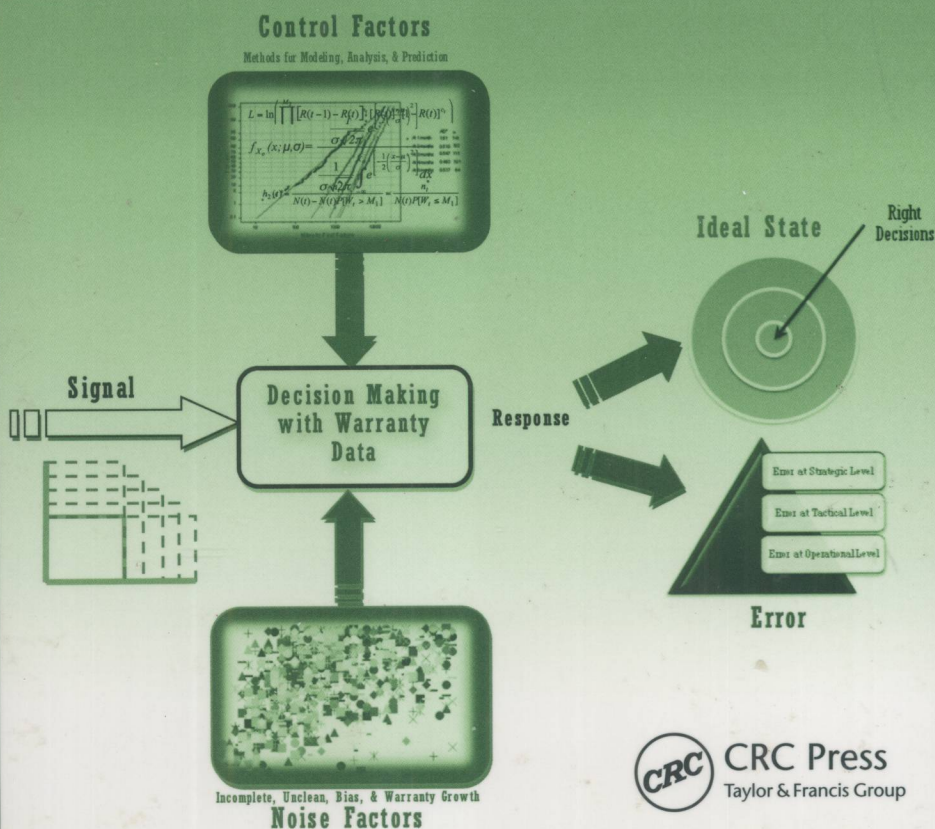


# RELIABILITY ANALYSIS and PREDICTION with WARRANTY DATA

Issues, Strategies, and Methods



BHARATENDRA K. RAI  
NANUA SINGH

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**RELIABILITY ANALYSIS**  
and **PREDICTION** with  
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# Notation

$M_1$	Warranty mileage limit
$M_2$	Warranty time limit
$t$	Months in service ( $t = 1, 2, \dots, M_2$ )
$N$	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

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# Acronyms

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

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# 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**



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**BKR**  
**NS**

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