INTRODUCTION TO Maintenance Engineering

Modeling, Optimization, and Management

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WILEY

INTRODUCTION TO MAINTENANCE ENGINEERING

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INTRODUCTION TO MAINTENANCE ENGINEERING

To our wives *Faouzia*, *Renu*, and *Jayashree* for their patience and understanding.

Preface

The Metal Age, which started around 3000 BC, saw the appearance of metal tools and the evolution of civilizations in different regions of the world. This led to the development of tools for warfare and farming, and the building of roads, boats, houses, and so on. The Industrial Revolution created new mechanical devices and machines. This, in turn, led to the development of the electrical, hydraulic, and other devices and equipment that are used nowadays in nearly all sectors – farming, processing, mining, manufacturing, transport, communication, and so on, all with specific needs for maintenance. The construction of infrastructures (such as electricity, water, gas and sewage networks, dams, roads, railways, bridges, etc.) resulted in new maintenance challenges in order to keep them operational.

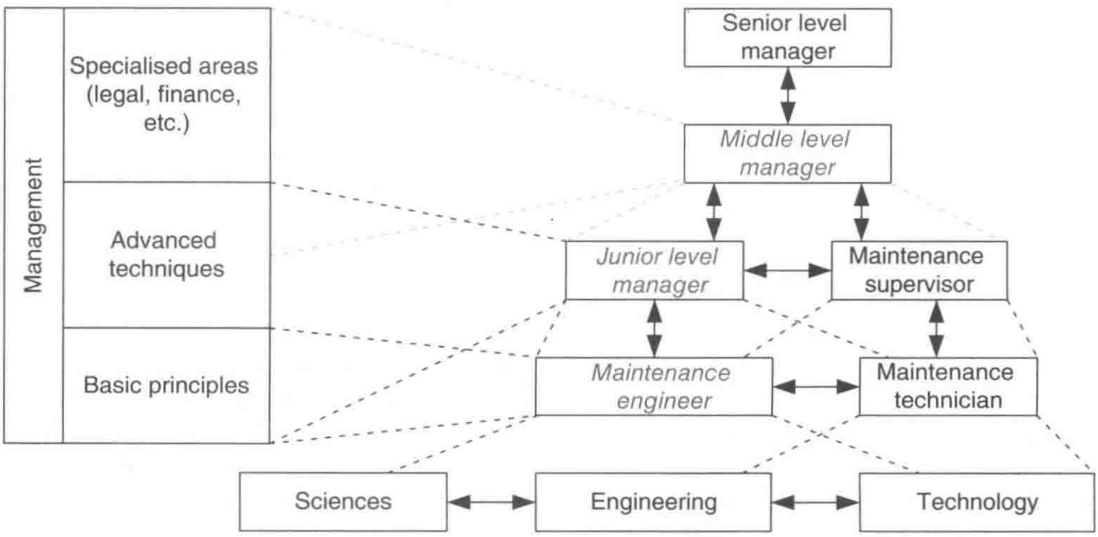
The reason why engineered objects (be they products, plants, or infrastructures) need maintenance is that every object is unreliable, in the sense that it degrades with age and/or usage and ultimately fails when it is no longer capable of discharging its function. Maintenance actions compensate for the inherent unreliability of an object and may be grouped broadly into two categories: (i) preventive maintenance (PM) to control the degradation process and (ii) corrective maintenance (CM) to restore a failed object to the operational state.

Maintenance actions were mainly of the corrective type until the middle of the last century – the adage being, "don't touch if it ain't broke." Also, preventive actions were viewed as money wasted. Maintenance was done by trained technicians who were very good at fixing failures (often fondly referred to as "grease-pit monkeys" in the popular literature). Maintenance was an afterthought in the design of new objects and was simply viewed as an unavoidable cost to be incurred after these objects were built and put into operation.

There was a dramatic change after the Second World War. Reliability evolved as a new discipline, and the theory of reliability dealt with various aspects, such as (i) the science of degradation, (ii) the use of statistical methods to assess reliability, and (iii) mathematical models to predict item failures and the importance of preventive maintenance. Investing in preventive maintenance lowers the cost of corrective maintenance but results in additional costs. Operational Research (the application of scientific methods to solve industrial problems) focused on models to decide on the optimal level of preventive maintenance to achieve a proper trade-off between the costs of corrective and preventive maintenance.

The next stage of evolution was the emergence of alternative approaches to the maintenance of objects in different industry sectors. Two methods that have been used extensively across the world are: (i) reliability-centered maintenance (RCM), which had its origins in the airline industry, and (ii) total productive maintenance (TPM), which had its origins in manufacturing. Advances in technology (sensors, data collection, computers, and communication) have resulted in the evolution of condition-based maintenance (CBM) and e-maintenance.

Maintenance in the twenty-first century has moved from the trial and error approach of the technicians of the early twentieth century to a multi-disciplinary subject with science, engineering, and technology as its foundations. A maintenance engineer is a professional engineer with this background, and so is different from a maintenance technician, who is skilled in carrying out specified maintenance tasks. An understanding of the basic principles of management is also an important element of modern maintenance practice. Furthermore, maintenance engineers/managers need advanced techniques for maintenance data analysis and also need to build models to assist effective maintenance decision making. The need to interact with other disciplines (such as law, accounting, etc.) is also needed by senior-level maintenance managers. The figure below shows this in a schematic format.



Over the last few decades, hundreds of books on maintenance have appeared in print. The authors are not aware of any book for use in a first course on maintenance that takes the comprehensive view needed for the twenty-first century. This book aims to fill this gap and is meant for use as a textbook on maintenance at the senior undergraduate or graduate level in engineering programs. The unique features of the book are as follows:

- It provides a unified approach linking science, engineering, technology, mathematics and statistics, and management.
- It focuses on concepts, tools, and techniques.
- It links theory and practice using real, illustrative cases involving products, plants, and infrastructures (many chapters have three sections dealing with specific issues for these different types of items).

The book provides a good foundation for a new graduate to work as a maintenance engineer and to build a career by moving through the ranks of junior- and middle-level management responsible for maintaining the various types of engineered objects. It can also be used as a reference book by practicing maintenance engineers/managers to understand the modern knowledge-based approach to maintenance. The book can also be used as a starting point for researchers in maintenance.

The book is flexible enough to be used as a textbook in various undergraduate and graduate programs. A suggested sequence for four programs is as follows:

- Undergraduate level
  - Industrial engineering programs: Chapters 1–7, 8–9, 17, 19–22
  - Other engineering programs: Chapters 1–4, 6–7, 17, 19, 22
- Graduate level
  - Maintenance engineering programs: Chapters 1–4, 6, 8–12, 13–20
  - Engineering management programs: Chapters 1–7, 17–22

Each chapter deals with several topics. The book is suitable for one or two full courses or part of one or more courses depending on the topics selected.

The background needed to understand and fully appreciate the contents of the book is an understanding of the basic concepts from the following disciplines:

- Mathematics;
- Physics and Chemistry;
- Engineering (covering design, manufacturing, construction, and operations);
- Probability and Statistics.

This book evolved through a joint partnership between three researchers/educators from three different continents and is based on the experiences of the authors in teaching and research in maintenance over the last three decades.

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Abbreviations

A–D	Anderson and Darling
AE	Acoustic emission
AI	Artificial Intelligence
AIC	Akaike information criterion
ASCE	American Society of Civil Engineers
BIT	Built-in-testing
BOT	Build, operate, transfer
CAPEX	Capital expenditure
CBM	Condition-based maintenance
CC	Cycle cost
CEN	Comité Européenne de Normalisation (French) European Committee for Standardization
CEO	Chief Executive Officer
CL	Cycle length
CM	Corrective maintenance
CMMS	Computerized maintenance management system
CPM	Critical path method
DBFO	Design, build, finance, and operate
DIKW	Data, information, knowledge, and wisdom
DoD	Department of Defense
DOM	Design out maintenance
DTC	Diagnostic trouble code
EAC	Equivalent annual cost
ECC	Expected cycle cost
ECL	Expected cycle length
EDF	Empirical distribution function
EMMS	e-maintenance management system
EN	Europäische Norm (German): European Standard
EPP	Exponential probability plot

ET	Electromagnetic testing
FF	Failure finding
FHWA	Federal Highway Authority
FM	Facilities management
FMEA	Failure mode and effects analysis
FMECA	Failure mode, effects, and criticality analysis
FMMEA	Failure modes, mechanisms, and effects analysis
FRW	Free repair/replacement warranty
FT	Fault tree
FTA	Fault tree analysis
GPR	Ground-penetrating radar
GPRS	General packet radio service
HPP	Homogeneous Poisson process
HSE	Health, safety, and environmental
ICT	Information and communication technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEV	International electrotechnical vocabulary
IMU	Intelligent monitoring unit
IQR	Inter-quartile range
ISO	International Standards Organization
JIT	Just-in-time
KPI	Key performance indicator
K–S	Kolmogorov and Smirnoff
LC	Lease contract
LCC	Life cycle cost
LCC_C	Life cycle cost (customer perspective)
LCC_M	Life cycle cost (manufacturer perspective)
LCCA	Life cycle cost analysis
LIDAR	Laser imaging detection and ranging
LORA	Level of repair analysis
LT	Leak testing
LTM	Laser testing method
M&R	Maintenance and rehabilitation
MCF	Mean cumulative function
MEMS	Micro-electromechanical sensor
MFL	Magnetic flux linkage
MGT	Million gross tons
MIL-HDBK	Military handbook
ML	Maximum likelihood
MLE	Maximum likelihood estimate
MMS	Maintenance management system
MPI	Maintenance performance indicator
MPM	Maintenance performance metric
	Maintenance performance management
MPMS	Maintenance performance management system

MPT	Magnetic particle testing
MTBF	Mean time between failures
MTTF	Mean time to failure
MTTR	Mean time to repair
NASA	National Aeronautic and Space Administration
NDT	Non-destructive testing
NFF	No fault found
NHPP	Non-homogeneous Poisson process
NN	Neural network
NPD	New product development
NPV	Net present value
NRT	Neutron radiographic testing
NTC	Negative temperature coefficient
O&M	Operation and maintenance
OBD	On-board diagnostics
OEE	Overall equipment effectiveness
OEM	Original equipment manufacturer
OOR	Out-of-round
OPEX	Operating expenditure
OPG	One-pass grinding
OR	Operations Research
PDCA	Plan, do, Check, Act
PFI	Private financing initiative
PI	Performance indicator
PLC	Product life cycle
PM	Preventive maintenance
PMS	Performance management system
	Production management system
PPE	Property, plant, and equipment
PPP	Public–private partnership
PT	Penetrant testing
PTC	Positive temperature coefficient
R&D	Research and development
R&M	Reliability and maintainability
RAIB	Rail Accident Investigation Branch
RAM	Reliability, availability, and maintainability
RBD	Reliability block diagram
RBM	Risk-based maintenance
RCD	Residual current device
RCF	Rolling contact fatigue
RCM	Reliability-centered maintenance
RFID	Radio frequency identification
RIW	Reliability improvement warranty
RLC	Regional logistic center
ROCOF	Rate of occurrence of failures
RP	Renewal process

RT	Radiographic testing
RTD	Resistance temperature detector
RTF	Run to failure
SAE	Society of Automotive Engineers
SCC	Stress corrosion cracking
SOLE	The International Society of Logistics
SRB	Solid rocket booster
TAM	Turn around maintenance
TLC	Technology life cycle
TPM	Total productive maintenance
TQM	Total quality management
TR	Thermal/infrared testing
UHF	Ultra high frequency
UT	Ultrasonic testing
VA	Vibration analysis
VHF	Very high frequency
VT	Visual testing
WLAN	Wireless local area network
WPAN	Wireless personal area network
WPP	Weibull probability plot
WSN	Wireless sensor network
WT	Wind turbine
WWAN	Wireless wide area network

Contents