9TH EDITION

CONSTRUCTION PLANNING, EQUIPMENT, & METHODS

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ROBERT L. SCHMITT | AVIAD SHAPIRA

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Construction Planning, Equipment, and Methods

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Ninth Edition

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Mc Graw Hill Education

New York Chicago San Francisco Athens London Madrid Mexico City
Milan New Delhi Singapore Sydney Toronto

ISBN: 978-1-26-010881-1
MHID: 1-26-010881-3

The material in this eBook also appears in the print version of this title: ISBN: 978-1-26-010880-4,
MHID: 1-26-010880-5.

eBook conversion by codeMantra
Version 1.0

DEDICATION

Since the 8th edition of our book the universe lost two of its brightest lights, men who dedicated themselves to the success of every individual they encountered.

John R. Lamberson a driving spirit within the original group of construction professionals who came together in 2000 to organize the Construction Institute (CI) of the American Society of Civil Engineers passed away in 2012.

John served as a Director for several major construction companies and was honored in 1990 with the Golden Beaver Award. He was elected to the National Academy of Construction in 2004. A great believer in giving back, John was a trustee of the Beavers Charitable Trust and led the efforts of the trust to bring practical construction industry experience into the university. During the time of his leadership the Beavers established chairs of heavy construction practice at Arizona State University, California State University–Long Beach, Oregon State University, Purdue University, University of Washington, and Texas A&M University.

Tudor W. Van Hampton, a man with a contagious enthusiasm for our industry and Managing Editor for Engineering News Record passed away in 2017.

During his nearly two-decade career, until his death at the age of 39, Tudor established himself as "the voice of ENR" about everything concerning construction equipment and methods. Knowledgeable about machine engineering and safety no less than skillful in journalism and current digital-age media, he earned the highest respect of all who have been exposed to his writing, industry professionals and academia researchers alike. Working diligently for the betterment of the industry, Tudor believed in the importance of connecting people of mutual professional interests and of sharing information and insights. The authors of this book owe Tudor a great many thanks for his zeal in helping them advance equipment practice.

Construction practice has lost two inspiring friends who dedicated their lives to mentoring others for success.

Requiescat in Pace
Cliff Schexnayder
Robert Schmitt
Aviad Shapira

ABOUT THE AUTHORS

R. L. Peurifoy (1902–1995), after serving as principal specialist in engineering education for the U.S. Office of Education during World War II, began teaching construction engineering at Texas A&M University in 1946. In the years that followed, Peurifoy led the transformation of the study of construction engineering into an academic discipline. In 1984 the Peurifoy Construction Research Award was instituted by the American Society of Civil Engineers upon recommendation of the Construction Research Council. This award was instituted to honor R. L. Peurifoy's exceptional leadership in construction education and research. The award recipients since the last edition of the book are:

2010 Jeffrey S. Russell
2011 Jesus M. De La Garza
2012 Michael C. Vorster
2013 Clyde B. (Bob) Tatum
2014 Iris D. Tommelein
2015 Carl T. Haas
2016 George E. Gibson, Jr.
2017 Martin A. Fischer

Clifford J. Schexnayder is an Eminent Scholar Emeritus at the Del E. Webb School of Construction, Arizona State University. Taking over from Robert L. Peurifoy, he previously authored four editions of this book. He received his Ph.D. in civil engineering from Purdue University, and a Master's and Bachelor's in civil engineering from Georgia Institute of Technology. A construction engineer with over 50 years of practical experience, Dr. Schexnayder has worked with major heavy/highway construction contractors as field engineer, estimator, and corporate chief engineer. Additionally, he served with the U.S. Army Corps of Engineers on active duty and in the reserves, retiring as a colonel. His last assignment was as Executive Director, Directorate of Military Programs, Office of the Chief of Engineers, Washington, D.C. He has served as a consultant to the Autoridad del Canal de Panama, Secretary of the Business, Transportation & Housing Agency of California to review risks associated with constructing the main east span of the San Francisco-Oakland Bay Bridge, and the Smithsonian's National Museum of the American Indian for its *The Great Inka Road: Engineering an Empire* exhibit. Dr. Schexnayder is a registered professional engineer in four states, a Distinguished Member of the American Society of Civil Engineers and a member of the National Academy of Construction. He served as chairman of the ASCE's Construction Division and on the task committee, which formed the ASCE Construction Institute. From 1997 to 2003 he served as chairman of the Transportation Research Board's Construction Section.

Robert L. Schmitt is a Professor of Civil Engineering at the University of Wisconsin, Platteville campus. He received his Ph.D. in civil engineering (construction engineering and management) from the University of Wisconsin-Madison, a Master's of civil engineering from Purdue University, and a Bachelor's of civil engineering from the University of Wisconsin–Platteville. Dr. Schmitt has 30 years of construction industry practice, research, and teaching experience. He was an estimator and project manager for a building contractor in the Midwest, a public works construction engineer, a highway construction materials engineer, and consulted for a Top-100 general contractor in the Washington, D.C. metro region. Dr. Schmitt has been a construction engineering consultant for domestic and international building projects and participates in constructability reviews, risk analysis workshops, value engineering studies, and cost estimating from concept through final design. Dr. Schmitt has served on regional technical committees of Associated General Contractors, American Society of Civil Engineers, State Departments of Transportation, and the NCHRP. He was a project management instructor for the National Asphalt Pavement Association. Dr. Schmitt was a Fulbright Scholar in Peru and continues to teach Master's courses and provide construction equipment and materials expertise to practicing engineers in South America. Dr. Schmitt is a registered professional engineer and member of the American Society of Civil Engineers, American Concrete Pavement Association, Association of Asphalt Paving Technologists, AACE

International (Association for the Advancement of Cost Engineering), and educational member of the local chapter of Associated General Contractors of America.

Aviad Shapira is a Professor of Construction Engineering and Management in the Faculty of Civil and Environmental Engineering at the Technion–Israel Institute of Technology. He received his BSc, MSc, and DSc degrees in Civil Engineering from the Technion. He spent one year as a post-doctoral fellow at the University of Illinois at Urbana-Champaign under a grant from the US Air Force. Over the years he was also a Visiting Professor at the University of New Mexico in Albuquerque and at the University of Wisconsin–Madison. Dr. Shapira accrued his practical experience as a project engineer and project manager in a general contracting firm prior to pursuing an academic career. He has taught construction equipment and formwork design in Israel and the United States since 1985, and authored or co-authored various texts addressing these subjects, including Peurifoy's *Construction Planning, Equipment, and Methods* (2006, 2011), which was also translated to Chinese and Portuguese. His research in construction engineering and management has focused on equipment planning, selection, operation, productivity, and safety. He is the co-developer of an innovative crane-mounted video camera system that serves as an operator aid; this system has been used on most of the high-rise building projects built in Israel since 1998. Dr. Shapira has conducted his research in Israel, the United States, and Germany; he is an avid visitor of construction sites all over the world, where he likes to engage in discussions about local construction equipment cultures. He is a Fellow of the American Society of Civil Engineers, an active member of Committee 347 Formwork for Concrete of the American Concrete Institute, and the Chair of the various formwork standardization committees of the Standard Institution of Israel. Dr. Shapira is the recipient of both the ASCE Construction Management Award and the ASCE *Journal of Construction Engineering and Management* Best Paper Award. In 2009 he was recognized by *ENR* as a Top-25 Newsmaker.

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Web resources to accompany the book can be downloaded from www.mhprofessional.com/peurifoy9E.

PREFACE

Technologies used across all phases of the constructed project life cycle continue to evolve at an ever increasing rate. Existing and emerging technologies can assist with overall project planning, design, construction, and maintenance activities by providing efficient data retrieval and information in visual formats. Construction equipment telematics now provide operators and managers with real-time equipment positioning, pressure sensing, fuel rate consumption, automated path guidance, alerts, and other specific measures to optimize machine performance.

Owners play a vital role in seeking new ways to accelerate project delivery and this edition of the text addresses the key to successful execution of an acceleration effort—***planning***. The Critical Path Method (CPM) and the Project Evaluation and Review Technique (PERT), planning tools developed in the late 1950s, are still the mainstays for project scheduling. Building Information Modeling (BIM), an idea dating from the 1970s, did not receive wide acceptance until 2002 but is now commonly used to support both building and infrastructure construction. CPM and PERT are scheduling algorithms while BIM is a digital representation of the building process. Lidar (light and radar) sensing technology, sometimes written LIDAR or LiDAR, now allows the engineer to rapidly create a DTM (Digital Terrain Model) of a project site. This model of the existing site can be overlaid with the proposed project grading. Together, the DTM and the design drawing provide another planning support tool. There is still one other new piece of equipment to support planning, or more specifically surveying and machine guidance, the Unmanned Aerial Vehicle (UAV) or what is commonly called a drone. UAVs have the potential to become tools as important as individual pieces of yellow iron because they can provide the engineer accurate data or imaging almost instantaneously. They can be used to inventory jobsite materials and equipment, and to monitor site safety.

In spite of the aforementioned technologies, it is still necessary to understand machine capability and to compute the most economical grouping of machines to complete the tasks identified during project planning. This text describes the methods used to investigate equipment productivity and it provides equipment application understanding. Proficiency in analysis and familiarity with appropriate applications are critically important to those wishing to compete in the accelerated project environment.

A machine is economical only if used in the proper manner and in the environment in which it has the mechanical capabilities to function effectively. Technology planning tools greatly enhance our ability to formulate equipment planning and construction decisions, but to use the tools to an advantage, an equipment planner must have an understanding of individual machine capabilities and how to properly apply those capabilities to construction challenges.

This ninth edition follows in the tradition established by Robert L. Peurifoy over 60 years ago, and like the previous eight editions, provides the reader with the fundamentals of machine selection and production estimating in a logical, simple, and concise format. With a grounding in these fundamentals, the engineer/constructor is better prepared to evaluate economic equipment application options.

Significant changes have been made to this edition. The construction market place has experienced a shift in project types, with more work involving reconstruction of aging infrastructure and more projects being executed in congested urban environments. Equipment manufacturers have responded to these market dynamics with new machines and with changes to existing machines. Contracts for projects in urban environments continue to require more intense planning in order to accommodate restrictive regulations concerning construction nuisances particularly vibrations, light, and noise. Additionally, new government regulations designed to protect the environment, particularly emission rules, have caused equipment manufacturers to develop a new generation of engines and seek ways to reduce fuel usage. While energy savings yield fuel cost savings, the effect of these engine modifications on maintenance costs is still a question. Because of these market changes this text includes additional material about small machines used on urban projects and for building construction.

All chapters have undergone revision, ranging from simple clarification to major modifications, depending on the need to improve organization and presentation of concepts. Many photographs in the chapters have been updated to illustrate the latest equipment and methods, and more pictures of operating equipment have been used in this edition. Safety discussions are again presented in each of the chapters dealing with machine or formwork use.

This new text has 20 chapters. Chapter 11 "Finish Equipment" of the eighth edition has been eliminated with the essential material moved to other chapters. The grader information is in the "Dozers and Graders" chapter, gradalls are discussed in the "Excavators" chapter, and trimmers moved to the "Asphalt Mix Production and Placement" chapter. While dozers are still used as high production machines on some projects, it is more common to find them in support roles. Therefore, the "Dozers and Graders" chapter has been modified accordingly. Many of the details concerning dragline and clamshell excavators have been condensed because of the specialized nature of their employment. To reduce environmental harm utility providers have begun building wind farms. The erection of large wind turbines for generation of electricity has initiated new models of lifting equipment. Such machine advances are discussed in the "Cranes" chapter.

Equipment manufacturers are making greater use of the Internet as a means of making machine data and general information available. Therefore, this text follows the practice of the eighth edition by calling attention to Web resources. Problems at the end of each chapter reinforce the concepts and an electronic solution for most problems has been developed in spreadsheet format. These solutions and individual chapter Powerpoint™ presentations are available as Web-based supplements. Videos of select equipment in both English audio and Spanish subtitle have been exclusively developed to enhance delivery of textbook content.

Construction equipment is manufactured and used globally, and we continue to search worldwide for the latest ideas and trends in machine application and technology. Every three years the authors are participants at CONEXPO-CON/AGG sponsored by the Association of Equipment Manufacturers in Las Vegas and at the BAUMA in Germany. Previous editions of the text are now available in English, Chinese, and Portuguese.

While the book is structured primarily as a textbook for a college-level construction equipment course, it continues to enjoy wide use as a practical reference by construction professionals. The use of examples to reinforce the concepts through application has been continued. Based on professional practice, we have tried to present standard formats for analyzing production. Many companies use such formats to avoid errors when estimating production during the fast-paced efforts required for bid preparation.

We are deeply grateful to the many individuals and firms who have supplied information and illustrations. Mr. Scott Sanders at Manitowoc Cranes has always made himself available to discuss crane developments and we owe him a special thanks for his guidance. To Mr. Aaron Cohen, CPC, AGC Lecturer, in the Del E. Webb School of Construction at Arizona State University we offer our sincere thanks for his insightful comments. His help with the development and testing of the chapter problems in his construction equipment classes has added to the quality of this text. However, we take full responsibility for all content.

Most importantly we express our sincere appreciation and love for our wives, Judy, Lisa, and Reuma, who proofread too many manuscript pages, kept us healthy, and who otherwise got pushed farther into the exciting world of construction equipment than they probably wanted. Without their support this text would not be a reality.

We solicit comments on the edition.

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Construction Planning, Equipment, and Methods

List of Abbreviations

AAI	average annual investment
AASHTO	American Association of State Highway and Transportation Officials
AC	alternating current
AC and AR	asphalt grade designations
ACI	American Concrete Institute
ACPA	American Concrete Pumping Association
ADT	articulated dump truck
AED	Associated Equipment Distributors, Inc.
AEM	Association of Equipment Manufacturers
AGC	Associated General Contractors of America, The
AISC	American Institute of Steel Construction
ANFO	ammonium nitrate and fuel oil mixture
ANSI	American National Standards Institute
ASA	American Shotcrete Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASSE	American Society of Safety Engineers
ASTM	ASTM International (formerly American Society for Testing and Materials)
AWPA	American Wood Protection Association
bcy	bank cubic yards
bhp	belt or brake horsepower
BV	book value
ccy	compacted cubic yards
CECE	Committee on European Construction Equipment
cf	cubic feet
cfm	cubic feet per minute
CII	Construction Industry Institute
CPB	Contractors Pump Bureau
CPMB	Concrete Plant Manufacturers Bureau
cy	cubic yards
dB	decibel
dBA	A-weighted decibels
DRI	drilling rate index
EVW	empty vehicle weight
FHWA	Federal Highway Administration
FOG	fuel, oil, grease
fpm	feet per minute
fps	feet per second
ft	feet
ft-lb	foot-pound
fwhp	flywheel horsepower
fwhp-hr	flywheel horsepower hour
g	acceleration of gravity
GA	grade assistance
GC	General Contractor
g/cc	grams per cubic centimeter
gph	gallons per hour
gpm	gallons per minute
GPS	global positioning system
GR	grade resistance
GVW	gross vehicle weight
hr	hours
Hz	hertz
I.D.	inside diameter
IME	Institute of Makers of Explosives, The
in. Hg	inches of mercury
ISEE	International Society of Explosives Engineers, The
ISO	International Organization for Standardization
kip	1,000 lb

kN	kilonewton
kPa	kilopascals
ksi	kips per square inch
lb/sy-in	pounds per square yard-inch
LCD	liquid crystal device
lcy	loose cubic yard
lf	linear foot
LGP	low ground pressure
LL	liquid limit
MARR	minimum attractive rate of return
mph	miles per hour
ms	millisecond
NAPA	National Asphalt Pavement Association
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards
NPW	net present worth
NRMCA	National Ready Mixed Concrete Association
NVW	net vehicle weight
O&O	ownership and operating (cost)
O.D.	outside diameter
OMC	optimum moisture content
OSHA	Occupational Safety and Health Act (Administration)
PCA	Portland Cement Association
pcf	pounds per cubic foot
PCI	Prestressed Concrete Institute
PCSA	Power Crane and Shovel Association
pen	penetration grade measurement unit
PETN	pentaerythritol tetranitrate
PI	plasticity index
PL	plastic limit
PPV	peak particle velocity
psf	pounds per square foot of pressure
psi	pounds per square inch of pressure
PWCAF	present worth compound amount factor
RAP	reclaimed asphalt pavement
RCC	roller-compacted concrete
rev.	revolutions
ROPS	rollover protective structure (standards)
RR	rolling resistance
SAE	Society of Automotive Engineers
sec	second
sf	square foot
SG	specific gravity
SG_e	specific gravity of explosive
SG_r	specific gravity of rock
SPCAF	single payment compound amount factor
sq m	square meter
SR	stiffness ratio
sta.	station
sta.-yd	station-yards
St_v	relative bulk strength compared to ANFO = 100
sy	square yards
TMPH	ton-miles per hour
TNT	trinitroluene or trinitrotoluol
tph	tons per hour
TR	total resistance
TRB	Transportation Research Board
USCAF	uniform series, compound amount factor
USCRF	uniform series, capital recovery factor
USPWF	uniform series, present worth factor
USSFF	uniform series, sinking fund factor
VHN	Vickers hardness number
VHNR	Vickers hardness number rock
vpm	vibrations per minute
WF	wide flange
XL	extralong
yd	yard
yr	year

CHAPTER 1

Machines Make It Possible

Construction is the transformation of a design into a useful structure. This transformation is accomplished by men and women directing the employment of machines. The proper application of machines can prudently convert an engineer's plan into reality. Machines continually evolve to meet project requirements. Today, projects have become more constricted and as a result it is necessary to make machine application decisions only after visualizing what may not be apparent without careful attention to the environment. This book describes the fundamental concepts of machine utilization. It explains how to economically match machine capability to specific project conditions. With the expanded array of useful machines, it is important to have both a knowledge of construction methods and equipment economics.

A NEW CONSTRUCTION ENVIRONMENT

There is an ongoing change in project delivery methods, with owners seeking ways to accelerate project deliver while shifting risk and financing to the contractor. This is especially true in the case of large/complex infrastructure projects. While the majority of projects are still let using the Design-Bid-Build (DBB) method, owners are letting their large projects using Design-Build (DB) or Public-Private Partnership (P3s or PPP) methods. As a result the Design-Build Institute of America (DBIA) was formed in 1993. By 2010 the design–build contracting method was used on about 40% of non-residential construction projects in the United States. In 2014 alone public-private financing for transportation, energy, and water infrastructure projects in emerging economies around the world amounted to $107.5 billion.

These changes in contracting methods are forcing project planners to be superior critical thinkers. Critical thinking about planning is the key element leading to successful project execution. Planning must include detailed analyses of equipment utilization with consideration for the physical constraints of a project site, impacts to the surrounding community, sustainability requirements, and the skill level of available labor. Additionally, backup plans must exist for possible disruptive events—weather or accidents. Success in the execution of construction endeavors requires imagination and a knowledge of equipment productivity with an ability to think deeply in an age of information overload.

This text introduces the engineering fundamentals for machine planning, selection, and utilization. It can help you analyze operational problems and arrive at practical solutions for effectively completing construction tasks. The focus is on the application of engineering fundamentals and analysis to construction activities merged with an economic comparison of machine options.

A construction contractor's ability to win contracts and execute work at a profit is determined by two vital assets: people and equipment. To be economically competitive, a contractor's equipment must be superior both mechanically and technologically. An older machine in need of costly repairs cannot compete successfully with new equipment's lower repair costs and higher production rates.

In most cases, a piece of equipment does not work as a stand-alone unit. Machines normally work in a linked production system. An excavator will load a fleet of haul trucks for moving material to a fill location. At the location where the trucks dump the material a dozer or other machine will be employed to spread the material the trucks dumped into piles. After spreading, a roller compacts the material to the required density. Therefore, a group of machines—in this example an excavator, trucks, a dozer, and a roller—constitutes what is commonly referred to as an *equipment spread*.

Optimization in the management of an equipment spread is critical, both in achieving a competitive pricing position and in accumulating the corporate operating capital required to finance the expansion of project performance capability. The basic operational characteristics of the major construction equipment types are explained and the fundamental concepts of machine utilization are presented in detail. An understanding of machine capability matched with an ability to calculate production allows the planner to economically match machine capability to specific project requirements.

There are no unique solutions to the question of selecting a machine to work on a particular project or task. All machine selection questions are influenced by external environmental conditions. The noise and vibrations caused by construction operations and a machine's impact on those adjacent to the project are additional factors effecting machine selection. Nearby residents complain about noise and the glare from temporary lighting systems, and city codes may restrict operations. Therefore, while selecting a machine for a project involves an understanding of the physical environment of the project in terms of soil type and moisture conditions, it also requires planners to think in terms of the surrounding environment impacted by the construction operations.

THE HISTORY OF CONSTRUCTION EQUIPMENT

Machines are mechanical/electrical systems used to amplify human energy and improve our level of control. Today many machines have on board computers. These instantaneously process information and automate many operational functions of the machine. The modern machine is a vital resource necessary for the rapid accomplishment of most construction projects (Figure 1.1). One of the most obvious problems in constructing a project is how to transport heavy materials. Machines provide the solution. The proof of how well the planner understands the work and selects appropriate machines is revealed by counting the money when the contract is completed. Did the company make a profit or sustain a loss?

From the time the first man decided to build a simple structure for protection from the elements and to improve his ability to grow food through to the construction of the Egyptian pyramids, the 25,000 mile Inca road system, and continuing into the mid-nineteenth century, work was accomplished by the muscle of man and beast—ponder the legendary John Henry with his hammer. The development of construction equipment followed major changes in transportation modes. Where travel and commerce took place via water systems, builders dreamed of machines with the ability to dredge ports, rivers, and

FIGURE 1.1 Construction equipment

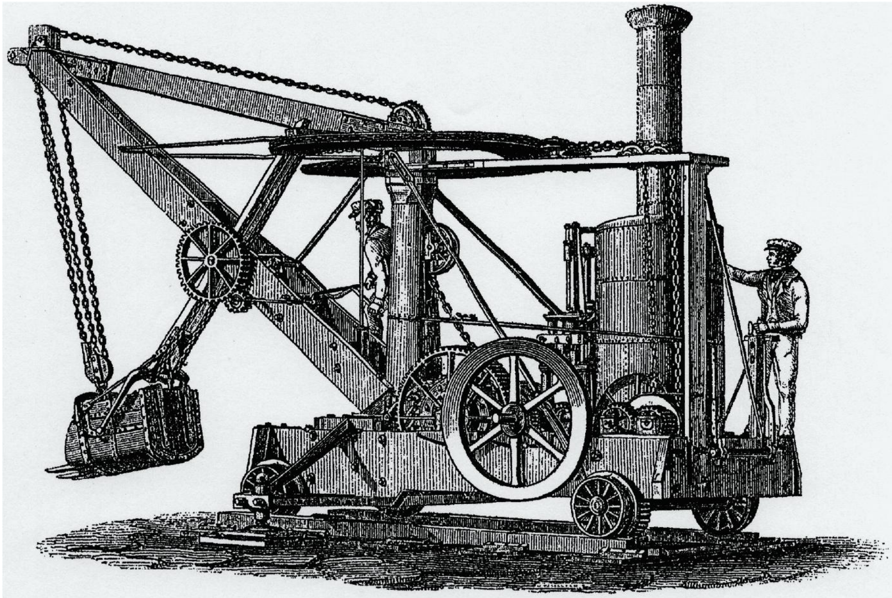


FIGURE 1.2 The Otis steam shovel; this machine was mounted on steel wheels that ran on rails[1]

canals. As early as 1420, the Venetian Giovanni Fontana was dreaming of and diagramming dredging machines. Leonardo da Vinci designed such a machine in 1503, and at least one of his machines was actually built, but the power source was a lonely runner on a treadmill.

In 1793 a group of men in Massachusetts came together to build the Middlesex canal, a 27 mile ditch from the Merrimack River to Boston. Finally in December 1803 water flowed the length of the canal. Then on July 4, 1817, at a site near Rome, New York, ground was broken for the 363-mile-long Erie Canal. It was another long ditch excavated by local laborers and Irish immigrants—human labor. However, by the 1830s, construction in the United States was changing from canal building to railroad construction. The economic life of the Middlesex Canal was only 32 years as it came to an end in 1835 when the Boston & Lowell Railroad, one of the earliest railroads in the United States, opened for service. Nevertheless, construction, be it building canals or railroads, was still achieved by the brawn of man and beast.

Steam Power Machines

William S. Otis (1813–1839), a civil engineer with the Philadelphia contracting firm of Carmichael & Fairbanks, built the first practical power-shovel excavating machine in 1837 (Figure 1.2). The first "Yankee Geologist," as his machines were called, was put to work in 1838 on a railroad project in Massachusetts. The May 10, 1838, issue of the *Springfield Republican* reported, "Upon the road in

[1] "Steam Excavating Machine," *London Journal of Arts and Science*, Vol. 22, 1843.

the eastern part of this town, is a specimen of what the Irishmen call 'digging by stame.' For cutting through a sand hill, this steam digging machine must make a great saving of labor."

Development of the steam shovel was driven by a demand for an economical way to perform mass excavations. In the early 1880s, an era of major construction projects began. These projects demanded machines to excavate large quantities of earth and rock. In 1881, Ferdinand de Lesseps's French company began work on the Panama Canal. Less than a year earlier, on December 28, 1880, the Bucyrus Foundry and Manufacturing Company, of Ohio, came into being. Bucyrus became a leading builder of steam shovels, and 25 years later when the Americans took over the Panama Canal work, the Bucyrus Company was a major supplier of steam shovels for the great work. Still, the most important driver in excavator development was the railroad. Between 1885 and 1897, approximately 70,000 miles of railway were constructed in the United States. William Otis developed his excavator machine because the construction company Carmichael & Fairbanks, for which he worked and in which his uncle Daniel Carmichael was a senior partner, was in the business of building railroads.

The Bucyrus Foundry and Manufacturing Company was organized because Dan P. Eells, a bank president in Cleveland, was associated with several railroads. In 1882, the Ohio Central Railroad gave the new company its first order for a steam shovel, and sales to other railroads soon followed.

Internal Combustion Engines

The German engineer Nikolaus Otto is credited with being the first to develop an internal-combustion engine capable of efficiently burning a petroleum-based fuel directly in a piston chamber. However, many engineers had obtained patents for such engines between 1861 and the 1890s when courts of law in Europe ruled the four-cycle gasoline engine was too valuable an improvement to keep restricted. Following the removal of the legal restraints, many companies began experimenting with gasoline-engine–powered carriages. The Best Manufacturing Company (the predecessor to Caterpillar, Inc.) demonstrated a gasoline tractor in 1893.

The first application of the internal combustion engine for excavating equipment occurred in 1910 when the Monighan Machine Company of Chicago shipped a dragline powered by an Otto engine to the Mulgrew-Boyce Company of Dubuque, Iowa. Henry Harnischfeger brought out a gasoline engine–powered shovel in 1914. Following World War I, the diesel engine began to appear in excavators. A self-taught mechanic named C. L. "Clessie" Cummins, working out of an old cereal mill in Columbus, Indiana, developed the Cummins diesel engine in the early 1900s. The Cummins engine soon replaced the steam boilers mounted on shovels. Warren A. Bechtel, who in 1898 entered the construction business in Oklahoma Territory and quickly built a reputation for successful railroad grading, pioneered the use of motorized trucks, tractors, and diesel-powered shovels in construction.

In the winter of 1922 to 1923, the first gas-powered shovel was brought into the state of Connecticut, and in the spring of 1923, it was employed on a federal-aid road project. The third phase of transportation construction had begun. Contractors needed equipment for road building.

Incubators for Machine Innovation

Los Angeles Aqueduct Large construction projects provide a fertile testing ground for equipment innovation. William Mulholland, as Los Angeles city engineer, directed an army of 5,000 men for five years constructing the Los Angeles Aqueduct, which stretches 238 miles from the Owens River to Los Angeles. In 1908, the Holt Manufacturing Company (the other predecessor to Caterpillar, Inc.) sold three gas-engine caterpillar tractors to the city of Los Angeles for use in constructing the aqueduct. In addition to crossing several mountain ranges, the aqueduct passed through the Mojave Desert, a severe test site for any machine. The desert and mountains served as a harsh work environment for the Holt machines and Benjamin Holt used the entire project as an experiment and development exercise to improve his machines.

The cast-iron gears Holt used in his machines wore out quickly from sand abrasion, so he replaced them with gears made of steel. The brutal terrain broke suspension springs and burned up the two-speed transmissions in his tractors. The low gear was simply not low enough for climbing the mountains. Holt made modifications to the tractors both at his factory and in the desert. His shop manager, Russell Springer, set up repair facilities in the project work camps. After completion of the project, Mulholland in his final report labeled the Holt tractors as the only unsatisfactory purchase made for the project. But Holt had developed a much better machine because of the experience.

Boulder Dam In the years between the two world wars, one particular construction project stands out because of its contribution to equipment development. The Boulder Dam project (later named the Hoover Dam) was an enormous proving ground for construction equipment and techniques.

The use of bolted connections for joining machine pieces together came to an end in the Nevada desert as the project provided a testing ground for R. G. LeTourneau's development of welded equipment and cable-operated attachments. LeTourneau, with his numerous innovations in tractor/scraper design tested at the Dam was later able to manufacture machines capable of speedily building airfields around the world during World War II. Other developments came from the Boulder Dam project:

- Sophisticated aggregate production plants
- Improvements in concrete preparation and placement,
- Long-flight conveyor systems for material delivery

torque converter *A fluid-type coupling that allows an engine to be somewhat independent of the transmission.*

Three Significant Developments

After World War II, road building surged, and in 1956 President Eisenhower signed the legislation for the Interstate Highway Program. To support the road-building effort, scrapers increased in capacity from 10 to 30 cubic yards (cy). With the development of the **torque converter** and the power shift transmission, the front-end loader began to displace the old "dipper" stick shovels. Concrete batch and mixing plants changed from slow, manually controlled contraptions to hydraulically operated and electronically controlled equipment. But the three most important developments were high-strength steels, nylon cord tires, and high-output diesel engines.

1. *High-strength steels*. Up to and through World War II, machine frames had been constructed with steels in the 30,000 to 35,000 psi yield range. After the war, steels in the 40,000 to 45,000 psi range with proportionally better fatigue properties were introduced. The new high-strength steel made possible the production of machines having a greatly reduced overall weight. The weight of a 40-ton off-highway truck body was reduced from 25,000 to 16,000 lbs, with no change in body reliability.
2. *Nylon cord tires*. The utilization of nylon cord material in tire structures made larger tires with increased load capacity and heat resistance a practical reality. Nylon permitted the actual number of plies to be reduced as much as 30% with the same effective carcass strength but with far less bulk or carcass thickness. This allowed tires to run cooler and achieve better traction, and so improved machine productivity.
3. *High-output diesel engines*. Manufacturers developed new ways to coax greater horsepower from a cubic inch of engine displacement. Compression ratios and engine speeds were raised, and the art of turbocharging was perfected, resulting in a 10 to 15% increase in flywheel horsepower.

Today, no radically new equipment appears on the horizon, but manufacturers are continually refining the inventions of the past, and the development of new attachments will mean improved utility for the contractor's fleet. The future of equipment technology or innovation can be divided into three broad categories.

- *Level of control*: equipment advancements to transfer operational control from the human operator to the machine.
- *Amplification of human energy*: shift of energy requirements from man to the machine.
- *Information processing*: gathering and processing of information by the machine.

The Future

A time may come when the base machine is considered only a *mobile counterweight with a hydraulic power plant*. The base machine will perform a variety of tasks through multiple attachments. This trend has started with hydraulic excavators having many attachments, such as hammers, compactors, shears (Figure 1.3), and material-handling equipment. Wheel loaders, no longer standard bucket machines, have seen the introduction of the tool-carrier concept. Other attachments such as brooms, forks, and stingers are available. These tool attachments enable a loader to perform a multitude of tasks. Other attachments will be developed, the contractor more versatility from a base investment.

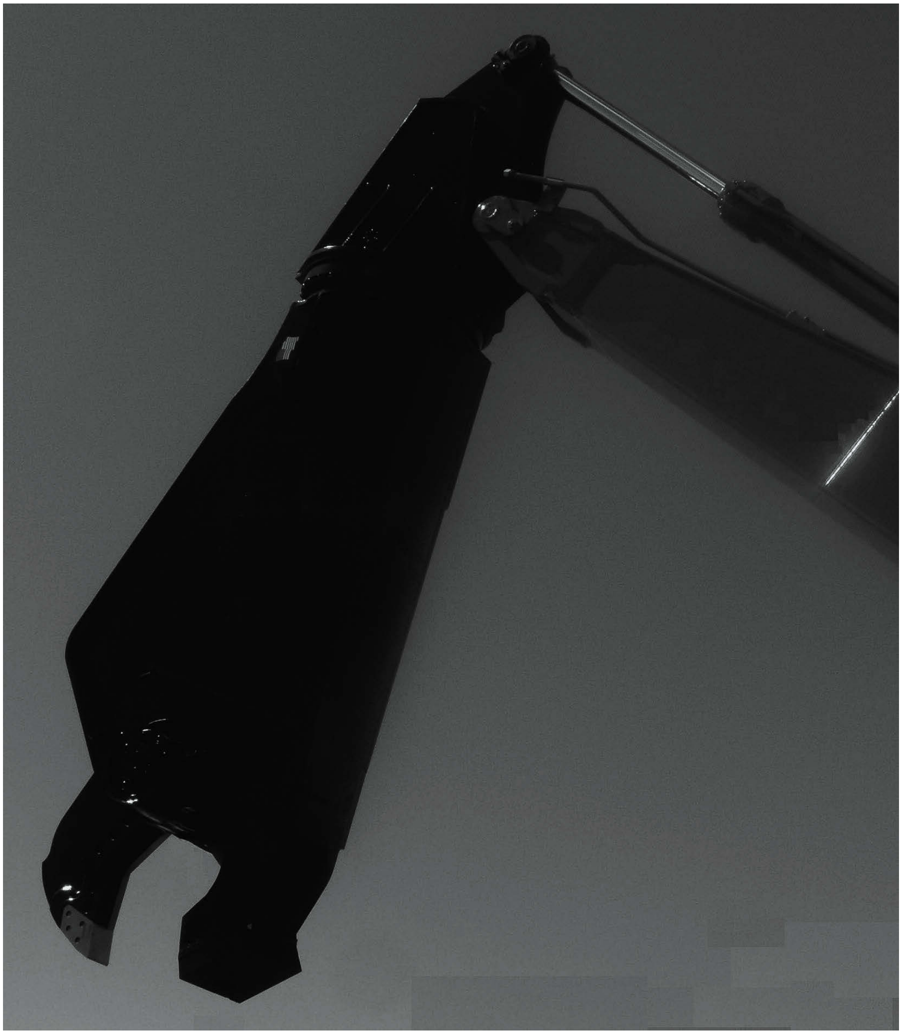


FIGURE 1.3 Shears on a hydraulic excavator

Safety features and operator station improvements are evolving to compensate for today's less experienced workforce. Related to workforce quality is the proliferation of supporting machine control technologies. Navigation of equipment is a broad topic, covering a large spectrum of different technologies and applications. It draws on some very ancient techniques as well as some of the most advanced in space science and engineering.

The new field of geospatial engineering is rapidly expanding, and a spectrum of technologies is being developed for the purposes of aeronautic navigation, mobile robot navigation, geodesy, and the use of drones. This technology is rapidly being transferred to construction applications (Figure 1.4).

FIGURE 1.4 Automatic blade control mounted on a dozer

GPS
A highly precise satellite-based navigation system.

The laser and global positioning system (**GPS**) guidance are becoming more common and reduce the need for surveyors to stake the work in the field. All the grader or dozer operator will need to do is load the digital terrain model into the machine's onboard computer (OBC) and then guide the machine where the display indicates. Machine position, along with cut or fill information, will appear on a screen in front of the operator at all times. This may turn the operator's job into a video game of sorts.

Ultimately, operators sitting in a machine cab may be eliminated altogether. Equipment manufactures are developing and testing automated rock-hauling units for mining—driverless trucks. These units are linked by radio to the office and tracked by GPS. The superintendent need only use a laptop to send the start signal and the trucks do the rest, leaving the lineup at set intervals and following the prescribed course. The superintendent can track the progress of each machine on the computer. If a truck develops a problem, the situation is signaled to the superintendent for corrective action. According to some authorities driverless truck technology could yield a 15 to 20% increase in output, 10 to 15% decrease in fuel consumption, and an 8% lowering in maintenance cost.

Further in the future, machine designers are thinking of an operator working from home. The field operations would be projected by large-scale display devices onto the walls of a room. The operator would operate the machine from these images enhanced by glasses used to provide a 3D effect. Machine performance data would go directly to the machine maintenance contractor. Historical data and an electronic design file will guide the operator's control activities. Machine work data will flow directly into the project schedule data file as work is accomplished.

THE CONSTRUCTION INDUSTRY

By the nature of the product, the construction contractor works under a unique set of production conditions and these directly affect equipment management. Whereas most manufacturing companies have a permanent factory where raw materials flow in and finished products flow out in a repetitive, assembly-line process, a construction company carries its factory with it from job to job. At each new site, the company proceeds to set up and produce a one-of-a-kind project. If the construction work goes as planned, the job will be completed on time with a profit.

Equipment-intensive projects present large financial risk. Many projects involving earthwork are bid on a unit-price basis, and large variations can exist between estimated and actual quantities. Some projects require a large equipment commitment in terms of total machine value employed to complete the work. This employed capital amount may be greater than the amount the contractor will be paid for completing the work. Such a situation forces a contractor into a continuing sequence of jobs to support the long-term equipment capital payments. Additional risk factors facing contractors in equipment-intensive work include a financing strategy for obtaining machines, construction activity levels (the amount of work being offered for bid), labor legislation and agreements, and safety regulations. Project size and weather-dependent outdoor work can contribute to long project durations. Projects requiring two or more years to complete are not uncommon in the industry.

Government-initiated actions particularly in the areas of labor legislation, safety regulation, and machine emissions seriously affect the operating environment of the construction contractor. In each of these areas, there are regulations impacting a contractor's operations. These actions can directly influence equipment decisions. Legislative acts exert direct pressure on equipment questions include the Davis-Bacon Act, which is concerned with wage rates, the Occupational Safety and Health Act (OSHA), which specifies workplace safety requirements, and the Environmental Protection Agency's (EPA) diesel engine emission standards. More than half of the dollar volume of work in the equipment-intensive fields of construction is subject to wage determinations under the Davis-Bacon Act, and this strongly influences the labor costs incurred by contractors. OSHA, by its rollover protective structures (ROPS) mandate, substantially increased the cost of all machines required to be equipped with such structures. This particular regulation had a single-point-in-time effect on equipment decisions, similar to the effect of new equipment technology. While there remains the possibility of additional safety requirements, sound and emissions are issues now receiving the greatest regulatory attention. Project owners, by clauses in the construction contract, are limiting machine noise levels. In recent years the EPA has mandated reduce emissions from non-road diesel engines. As a result equipment manufacturers are developing and producing new engines with advanced emission control technologies.

SAFETY

The construction industry employs nearly 6.6 million people—about 6% of the American workforce. However, according to the National Safety Council, the industry has the worse safety record of any industry in terms of worker deaths per 100,000 full-time equivalent workers. The record translates into 12 deaths every day. The Construction Industry Institute estimates the direct and indirect costs of construction accidents may be as high as $17 billion annually. Construction's "Fatal Four" responsible for more than half (57.7%) of construction worker deaths in 2013 are:

- Falls—(36.5%)
- Struck by Object—(10.1%)
- Electrocutions—(8.6%)
- Caught-in/between—(2.5%)

The safety of those on the construction site and the safety of the adjacent public is of paramount importance. No one wants to die on a project or cause someone else to be killed because of their actions or lack of vigilance. It is necessary to develop and maintain a safety culture and safety must be part of machine utilization and work process planning. It is the responsibility of construction managers to create the safety programs to prevent accidents (Figures 1.5 and 1.6). The key is to provide leadership for the creation of a safe work environment.

FIGURE 1.5 Loaded trucks can easily overturn

FIGURE 1.6 Housecleaning and neatness is important for safety

Over 45 years ago Congress began an investigation of construction safety, and in 1970, it enacted the Williams-Steiger Act, more commonly referred to as the Occupational Safety and Health Act. The act provided a comprehensive set of safety rules and regulations, inspection procedures, and safety record-keeping requirements. It imposed nationwide safety standards on the construction industry. The Act also permits states to enact their own OSHA legislation as long as the state legislation is at least as stringent as the federal legislation. Under the OSHA Act, employers are required to provide their employees a safe place to work and to maintain extensive safety records.

The Act established the Occupational Safety and Health Administration (OSHA), with regional offices in cities throughout the country. OSHA is responsible for the administration of the legislation and the development of rules and regulations to implement the act. The OSHA rules and regulations are published in the *Federal Register*. *OSHA Safety and Health Standards*, Code of Federal Regulations, Title 29, Part 1910, details safety features an architect or engineer must include in a project. The *Construction and Health Regulations*, Code of Federal Regulations, Part 1926, pertains specifically to construction contractors and construction work. The act provides both civil and criminal penalties for violations of OSHA regulations. The civil penalty for failure to correct a violation is $7,000 per day with a maximum penalty of $70,000. Criminal penalties can include both fines and imprisonment. It is OSHA's intent to establish a uniform set of safety standards for construction operations and to enforce those standards actively. Contractors must maintain a current, up-to-date file of OSHA regulations and work proactively to comply with OSHA requirements.

THE CONTRACTING ENVIRONMENT

Construction contractors work within a unique market situation. Typically job plans and specifications are supplied by the client and these dictate the sales conditions and product, but not the price. Almost all work in the equipment-intensive fields of construction is awarded on a bid basis, through either open or selective tender procedures. Under the Design-Bid-Build (D-B-B) method of contracting, the contractor states a price after estimating the cost based on a completed design supplied by the owner. The price offered by the contractor includes the estimated cost to perform the work tasks and supply the necessary materials, overhead for both project and home office, a project risk contingency, and the desired profit.

There is movement toward more Design-Build (D-B) contracts, where the contractor has control of the project design. With a design-build project, the contractor must state a guaranteed price before the design is completed. This adds an additional element of risk, because estimating the quantities of materials required to complete the project becomes very subjective as final plans have not been completed. But the advantage to the contractor is the ability to match the design to corporate construction skills. In either case, it is tacitly assumed that the winning contractor has been able to underbid the competition because of a more efficient work plan, lower overhead costs, or a willingness to accept a lower profit.

Not infrequently, however, the range between the high and low bids is much greater than these factors would justify. A primary cause of variance in the bid prices submitted by different companies is a contractor's inability to estimate costs accurately. The largest portion of estimating variance is probably caused by a lack of accurate historical cost records. Most contractors have cost-reporting systems, but in numerous cases the systems fail to allocate expenses to the proper sources and, therefore, the estimators arrive at false conclusions when the historical database is used for estimating future work.

A construction company owner will frequently use both contract volume and contract turnover to measure the strength of the firm. Contract volume refers to the total dollar value of awarded contracts a firm has on its books (under contract) *at any given time*. Contract turnover measures the dollar value of work a firm completes during a specific *time interval*. Contract volume is a guide to the magnitude of resources a firm has committed at any one time and to possible profit if the work is completed as estimated. But contract volume fails to answer any timing questions. A contractor who, with the same contract volume as the competition, is able to achieve a more rapid project completion, and, therefore, a higher capital turnover rate while maintaining the revenue-to-expense ratio, will be able to increase the firm's profits. Contractors who finish work ahead of schedule usually make money.

PLANNING EQUIPMENT UTILIZATION

Each piece of construction equipment is designed to efficiently perform certain mechanical operations. The task of the project planner/estimator or the engineer on the job is to match the right machine or combination (spread) of machines to the job at hand. Considering individual tasks, the quality of performance is measured by matching the equipment spread's production against its cost. Production is work done; it can be the volume or weight of material moved, the number of piles driven into the ground, the square yards of paving placed, or any similar measurement of progress. To estimate the equipment component of project cost, the planner/estimator must first determine machine *productivity*, which is governed by engineering fundamentals, planning, and finally project management. Engineering fundamentals—the power a machine can develop and the resistance encountered—control machine productivity, these are explained in Chapter 6. Each level of productivity has a corresponding cost associated with the effort expended. The expenses a firm experiences through machine ownership and use and the method of analyzing such costs are presented in Chapter 2.

Although each major type of equipment has different operational characteristics, it is not always obvious which machine is best for a particular project task. After studying the plans and specifications, visiting the project site, and performing a quantity take-off, the planner/estimator must visualize how best to employ specific pieces of equipment to accomplish the work. Is it less expensive to make an excavation with scrapers or to top-load trucks with an excavator? Both methods will yield the required end result, but which is the most economical approach for the given project conditions?

To answer this question, the planner/estimator develops an initial plan for employment of the scrapers and then calculates their production rate and the subsequent cost. The same process is followed for the top-load operation. The question then becomes which alternative "type of equipment" has the lowest estimated total cost, including mobilization of the machines to the site.

To perform such analyses, the planner/estimator must consider the physical project site, machine capability, and the method of employment. In developing suitable equipment employment techniques the first question is "what are the material quantities involved." This book does not cover quantity take-off per se, but the accuracy of the material calculation influences the equipment and methods analysis. If it is determined that specific equipment and methods will be used as an excavation progresses, then it is necessary to divide the quantity take-off in a manner compatible with the proposed equipment utilization. The person performing the quantity take-off must calculate the quantities by groups of similar material types (dry earth, wet earth, rock). It is not just a question of estimating the total quantity of rock or the total quantity of material to be excavated. All factors affecting equipment performance and choice of construction method must be considered in making the quantity take-off, such as location of the water table, clay, or sand seams; site dimensions; depth of excavations; and compaction requirements.

The normal operating modes of the particular equipment types are discussed in Chapters 5, 7 to 18, and 20. These overview presentations should not blind the reader to other possible applications. The most successful construction companies are those who, for each individual project, spend time carefully developing a construction plan. Such companies carefully study all possible approaches to the construction process. These companies use project preplanning, risk identification, and risk quantification techniques when formulating a project work plan. No two projects are exactly alike; therefore, it is important for the planner/estimator to begin each new project with a completely open mind and to carefully review all options. Additionally, machines are constantly being improved and new equipment is being introduced, so attention to machine evolution is required for success.

Heavy equipment is usually classified or identified by one of two methods: *functional* identification or *operational* identification. A bulldozer, used to push a stockpile of material, could be identified as a support machine for an aggregate production plant. The bulldozer could, however, be *functionally* classified as an excavator. In this book, combinations of functional and operational groupings are used. The basic purpose is to explain the significant performance characteristics of a particular piece of equipment and then to describe the most common applications for such machines.

The efforts of contractors and equipment manufacturers who strive to develop new ideas constantly advance machine capabilities. As the array of useful equipment expands, the importance of careful planning and execution of construction operations increases. New machines enable greater economies. It is the job of the planner/estimator and field personnel to match equipment to project situations. This matching of machines to tasks is the focus of this book.

SUMMARY

Civilizations are built by construction efforts. Every civilization had its birth with the advancement of its construction industry because construction is an important contributor to growth and quality of life. This chapter presented an abbreviated history of construction equipment, an overview of construction work, and the risks associated with bidding work. Machine productivity, the amount of earth moved or concrete placed, is only one element of the machine selection process. It is also necessary to identify the cost associated with machine production. The critical learning objectives are:

- An understanding of how construction equipment and machines have been developed in response to the demands of the work to be undertaken.
- An appreciation for the importance of considering safety when planning and operation.

These objectives are the basis for the problems.

PROBLEMS

1.1 Research these engineers on the Web and write a one-page paper about their accomplishments:

Emily Warren Roebling

Benjamin Holt

Nora Stanton

R. G. LeTourneau

Elsie Eaves

William S. Otis

1.2 Research these engineering accomplishments on the Web and write a one-page paper about the equipment used to accomplish their construction:

Inka Road

Hoover Dam

Panama Canal

Interstate highway program

1.3 What is the function of the Occupational Health and Safety Administration (www.osha.gov)?

1.4 Does your state operate an occupational safety and health program in accordance with Section 18 of the Occupational Safety and Health Act of 1970?

1.5 Why do some construction workers resist the use of safety equipment such as hard hats and fall protection harnesses? Why does the practice of resisting the use of safety equipment persist? What should be done about it?

1.6 Review several issues of *Engineering News Record*, or *ENR* (enr.com), to find reports about construction accidents. Be prepared to give your perspective in class about what should be done about the types of accidents mentioned in the reports.

RESOURCES

1. *Building for Tomorrow: Global Enterprise and the U.S. Construction Industry* (1988). National Research Council, National Academy Press, Washington, DC.
2. *Davis-Bacon Manual on Labor Standards for Federal and Federally Assisted Construction* (1993). The Associated General Contractors (AGC) of America, Alexandria, VA.
3. *OSHA Safety & Health Standards for Construction (OSHA 29 CFR 1926 Construction Industry Standards)* (2003). The Associated General Contractors (AGC) of America, Alexandria, VA.
4. Schexnayder, Cliff J., and Scott A. David (2002). "Past and Future of Construction Equipment," *Journal of Construction Engineering and Management*, ASCE, 128(4), pp. 279–286.

WEBSITE RESOURCES

Significant additional information about the construction industry can be found posted on the following websites.

Associations and Organizations

Following are sites about construction associations and organizations:

1. *www.asce.org* The American Society of Civil Engineers (ASCE) is a professional organization of individual members from all disciplines of civil engineering dedicated to developing leadership, advancing technology, advocating lifelong learning, and promoting the profession.
2. *www.asme.org* The American Society of Mechanical Engineers (ASME) is a nonprofit educational and technical organization that publishes many standards in reference to construction equipment.
3. *www.agc.org* The Associated General Contractors of America (AGC) is an organization of construction contractors and industry-related companies.
4. *www.construction-institute.org* The Construction Industry Institute (CII) is a research organization with the mission of improving the competitiveness of the construction industry. CII is a consortium of owners and contractors who have joined together to find better ways of planning and executing capital construction programs.

Codes and Regulations

Sites that provide information about codes or regulations that impact the construction industry include the following:

1. *www.osha.gov* The U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) establishes protective standards, enforces those standards, and reaches out to employers and employees through technical assistance and consultation programs. OSHA's mission is to ensure safe and healthful workplaces in America.

2. *www.nist.gov* The National Institute of Standards and Technology (NIST) is a non-regulatory federal agency within the U.S. Commerce Department's Technology Administration. NIST develops and promotes measurement, standards, and technology.
3. *www.ansi.org* The American National Standards Institute (ANSI) is a private, nonprofit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system.
4. *www.iso.ch* The International Organization for Standardization (ISO) is a non-governmental organization. It is a network of the national standards institutes from 148 countries, with one member per country and a Central Secretariat in Geneva, Switzerland, that coordinates the system.
5. *www.astm.org* ASTM International, formerly known as the American Society for Testing and Materials, is a not-for-profit organization that provides a global forum for the development and publication of voluntary consensus standards for materials, products, systems, and services.

Safety

1. *www.nsc.org* National Safety Council (NSC) has an excellent library for workplace safety consultants and human resources managers offering resources, member information, services, and publications.
2. *www.ntsb.gov* National Transportation Safety Board (NTSB) is an independent federal agency that conducts investigations on significant transportation accidents and offers synopses and public hearing overviews.
3. *www.crmusa.com* Contractors Risk Management (CRM), Inc., offers manuals, customized plans, and training programs for construction industry safety and health guidelines.

CHAPTER 2

Equipment Economics

A correct and thorough understanding of equipment ownership and operation costs gives companies a market advantage potentially leading to greater profits. Ownership cost is the cumulative result of those cash flows an owner experiences whether or not the machine is productively employed on a project. Operating cost is the sum of those expenses an owner experiences by using a machine on a project. The process of selecting a particular type of machine for use in constructing a project requires knowledge of the cost associated with operating the machine in the field. Three basic methods can be used for securing a particular machine to use on a project: (1) buy, (2) rent, or (3) lease.

IMPORTANT QUESTIONS

Equipment cost is often one of a contractor's largest expense categories, and it is a cost fraught with almost infinite variables and uncertainty. To be successful, equipment owners must carefully analyze and answer two separate questions about the cost of their machines:

1. How much does it cost to operate the machine on a project?
2. What is the optimum economic life and the optimum manner to secure a machine?

The first question is critical to bidding and operations planning. The only reason for purchasing equipment is for its ability to perform work economically and, thereby, generate a profit for the company. This question seeks to identify the expense associated with productive machine work, and it is commonly referred to as ownership and operating (O&O) cost. **O&O** cost is expressed in dollars per machine operating hour (e.g., $120/hr for a dozer) because it is used in calculating the cost per unit of machine production. If a dozer can push 300 cubic yards (cy) per hour and

O&O
The ownership and operating costs of a machine.

it has a \$120/hr O&O cost, production cost is \$0.400/cy (\$120/hr/300cy/hr). The planner/estimator can use the cost per cubic yard figure directly when bidding unit price work. On a lump-sum job, it will be necessary to multiply the unit price by the estimated quantity to obtain the total amount to charged.

The second question seeks to identify the optimum point in time to replace a machine and the optimum way to secure a machine. The answer to the second question is important as the decision will affect O&O cost and can lower production expense, enabling a contractor to achieve a better pricing position. The process of answering this question is known as *replacement analysis*. A complete replacement analysis must also investigate the alternatives of renting or leasing a machine.

The economic analyses to answer these two cost questions requires the input of many expense and operational factors. These input factors will be discussed first and the development of the analysis procedures will follow.

EQUIPMENT RECORDS

Data on both machine utilization and costs are the keys to making rational equipment decisions, but the collection of individual pieces of data is only the first step. The data must be assembled and presented in useful formats–the arrangement and graphical presentation must clearly emphasize critical information. Many contractors recognize this need and strive to collect and maintain accurate equipment records for evaluating machine performance, establishing operating cost, analyzing replacement questions, and managing projects.

Realizing the advantages to be gained from these efforts, owners are directing more attention to accurate record keeping. Advances in computer technology have reduced the effort required to implement record systems. Software companies offer record-keeping packages specifically designed for contractors. In many cases, the task is simply the retrieval of equipment cost data from existing accounting files.

Automation introduces the ability to handle more data economically and in shorter time frames, but the basic information required to make rational decisions is still the critical item. A commonly used technique in equipment costing and record keeping is the standard rate approach. Under such a system, jobs are charged a standard machine utilization cost rate for every hour the equipment is employed (often defined as when the engine is running, this is greater than actual production time). Machine expenses are charged either directly to the individual machine or to machine type cost accounts. This method is sometimes referred to as an internal or company rental system. Such a system presents a fairly accurate representation of investment consumption, and it properly assigns machine expenses. In the case of a company replacing machines each year and continuing in operation, this system enables a check at the end of each year on estimate rental rates as the internally generated rent should equal the expenses absorbed.

The first piece of information necessary for rational equipment analysis is not an expense, but a record of the machine's use. One of the implicit assumptions of a replacement analysis is the continuing need for a machine's production capability. Therefore, before one begins a replacement analysis, the disposal–replacement question must be resolved.

Is this machine really necessary for economical construction of future projects?

A projection of the ratio between total equipment capacity and utilized capacity provides a quick guide for the dispose–replace question.

The level of detail for reporting equipment use varies. Both independent service vendors and equipment companies offer data collection devices. These can provide accurate real-time information about machine use. The systems are installed on the machine and transmit data via the most cost-effective wireless network (satellite or cellular networks). As a minimum, data should be collected on a daily basis to record whether a machine worked or was idle. More sophisticated systems seek to identify use on an hourly basis, accounting for actual production time and categorizing idle time by classifications such as standby, down weather, and down repair. The input for either type of system is easily incorporated into regular personnel timekeeping reports, with machine time and operator time being reported together.

Most of the information required for ownership and operating or replacement analyses is available in the company's accounting records. All owners keep records on a machine's initial purchase expense and final realized salvage value as part of the accounting data required for tax filings. Maintenance expenses can be tracked from mechanics' time sheets, from purchase orders for parts, or from shop work orders. Service logs provide information concerning consumption of consumables. Fuel amounts can be recorded at fuel points or with automated systems. Fuel amounts should be cross-checked against the total amount of purchased fuel. When detailed and correct reporting procedures are maintained, the accuracy of equipment costs analyses is greatly enhanced.

THE RENT PAID FOR THE USE OF MONEY

What is commonly referred to as the *time value* of money is the value difference between funds borrowed and spent today, and the amount to be repaid at a future date. It as the *rent* paid to use someone else's money immediately. As the proliferation of credit cards makes apparent, many individuals take this charge for granted. This rent or added charge is termed *interest*. It reflects both the profit and risk a lender applies to the base amount of money borrowed. Interest, expressed as a percentage of the amount borrowed (owed), becomes due and payable at the close of each billing period. It is typically stated as a yearly rate. Here's an example: If \$1,000 is borrowed at 8% interest, then \$1,000 × 0.08, or \$80, in interest will accrue over a period of 1 year. After 1 year, the borrower will owe the original \$1,000 plus \$80 of interest. Therefore, to repay the debt, the borrower would have to pay \$1,080 at the end of a 1-year time period. If this new total amount is not repaid at the end of the 1-year period, the interest for the second year would be calculated based on the new total debt, $1,080, and thus the interest is *compounded*. After a 2-year period, the amount owed would be $1,080 + ($1,080 × 0.08), or $1,166.40. If the company's credit is good and it has borrowed the $1,000 from a bank, the banker normally does not care whether repayment is made after 1 year at $1,080 or after 2 years at $1,166.40. To the bank, the three amounts—$1,000, $1,080, and $1,166.40—are equivalent. In other words, $1,000 today is equivalent to $1,080 one year in the future, which is also equivalent to $1,166.40 two years in the future. The three amounts are obviously not equal, they are *equivalent*. The concept of equivalence involves time and a specific interest rate. The three amounts are equivalent only for the case of an interest rate of 8%, and then only at the specified points in time. Equivalence means a single sum or series differs from another only by the accrued, accumulated interest at rate i for n periods of time.

Note the principal amount was multiplied by an interest rate to obtain the amount of interest due. To generalize this concept, the following symbols are used:

P = present single amount of money
F = future single amount of money, after n periods of time
i = rate of interest per period of time (usually 1 year)
n = number of time periods

Different situations involving an interest rate and time are presented next, and the appropriate analytical formulas are developed.

Equation for Single Payments

To calculate the future value F of a single payment P after n periods at an interest rate i, these formulations are used:

At the end of the first period, $n = 1$: $F_1 = P + Pi$
At the end of the second period, $n = 2$: $F_2 = P + Pi + (P + Pi)i = P(1 + i)^2$
At the end of the nth period, $F = P\ (1 + i)^n$

Or the future single amount of a present single amount is

$$F = P(1 + i)^n \qquad \textbf{[2.1]}$$

Observe how F is related to P by a factor that depends only on i and n. This factor is termed the *single payment compound amount factor (SPCAF)*; it makes F equivalent to P.

If a future amount F is given, the present amount P can be calculated by transposing the equation to

$$P = \frac{F}{(1 + i)^n} \qquad \textbf{[2.2]}$$

The factor $1/(1 + i)^n$ is known as the *present worth compound amount factor (PWCAF)*.

EXAMPLE 2.1

A constructor wishes to borrow \$100,000 to finance a project. The interest rate is 6% per year. If the borrowed amount and the interest are paid back after 4 years, what will be the total amount of the repayment?

To solve, use Eq. [2.1]:

$$F = \$100{,}000\,(1 + 0.06)^4 = \$100{,}000 \times 1.26247696$$

$$= \$126{,}247.70$$

The amount of interest is \$26,247.70.

EXAMPLE 2.2

A constructor wants to set aside enough money today in an interest-bearing account to have \$200,000 three years from now for the purchase of a replacement piece of equipment. If the company can receive 5% per year on its investment, how much should be set aside now to accrue the \$200,000 three years from now?

To solve, use Eq. [2.2]:

$$P = \frac{\$200{,}000}{(1+0.05)^3} = \frac{\$200{,}000}{(1.1576250)}$$

$$= \$172{,}768$$

In Examples 2.1 and 2.2, single payments now and in the future were equated. Four parameters were involved: P, F, i, and n. *Given any three parameters, the fourth can be calculated.*

Formulas for a Uniform Series of Payments

Often payments or receipts occur at regular intervals, and such uniform values can be handled by use of additional formulas. First, let us define another symbol:

A = uniform *end-of-period* payments or receipts continuing for a duration of n periods

If this uniform amount A is invested at the end of each period for n periods at a rate of interest i per period, then the total equivalent amount F at the end of the n periods will be

$$F = A[(1 + i)^{n-1} + (1 + i)^{n-2} + \ldots + (1 + i) + 1]$$

By multiplying both sides of the equation by $(1 + i)$, we obtain

$$F(1 + i) = A[(1 + i)^n + (1 + i)^{n-1} + (1 + i)^{n-2} \ldots + (1 + i)]$$

Now by subtracting the original equation from both sides of the new equation, we obtain

$$Fi = A(1 + i)^n - 1$$

which can be rearranged to

$$F = A\left[\frac{(1+i)^n - 1}{i}\right] \qquad \textbf{[2.3]}$$

The relationship $[(1 + i)^n - 1]/i$ is known as the *uniform series compound amount factor (USCAF)*. The relationship can be rearranged to yield

$$A = F\left[\frac{i}{(1+i)^n - 1}\right] \qquad \textbf{[2.4]}$$

The relationship $i/[(1 + i)^n - 1]$ is known as the *uniform series sinking fund factor (USSFF)*, because it determines the uniform end-of-period investment A needed to provide an amount F at the end of n periods.

To determine the equivalent uniform period series required to replace a present value of P, simply substitute Eq. [2.1] for F into Eq. [2.4] and rearrange. The resulting equation is

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad \textbf{[2.5]}$$

This relationship is known as the *uniform series present worth factor (USPWF)*.

By inverting Eq. [2.5], the equivalent uniform series end-of-period value A can be obtained from a present value P. The equation is

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad \textbf{[2.6]}$$

This relationship is known as the *uniform series capital recovery factor (USCRF)*.

Cash flow diagrams can be drawn of the six preceding equivalence relationships. *Cash flow diagrams* are drawings where the horizontal line represents time and the vertical arrows represent cash flows at specific times (up positive, down negative). The cash flow diagrams for each relationship are shown in Figure 2.1. These relationships, which are summarized in Table 2.1, form the basis for many complicated engineering economy studies involving the time value of money.

Most engineering economy problems are more complicated than examples 2.1 and 2.2 and must be broken down into parts.

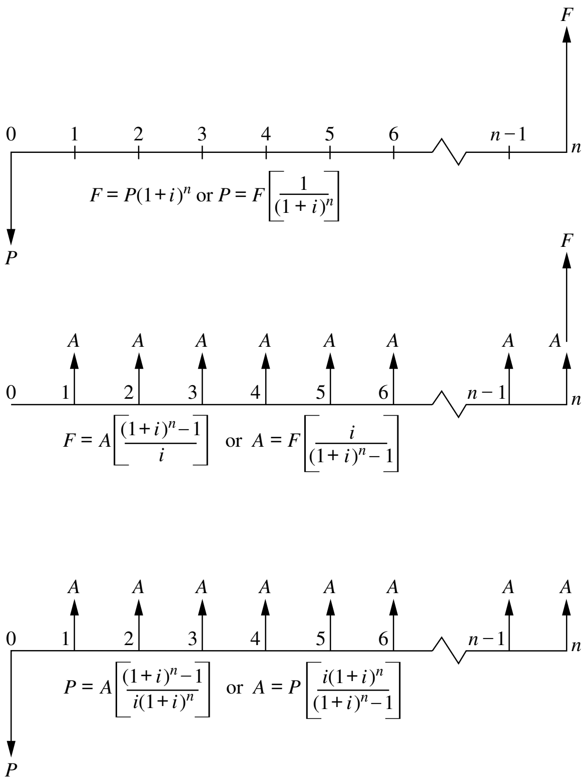
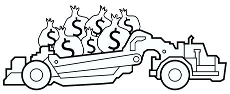


FIGURE 2.1 Cash flow diagrams

TABLE 2.1 Economic analysis relationships

Name	Symbol	Converts	Icon	Formula
Single payment compound amount factor	SPCAF	given P to F	(F/P, i%, n)	$(1+i)^n$
Present worth compound amount factor	PWCAF	given F to P	(P/F, i%, n)	$1/(1+i)^n$
Uniform series compound amount factor	USCAF	given A to F	(F/A, i%, n)	$\frac{(1+i)^n - 1}{i}$
Uniform series sinking fund factor	USSFF	given F to A	(A/F, i%, n)	$\frac{i}{(1+i)^n - 1}$
Uniform series present worth factor	USPWF	given A to P	(P/A, i%, n)	$\frac{(1+i)^n - 1}{i(1+i)^n}$
Uniform series capital recovery factor	USCRF	given P to A	(A/P, i%, n)	$\frac{i(1+i)^n}{(1+i)^n - 1}$

EXAMPLE 2.3



A machine cost \$45,000 to purchase. Fuel and minor maintenance are estimated to cost \$12.34 per operating hour (those hours when the engine is operating and the machine is doing work). A set of tires cost \$3,200 to replace, and their estimated life is 2,800 use hours. A \$6,000 major repair will probably be required after 4,200 hr of use. The machine is expected to last for 8,400 hr, after which it will be sold at a price (salvage value) equal to 10% of the original purchase price. A final set of new tires will not be purchased before the sale. How much should the owner of the machine charge per hour of use, if it is expected that the machine will operate 1,400 hr per year? The company's cost of capital rate is 7%. First solve for n, the life:

$$n = \frac{8{,}400 \text{ hr}}{1{,}400 \text{ hr per yr}} = 6 \text{ yr}$$

Usually ownership and operating cost components are calculated separately. Tires are considered an operating cost element because they wear out much faster than the basic machine. Therefore, before calculating the ownership cost of a machine having pneumatic tires, the cost of the tires should be subtracted from the purchase price:

$$\$45{,}000 - \$3{,}200 = \$41{,}800$$

Now the annualized purchase expense can be calculated using the *uniform series capital recovery factor*:

$$A_{\text{ownership}} = \$41{,}800 \left[\frac{0.07(1+0.07)^6}{(1+0.07)^6 - 1} \right] = \$41{,}800 \times 0.209796 = \$8{,}769.46$$

Salvage value at the end of 6 years is

$$\$45{,}000 \times 0.1 = \$4{,}500$$

The annualized *value* of the salvage amount 6 years in the future can be calculated using the *uniform series sinking fund factor*:

$$A_{\text{salvage}} = \$4{,}500 \left[\frac{0.07}{(1+0.07)^6 - 1} \right] = \$4{,}500 \times 0.139796 = \$629.08$$

The annualized *value* of the salvage amount 6 years in the future can also be calculated using the *present worth compound amount factor* with the *uniform series capital recovery factor*:

$$A_{\text{salvage}} = \left[\frac{\$4{,}500}{(1+0.07)^6} \right] \left[\frac{0.07(1+0.07)^6}{(1+0.07)^6 - 1} \right] = \$629.08$$

The annual fuel and minor maintenance cost is

$$\$12.34 \text{ per hr} \times 1{,}400 \text{ hr per yr} = \$17{,}276.00$$

In addition to the original set of tires, two sets of replacement tires will have to be purchased, one set 2 years into the life of the machine and a second set 4 years into the life. To annualize the tire replacement cost (convert to a yearly basis), these future point-in-time costs must be made equivalent to a present amount at time zero, and then the resulting amount is annualized across the 6-year life of the machine. To do this, use the *present worth compound amount factor* with the *uniform series capital recovery factor*:

$$A_{\text{tires}} = \left[\$3{,}200 + \frac{\$3{,}200}{(1+0.07)^2} + \frac{\$3{,}200}{(1+0.07)^4}\right]\left[\frac{0.07(1+0.07)^6}{(1+0.07)^6 - 1}\right]$$
$$= (\$3{,}200.00 + \$2{,}795.00 + \$2{,}441.26)(0.209796) = \$1{,}769.89$$

The annualized cost for the major repair 3 years into the life is

$$A_{\text{major repair}} = \left[\frac{\$6{,}000}{(1+0.07)^3}\right]\left[\frac{0.07(1+0.07)^6}{(1+0.07)^6 - 1}\right]$$
$$= (\$4{,}897.79)(0.209796) = \$1{,}027.54$$

The resulting total annual cost is

$$A_{\text{total}} = \$8{,}769.46 - \$629.08 + \$17{,}276.00 + \$1{,}769.89 + \$1{,}027.54$$
$$= \$\ 28{,}213.81$$

The total cost per hour is

$$\text{Total cost} = \frac{\$28{,}213.81 \text{ per yr}}{1{,}400 \text{ hr per yr}} = \$20.153 \text{ per hr}$$

In this chapter, all of these costs and methods for their calculation are discussed in detail.

COST OF CAPITAL

The cost-of-capital interest rate a company experiences is a weighted average rate resulting from the combined costs associated with external and internal sources of capital funds.

External

- Debt (borrowing)
- Equity (sale of stock)

Internal

- Retained earnings (reinvest profits in the business)
- Internally generated (pay bills later and encourage speedier payment from customers)

Furthermore, the cost-of-capital interest rate a company experiences is affected by the risk associated with its business type. The market perceives the risk of the business and applies an after-tax discount rate to the future wealth it expects to derive from the firm. Consequently, the rate banks charge for borrowed funds cannot be taken alone as the company's cost-of-capital interest rate when evaluating investment alternatives. For a complete treatment of cost-of-capital see

Modigliani and Miller's classic paper "The Cost of Capital, Corporate Finance and the Theory of Investment" published in *The American Economic Review*.

Many discussions of equipment economics include *interest* as a cost of ownership. Sometimes the authors make comparisons with the interest rates that banks charge for borrowed funds or with the rate that could be earned if the funds were invested elsewhere. Such comparisons imply that these are appropriate rates to use in an equipment cost analysis. A more thoughtful analysis yields the proper character of the interest rate a company experiences. A company requires capital funds for all of its operations. Hence, it is not logical to assign different interest costs to machines purchased wholly with retained earnings (cash) as opposed to those purchased with borrowed funds. A single interest rate should be determined by examination of the combined costs associated with all sources of capital funds: debt, equity, and retained earnings.

There are two parts to the common misunderstanding concerning the proper way to account for interest. First, as just discussed, the correct interest rate should reflect the combined effect of the costs associated with all capital funds. The second error comes in trying to recoup *interest costs*. Interest is not a cost to be added together with purchase expense, taxes, and insurance when calculating the total cost of a machine.

This might be easier to understand using an analogy. Consider the situation of a bank trying to decide whether a loan should be granted. The question before the bank is one of *risk*: what are the chances the money will be repaid? Based on the perceived risk, a decision is made on how much return must be received to *balance* the risk. If 100 loans are made, the banker knows some will not be repaid. Those borrowers who repay their loans as promised have to provide the total profit margin for the bank. The good loans must carry the bad loans. A company utilizing equipment should be making a similar analysis every time a decision is made to invest in a piece of equipment.

Based on the risk associated with the type of work the company will undertake, interest is the fulcrum for determining whether the value a machine will create for the company is sufficient. A proper interest rate ensures there is a gain in value compared to cost and risk.

The interest rate at issue is referred to in the economic literature as the *cost of capital* to the company, and a market value technique has been developed for its calculation. A complete development of the market value cost-of-capital calculation is beyond the scope of this text, but Reference 4 (Lewellen 1976) at the end of this chapter provides a good presentation of the subject. The resulting cost-of-capital rate is the correct interest rate to use in economic analyses of equipment decisions.

EVALUATING INVESTMENT ALTERNATIVES

The purchase, rental, lease, or replacement of a piece of equipment is a financial investment decision, and as such the real question is how best to use a company's assets. Financial investment decisions are analyzed using time value of money principles. Such analyses require an input interest rate or the calculation of the interest rate that results from the assumed cash flows.

Discounted-Present-Worth Analysis

A discounted-present-worth analysis involves calculating the *equivalent* present worth or present value of all the dollar amounts involved in each of the individual alternatives to determine the present worth of the proposed alternatives. The present worth is discounted at a predetermined rate of interest i, often termed the minimum attractive rate of return (MARR). The MARR is usually equal to the current cost-of-capital rate for the company. Example 2.4 illustrates the use of a discounted-present-worth analysis to evaluate three mutually exclusive investment alternatives.

EXAMPLE 2.4

Ace Builders is considering three different acquisition methods for obtaining pickup trucks. The alternatives are

A. Immediate cash purchase the trucks for $16,800 each, and after 4 years sell each truck for an estimated $5,000.

B. Lease the trucks for 4 years for $4,100 per year paid in advance at the beginning of each year. The contractor pays all operating and maintenance costs for the trucks, and the leasing company retains ownership.

C. Purchase the trucks using a time payment plan requiring an immediate down payment of $4,000 and $4,500 per year at the end of each year for 3 years. Assume the trucks will be sold after 4 years for $5,000 each.

If the contractor's MARR is 8%, which alternative should be used? To answer the question, calculate the net present worth (NPW) of each alternative using an 8% interest rate and select the least costly alternative.

For alternative A, use the present worth compound amount factor to calculate the equivalent salvage value at time zero. Add the purchase price, which is negative because it is a cash outflow, and the equivalent salvage value, which is positive because it is a cash inflow. The result is the net present worth of alternative A:

$$\text{NPW}_A = -\$16{,}800 + \frac{\$5{,}000}{\text{PWCAF}}$$

Calculate the PWCAF with i equal to 8% and n equal to 4:

$$\text{NPW}_A = -\$16{,}800 + \frac{\$5{,}000}{1.360489} = -\$13{,}125$$

For alternative B, use the uniform series present worth factor to calculate the time-zero equivalent value of the future lease payments, and add to that result the value of the initial lease payment; both of these are negative because they are cash outflows. There is no salvage in this case, as the leasing company retains ownership of the trucks.

$$\text{NPW}_B = -\$4{,}100 - \$4{,}100\ (\text{USPWF})$$

Calculating the USPWF with i equal to 8% and n equal to 4,

$$\text{NPW}_B = -\$4{,}100 - \$4{,}100\left[\frac{0.259712}{0.100777}\right] = -\$14{,}666$$

For alternative C, use the uniform series present worth factor to calculate the time-zero equivalent value of the future payments and the present worth compound amount factor to calculate the equivalent salvage value at time zero. Add the three values, the initial payment and the equivalent annual payment both being negative and the salvage being positive, to arrive at the net present worth of alternative C.

$$NPW_C = -\$4{,}000 - \$4{,}500(\text{USPWF}) + \left[\frac{\$5{,}000}{\text{PWCAF}}\right]$$

$$NPW_C = -\$4{,}000 - \$4{,}500\left[\frac{0.259712}{0.100777}\right] + \left[\frac{\$5{,}000}{1.360489}\right] = -\$11{,}922$$

The least costly alternative is C.

Example 2.4 was simplified in two respects. First, the number of calculations required was quite small. Second, all three alternatives involved the same time duration (4-year lives). Problems involving more data may require more calculations, but the analysis approach is the same as shown in Example 2.4. When the alternatives involve different time durations (machines have different expected durations of usefulness), the analysis must be modified to account for the different time durations. Obviously, if a comparison is made of one alternative having a life of 5 years and another with a life of 10 years, the respective discounted present worths are not directly comparable. How is such a situation handled? Two approaches are generally used:

Approach 1. Truncate (cut off) the longer-lived alternative(s) to equal the shorter-lived alternative and assume a salvage value for the unused portion of the longer-lived alternative(s). Then make the comparison on the basis of equal lives.

Approach 2. Compute the discounted present worth on the basis of the least common denominator of the different alternatives' lives.

ELEMENTS OF OWNERSHIP COST

Ownership cost is the cumulative result of those cash flows an owner experiences whether or not the machine is productively employed on a job. It is a cost related to finance and accounting exclusively, and it does not include the wrenches, nuts and bolts, and consumables necessary to keep the machine operating.

Most of ownership cash flows are expenses (outflows), but a few are cash inflows, and one serves to prevent a cash outflow. The most significant cash flows affecting *ownership cost* are:

1.	Purchase expense	outflow
2.	Salvage value	inflow
3.	Tax saving from depreciation	prevention of a cash outflow
4.	Major repairs and overhauls	outflow

5. Property taxes outflow
6. Insurance outflow
7. Storage and miscellaneous outflow

Purchase Expense

The cash outflow a firm experiences in acquiring ownership of a machine is the purchase expense. It is the total delivered cost (drive-away cost), including amounts for all options, shipping, and taxes, less the cost of tires if the machine has pneumatic tires. Tires have a significantly shorter service than the machine iron, so they are handled separately. The machine will show as an asset in the firm's accounting records. The firm has exchanged money (dollars), a liquid asset, for a machine, a fixed asset with which the company hopes to generate a future revenue stream. As the machine is used on projects, wear takes its toll and the machine can be thought of as being used up or consumed. This consumption reduces the machine's value because the revenue stream it can generate is likewise reduced. Normally, an owner tries to account for the decrease in value by prorating the consumption of the investment over the *service life* of the machine. This prorating is known as **market depreciation.**

market depreciation *The asset's loss in value over time as determined by market forces (demand for used equipment).*

In discussing equipment economics, three different types of depreciation impact a machine owner's decisions. First is actual market depreciation in value, which is the difference in purchase price and the salvage amount actually received, or how the marketplace values the machine at two different points in time. The magnitude of difference between the initial acquisition expense and the expected future salvage value should be prorated across the life of the machine. The second type of depreciation is known as **book depreciation.** It is how accountants, following accepted accounting principles, prorate the machine's loss in value.

book depreciation *An accounting method used to describe an asset's loss in value.*

Book depreciation is correct to the extent of accounting for the amounts involved, but it neglects the timing of the cash flows. Therefore, it is recommended to treated each cash flow separately, use a time value analysis, and employ various assumptions during sensitivity analyses of decision scenarios.

The third type of depreciation is **tax depreciation**, which is discussed in the next section. It is the amount the governmental tax codes permit as a deduction when calculating taxable income.

tax depreciation *The loss in value of an asset over time as specified by the government.*

Salvage Value

Salvage value is the cash inflow a firm receives if a machine still has value at the time of its disposal. This is a cash inflow that will occur at a future date.

Used equipment prices are difficult to predict. Machine condition (Figure 2.2), the movement of new machine prices (Figure 2.3), and the machine's possible secondary service applications affect the amount an owner can expect to receive. A machine having a diverse and layered service potential will command a higher resale value. Medium-size dozers, which often exhibit rising

FIGURE 2.2 Salvage value is dependent on machine condition

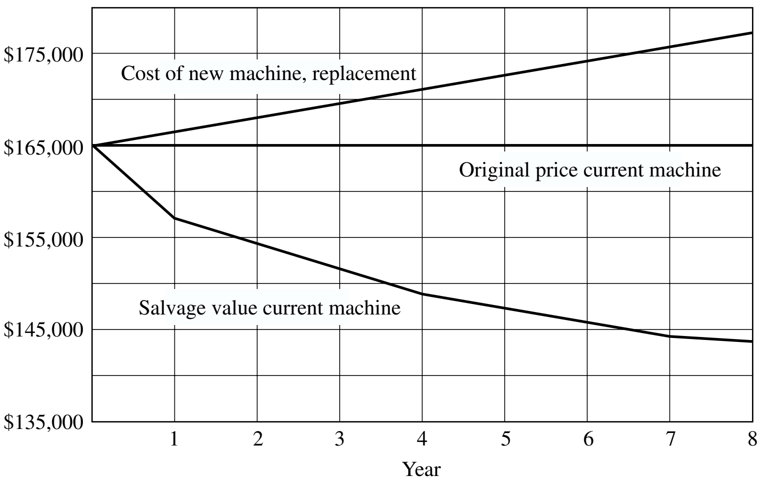


FIGURE 2.3 The movement of new machine prices, or cost, is one factor affecting salvage value

salvage values in later years because these machines can have as many as seven different levels of useful life. The useful application of such dozers may range from an initial assignment as a high-production machine on a dirt spread to an infrequent land-clearing assignment by a farmer.

Historical resale data can provide some guidance in making salvage value predictions. Such data can easily be accessed from auction price books. By studying such historical data and recognizing the effects of the economic environment, the magnitude of salvage value prediction errors can be minimized and accuracy of an ownership cost analysis improved.

Tax Savings from Depreciation

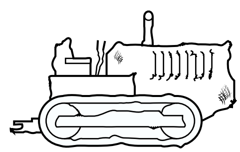
The tax savings from depreciation are a phenomenon of the tax system in the United States. (This may not be an ownership cost factor under the tax laws in other countries.) Under the tax laws of the United States, depreciating a machine's loss in value with age will lessen the net cost of machine ownership. The cost saving, the prevention of a cash outflow, afforded by tax depreciation is a result of shielding the company from taxes. This is an applicable cash flow factor only if a company is operating at a profit. Carry-back features in the tax law allow the savings to be preserved even if a loss is incurred in any one particular year, but the long-term operating position of the company must be at a profit for the company to realize tax savings from depreciation.

The rates at which a company can depreciate a machine are set by the revenue code. These rates usually have no relation to actual consumption of the asset (machine). Therefore, many companies keep several sets of depreciation numbers: one for depreciation tax purposes, one for corporate earnings tax accounting purposes, and one for internal and/or financial statement purposes. The first two are required by the revenue code. The last tries to match the consumption of the asset accurately based on work application and company maintenance policies.

Under current U.S. tax code, tax depreciation accounting no longer requires the assumption of a machine's future salvage value and useful life. The only piece of information necessary is *basis*, which refers to the cost of the machine for purposes of computing gain or loss. Basis is essential. To compute tax depreciation amounts, fixed percentages are applied to the unadjusted basis. The terminology *adjusted/unadjusted* refers to changing the book value of a machine by depreciation or major mechanical improvements.

The U.S. tax code allows the postponement of taxation on financial gains derived from the exchange of like-kind depreciable property. If a gain is realized from a like-kind exchange, the depreciation basis of the new machine is reduced by the amount of the gain. However, if the exchange involves a disposal sale to a third party and a separate acquisition of the replacement, the gain from the sale is taxed as ordinary income.

EXAMPLE 2.5



A tractor with an adjusted basis (from depreciation) of $25,000 is traded for a new tractor that has a fair market value of $400,000. A cash payment of $325,000 is made to complete the transaction. Such a transaction is a nontaxable exchange, and no gain is recognized on the trade-in. The unadjusted basis of the new tractor is $350,000, even though the cash payment was $325,000 and the apparent gain in value for the traded machine was $50,000 [($400,000 – $325,000) – $25,000].

Cash payment	$325,000
Adjusted basis of the trade-in tractor	25,000
Basis of the new tractor	$350,000

If the owner had sold the old tractor to a third party for $75,000 and then purchased a new tractor for $400,000, the $50,000 profit on the third-party sale would have been taxed as ordinary income and the unadjusted basis of the new tractor would be $400,000.

The current tax depreciation code establishes depreciation percentages based on the specific year of machine life. These are usually the optimum depreciation rates in terms of tax advantage. An owner can, however, still utilize the straight-line method of depreciation or methods not expressed in terms of time duration (years). Unit-of-production would be an example of a non–time-based depreciation system.

Straight-Line Depreciation Straight-line depreciation is easy to calculate. The annual amount of depreciation D_n, for any year n, is a constant value, and thus the book value (BV_n) decreases at a uniform rate over the useful life of the machine. Here are the equations:

$$\text{Depreciation rate, } R_n = \frac{1}{N} \qquad [2.7]$$

where N = number of years.

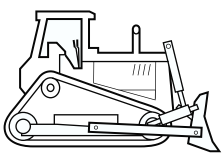
$$\text{Annual depreciation amount, } D_n = \text{Unadjusted basis} \times R_n$$

Substituting Eq. [2.7] yields

$$D_n = \frac{\text{Unadjusted basis}}{N} \qquad [2.8]$$

$$\text{Book value year } m, \text{BV}_n = \text{Unadjusted basis} - (n \times D_n) \qquad [2.9]$$

EXAMPLE 2.6



Consider the new tractor in Example 2.5 and assume it has an estimated useful life of 5 years. Determine the depreciation and the book value for each of the 5 years using the straight-line method.

$$\text{Depreciation rate, } R_n = \frac{1}{5} = 0.2$$

Annual depreciation amount, D_n = $350,000 × 0.2 = $70,000

m	BV_{n-1}	D_n	BV_n
0	$ 0	$ 0	$350,000
1	350,000	70,000	280,000
2	280,000	70,000	210,000
3	210,000	70,000	140,000
4	140,000	70,000	70,000
5	70,000	70,000	0
