager became the person who organized the factory and the work. Many aspects of the organization of work now performed by IEs, including facility layout and production scheduling, were done by managers now, not by workers. [where?] Specialization, a trend we have discussed earlier, often meant that a worker became skilled at a particular task. The factory, on the other hand, has supported a long term trend of deskilling. Noble, in his book *Forces of Production* argues that ....

Production methods have become largely a matter of specialized technical training instead of being based on the foreman's lifelong experience. (Drucker, page 144)

12.5 Analysis of work into parts:

Frederick W. Taylor (1856-1915) 1907 paper on metal cutting in Transactions of the American Society of Mechanical Engineers Frank M. Gilbreth (1868-1924) and Lillian Moller Gilbreth (1878-1972) What the term Taylorism means. One best way?

12.6 The assembly line

Henry Ford (1863-1947) was not the first to make a horseless carriage; he was not even the first to drive a gasoline powered vehicle on Detroit streets (pages 40 and 46, Watts). He wasn't the first to manufacture automobiles and the Ford Motor Company wasn't his first attempt to form a company to do so (his other attempts were unsuccessful). Between 1900 and 1908, 501 companies were formed in the US to manufacture automobiles (page 58, Watts).

What did Ford accomplish? First, he manufactured a car for the masses. Second, he, with others, invented the modern assembly line. And third, he paid his workers enough that they could buy the cars they made. These three contributions are intertwined and each succeeded only because of the other.

Ford's vision of "an inexpensive, simple lightweight car for a mass audience of buyers" won out over others at Ford Motor Company who wanted to make an expensive car for rich buyers (page 97, Watts). Through his production of such automobiles, through his role as a symbol of consumption, and through the car as the symbol of consumer prosperity, Ford helped create the idea of consumption as self-fullfillment and the idea of mass culture (page xii, Watts).

In 1903, the Ford Motor Company was incorporated and began producing Model As, with each car assembled as it rested in one spot; sales quickly followed. Working with Walter Flanders, Charles Sorenson, William C. Klann, and others, Ford created a new production system centered on the assembly line, where the car moved, each worker did specialized tasks at a fixed location, and parts were delivered as needed (pages 103-104, 142, Watts; Pages 79-81, Halberstam). The time to assemble a chassis dropped from over twelve hours to about one and a half hours (Watts, page 144).
The drive for efficiency seemed to be second nature to Ford (Watts, pages 14-15). "In his memoirs, My Life and Work, Ford explained away his aversion to labor [on his parents' farm]: 'My earlier recollection is that, considering the results, there was too much work on the place.' He added, 'Even when very young I suspected that much might be done in a better way.'" (Brinkley, page 9).
Ford continually sought improvement in the design of his automobile and in the design of the production system. Ford focused on the consumer, saying he started with consumer, then the design, then the manufacture (page 121, Watts). He used vanadium steel to reduce the weight of the vehicle (page 113, Watts). The plants were designed with "tightly placed machines discouraging the accumulation of work in aisles" so that "a continuous flow of production from site to site became the norm (Watts page 138). Halberstam argues that Ford, not Toyota, deserves credit for the just-in-time concept (page 88, Halberstam). Special purpose machines were designed and built to speed up each step. First operated in 1920, the River Rouge plant was located to use water transportation and laid out to facilitate efficient operations. Movement of product between buildings was accomplished by ninety miles of railroad track and movement within buildings used a network of conveyors and cranes (Brinkley, page 285). Waste was turned into useful products, although these operations were not always money makers. The slag left over from burning coal dust in the blast furnaces in the steel plant was used in a cement factory; ammunion sulfate fertilizer, another by-product, was also sold (Brinkley, page 286). By 1928, as Ford had envisioned, steel came in one end and cars came out the other -- only four days later. Ford was not bookish and while he "certainly never read Taylor, and there is little to suggest that his managers did, either -- much evidence indicates that the spirit of scientific management was in the air" at Ford. "The broad impulse to rationalize the labor system, to break down and reorganize its component parts, to eliminate waste motion through time-and-motion studies, and to select workers for tasks scientifically, animated Ford managers in the years when the assembly line was developed." (Watts page 153). Brinkley argued that Taylor's influence on manufacturing practice has been exaggerated, with Ford providing the large-scale demonstration of how to achieve efficiency (Brinkley, page140). Brinkley also points out that other Detroit automobile plants used advanced techniques, but Ford's contribution was the continual improvement of the assembly line (Brinkley, page 141). "New and better machinery was in constant development at Ford Motor Company. It was said, in fact, that throughout the long production run of the Model T, at least one new machine or tool was introduced at the factory every single day. Not much of importance may have changed on the T to make it new, improved, or different during its nineteen-year model run, but nothing remained the same about the methods used to produce it. That was the imperative laid down by Henry Ford" (Brinkley, page 151).
The scale of production was astounding. "In the assembly line's first year of operation [1913], output of Model Ts shot up from 82,000 to 189,000. By 1916, it stood at 585,000. In

1921, Ford produced one million automobles; by 1923, two million." (Watts, page 135). In 1923 the population of the US was xxx. The Highland Park plant covered 65 acres (page 14, Watts) and the River Rouge plant covered xx acres. In 1913, a Model T cost $500 (Watts, page 146). The average worker in the US earned xxx.

These two concepts - a car with mass appeal and the assembly line as a means for efficient production -- required each other. Because of the scale of production, efficient methods were possible; because of the efficient production methods, the price of the car could be kept low enough to have mass appeal. But the two ideas required a third idea.

Ford found that production by an assembly line allowed him to hire workers with less skill, some of whom were immigrants who spoke little English, making communication difficult (Ford started a school for immigrants), but he also found that such work and such workers led to turnover, absenteeism, and poor quality. "For example, daily absences ... in 1913 amounted to 10 percent; the rate of labor turnover during that same year reached a stunning 370 percent" (Watts, page 181). The gains in productivity from new methods had been impressive but were still disappointing.

In January 1914, the Ford Motor Company announced that it would pay its workers $5 per day, almost double what they had been getting. The decision was a combination of genuine desire to share the profits and reduce the worries of workers, a practical solution using good will to hire loyal employees, a way to reform and perhaps control workers (the $5 per day was paid only to workers if Ford investigators found they met certain moral and social standards in their private as well as work lives), and, perhaps most importantly, the desire to fuel consumerism. A worker making $5 a day could buy a car (Watts pages 182-184). Efficient production was linked to a mass market which now, in turn, was linked to the ability of ordinary workers to buy the product they were making.

Ford was an amazingly well known figure in America, although he significantly embellished his personal history, his accomplishments, and himself in order to promote himself -- and his product. Watts sets the story straight, for example, that, while Ford's father would have preferred his son become a farmer, they did not, as Ford told the tale, clash over the son's mechanical hobbies, especially watch repair, when Ford was a child. His book *My Life and Work* (1922) was a best seller (Watts page 4). In his second book *Today and Tomorrow* (1926), he pointed out that Americans now had to decide how to spend their leisure time (Watts page 110). He promoted camping, going camping with his friends John Burroughs (naturalist, poet, and philosopher), Thomas Edison, and Harvey Firestone; they called themselves the Four Vagabonds (Watts, page 159). He was portrayed in the press as "a man of the people, defender of the work ethic, and responsible steward of wealth who shied away from the glare of direct publicity" (page 174, Watts). Watts says that Ford's family minister, Samuel S. Marquis, concluded that "Ford's folk-hero image was partly genuine and party contrived, accurate in its essence yet self-consciously magnified" (page 176).

Ford was obviously a complicated human being. His dark side was shown in his autocratic domination, even humiliation of his only child, his son, Edsel Ford, who died at age 49 in 1943, Edsel's ill health at least exacerbated by the stress of working with his father. Ford was also a vicious anti-Semite. Ford's behavior during his defense in a slander trial brought by a Jewish labor organizer in the late 1920s and during labor unrest in the 1930s led many to change their opinion of him (Watts, page 462).

[What the term Fordism means to sociologists and historians. Charlie Chaplin Modern Times. Aldous Huxley Brave New World In the year of our Ford, with dates calculated from the date of the first Model T.]
Ford deserves to be remembered as a builder of systems. Thomas P. Hughes, in his book American Genesis, points out that inventions such as "the incandescent light, the radio, the airplane, and the gasoline-driven automobile, occupy center stage, but these inventions were embedded within technological systems" (page 3). Samuel Insull and others had in the early 1900s created a reliable electrical system (page 232). Edison, upon whose inventions this system relied, wrote about how each part of the system, including the lightbuld, had to work together (Hughes, page 73).

12.7 Worker rights

[Upton Sinclair, The Jungle. Safety National Safety Council founded in 1913. Cite reduction in accident rate. Goetsch p 4ff.]

12.8 Mobilization for World War II:

Drucker described the mobilization of production for World War II as being much more than replacing the machines in a plant from machines to make lamp shades to machines to make planes. He never uses the term "industrial engineering" but the following passage describes what IEs do:
"The wrecking of the old machinery, the new buildings, even the designing of the new machinery, were more or less incidental to the real problems and the real achievements of conceptual and human organization. First came the design -- not of machines but of the plan as an assembly of identical and interchangeable parts. Then came the analysis of each part as a problem in mass production, as something that is being produced in a sequence of elementary and basic operations, performance fast and accurately by an unskilled or semiskilled worker. Next came the task of merging the production of each part into a plant producing the whole -- a task involving three distinct problems of organization: one of people working as members of a team to a common end, one of technical processes, one of materials flow. Finally came the job of training thousands of new workers and hundreds of new supervisors many of whom had never seen the inside of a plant before. On those four pillars, design of the final product as a composite of interchangeable parts, design of the production of each part as a series of simple, repetitive operations, design of a plant to integrate human labor, machines, and materials into one whole, and training in skills and in teamwork, rested every achievement of our war production" (pages 32-33, Drucker, The Concept of the Corporation, 1983)
Drucker points out that mass production is

> "based on the combination of three factors: standardization and interchangeability of parts; a principle of production which sees each process as a composite of elementary and unskilled manipulations; and a principle of materials control which aims at bringing all pieces needed for any given step of the operation to the operator at the same time" (page 154-5).

Operations research (called operational research in Britain) was also developed during World War II. This research on operations helped improve the effectiveness of the use of people and machines. The book *Methods of Operations Research* (First Edition, revised, 1951) by Philip M. Morse (Dr. Morse was my academic grandfather: his Ph.D. student, Robert M. Oliver, was my academic advisor for my Ph.D.) and George E. Kimball collected material written by various authors during the war, and was first published as a classified document shortly after the war. The book describes how quantitative analysis of data, quantitative reasoning, and experimentation were used to improve aircraft search for submarines, the setting of depth charges when dropped on submaries, the appropriate maneuvers by a ship to evade an incoming suicide plane, and more.

12.9 Japan after World War II:

The recovery of Japan after World War II has many explanations: Japan was forbidden to be involved in military industries, the Japanese concentrated on consumer products; powerful conglomerates of industry and banks (zaibatsus) poured money into selected companies; the Japanese people consented to great sacrifices in order to support the recovery.

The Japanese themselves point to American W. Edwards Deming as one factor in their success. During the War, Deming was one of many who helped apply statistical quality control methods developed by Walter Shewhart at Bell Labs to help with the industrial mobilization. After the war, Deming was disappointed by American industry's rejection of these methods. Deming visited Japan after the war as representative of the US government, to help the Japanese set up a census. He met with Japanese engineers interested in applying Shewhart's methods. In 1950, the Japanese Union of Engineers invited Deming to give a series of lectures on quality control, which were attended by top Japanese industrialists.Within months, they found amazing increase in productivity and statistical quality control took off in Japan. "The top people came to Deming with a desire to learn that bordered on obssession." (Halberstam, page 316). The Japanese integrated the statistical methods into their companies, involving all the workers in the movement to improve quality.

American industry flourished in the postwar boom in the US, but found itself getting hints and finally clear indications of Japanese competition in the 1970s. Halberstam tells how Hal Sperlich, a Ford executive, visited a Japanese auto factory in the early seventies and was amazed to find that the factories had no area dedicated to repairing shoddy work; in fact the plant had no inspectors. "Sperlich left that factory somewhat shaken: In America, he thought, we have repair bins the size of football fields" (Halberstam, page 716). William Ouchi wrote that when he began to study Japanese practices in 1973, there was little interest in the US in his findings. When his book, Theory X, was published in 1981, interest had grown tremendously and the book was a best seller. However, even in 1981, a top officer in Motorola warned American manufacturers of computer chips that they were complacent and not paying enough attention to Japanese quality (Warshofsky, page 14). In 1981, Ford engineers compared automatic transmissions, some built by Mazda for the Ford Escorts, and some built by Ford. "The ones made in Japan were well liked by our customers; many of those from Ohio were not. Ours were more erratic; many shifted poorly through the gears, and customers said they didn't like the way they performed." The difference was due to the tighter tolerances in the Japanese made transmissions. (Peterson, page 15).

In 19xx, NBC aired a documentary If Japan Can, Why Can't We. The documentary explained what Japan was doing and especially stressed the contributions of Deming. Donald Peterson, then president of Ford, was one of many CEOs motivated to call Deming. Deming said his phone rang off the hook.

Deming began with statistical quality control, but he recognized that success depended on involving everyone. His 14 points are a manifesto for worker involvement and worker pride. Peterson sent teams from Ford to visit Japanese companies: "Before those visits, many of the people at Ford believed that the Japanese were succeeding because they used highly sophisticated machinery. Other thought their industry was orchestrated by Japan's government. The value of our visits, however, lay in Ford people's discovery that the real secret was how the people worked together -- how the Japanese companies organized their people into teams, trained their workers with the skills they needed, and gave them the power to do their jobs properly. Somehow or other, they had managed to hold on to a fundamental simplicity of human enterprise, while we built layers of bureaucracy" (Peterson, page 20).

In a return to using the brain, not just the brawn, of the worker, the Japanese methods, building on Deming, actually deTaylorize work. "The classical Taylor model of scientific management, which favored the separation of mental from physical labor and the retention of all decision making in the hands of management, is abaondoned in favor of a cooperative team approach designed to harness the full mental capabilities and work experience of everyone involved in the process ..." (Rifkin, page 97).

While Deming's principles as filtered through the Japanese methods argue for reskilling work and reject of Taylor's belief that workers should just do what they are told, Taylorism lives on, only now it is called McDonaldization.

Taiichi Ohno, Toyota Production System developed between 1945 and 1970.

While the US had much to learn from Japanese methods, careful observers realized that the differences between Japanese and American societies were so great that not all ideas could be imported (some of the cooperation among Japanese companies would violate US antitrust laws), that the Japanese methods were not always what they seemed (for example, life time employment was limited to a minority), and American companies, unheralded, were already using many of the new Japanese methods. Ouchi in Theory Z, examined Japanese practices in their treatment of workers, distilled them to the central ideas which he called Theory Z, and discovered that the best examples of Theory Z management were American companies.

12.10 Programmable controls, computers, and communication technology

Computation has been a goal since prehistoric times. We use a decimal counting base because humans first used their hands, with ten digits, to count and to compute. The Mayans used a base 20 system, perhaps counting on fingers and toes. Stonehenge, the large stone structure near Salisbury, England, is just one example of a computer for astronomical events. Archaeoastronomy is the study of such ancient sites, including the Great Pyramid in Egypt, Mayan structures in Yucatan, Mexico, and astronomical structures in Chaco Canyon, Arizona. Many sites in the Western United States have rock carvings that function as solar calendars.

We owe a large debt to contributions from Arabic mathematicians, as shown in the Arabic roots of words like algebra and algorithm.

Explorers and travelers needed accurate navigational tools and computation. Geoff Watts wrote about the need for accurate tide charts:

"I was in a West Indies ship running for a bar harbour in Ireland ... when we beat off our gripe, rudder and a great deal of the stern port, and an after part of the keel upon the bar, and had seven feet water in the hold, and was obliged to run on shore to prevent sinking." William Hutchinson, dock master of the Old Dock at Liverpool, knew from experience what could happen if you misjudge the tide.

In the 18th century, ships on their way into port were frequently stranded or holed when they unexpectedly hit a sandbar or rammed the stone sill at the dock entrance. The common methods of predicting the height of the tide were woefully inadequate and such accidents were an occupational hazard.

The modern computer has roots in the invention of digital logic by George Boole (1815-1864) and the designs of the Difference Engine and Analytical Engine by Charles Babbage (1792-1871). Boolean logic allows numerical calculations to be performed by mechanical operations on switches, each of which can be on or off. Babbage and other inventors were hampered by the slowness and lack of precise tolerances of known technologies, but progress continued to be made; numbers from the 1890 US census were tabulated by a punched-card machine invented by Hans Hollerith (1860-1929).

Campbell-Kelly and Aspray also describe the roots of computing in business machines, used for calculating and accounting. They describe developments during the end of the 18th century (page 28):

Two lines of development emerged in this period: The basic technologies of small calculating machines, such as desk calculators, accounting machines, and cash registers, were settled; and a business machines industry was established to build these machines. The U.S. government supported the development of the first large-scale calculating technology, the punched-card system. However, during the nineteenth century neither of these technologies was widespread. Accurate figures are hard to come by, but we know, for example, that Burroughs, the leading accounting machine manufacturer, sold only 236 machines in 1895. Hollerith had almost no business in the 1890s after the census was tallied, and his company was reduced to four employees. But as the new century dawned, these technologies began to catch on.

The invention of the vacuum tube in the early 1900s opened new possibilities. John Mauchly (1907-1980) and J. Presper Eckert (1919-1995) are usually credited with building the first serious computer, the ENIAC, commissioned by the US Department of Defense. It used 18,000 vacuum tubes, consumed huge amounts of electricity, and emitted huge amounts of heat.

An even better on/off switch was invented in 1947 by a team at Bell Laboratories, the transistor. Other crucial inventions include the integrated chip (with transistors and other electronic components embedded in a single piece of silicon, reducing the need for the often faulty soldered connections), the microprocessor (a computer on a chip), and various inventions allowing even more transistors to be packed into a smaller space.

The invention of computers and the growth in their use has been fueled by three types of use:

1. office uses: document preparation; information storage and retrieval; accounting computations and financial records; and the tabulation of data, such as census results.
2. science and engineering uses: calculations for tables, such as the calculation of tide tables; military uses such as the calculation of ballistic flight paths and calculations for the design of atomic bombs and other weapons;
3. manufacturing production and control: automation of production, for example, the Jacquard loom;

12.11 The future

[Sustainability - economic, environmental, use of people as workers]
[Nanotechnology - how important? how big a difference?]
[biology based products - how important? how big a difference?]
[Globalization - blame faults of US management on US workers.]

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I recommend the following web sites to you as good sources of definitions and explanations of topics discussed in this book.

- The Improvement Encyclopedia
- iSixSigma
- Quality Encyclopedia