INTRODUCTION TO INDUSTRIAL ENGINEERING

SECOND EDITION

Avraham Shtub • Yuval Cohen

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INTRODUCTION TO

INDUSTRIAL ENGINEERING

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Industrial Innovation Series

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To my wife Ailona Shtub—Avi Shtub

To my family—Yuval Cohen

Contents

Preface

This book presents the major tasks performed by industrial engineers, and the tools that support these tasks. The focus is on the organizational processes for which these tasks are needed, and the terminology used to describe the tasks, tools, and processes. The tools discussed here are basic tools that do not require in-depth knowledge of mathematics, statistics, psychology, or sociology. The book also examines the role of the industrial engineer in the production and service sectors. The intention is to help new students understand current pathways for professional development, and help them decide in which area to specialize during the advanced stages of their studies.

This book delineates the broad scope of areas in which industrial engineers are engaged, including areas that became part of industrial engineering (IE) in recent decades such as information systems, supply chain management, and service engineering. These fields are becoming an important part of the IE profession, alongside the traditional areas of IE such as operations management, project management, quality management, work measurement, and operations research. Industrial engineers require a strong understanding and good knowledge in all of these fields in order to perform their tasks.

This book contains the following chapters.

Chapter 1. Introduction

Here we discuss the nature of the IE profession and provide answers to basic questions such as

- What is engineering?
- What is IE?
- What is the IE profession?
- How do you acquire this profession?

Other points covered in this chapter are

- The system concept and its implementation in manufacturing and service.
- Tools needed by industrial engineers in order to perform their jobs.
- Frequently used methods of teaching in this field.

To give students a historical perspective, we show the development of the profession from its early days until recent years. Today, the profession must take into consideration the intense competition in industry due to globalization. Elements of competition include

- Cost reduction
- Shortening delivery times—time-based competition
- Quality improvement
- Achieving maximum flexibility

These elements of competition are the essence of the challenge facing industrial engineers. They are charged with designing systems and organizations that not only survive in the global competitive environment but also succeed.

Chapter 2. Organizations and Organizational Structures

This chapter deals with the organization of people and resources in order to achieve organizational goals. The chapter begins by explaining the need for a well-designed organization of human resources. Classical organizational structures are presented as

- Functional organization
- Project organization
- Matrix organization

Relative advantages and disadvantages of each of these organizational types are discussed, with an emphasis on communication, responsibility, and authority as tools for achieving a competitive advantage.

The discussion leads to the question of which organizational structure is best for today's competitive environment and the conclusion is that the organization must be (1) modern, (2) process based, and (3) supported by an appropriate information system. These three conditions are essential for success.

In addition to the organization of human resources, other resources such as production resources must also be efficiently organized. Production resources are mainly machines and equipment such as material handling equipment. The chapter reviews different layouts used to organize these resources:

- Flow shop

- Job shop
- Cells of group technology-based layout

Advantages and disadvantages of these layouts are discussed, alongside a survey of the fixed location layout where people, material, and equipment are transported to the place of work. This layout is quite common in nonrepetitive environments or projects such as home or ship building.

The relationship between the organizational structure and equipment layout leads to a discussion on processes in production and services and how these processes should be organized.

Chapter 3. Project Management

This chapter discusses organizations that perform projects (i.e., nonrepetitive undertakings). The discussion opens with a mapping of a project's stakeholders and understanding their needs and expectations from the project. Needs and expectations are translated into a conceptual design, using special decision-making tools to choose between technological and operational alternatives. Analysis of the cost/benefit/risk and time is discussed and the appropriate analytical tools are presented. A review of the project life cycle serves as a guideline for displaying methods for scheduling, budgeting, management, and control of projects, with emphasis on the relatively simple methods used in the industry.

The discussion of project management leads to discussion on information and its use—especially, turning data into information that supports decision making.

Chapter 4. Information and Its Uses

This chapter extends the discussion on data and information. It examines data collection, storage, retrieval, and processing, and using appropriate models to create the information necessary to support decision making.

The discussion emphasizes the following topics:

- Quality of information
- Data collection methods and how to use raw data to create useful information
- How to forecast future data

The chapter aims to develop a basic understanding of the nature of information systems, decision support systems, and database systems. We show the relationship between the knowledge base and models used to analyze data and to support decision-making processes.

Chapter 5. Marketing Considerations

This chapter is the first in a series of two chapters focusing on the interface between the industrial engineer and other professionals within the organization. This chapter deals with the customers, while the following chapter deals with suppliers and subcontractors. We present the tool that links production to marketing—the Master Production Schedule—and discuss the relationship between inventory and delivery times. The chapter introduces the classic dilemma between having high levels of inventory (for which a price must be paid) and the resulting shorter delivery times and lower inventory levels causing longer lead times. We discuss some policies including

- Make to stock
- Make to order
- Assemble to order
- Design/engineer to order

Chapter 6. Purchasing and Inventory Management

The industrial engineer must understand the organization's relationship with suppliers and subcontractors. Procurement is important in the competitive world, and this chapter discusses some key points of this topic:

- What to buy from suppliers and subcontractors and what to make in house—the make or buy problem.
- If the decision is to buy, how to find suitable suppliers to form a list of candidates.
- How is a supplier chosen from the list of suitable suppliers?
- How to manage the relationship with the supplier over time.

When it comes to purchasing materials, inventory management issues are also important such as

- How often to order?
- What quantity to order?
- What are the costs associated with inventories?
- What are the advantages in maintaining inventories?

Resolving these issues is not simple, and there is a need for decision support tools. This chapter presents the basic models and the assumptions underlying each model.

Some purchasing decisions are repetitive, and some are not. How these decisions are made and how to take advantage of procurement and inventory to achieve competitive advantage are the main subjects of this chapter.

Chapter 7. Scheduling

This chapter focuses on scheduling the organization's operations. Scheduling an organization's operations is dependent both on marketing and the interface with customers (Chapter 5) and on procurement and the interface with suppliers (Chapter 6).

Scheduling issues exist in both manufacturing and service systems. Competition drives many scheduling goals and constraints. After setting scheduling goals and constraints, the industrial engineer has to select the right scheduling method.

Our discussion starts with scheduling of the job shop. Next, we discuss the scheduling of the flow shop, and finally we present a general discussion about scheduling, using a concept of the Toyota production system (TPS): Just In Time (JIT), and we also discuss the Theory of Constraints (TOC) that focuses on scheduling bottlenecks.

We explain the logic of simple scheduling methods and provide examples highlighting the effectiveness, advantages, and disadvantages of these methods.

Chapter 8. Material Requirements Planning

This chapter introduces the basic computerized approach for managing production and procurement of material. Material requirements planning (MRP) was developed in the 1970s when the price of computers dropped enough for commercial organizations to be able to buy them. The method is based on simple logic and common processing of data from multiple files including

- The bill of material (BOM) file
- Inventory files
- The master production schedule (MPS)

Processing these files enables detailed planning and coordination between procurement and manufacturing activities. MRP logic comprises several components such as

- Gross to net
- Time phasing
- Lot sizing

MRP systems are the basis for planning and management of material in many organizations. It is important that industrial engineers understand, early on in their studies, the logical principles underlying these systems.

The discussion in this chapter reveals the weakness of the first generation MRP systems, which did not include mechanisms for planning production capacity. Solutions to this problem were developed later in the form of rough-cut capacity planning and capacity requirement planning (CRP).

Chapter 9. Enterprise Resource Planning

This chapter presents a framework of the information systems that manage the entire enterprise: enterprise resource planning (ERP) systems.

ERP systems are advanced organizational information systems, and many organizations have implemented them.

Industrial engineers play a major role in implementing these systems. Their tasks include, among others:

- Setting the system requirements
- Defining organizational processes
- Choosing the suitable system for the organization
- Recruiting participants
- Implementing the ERP system

We explain the principles of ERP systems and discuss their selection and implementation.

Chapter 10. The Human Factor and Its Treatment

This chapter presents principles from psychology, sociology, and ergonomics that industrial engineers use in their work.

Industrial engineers must learn how to integrate the human factor as a key component in their analysis and design. Questions concerning motivation, team-building, leadership, and organizational learning are discussed in this chapter, focusing on integrating the human factor in the different systems. In addition, industrial engineers must have knowledge of ergonomics in order to fit the environment and the task to the human operator. The chapter introduces basic issues in ergonomics and human–machine interface that are often used by industrial engineers.

Chapter 11. Supply Chain Management

In this chapter, we explain the need for the management of supply chains. Each organization is a link in the chain receiving goods and/or services from its suppliers and supplying goods and/or services to its customers. The end customers can choose between products produced by alternative supply chains. Thus, a competitive supply chain must act as a coordinated team to reduce costs and provide high quality products in a competitive time and with flexibility.

Characteristics of supply chains and the bullwhip effect are discussed and explained as the basis for understanding the advantage of managing the chain in an integrated manner. In particular, we emphasize the importance of information systems and their integration along the supply chain.

Primary considerations in the design of supply chains are discussed, including the selection of participants in the chain, and the design of interfaces between participants. Finally, the chapter discusses the necessary information for supply chain design, implementation, monitoring, and control of the chain's operations.

Chapter 12. Service Engineering

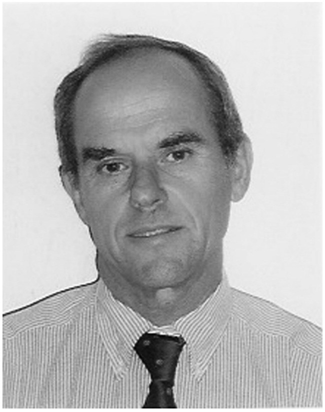
This chapter opens with a review of service processes, and the characteristics of service systems and service systems design. Next, we discuss arrival processes and randomness inherent to these processes. The calculation of queue lengths and waiting times in simple systems is discussed and the relationship between the level of service and the workforce is explained, including the tradeoff between waiting time cost and service capacity cost.

The chapter presents simulation as a major tool in analyzing service systems, which have inherent uncertainty in their processes. Simulation is an invaluable tool in analyzing the effect of service capacity (e.g., number of servers) on waiting times, queue length, and service level.

We also introduce basic considerations regarding reliability, maintenance, and issue of warranty.

Finally, the chapter ends with a discussion of the important subject of customer feedback that often needs to be actively explored using various techniques including questionnaires.

Authors



Professor Avraham Shtub holds the Stephen and Sharon Seiden chair in project management at the faculty of Industrial Engineering and Management of the Technion—Israel Institute of Technology. He earned a BSc in electrical engineering from the Technion—Israel Institute of Technology (1974), an MBA from Tel Aviv University (1978), and a PhD in management science and industrial engineering from the University of Washington (1982).

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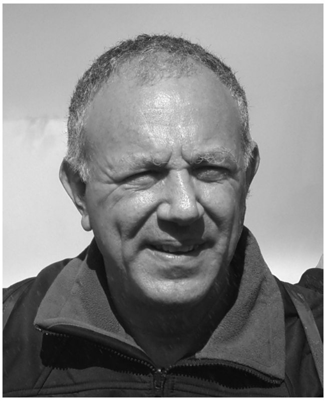
Professor Shtub was a department editor for *IIE Transactions* and was on the editorial boards of the *Project Management Journal*, *The International Journal of Project Management*, *IIE Transactions*, and the *International Journal of Production Research*. He was a faculty member of the Department of Industrial Engineering at Tel Aviv University from 1984 to 1998 where he also served as a chairman of the department (1993–1996). He joined the Technion in 1998 and was the associate dean and head of the MBA program.

He has been a consultant to industry in the areas of project management, training by simulators, and the design of production operation systems. He has been invited to speak at special seminars on project management and operations in Europe, the Far East, North America, South America, and Australia.

Professor Shtub visited and taught at Vanderbilt University, The University of Pennsylvania, Korean Institute of Technology, Bilkent University in Turkey, Otego University in New Zealand, Yale University, Universidad Politécnica de Valencia, and the University of Bergamo in Italy.



Yuval Cohen is a senior faculty member at the Industrial Engineering Department of the Tel-Aviv Afeka College of Engineering. Previously, he was the head of the Industrial Engineering Program at the Open University of Israel. His areas of expertise are planning and operation of assembly lines, design and management of production and logistic systems, project management, supply chain management, and business decision making. He has published many papers in these areas. Dr. Cohen served several years as a senior operations planner at FedEx Ground (USA) and received several awards for his contributions to hub and terminal network planning. Dr. Cohen earned his PhD from the University of Pittsburgh (USA), his MSc from the Technion—Israel Institute of Technology, and BSc from Ben-Gurion University. Dr. Cohen is a fellow of the Institute of Industrial Engineers (IIE), and a full member of the Institute for Operations Research and Management Sciences (INFORMS).

1

Introduction

Educational Goals

This chapter presents the profession of industrial engineering (IE), the broad scope of areas in which industrial engineers are engaged in manufacturing and services, the market in which they operate, and the roles that they play in the economy.

Understanding the historical background is an important component of the training in IE. The following historical review highlights significant events and people that have contributed to the development of the profession.

We explain the need for integrated processes, supported by modern information systems, with an emphasis on the competitive market today.

1.1 Definitions and Examples Related to Industrial Engineering

1.1.1 Engineering

The Merriam-Webster dictionary defines engineering as the design and creation of large structures such as roads and bridges or new products or systems by using scientific methods.

According to the Merriam-Webster dictionary, "to design" is to plan and make decisions about something that is being built or created—to create the plans, drawings, etc., that show how something will be made.

Engineering design is a process of translation of requirements, specifications, and needs into a language understood by the people responsible for making the new product, service, facility, or system.

For example, the civil engineer translates the requirements for transporting a volume of traffic over a water barrier into the design of a bridge, including the geometry of the bridge, quantities of materials required to construct the bridge, the processing of materials, the layout and assembly of the parts, and finally the testing of the bridge during its construction and after its completion. The design is in a language understood by construction workers, purchasing agents, suppliers, subcontractors, quality control experts, and so on.

1.1.2 Industrial Engineering

According to the Merriam-Webster dictionary, IE deals with the design, improvement, and installation of integrated systems (as of people, materials, and energy) in the industry.

Modern IE is concerned with the design, management, and control of operational processes. For that purpose, IE combines classical knowledge in physics, mathematics, computing, and statistics with tools for incorporating the human factor, ergonomics, sociology, and psychology.

For example, in the design of a new business branch, industrial engineers plan the work packages and their allocation to operators. Industrial engineers also design the work positions using their knowledge of ergonomics, facility layout planning, and efficient work planning.

1.1.3 Industrial Engineers

Industrial engineers design organizational processes and perform projects and ongoing activities that may involve facilities, products, and systems. The facilities, products, systems, and processes are used to supply products or services. Industrial engineers often focus on processes that take into account the human factor. For designing organizational processes, industrial engineers collaborate with managers and their subordinates, and sometimes with peers, such as engineers (e.g., mechanical engineers, electrical engineers, software engineers, etc.).

An industrial engineer is also involved in determining how to best utilize the resources of the organization. Resources such as workers, raw materials, capital, information, buildings, equipment, energy, and technological knowledge are used by industrial engineers to perform their tasks. Industrial engineers translate the goals of the organization, the constraints imposed, and the uncertainty, to find the best solutions for the organization. They do so by utilizing the rules of physics, mathematics, and statistics along with human factor related knowledge, such as ergonomics and psychology, and the rules of law, morality, and ethics.

A relatively new area of industrial engineering is the design and implementation of information systems that supports processes. In the past, industrial engineers integrated material requirement planning (MRP) systems into industrial organizations. Later on, they played a vital role in the incorporation of enterprise resource planning (ERP) systems in many organizations. Today, many industrial engineers work with ERP systems on a daily basis. With the advent of supply chain management, some industrial engineers entered the challenging world of interorganization data sharing.

1.1.4 Production/Service Systems

Some organizations are engaged in the production or supply of products. Other organizations provide services and some do both. These organizations use systems to perform their operations. We define a system as a collection of resources such as people, computers, information, machinery, and facilities working to achieve a common goal. The role of this system is to transform "inputs" such as raw material, energy, and demand information into "outputs," which are products, information, and customer service. The output may include damaged items, which should be avoided or minimized as much as possible.

1.1.5 What Do Industrial Engineers Do?

Industrial engineers are involved in designing organizational processes, performing projects and ongoing activities, and planning their operations. This includes a large variety of activities. A partial example includes, among others, the following: Design of production and service systems, design and implementation of processes, production management, design of supply chains, planning and managing supply-chains operations, project management, economics analysis, quality control, and design and operations of information systems.

1.1.6 Tools Used by the Industrial Engineer

To succeed in his or her job, the industrial engineer needs understanding, skills, tools, and techniques in a variety of fields. We will review the skills necessary and demonstrate how these skills are used in the case of a company in the automotive industry.

1.1.6.1 Understanding "Engineering Language": Drawings, Specifications, etc.

For example, in the production of cars, engineering design passes the detailed drawings of the car to production engineering. An industrial engineer in a production engineering department will translate the design into a bill of material with information regarding the car assemblies, subassemblies, and the parts from which it is composed, determine which machines will be used in order to produce parts, design the supply chain that supplies car parts not manufactured by the factory, etc.

1.1.6.2 Understanding the Physical Processes, Knowledge of the Basic Laws of Physics

Physical processes affect machine operation, maintenance, quality, and efficiency, as well as human performance and the associated ergonomics.

Dexterity requires a compact comfortable work environment. It also requires lightweight tools and parts that are easy to handle and manipulate.

The manufacturing process of a product is a process that combines a sequence of operations, performed by machines and humans, aimed at transforming raw materials into a finished product. The industrial engineer must understand the process and the physical principles involved in the process such as metal cutting, forging, etc.

For example, in car assembly lines such as those used by Toyota or General Motors, quality problems are caused by physical processes. Industrial engineers should be able to analyze these problems and find effective solutions. Physical factors also affect the load and human posture of the assembly operator. The industrial engineer should be able to identify problems along the assembly line, and use ergonomic principles to design solutions for the problematic workstations.

1.1.6.3 Knowledge of Economics and Financial Management

The industrial engineer's main role in many organizations is contribution to the bottom line profits. Therefore, operational decision making involving intensive financial considerations is a main specialty of an industrial engineer. Investment decisions, and the effects of interest rate and taxation, are common problems that an industrial engineer should be able to tackle. Such problems appear in a car assembly line when buying a new machine or improved conveyor system. In service industries, these problems may be connected to the number of waiting positions (such as car spaces in a parking lot, number of chairs in a dentist waiting room, etc.).

Industrial engineers have to decide what to produce inhouse and what to buy. For purchased items, they must decide from which country and which supplier to buy in order to minimize cost and maximize quality. The industrial engineer must make a decision that combines economic considerations, like the cost of production in each country and the cost of transportation of the various parts between the countries, as well as aspects of taxation and customs that should be considered in the decision process.

1.1.6.4 Understanding Mathematical and Statistical Models

For example, in determining the size of production batches on a machine with long set-up time (the time to switch from one operation to another) compared to the time needed to process a single item, it might be better to produce in large batches to reduce the number of set-ups and, thus, the total machine time required. However, large batches create large and expensive inventories.

To solve this problem, mathematical models trade off the desire to minimize set-up times and consequently produce large batches and the desire to minimize inventories by producing small batches "just in time." When demand is random, that is, uncertain, the problem is harder to solve and the industrial engineer must use statistical tools to determine the size of each batch.

1.1.6.5 Knowledge of Human Resources Management

Since human resources are the center of any organization, and since industrial engineers are the designers of organizational processes, they need knowledge of human resource management. Some examples of the areas that they need to understand are task design, workplace design (ergonomics), workforce scheduling, determining incentives and remunerations, etc.

For example, the decision to implement an incentive-based payment system and how to apply it is a traditional task of industrial engineers. Understanding the structure and the pros and cons of such systems is important, as different employees performing different tasks in different departments of the same organization may react differently to the same incentive-based payment system. Therefore, proper selection and implementation of such systems is crucial.

1.1.6.6 Knowledge of Computerized Information Systems

Organizations handle and generate vast amounts of data in the course of their operations. Daily data updates are commonplace in areas relating to inventories, orders, quality, production, deliveries, workforce, maintenance, sales, payments, etc. No organization can efficiently operate without this data stored and optimally accessed and organized by a computerized information system.

Efficient scheduling of resources such as machines and employees and their integration with the timing of material supply requires advanced information systems that can process huge amounts of data, transforming it into information that supports management decisions.

For example, the final assembly of cars, which consists of thousands of parts manufactured by thousands of operations and supplied by hundreds of suppliers, needs to be scheduled. To schedule such operations efficiently, an enterprise information system is necessary. Industrial engineers define the requirements for these enterprise information systems, and help install, adapt, modify, and integrate such systems for the organization.

1.2 Models

Problem solving and decision making are important parts of the job of the industrial engineer. Textbooks and courses are often organized according to the types of problems. Industrial engineering textbooks have chapters dealing with problems related to inventory, production scheduling, service

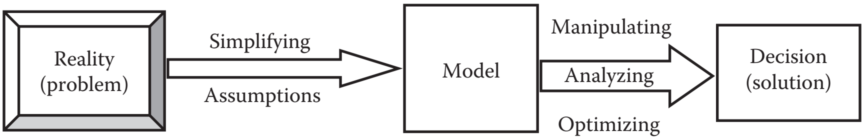


FIGURE 1.1
Models and their use.

system design, procurement, and the like. One of the primary tools presented to students in all their classes and textbooks, which will become a part of their professional toolkit, is problem modeling.

A model is a simplified presentation of reality. Many real problems are very complex due to their size, the number of different factors to consider, and the dynamic and stochastic nature of interactions between many of these factors. By using simplifying assumptions, one develops a model of the problem. A good model of a real problem must not only be simple enough to understand and analyze but also be sufficiently a representative of the real problem so that, its solution can be implemented successfully on the real problem.

Many models are mathematical ones. Most mathematical programming models define an objective function and a set of constraints. Such models are designed to find the values of the "decision variables" that meet the constraints, while minimizing or maximizing the objective function.

Conceptual models are also common. An organizational chart, for example, is a model that conceptually describes the relationships among members in the organization.

When the level of uncertainty is high, statistical or stochastic models that represent the uncertainty of the real problem are used. Such tools include regression analysis and stochastic dynamic programming.

When decision makers analyze a model, they are trying to find a good solution to the problem that the model represents. This solution is appropriate for solving the original problem if it is not too sensitive to the simplifying assumptions underlying the model. Therefore, a sensitivity analysis of the solution obtained must be performed to assess its suitability for solving the original problem. The relationship between the original problem, the model, and the solution is shown in Figure 1.1.

1.2.1 Use of Models

Models are frequently used for routine repetitive decisions. A computer can handle some of these decisions automatically. Inventory management in a supermarket is a typical example of routine decisions: Orders for new shipments are required when the existing inventory level drops below a certain level. The value of this so-called "reorder level" or "order point" is calculated by fitting a model. Computer software can be set up to continuously monitor and update the level of inventory available based on transactions recorded at the checkout counters and order automatically from suppliers when the inventory level drops below the reorder level.

Commercial business software packages are designed to support routine decisions. For example, software systems based on the logic of MRP automatically issue production and purchasing orders of certain items. These systems also provide data about past events, inventory, etc. Historical data are essential for the development of policies and are used to support the cost estimates of labor and materials, needed for bidding and marketing.

Models can be used to solve nonroutine or ad hoc problems as well. A map is an example of such a model. A tourist can find his or her way in a city he or she never visited before using a map that represents real streets and available attractions. The map has only two dimensions and in reality there are three dimensions, it is much smaller than the real city, and it is static while in the real city people and vehicles are moving. Despite all the simplifying assumptions, following the route from an origin to a destination on the map can help the tourist find his or her way in the real city. In much the same way, industrial engineers use various charts that model various aspects of processes (e.g., flow, quality, etc.).

While a map and a chart are static models, industrial engineers often use dynamic simulation modeling to check different scenarios and support a decision-making process seeking the best scenario. This is discussed next.

1.2.2 Dynamic Aspect: Simulation and Dynamics Systems

Simple models such as a map are static in nature, that is, these models present a snapshot at a given moment of the organization and its environment. In reality, time plays a very important role in decision making. Values of key parameters change over time. These include various factors in the organization and its environment, which are dynamic. Information is collected over time. Competitors enter the market and develop new products at certain points along the timeline.

Lecturers and practitioners in industrial engineering strive to integrate the dynamic aspect into their models. In the 1960s, the system dynamics approach was developed as a new tool for analyzing the dynamic nature of systems and processes (Forrester, 1961, 1968). Advanced simulation modeling tools are based on the system dynamics approach.

Forrester modeled systems and processes using two types of entities: Levels and rates. Rates generate changes in the levels, and levels are used as state variables so that the value of the levels at a given time determines the state of the system.

Consider the following example of system dynamics: The fuel system in a car is analyzed to develop the best strategy for refueling the car. The objective is to minimize fuel cost, and the constraints are the capacity of the fuel tank and the location of fueling stations. The rate of the car's fuel consumption is determined by factors such as speed, load, road conditions, etc.

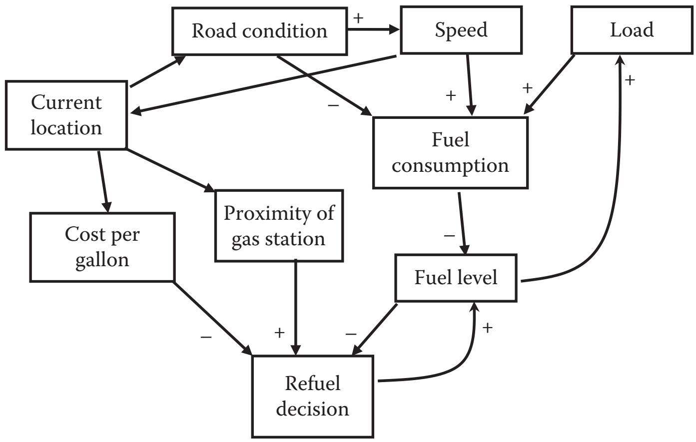


FIGURE 1.2
Levels and rates flow diagram (+ is positive correlation, – is negative).

Most drivers (decision makers) base their decision on when to refuel on factors such as the current fuel level, the distance to the next fueling station, and the cost per gallon/liter of fuel at each station. Figure 1.2 shows the relationship between levels and rates in this example.

Another simulation model is discrete event simulation (DES) developed at IBM in 1961 by Geoffrey Gordon and initially called general purpose simulation system (GPSS). Since the development of DES, many simulation languages have been developed and evolved. For example, SIMULA evolved into BETA and its concepts are used in SimPy (Python based DES library). SLAM (simulation language for alternative modeling) evolved into SLAM-II, which developed into SIMAN, and finally into ARENA simulation software. Since the turn of the twenty-first century, many other DES software packages have emerged: Promodel, Simul8, SimEvent, Plant Simulation, and SimCAD Pro—to name a few. Modern simulation languages are user-friendly, powerful, and flexible. Simulation is considered an important tool that is used by industrial engineers for analyzing complex systems, most of which include random processes.

1.2.3 Simulation Models and Decision Making

When using simulation as a tool for decision support, the simulation model presents three aspects of the real world:

1. The flow of objects such as materials, equipment, and people
2. The flow of information
3. The decision-making process

In the inventory system simulation example, the flow of material deals with materials entering the system, their storage, and exit from the system. Information related to the flow of materials is collected during the simulation run. The user can see the exact time when a unit of material is created, and when it moves within the system or leaves it. The data collected during the simulation serve as a basis for understanding and analyzing the inventory system.

The logic of decision making is part of the simulation model. Such logic can be based, for example, on a simple model that recommends issuing an order for new materials each time the inventory level drops below the designated order point. In this case, the order level is the decision variable, and the simulation compares system performance for various reorder levels. The parameters of the model's input and the logic by which it operates are built into the simulation model. The advantage of this approach is that one can try out a large number of different decision rules by running the simulation. One more advantage is the possibility of running large simulations offline, that is, when the decision makers are not present. For example, the model can run at night, and in the morning the users get the results for analysis.

The disadvantage of using simulation for decision making is that in real life many decisions are based on intuition and experience, and it is very difficult (sometimes impossible) to program a computer to model intuition and experience. Furthermore, in many organizations, decisions are made by a group of employees from different fields. Group decision making is a very complex process, and there is not enough knowledge to model it with a reasonable degree of precision.

1.3 Teaching Industrial Engineering

IE is taught through lectures, books, and projects; mostly using two approaches:

1. *The case study approach:* based on the analysis of events/specific situations. Some case studies describe real problems and some describe imaginary situations. Each event presents a particular problem and students discuss the problem, analyze it, and find an appropriate solution.
2. *The modeling approach:* based on the development of models designed to handle the most important aspects of a problem. Some models are based on mathematical programming tools (e.g., linear programming), statistical tools (e.g., regression analysis), search techniques (e.g., genetic algorithms), and simulation. These tools are used to get insight into the model and the problem it represents.

For example, consider the relationship between the price of a product and the demand for this product. Assuming that there is no randomness, a mathematical expression will find the price that will maximize revenue. The mathematical expression is a simple model that shows the relationship between the price and the resulting demand. Using calculus, it is possible to find the optimal price that will maximize revenues. If randomness is considered, a mathematical expression may enable finding the optimal expected (mean) revenue.

Some industrial engineering courses combine the two approaches and present case studies that can be analyzed using the models learned during the course.

1.3.1 Industrial Engineering Curricula

Curricula in IE programs in academic institutions, though not uniform, are based on similar principles.

Freshman (first year) curriculum usually covers all core subjects including mathematics, physics, and information systems, along with the course "Introduction to Industrial Engineering," which focuses on the role the industrial engineer fills in organizations, the training he or she needs, and the tools that he or she uses.

Sophomore (second year) curriculum focuses on advanced courses in mathematics including courses in operations research, probability and statistics, as well as basic courses in psychology, sociology, and process-product design.

Junior (third year) curriculum moves to cover advanced courses on production and service systems.

Senior (fourth year) curriculum is usually reserved for elective courses. Students select subjects that interest them. In many schools, fourth year students perform a final project. The final project is based on a real IE problem, which gives students an opportunity to get experience in IE, implement the knowledge they learned in the previous three years, and learn about new tools and techniques and new situations.

1.4 Historical Overview

Humanity has been systematically planning major undertakings for thousands of years. The Egyptian pyramids, the two Temples in Jerusalem, ancient Roman roads and structures, the Great Wall in China, and Watt Angkor in Cambodia are examples of huge building projects carried out thousands of years ago. These undertakings required the organization of many people and proper planning. They were probably planned using methods that are very different from the methods used today by industrial engineers. For example, the production of most products in the past was carried out in workshops, by expert craftsmen. These craftsmen acquired their profession by serving for many years as apprentices, and learning how to make the whole product, without any help from other people. Today, factories divide the production process into stages or steps, and most workers work on a small part of the whole production process, in production or assembly lines. Furthermore, computers, automated machines, and robots are parts of many production processes in the modern factory. The transition from the small shops of individual craftsmen to the modern automated factory with multiple workers (dividing the work among them and using automated machines and robots) was a long process spanning over more than 100 years.

1.4.1 Industrial Revolution: Eighteenth Century

A turning point in the development of industrial engineering was the Industrial Revolution that started in England in the eighteenth century. Two main factors led to the transformation. One factor was the introduction of mechanical energy, which replaced human energy or energy from other sources such as animals, water, or wind. The invention of the steam engine in 1764 made this possible. The second factor was the transfer of production from the small workshops of craftsmen into factories where production was done by many workers, applying the principle of division of labor.

In 1776, Adam Smith published a book analyzing the economic benefits of the division of labor. His theory is that breaking up the work required to produce a product into a series of small simple tasks performed by a number of production workers increases efficiency. Each worker needs to know only a small part of the whole process required to manufacture the product, unlike earlier methods where craftsmen had to learn the whole process required to produce and assemble a product from start to finish. The application of division of labor resulted in the need to organize and manage the teams of production workers.

In 1798, the American inventor Eli Whitney developed the idea of standard product parts. Whitney developed a system for producing muskets for the U.S. government. In his system, all the pieces of the same type produced by any worker (e.g., the barrel of the musket) were exactly the same. The finished product could be assembled from standard parts randomly selected from the stock and no special adjustments for each gun were needed. Division of labor and Eli Whitney's standardization of parts are the basis of the modern mass production system: identical parts are manufactured in batches, and a random selection of a set or kit of parts can be assembled into the final product, without needing adjustments.

1.4.2 New Developments in the Early Twentieth Century

In 1911, Frederick Taylor (1856–1915) published his "scientific management theory." His goal was to improve productivity by making employees more efficient. Taylor claimed that management should define the desired output, provide training for employees, and monitor them in order to generate the desired output. In addition, Taylor argued that to manage a production system, quantitative measurements of working time, material, and resources are needed in order to minimize waste and to build an efficient production system.

Taylor brought awareness of the importance of proper production planning to the world of manufacturing and beyond. His planning relies on accurate measurements and deals with employee placement, training, and supervision. Taylor's philosophy highlighted the importance of work standards, which are the point of departure for performance planning and evaluation.

At about the same time, Frank and Lillian Gilbert developed a method for predicting the time it will take to perform a given task. This method and philosophy aligned well with Taylor's scientific management theory and was accepted with enthusiasm by Taylor's followers. However, its application was too detailed and tedious. Ten years later, a more efficient technique called Motion & Time Measurement (MTM) was developed by Westinghouse Corporation and spread throughout the business world.

In 1913, Henry Ford developed the assembly line. His idea was to bring division of labor and work standardization to perfection. The worker repeats short cycles of identical work and the product is conveyed to the worker on the line. Before Ford's car production assembly line began operation, the average time for the assembly of a car was about 12.5 h. Eight months later, when the assembly line was completed, and each worker had a specific role in the line, the average time for the production of a car was reduced to 93 min.

Ford's assembly line applied the principles of scientific management—standard product design, division of labor, mass production of standard parts, and reduction of production costs. Ford's factory integrated these ideas, which led to peak efficiency at the time.

In 1914, Henry Gantt developed a chart for scheduling process activities. The chart used the timeline as the horizontal axis and the vertical axis was dedicated to machines or operators (each one having its own horizontal timeline). In this way, the activities done at any point in time could be easily illustrated. The Gantt graphical model still serves as a popular tool for scheduling workstations, machines, and projects.

In 1917, F. W. Harris developed an optimization model for determining batch sizes for management and control of inventories. Proper management of inventory has a great impact on the profits of enterprises, and hence the importance of this development.

Between 1927 and 1930, Elton Mayo at the Hawthorne plant of Western Electric studied psychological and sociological factors impacting the efficiency of a group of workers. These studies were based on experiments aimed at examining the effects of environmental changes such as lighting and noise on employees' performance. The results were surprising. For example, in some cases, even though the physical conditions of the workers deteriorated, performance of the workers did not change, and sometimes even improved. The conclusion was that the fact that employees were aware that they were part of an experiment raised the level of their motivation and made them work more efficiently. This finding was the trigger leading managers and researchers to realize the importance of psychological and behavioral factors, and their direct impact on employee motivation and work efficiency. Studies of this kind have led to the management focus on the human factor, with an emphasis on creating conditions that encourage the employee to contribute to the organization. These were the early steps in the development of the discipline of management of human resources.

During World War II, armies were faced with complex logistical problems, such as the transfer of aircraft, ships, supplies, and troops between different parts of the world. At the same time, the operation of newly developed complex weapons (such as the new radar system) posed a planning, modeling, and optimizing challenge. To cope with these challenges, operations research methodologies were developed. Operations research is based on the construction of mathematical and statistical models of complex problems. At that period, the model was typically a combination of objective function and constraints, and mathematical analysis was used to find an optimal, implementable solution for the model, and hence for the problem.

After the war, experts in operations research returned to academia and industry and applied the new knowledge in public and private sectors. The wide applicability of operations research and its fast evolution has made it into a separate field of research and study. It has developed rapidly and continues to do so today.

Work in operations research requires complex calculations and nowadays is based on extensive computer use due to the need to deal with complex, large mathematical models. Operations research models are used to support complex decision making.

A typical example of operations research models is the case of fashion goods supply chain management by international companies. Sewing factories located in different countries sell their products around the world. The decision of which products to produce in each factory and how to ship the products from factories to the wholesale and retail stores is a very complex one that involves considerations such as the cost of transportation, the production capacity of the factories, the distances between the factories and the shops, the cost of labor and raw material in each country, the demand for different products in every country, etc. Operations research models support decision making in such complex problems.

After World War II, a significant expansion of the public and private service sectors motivated the development of tools and techniques for planning and managing service operations. Today, more than two-thirds of the workforce in the United States is employed in the service sector. Services are characterized by uncertainty related to customer arrivals and requirements. Operations research models were developed for analyzing queues and dealing with demand uncertainty, for these kinds of problems.