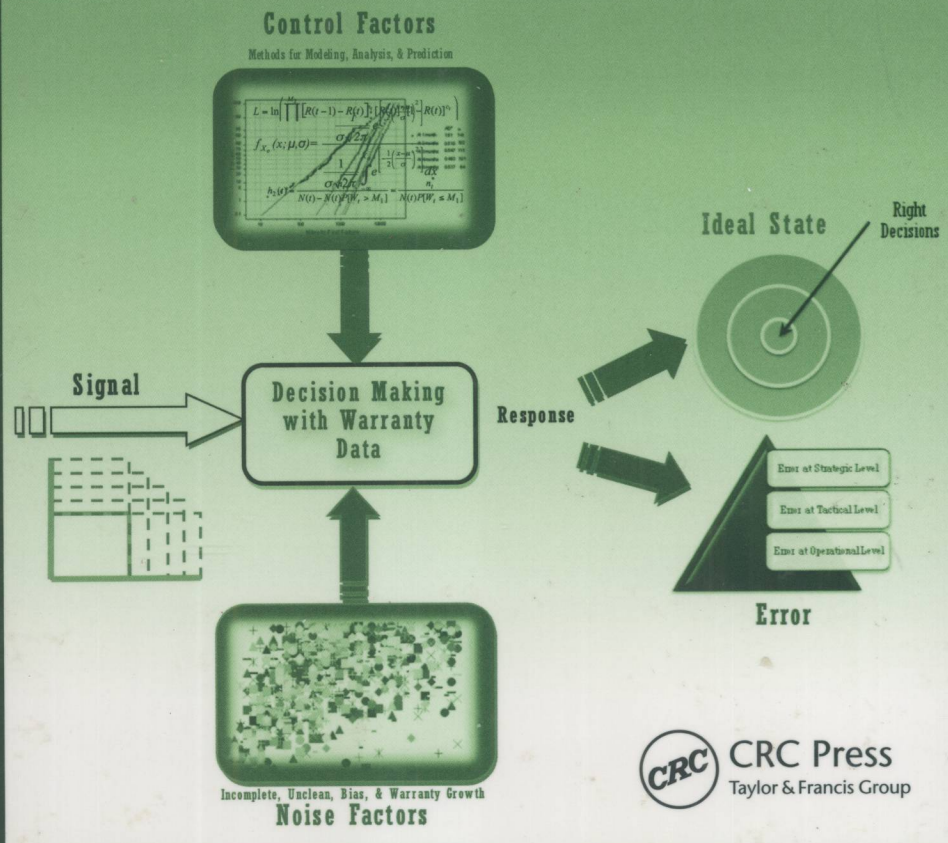
RELIABILITY ANALYSIS and PREDICTION with WARRANTY DATA

Issues, Strategies, and Methods



CRC Press
Taylor & Francis Group

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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

CRC Press is an imprint of Taylor & Francis Group, an Informa business

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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: 978-1-4398-0325-7 (Hardcover)

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Notation

M_1	Warranty mileage limit
M_2	Warranty time limit
t	Months in service ($t = 1, 2, \ldots, M_2$)
N	Total number of vehicles in the field
V_t	Number of vehicles in the field up to t MIS
$N(t)$	Number of vehicles in the field without any claim at the beginning of MIS = t
a	Mileage value below which warranty data is artificially truncated
M_1–b	Mileage value above which warranty data is artificially truncated
n_t	Number of first claims in the mileage interval $(a, M_1–b)$ miles at MIS = t with $0 < a < b < M_1$
n_t^*	Number of first warranty claims at t
c_t	Number of left censored first claims at MIS = t
r_t	Number of vehicles that have not yet completed t MIS
W_t	Random variable denoting miles driven by a vehicle at MIS = t
$R(t)$	Reliability function at MIS = t
$h(t)$	Hazard function
$H(t)$	Cumulative hazard function

Acronyms

ANOVA	Analysis of variance
CCPR	Cumulative cost per repair
Cdf	Cumulative density function
CFR	Constant failure rate
CPU	Cost per unit
CRC	Customer reported concern
DFR	Decreasing failure rate
ICPR	Incremental cost per repair
IFR	Increasing failure rate
LN	Lognormal
MIS	Month(s) in service
MLE	Maximum likelihood estimator
MLP	Multilayer perceptron
OEM	Original equipment manufacturer
Pdf	Probability density function
R/1000	Repairs per thousand
RBF	Radial basis function
SND	Standard normal distribution

Preface

"What goes up, must come down" is an age-old saying. An exception to this seems to be warranty spending in the North American automotive industry. Warranty spending has reached close to double digits in billions of dollars per year, and all efforts to apply the brakes appear to be failing, time and again. In addition, there are market pressures from competitors to provide increased warranty coverage, leading to higher warranty costs and reduced profit margins.

Warranty costs affect companies financially, and are also a massive loss to society. Assuming a $50,000-a-year job, a loss of $8 billion implies an equivalent of 160,000 jobs lost. It also implies millions of dissatisfied customers. Why is this happening? Are engineers too busy looking in their rear mirrors to fix problems, with very little or no time left for looking forward?

It is time we ask where the problem lies. Are we doing our engineering right? Are we designing right, manufacturing right, and assembling right? Where did we lose a handle on such massive waste? The time has come to strike at the roots of the problem. Stephen Covey observes that from the same roots you will get the same fruits. If you want to change the fruits, you need to change the roots.

We believe that a major root cause, among others, is not utilizing a wealth of information hidden in the warranty data to make appropriate design-, manufacturing-, assembly-, or service-related improvements. It would not be an overstatement to say that every company strives to provide the best-quality products to their customers. For complex products such as an automobile, the majority of such efforts are directed at the R&D stage. At the development stage, activities such as concept/design failure mode and effects analysis, design verification planning and reporting, robust design experiments, etc., are performed to develop confidence that highly reliable and robust products have been developed and delivered. Various systems, subsystems, and components undergo prototype testing, life testing, and accelerated life testing for design verification and validation. In spite of employing the best quality and reliability practices, unexpected failures during the warranty period do occur and cost automobile companies billions of dollars annually in warranty alone.

Engineers seeking reliability/robustness improvements extensively use warranty data for feedback as they capture vehicle failures in true field conditions. In general, warranty data provide a rich source of information for modeling, analysis, and prediction to support strategic, tactical, and operational levels of decision making in automobile companies. However, the very nature of the warranty data makes such a task challenging on four counts: (1) availability of vehicle failure information is restricted to failures inside warranty limits (incompleteness), (2) failure reporting and diagnosis are not always accurate ("unclean"), (3) customer-rush leads to higher claims near warranty expiration limit (biased), and (4) increase in the warranty performance numbers when more data become available (warranty growth). Thus, to obtain valid and meaningful information/feedback from warranty data and to

reduce errors at strategic, tactical, and operational levels of decision making, methods addressing such issues are useful.

This book aims to provide such methods and strategies for reliability analysis and prediction with warranty data that can help Six Sigma black belts and engineers to move in the right direction. It provides simple and practical approaches to address the issues identified. The book will be useful to engineers and Six Sigma black belts who extensively use warranty data to define and analyze field problems and seek guidelines for zeroing in on the root causes for warranty cost reduction. The book will also help quality and reliability engineers and professionals to be aware of the issues associated with warranty data and approaches to overcome them.

To achieve the stated goals, the book is divided into three parts. Part 1 provides background and introduction to reliability analysis and prediction using warranty data and highlights the issues involved. Part 2 gives the strategies and methods to obtain component-level nonparametric hazard rate estimates that provide important clues toward probable root causes and help reduce warranty costs. Part 3 of the book deals with prediction of the warranty performance. The methodologies covered help assess the impact of changes in warranty limits and forecast warranty performance.

Bharatendra K. Rai
Nanua Singh

Acknowledgments

We are thankful to John Koszewnik (Director, NA Diesel) and Katherine Franz (Diesel Quarterback Manager) of Ford Motor Company for taking interest in our work and supporting the research position in the company. We are grateful to Bob Knecht (Manager, Warranty Analysis and Administration) for allowing the use of the previous model-year warranty data for research purposes by masking information such as model year, vehicle line, repair type, subsystem, part name/number, etc. We would also like to acknowledge the thought-provoking ideas of Tim Davis and Vasiliy Krivtsov of Ford Motor Company during their reliability and robustness seminars, which motivated the authors' interest in this field of research.

We thank Kurt Schieding of Bank of America (formerly with Ford Motor Company) for continuous encouragement and support during the research work. We also like to thank section supervisors Lisa Fullerton, Dianna Ball, Gary Mazzella, and Ramana Divakaruni of Ford Motor Company for providing opportunities to work on research-related problems and for taking interest in the research work.

We are also very thankful to Cindy Renee Carelli, Jim McGovern, Jennifer Ahringer, and Ashley Gasque of the Taylor & Francis Group for their continued support throughout this book project.

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The Authors

Bharatendra K. Rai, Ph.D., is an assistant professor of business statistics at the Earle P. Charlton College of Business, Wayne State University, Detroit. He received his Ph.D. in industrial engineering from Wayne State. His two master's degrees include specializations in quality, reliability, and operations research from the Indian Statistical Institute and statistics from Meerut University, India. He has vast experience in the area of applied statistics. This includes over seven years of consulting and training experience with various Indian industries such as automotive, cutting tool, electronics, food, pharmaceutical, software, chemical, defense, etc., in the areas of statistical process control, design of experiments, quality engineering, problem solving tools, Six Sigma, and quality management systems. He also has over five years worth of extensive research and work experience at Ford Motor Company in the area of quality, reliability, and Six Sigma.

Dr. Rai's research interests include applications in multivariate diagnosis/pattern recognition and data mining, developing meta models using computer experiments, prediction of unexpended warranty costs, and field performance studies from large warranty datasets. His research publications have appeared in journals such as *IEEE Transactions on Reliability, Reliability Engineering and System Safety, Quality Engineering, International Journal of System Sciences, International Journal of Product Development,* and *Journal of System Science and System Engineering.* He has presented his research work at professional meetings and conferences such as the SAE World Conference, INFORMS annual meetings, the Industrial Engineering Research Conference, American Society for Quality's (ASQ) Annual Quality Congress, Taguchi's Robust Engineering Symposium, and the Canadian Reliability and Maintainability Symposium. He has also coauthored book chapters in the area of applied statistics.

Dr. Rai has won awards for excellence and exemplary teamwork at Ford Motor Company for his contributions in the area of applied statistics. He also received an Employee Recognition Award by Ford Asian Indian Association (FAIA) for his Ph.D. dissertation in support of Ford Motor Company. He is certified as an ISO 9000 lead assessor from the British Standards Institute and as an ISO 14000 lead assessor from Marsden Environmental International, and has been designated a Six Sigma black belt by the American Society for Quality. He can be contacted at:

Email: brai@umassd.edu
Phone: (508) 999-6434
Office: CCB 326

Nanua Singh, Ph.D., is the president of RGBSI (Rapid Global Business Solutions, Inc.). Dr. Singh sets the strategic direction and goals for the global growth of RGBSI. His main objective is to provide innovative solutions to global clients by leveraging the talent and years of expertise that RGBSI resources possess. RGBSI is an American company, founded in March 1997 with its headquarters in Madison

Heights, Michigan, and offices in Manhattan (New York), Bangalore (India), Shanghai (China), Dusseldorf (Germany), and Toronto (Canada).

An academician-turned-entrepreneur, Dr. Singh has published three books in engineering, with another forthcoming. He has supervised over twenty Ph.D.s and over sixty master's theses, and published and presented over 130 research papers in a variety of international journals/conferences.

His career highlights include being a professor at the prestigious India Institute of Technology (IIT) Delhi (India), head of the Department of Industrial Engineering at the University of Windsor (Canada), and tenured professor of manufacturing engineering at Wayne State University in Detroit. Dr. Singh spent one year on his sabbatical in the Department of Industrial and Operations Engineering at the University of Michigan, Ann Arbor, Michigan.

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