

Human Reliability, Error,
and Human Factors *in*
Engineering Maintenance

*with Reference to Aviation
and Power Generation*

Human Reliability, Error, *and* Human Factors *in* Engineering Maintenance

*with Reference to Aviation
and Power Generation*

B.S. Dhillon



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2009 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-13: 978-1-4398-0383-7 (Hardcover)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Dhillon, B. S.

Human reliability, error, and human factors in engineering maintenance : with reference to aviation and power generation / B.S. Dhillon.

p. cm.

"A CRC title."

Includes bibliographical references and index.

ISBN 978-1-4398-0383-7 (hardcover : alk. paper)

1. Human engineering. 2. Human-machine systems. 3. Errors--Prevention. 4. Reliability (Engineering) 5. Fallibility. 6. Airplanes--Maintenance and repair--Quality control. 7. Electric power plants--Maintenance and repair--Quality control. I. Title.

TA167.D468 2009

620'.0046--dc22

2009005529

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

Dedication

This book is affectionately dedicated to all my schoolteachers, including Mr. C. Bell and Mr. G. B. Gill at the Dale School for Boys, Derby, England, for their inspirational comments and constant encouragement.

Contents

Preface xiii
Author Biography..... xv

Chapter 1

Introduction..... 1
1.1 Background..... 1
1.2 History 1
 1.2.1 Human Factors..... 1
 1.2.2 Human Reliability and Error 2
 1.2.3 Engineering Maintenance..... 2
1.3 Human Reliability, Error, and Human Factors in Engineering
 Maintenance–Related Facts and Figures..... 2
1.4 Terms and Definitions..... 4
1.5 Useful Information on Human Reliability, Error,
 and Human Factors in Engineering Maintenance 5
 1.5.1 Publications..... 5
 1.5.1.1 Books 5
 1.5.1.2 Technical Reports 6
 1.5.1.3 Conference Proceedings 6
 1.5.1.4 Journals 7
 1.5.2 Data Sources 8
 1.5.3 Organizations..... 8
1.6 Scope of the Book..... 9
1.7 Problems 10
References..... 10

Chapter 2

Basic Mathematical Concepts..... 13
2.1 Introduction 13
2.2 Boolean Algebra Laws and Probability Properties 13
2.3 Useful Definitions..... 16
 2.3.1 Probability 16
 2.3.2 Cumulative Distribution Function Type I..... 17
 2.3.3 Probability Density Function Type I 17
 2.3.4 Probability Density Function Type II 17
 2.3.5 Cumulative Distribution Function Type II 17
 2.3.6 Reliability Function 18
 2.3.7 Hazard Rate Function 18
 2.3.8 Expected Value Type I..... 18
 2.3.9 Expected Value Type II 18

2.3.10	Laplace Transform	18
2.3.11	Laplace Transform: Final-Value Theorem.....	19
2.4	Probability Distributions	20
2.4.1	Poisson Distribution.....	20
2.4.2	Binomial Distribution	21
2.4.3	Geometric Distribution	21
2.4.4	Exponential Distribution.....	22
2.4.5	Normal Distribution.....	23
2.4.6	Gamma Distribution	23
2.4.7	Rayleigh Distribution.....	24
2.4.8	Weibull Distribution	24
2.5	Solving First-Order Differential Equations Using Laplace Transforms.....	25
2.6	Problems	26
	References.....	27

Chapter 3

	Introductory Human Factors, Reliability, and Error Concepts.....	29
3.1	Introduction	29
3.2	Human Factors Objectives and Man–Machine System Types and Comparisons	29
3.3	Human Sensory Capacities and Typical Human Behaviors and Their Corresponding Design Considerations	31
3.3.1	Touch.....	31
3.3.2	Sight	31
3.3.3	Vibration	32
3.3.4	Noise	32
3.4	Human Factors–Related Formulas	33
3.4.1	Formula for Estimating Inspector Performance	33
3.4.2	Formula for Estimating Rest Period	33
3.4.3	Formula for Estimating Character Height	33
3.4.4	Formula for Estimating Glare Constant	34
3.5	Useful Human Factors Guidelines and Data Collection Sources.....	34
3.6	Human Performance Effectiveness and Operator Stress Characteristics	35
3.7	Occupational Stressors and General Stress Factors	36
3.8	Human Performance Reliability and Correctability Functions.....	37
3.8.1	Human Performance Reliability Function.....	37
3.8.2	Human Performance Correctability Function	39
3.9	Human Error Occurrence Reasons, Consequences, Ways, and Classifications	39
3.10	Human Reliability and Error Data Collection Sources and Quantitative Data	40
3.11	Problems	41
	References.....	42

Chapter 4

Methods for Performing Human Reliability and Error Analysis in Engineering Maintenance..... 45

- 4.1 Introduction 45
- 4.2 Failure Modes and Effect Analysis (FMEA)..... 45
- 4.3 Man–Machine Systems Analysis 47
- 4.4 Root Cause Analysis (RCA) 47
- 4.5 Error-Cause Removal Program (ECRP)..... 49
- 4.6 Cause-and-Effect Diagram (CAED)..... 49
- 4.7 Probability Tree Method..... 50
- 4.8 Fault Tree Analysis (FTA)..... 53
 - 4.8.1 Fault Tree Symbols 53
 - 4.8.2 Steps for Performing FTA 54
 - 4.8.3 Probability Evaluation of Fault Trees 54
- 4.9 Markov Method 57
- 4.10 Problems 60

References..... 60

Chapter 5

Human Error in Maintenance 63

- 5.1 Introduction 63
- 5.2 Facts, Figures, and Examples 63
- 5.3 Occurrence of Maintenance Error in Equipment Life Cycle and Elements of a Maintenance Person’s Time 64
- 5.4 Maintenance Environment and Causes for the Occurrence of Maintenance Errors 65
 - 5.4.1 Noise 65
 - 5.4.2 Poor Illumination..... 65
 - 5.4.3 Temperature Variations 65
- 5.5 Types of Maintenance Errors and Typical Maintenance Errors 66
- 5.6 Common Maintainability Design Errors and Useful Design Improvement Guidelines to Reduce Equipment Maintenance Errors 67
- 5.7 Maintenance Work Instructions..... 68
- 5.8 Maintenance Error Analysis Methods..... 69
 - 5.8.1 Probability Tree Method..... 69
 - 5.8.2 Pontecorvo Method..... 71
 - 5.8.3 Pareto Analysis 74
 - 5.8.4 Markov Method 74
- 5.9 Problems 76

References..... 76

Chapter 6

Human Factors in Aviation Maintenance 79

- 6.1 Introduction 79

- 6.2 The Need for Human Factors in Aviation Maintenance and How Human Factors Impact Aircraft Engineering and Maintenance 79
- 6.3 Human Factors Challenges in Aviation Maintenance 80
- 6.4 Practical Human Factors Guide for the Aviation Maintenance Environment 80
- 6.5 Integrated Maintenance Human Factors Management System (IMMS) 83
- 6.6 Aviation Maintenance Human Factors Training Program and Human Factors Training Areas for Aviation Maintenance Personnel 84
- 6.7 Common Human Factors–Related Aviation Maintenance Problems 86
- 6.8 Problems 86
- References 87

Chapter 7

- Human Factors in Power Plant Maintenance 89
- 7.1 Introduction 89
- 7.2 Human Factors Engineering Maintenance–Related Deficiencies in Power Plant Systems 89
- 7.3 Desirable Human Factors Engineering Maintenance–Related Attributes of Well-Designed Systems in Power Generation 90
- 7.4 Power Generation Plant Performance Goals That Drive Decisions about Human Factors 91
- 7.5 Study of Human Factors in Power Plants 92
- 7.6 Human Factors Approaches for Assessing and Improving Power Plant Maintainability 93
 - 7.6.1 Task Analysis 93
 - 7.6.2 Maintainability Checklist 94
 - 7.6.3 Potential Accident/Damage Analyses 94
 - 7.6.4 Structured Interviews 94
 - 7.6.5 Critical Incident Technique 95
 - 7.6.6 Surveys 95
- 7.7 Benefits of Human Factors Engineering Applications in Power Generation 96
- 7.8 Problems 96
- References 97

Chapter 8

- Human Error in Aviation Maintenance 99
- 8.1 Introduction 99
- 8.2 Facts, Figures, and Examples 99
- 8.3 Causes of Human Error in Aviation Maintenance and Major Categories of Human Errors in Aviation Maintenance and Inspection Tasks 100
- 8.4 Types of Human Error in Aircraft Maintenance and Their Frequency 100
- 8.5 Common Human Errors in Aircraft Maintenance Activities 101
- 8.6 Aircraft Maintenance Error Analysis Methods 101

8.6.1	Cause-and-Effect Diagram	101
8.6.2	Error-Cause Removal Program (ECRP).....	102
8.6.3	Fault Tree Analysis	104
8.7	Maintenance Error Decision Aid (MEDA)	106
8.8	Useful Guidelines for Reducing Human Error in Aircraft Maintenance Activities.....	107
8.9	Case Studies in Human Error in Aviation Maintenance	109
8.9.1	Continental Express Embraer 120 Accident.....	109
8.9.2	Air Midwest Raytheon (Beechcraft) 1900D Accident	109
8.9.3	British Airways BAC1-11 Accident	110
8.10	Problems	110
	References.....	110

Chapter 9

	Human Error in Power Plant Maintenance.....	113
9.1	Introduction	113
9.2	Facts and Figures	113
9.3	Causes of Human Error in Power Plant Maintenance.....	114
9.4	Maintenance Tasks Most Susceptible to Human Error in Power Generation	116
9.5	Methods for Performing Maintenance Error Analysis in Power Generation	116
9.5.1	Fault Tree Analysis	116
9.5.2	Markov Method	119
9.5.3	Maintenance Personnel Performance Simulation (MAPPS) Model.....	122
9.6	Steps for Improving Maintenance Procedures in Power Generation and Useful Guidelines for Human Error Reduction and Prevention in Power Generation Maintenance.....	122
9.7	Problems	123
	References.....	124

Chapter 10

	Safety in Engineering Maintenance	127
10.1	Introduction	127
10.2	Facts, Figures, and Examples	127
10.3	Causes of Maintenance Safety Problems and Factors Responsible for Dubious Safety Reputation in Maintenance Activity.....	128
10.4	Factors Influencing Safety Behavior and Safety Culture in Maintenance Personnel.....	129
10.5	Good Safety-Related Practices during Maintenance Work and Maintenance-Related Safety Measures concerning Machinery.....	129
10.6	Maintenance Safety-Related Questions for Engineering Equipment Manufacturers.....	131
10.7	Guidelines for Engineering Equipment Designers to Improve Safety in Maintenance	132

- 10.8 Mathematical Models 132
- 10.9 Problems 135
- References..... 136

Chapter 11

- Mathematical Models for Performing Human Reliability
and Error Analysis in Engineering Maintenance 139
- 11.1 Introduction 139
- 11.2 Models for Predicting Maintenance Personnel Reliability
in Normal and Fluctuating Environments 139
 - 11.2.1 Model I..... 140
 - 11.2.2 Model II 141
 - 11.2.3 Model III..... 145
- 11.3 Models for Performing Single Systems Maintenance Error Analysis..... 147
 - 11.3.1 Model I..... 148
 - 11.3.2 Model II 150
- 11.4 Models for Performing Redundant Systems Maintenance
Error Analysis..... 153
 - 11.4.1 Model I..... 153
 - 11.4.2 Model II 156
- 11.5 Problems 158
- References..... 159
- Appendix..... 161

Preface

Each year billions of dollars are spent to maintain engineering systems throughout the world. For example, U.S. industry spends over \$300 billion on plant maintenance and operation annually. It is estimated that about 80 percent of this amount is spent to rectify the chronic failure of systems, machines, and humans.

Over the years, the occurrence of human errors in maintenance activities has been following an upward trend due to various factors, and the resulting consequences can be very serious. Two examples of these consequences are the Three Mile Island nuclear accident and the crash of a DC-10 aircraft at O'Hare Airport in Chicago.

Over the years, a large number of journal and conference proceedings articles on human reliability, error, and human factors in engineering maintenance have appeared, but to the best of this author's knowledge, there is no book that covers these three topics and includes maintenance safety within its framework. This causes a great deal of difficulty for engineering maintenance professionals because they have to consult many different and diverse sources.

Thus, the main objective of this book is to combine these topics into a single volume and eliminate the need to consult many diverse sources in obtaining desired information. The sources of most of the material presented are listed in the reference section at the end of each chapter. These will be useful to readers if they desire to delve more deeply into a specific area or topic of interest.

The book contains a chapter on mathematical concepts and another chapter on introductory material to human factors, reliability, and error, which are useful for understanding materials presented in subsequent chapters. Furthermore, another chapter is devoted to methods considered useful for performing human reliability and error analysis in engineering maintenance.

The topics covered in the book are treated in such a manner that the reader will require no previous knowledge to understand the contents. At appropriate places the book contains examples along with their solutions, and at the end of each chapter there are numerous problems to test the reader's comprehension. An extensive list of publications dating from 1929 to 2007, directly or indirectly on human reliability, error, and human factors in engineering maintenance, is provided at the end of this book to give readers a view of the intensity of developments in the area.

This book is composed of 11 chapters. Chapter 1 presents historical developments in human factors, human reliability and error, and engineering maintenance; important human reliability, error, and human factors in engineering maintenance—related facts, figures, terms, and definitions; and sources for obtaining useful information on human reliability, error, and human factors in engineering maintenance.

Chapter 2 reviews mathematical concepts considered useful to understanding subsequent chapters. Some of the topics covered in the chapter are Boolean algebra, probability properties, probability distributions, and useful definitions. Chapter 3 presents various introductory human factors, reliability, and error concepts.

Chapter 4 presents a total of eight methods considered useful for performing human reliability and error analysis in engineering maintenance. These methods are failure modes and effect analysis, man-machine systems analysis, root cause analysis, error-cause removal program, the cause-and-effect diagram, the probability tree method, fault tree analysis, and the Markov method. Chapter 5 is devoted to human error in maintenance. Some of the topics covered in this chapter are the maintenance environment, causes for the occurrence of maintenance errors, types of maintenance errors, typical maintenance errors, and useful design improvement guidelines to reduce equipment maintenance errors.

Chapters 6 and 7 present various important aspects of human factors in aviation maintenance and power plant maintenance, respectively. Chapter 8 is devoted to human error in aviation maintenance. It covers topics such as human error occurrence causes in aviation maintenance, types of human errors in aircraft maintenance, common human errors in aircraft maintenance activities, maintenance error decision aid (MEDA), and useful guidelines for reducing human error in aircraft maintenance activities.

Chapter 9 presents various important aspects of human error in power plant maintenance, including facts and figures, causes of human error in power plant maintenance, maintenance tasks most susceptible to human error in power generation, and steps for improving maintenance procedures in power generation. Chapter 10 is devoted to safety in engineering maintenance. Some of the topics covered in the chapter are facts and figures, maintenance safety problem causes, factors influencing safety behavior and safety culture in maintenance personnel, and guidelines for engineering equipment designers to improve safety in maintenance.

Finally, Chapter 11 presents a total of seven mathematical models for performing human reliability and error analysis in engineering maintenance.

The book will be useful to many individuals, including engineering professionals working in the area of engineering maintenance; maintenance engineering administrators; engineering undergraduate and graduate students; maintenance engineering researchers and instructors; maintainability, safety, human factors, and psychology professionals; and design engineers and associated engineering professionals.

The author is deeply indebted to many individuals, including friends, colleagues, and students for their invisible input. I thank my children, Jasmine and Mark, for their patience and intermittent disturbances that resulted in many coffee breaks! Last, but not least, I thank my wife, Rosy, my other half and friend, for typing various portions of this book and for her timely help in proofreading.

B.S. Dhillon
Ottawa, Ontario

Author Biography

Dr. B. S. Dhillon is a professor of engineering management in the Department of Mechanical Engineering at the University of Ottawa. He has served as chairman/director of the Mechanical Engineering Department/Engineering Management Program for over ten years at the same institution. He has published over 340 articles (199 journal and 141 conference proceedings) on reliability, safety, and engineering management. He is or has been on the editorial boards of nine international scientific journals. In addition, Dr. Dhillon has written thirty-four books on various aspects of reliability, design, safety, quality, and engineering management published by Wiley (1981), Van Nostrand (1982), Butterworth (1983), Marcel Dekker (1984), Pergamon (1986), and so on. His books are being used in over 85 countries, and many of them have been translated into languages such as German, Russian, and Chinese. He served as general chairman of two international conferences on reliability and quality control held in Los Angeles and Paris in 1987.

Professor Dhillon has served as a consultant to various organizations and bodies and has many years of experience in the industrial sector. At the University of Ottawa, he has been teaching reliability, quality, engineering management, design, and related areas for over 29 years. He has also lectured in over 50 countries, including giving keynote addresses at various international scientific conferences held in North America, Europe, Asia, and Africa. In March 2004, Dr. Dhillon was a distinguished speaker at the Conference/Workshop on Surgical Errors (sponsored by the White House Health and Safety Committee and the Pentagon), held on Capitol Hill (1 Constitution Avenue, Washington, D.C.).

Professor Dhillon attended the University of Wales, where he received a BS in electrical and electronic engineering and an MS in mechanical engineering. He received a PhD in industrial engineering from the University of Windsor.