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Wallace R. Blischke
M. Rezaul Karim
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Warranty Data Collection and Analysis

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Warranty Data Collection and Analysis

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Dedicated to

Douglas Paul Satterblom, in Memorium

WRB

*My wife Tahmina and daughters Nafisa and
Raisa*

MRK

*The Memory of my parents, Seethamma and
Narsimha Murthy*

DNPM

Preface

Warranty is a critical element in the marketing of products. It provides assurance to customers that the manufacturer will provide compensation, through repair, replacement or refund, for purchased items that do not perform satisfactorily. This has become more critical with the increase in consumer expectations that has occurred over recent years and the passage of legislation demanding better customer protection.

Offering warranty has serious implications for manufacturers. Although offering better warranty terms may give a manufacturer a marketing advantage over competitors, this entails an additional cost, namely that associated with the servicing of warranty claims. Depending on the product and the manufacturer, these costs typically vary from 1 to 10% of the sale price of the item, and may have serious implications with regard to the manufacturer's reputation and the profitability of the business.¹

Warranty costs depend on the number of warranty claims and the servicing strategy used by the manufacturer. The number of claims depends on the field reliability of the product, which is influenced by both consumer actions (such as operating environment, usage intensity, maintenance, due care, etc.) and decisions of the manufacturer (design, development, production, testing, etc.).

Manufacturers must make decisions with regard to product launch based on the limited information gathered during the design and development stages of the new product development process. Warranty data provide useful information for assessing product reliability and detecting reliability problems (e.g., those associated with design, production, component suppliers, etc.), as well as problems associated with the servicing of warranty claims. Warranty data consist of (1) claims data and (2) supplementary data. Claims data are data that are collected during the servicing of warranty claims. Supplementary data are additional data and information needed for proper analysis of the claims data. These data are

¹ See *Warranty Week*—a weekly electronic newsletter—for reports on warranty costs in different industry sectors.

obtained from various sections of the manufacturing business as well from many other sources external to the manufacturer, and can be used to reduce not only the costs of servicing warranty for current products on the market, but, equally importantly, for products to be developed and launched in the future.

This book deals with warranty data collection and analysis, and the use of these results in improving business performance for both current and future products. The intent is to develop an appropriate framework for this purpose. The book consists of an introductory chapter ([Chap. 1](#)) and six parts (Parts I–VI), with each part consisting of two or more chapters. The six parts are as follows:

- Part I (2 chapters) gives an introduction and overview of reliability theory and product warranty.
- Part II (2 chapters) deals with warranty data collection. It looks at the issues and challenges associated with the collection of claims and supplementary data.
- Part III (5 chapters) looks at tools and techniques. The first two chapters deal with modeling of warranty claims and predicting warranty costs for several one-dimensional (1D) and two-dimensional (2D) warranties. The next three chapters deal with a review of some of the basic tools of statistical analysis and statistical inference.
- Part IV (4 chapters) deals with the analysis of warranty data using the tools and techniques of Part III. Several different data scenarios are considered and the methods are illustrated by application to claims and supplementary data for several types of products.
- Part V (2 chapters) looks at the framework for the improvement process. The first chapter deals with improvements for current (or existing) products and the second with new products.
- Part VI (2 chapters) examines two real case studies. The first case deals with air-conditioner data sold with a 1D warranty and the second with a component of an automobile sold with 2D warranty.

Effective management of reliability and warranty in a manufacturing business requires an interdisciplinary team consisting of engineers, scientists, operations researchers, statisticians, IT and management experts. The book is aimed at all of these groups of practitioners. Some practitioners want only to be trained to use a method. A book written for that purpose would be a training manual. This book is intended to educate the practitioner and provide an understanding of the underlying concepts and the issues involved. As such, the book should appeal to practitioners who want more than a manual. The concepts, tools and techniques are highlighted through examples and case studies in order to emphasize proper techniques for data collection and analysis and to show how the results may be used for effective decision making.

The book is also intended for researchers in industry and academia. We raise new and challenging issues that would be of interest to researchers and, in the process, bridge the gap between theory and practice. This book would be of interest to analytically oriented practitioners and to researchers wanting to tackle complex real world warranty problems of importance to manufacturers. As indicated earlier,

the book is structured in a manner to facilitate both readers, in that we aim for a middle ground that will have practical content for the practitioner and discussion of unsolved or partially solved problems that will interest the researcher. In the process, we give both a realistic notion of the strengths as well as the limitations of the current state of knowledge.

It is assumed that the reader has some knowledge of statistics, mathematics, operations analysis, and warranty, though reviews of many basic concepts in these areas are included in the book.

The authors bring an interdisciplinary perspective to the book through their backgrounds, research into various aspects of reliability and warranty, and their interaction with many businesses in Asia, Australia, Europe and the USA.

The authors are grateful to their ex-students and other researchers with whom they have collaborated over many years (ranging from 15 to nearly 40). These include

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Chapter 1

An Overview

1.1 Introduction

A salient feature of modern industrial societies is that new products are appearing on the market at an ever increasing pace. This is due to (i) rapid advances in technology and (ii) constantly increasing demands of customers, with each a driver of the other. As a result, products are becoming more complex and their performance capabilities are increasing with each new generation.

Customers need assurance that a product will perform satisfactorily over its designed useful life. Product performance depends on the reliability of the product, which, in turn, depends on decisions made during its design, development and production. One way in which manufacturers can assure customers of satisfactory product performance is through warranty. A warranty is a contractual obligation that requires the manufacturer to remedy any problems or failures that occur during a specified period of warranty coverage. The base warranty on an item is part of the initial transaction. In contrast, extended warranties are optional additional warranty coverages that are purchased separately by the customer.

Offering warranty results in additional costs to the manufacturer. This cost depends on the reliability of the product (which is at least partially under the control of the manufacturer) and on operating environment, usage mode, and usage intensity (all of which are determined by the users). The costs associated with the base warranty are factored into the sale price and, as mentioned earlier, the customer pays extra to cover the costs associated with extended warranties. For large manufacturers, annual warranty costs often run into billion of dollars and as a fraction of the sale price they typically vary from 2 to 10%. As a consequence, warranty costs have a significant impact on overall profits.

Manufacturers arrive at decisions about reliability based on their understanding of customer behavior and on engineering judgment during product design, development, and production. In the early stages of this process, there will be limited data and other information available on product performance. As a result,

there will be considerable uncertainty in predictions of item reliability and hence in assessment of warranty costs based on these estimates.

Warranty claims data are data that are collected during the processing of claims under warranty. Together with supplementary data, they provide valuable information for assessing product reliability and the impact of operating environment, usage mode, and usage intensity on the performance of the product. Through proper analysis, one can obtain better estimates of product reliability and of warranty costs. These, in turn, help manufacturers take appropriate actions relating to product reliability over the remainder of the product life cycle and to address warranty issues from an overall business perspective.

There are several possible problems associated with the use of warranty data. These make data analysis and extraction of useful information more difficult and challenging. This book deals with issues relating to warranty data collection and analysis. In this chapter we give an overview of the book.

The outline of the chapter is as follows. In [Sect. 1.2](#), we discuss various issues regarding products themselves. [Section 1.3](#) deals with product performance and introduces the notion of product failure. In [Sects. 1.4](#) and [1.5](#), we look at various issues relating to product warranty and product reliability, respectively. [Section 1.6](#) discusses some aspects of warranty data. The objectives of the book are discussed in [Sect. 1.7](#) and an outline of the book is given in [Sect. 1.8](#).

1.2 Products

According to [4]:

A product can be tangible (e.g., assemblies or processed materials) or intangible (e.g., knowledge or concepts), or a combination thereof. A product can be either intended (e.g., offering to customers) or unintended (e.g., pollutant or unwanted effects)

In this book, we are concerned with tangible products, specifically manufactured goods sold with warranty. This includes most consumer goods, with the exception of food and other agricultural products. It also includes many products that are acquired in commercial transactions and government procurement. The following is an example of a typical consumer product:

Example 1.1 [Cell Phone] A cell phone has the capacity to send and receive radio signals. This provides a seamless transmission of voice as long as the telephone sending the message and the one receiving the message are within geographical range of the communication satellite involved. Millions of people around the world use cellular phones. A modern cell phone may perform an array of functions in addition to sending and receiving voice messages. These include¹:

¹ This list is not intended to be exhaustive and will quite likely be out of date by the time this book is in print.

- Accessing information (such as news, entertainment, stock quotes) from the internet
- Sending and receiving text mail
- Sending and receiving e-mails
- Storing contact information details
- Serving as an alarm clock
- Receiving FM radio
- Taking digital pictures
- Sending and receiving digital pictures
- Making task and do lists
- Keeping a calendar of appointments and reminders
- Carrying out simple arithmetic calculations
- Providing a games console
- Integrating other devices, such as MP3 players

Worldwide sales of these devices have been growing exponentially.

1.2.1 Product Classification

Products can be classified in many different ways.² Two of these are the following:

1.2.1.1 Classification 1

1. *Consumer non-durables and durables*: These are products that are bought by households. Non-durables differ from durables in the sense that the life of a nondurable item (for example, food) is relatively short, and the item is less complex than a durable item (for example, television, automobile).
2. *Industrial and commercial products*: These are products used by businesses for their operations. The technical complexity of such products can vary considerably. The products may be either complete units (for example, trucks, pumps) or components (for example, batteries, bearings, disk drives).
3. *Specialized products*: Specialized products (for example, military and commercial aircraft, ships, rockets) are usually complex and expensive, often involve state-of-the-art technology, and are usually designed and built to the specific needs of the customer. Still more complex are very large systems that are collections of many inter-linked products (for example, power stations, communication networks, chemical plants).

² See [6] for more details.

1.2.1.2 Classification 2

1. *Standard products*: These are manufactured in anticipation of a subsequent demand. Standard products are manufactured based on previous products of the same type, competing goods, and the results of market surveys. They include all consumer non-durables and durables and most commercial and industrial products.
2. *Custom-built products*: These are manufactured in response to a specific request from a customer. They include airliners, ships, railroad equipment, apartment and office buildings, refineries, specialized defense products, and many other items.

1.2.2 Product Complexity

The complexity of products has been increasing with technological advances. As a result, a product must be viewed as a system consisting of many elements and capable of decomposition into a hierarchy of levels, with the system at the top level and parts at the lowest level. There are many ways of describing this hierarchy. One such is the nine-level description shown in Table 1.1 and based on a hierarchy given in [1]:

Example 1.2 [Automobile] The modern automobile is a complex system consisting of over 15,000 components. This system can be decomposed into the following sub-systems³:

- Body (passenger compartment)
- Engine (power source)
- Chassis (for supporting the engine and body)
- Transmission (for transmitting power from the engine to the wheels through shafts and gears)
- Controls (for accelerating, braking, steering, etc.)
- Cooling (for cooling the engine, providing comfort to passengers)
- Electrical (battery, starting motor, lights, logic controllers)
- Safety (seat belts, air bags, locks)
- Lubrication (oil pump, grease)
- Fuel (tank, carburetor, filters, fuel lines)
- Exhaust system (muffler, catalytic converter)
- Others (seats, doors, windows, radio, etc.)

³ See <http://auto.howstuffworks.com> for a discussion of the principles of how these sub-systems work.

Table 1.1 Multilevel decomposition of a product

Level	Characterization
0	System
1	Sub-system
3	Assembly
4	Sub-assembly
5	Module
6	Sub-module
7	Component
8	Part

Comment The number of levels needed to describe a product from the system level down to the part level depends on the complexity of the product

Each of these, in turn, can be decomposed into assemblies, sub-assemblies, and so forth, down to the part level.

To illustrate the complexity of the system, the following is a partial list of the components and parts for the engine sub-system: cylinder block, cylinder heads, pistons rings, connecting rods, bearings, crankshaft main bearings, camshaft bearings, cam followers, timing chain or belt; timing gears, guides, rocker arms, rocker shaft, rocker bushings, cylinder head valves, valve guides, valve lifters, valve springs, valve seals, valve retainers, valve seats, push rods, water pump, oil pump and oil pump housing, oil pan, intake and exhaust manifolds, valve covers, engine mounts, turbocharger/supercharger housing seals and gaskets.

1.3 Product Performance

1.3.1 Concept and Notions

We begin with a basic definition of performance [8]:

Performance, n. The accomplishment, execution, carrying out, working out of anything ordered or undertaken; the doing of any action or work; working, action (personal or mechanical); spec. the capabilities of a machine or device, now esp. those of a motor vehicle or aircraft measured under test and expressed in a specification

Many different definitions of performance can be found in the technical literature. The following two are a small illustrative sample:

Performance is the measure of function and behavior—how well the device does what it is designed to do. [9]

How well a product implements its intended functions. Typical product performance characteristics are speed, efficiency, life, accuracy, and noise. [10]

In general, product performance is a measure of the functional aspects of the product. It is a *vector of variables*, where each variable is a *measurable property of the product or its elements*. The performance variables can be:

- Functional properties (e.g., power, throughput, and fuel consumption)
- Reliability related (defined in terms of failure frequency, mean time to failure [MTTF], etc.)

Products are designed for a specified set of conditions such as the usage mode, usage intensity, and operating environment. When the conditions differ significantly from those specified, the performance of the product is affected. Product performance is also influenced by the skills of the operator and other factors.

1.3.2 Product Failure

Product failure is closely linked to product function, as can be seen from the two following two definitions of failure:

The termination of the ability of an item to perform a required function [3]
 Equipment fails if it is no longer able to carry out its intended function under the specified operational conditions for which it was designed [7]

1.3.3 Consumer Perspective

Consumers view a product in terms of its attributes. According to [5],

To a potential buyer a product is a complex cluster of value satisfactions.

Reference [2] states:

Consumers seek benefits rather than products per se.

As a result, we have the following relationship:

Attributes (Features) → Bundle of benefits → Value to the customer

A successful new product

1. Satisfies new (or earlier unsatisfied) needs, wants or desires.
2. Possesses superior performance in such need satisfactions, compared to other products on the market.

Products are becoming more complex in order to meet ever-growing consumer needs and expectations.

When a failure occurs, no matter how benign, its impact is felt. For customers, the consequences of failures may range from a mere nuisance value (for example, failure of air-conditioner) to actual economic loss (for example, loss of food due to failure of a freezer) to something resulting in serious damage to the environment and/or loss of life (for example, brake failure in a car). All of these lead to customer dissatisfaction with the product, at the very least.

When the customer is a business enterprise, failures may lead to downtimes. This affects the production of services and goods, which, in turn, affects both the goodwill of clients as well the bottom line of the balance sheet of the seller.

1.4 Product Warranty

Consumers are often uncertain about product performance. As a result, they look for assurance that the product will perform satisfactorily over its useful life. One way of providing this assurance is through product warranty. This is a service element bundled with the product. Different types of warranties are offered, depending on the product and the anticipated buyer.

1.4.1 Warranty Concept

A warranty is a manufacturer's assurance to a buyer that a product or service is or shall be as represented. It may be considered to be a contractual agreement between buyer and manufacturer (or seller) that is entered into upon sale of the product or service.

In broad terms, the purpose of a warranty is to establish liability of the manufacturer in the event that an item fails or is unable to perform its intended function when properly used. The contract specifies both the performance that is to be expected and the redress available to the buyer if a failure occurs or the performance is unsatisfactory. The warranty is intended to assure the buyer that the product will perform its intended function under normal conditions of use for a specified period of time.

The terms warranty and guarantee are often used synonymously. The distinction is that a guarantee is defined to be a pledge or assurance of something; a warranty is a particular type of guarantee, namely a guarantee concerning goods or services provided by a seller to a buyer. Another related concept is that of a service contract or "extended warranty." The difference between a warranty and a service contract is that the latter is entered into voluntarily and is purchased separately—the buyer may even have a choice of terms—whereas the basic warranty is a part of the product purchase and is an integral part of the sale.

1.4.2 Manufacturer's Perspective

From the manufacturer's point of view, warranties also serve another important role, as buyers typically compare characteristics of comparable models of competing brands in making their purchase decisions. When competing brands are nearly identical, it is very difficult, in many instances, to choose a particular

product solely on the basis of product-related characteristics such as price, special features, perceived product quality and reliability, financing offered by the manufacturer, and so on. In such situations, post-sale factors—warranty, parts availability and cost, service, maintenance, and so forth—take on added importance in product choice. Of these, warranty is a factor that is known (or at least potentially known) to the buyer at the time of purchase, and buyers may reasonably interpret longer warranties as a signal of a more reliable and durable product. As such, warranty can become an effective promotional tool.

1.4.3 Warranty Costs

Offering warranty results in additional costs to the manufacturer. This cost depends on several factors, the most important of which are shown in Fig. 1.1.

Warranty terms offered by a manufacturer are influenced by warranty legislation and by the warranties offered by competitors. Customer usage can vary across the customer population and is outside of the control of the manufacturer. As a result, product reliability is the only factor affecting claims that is solely under the control of the manufacturer, and it has a significant impact on warranty claims and costs. Warranty costs are high, typically varying from 2 to 10% of the sale price. Table 1.2 shows 2006 warranty costs for a sample of US companies.⁴ Viewed as a fraction of profits, this number can vary by an order of magnitude.

Warranty costs are inversely related to product reliability. It follows that one way of reducing warranty costs is to improve reliability. This, however, can be a costly exercise, as it involves considerable investment in research and development. The optimum reliability program is one that achieves a sensible trade-off between the cost of building in reliability and the cost of warranty.

1.5 Product Reliability

Product reliability is determined primarily by decisions made during the early stages (design and development) of the product life cycle and it has implications for later stages (marketing and post-sale support) because of the impact of unreliability on sales and on warranty costs.

Assessment of product reliability prior to launch of the product on the market is based on limited information—data supplied by vendors, subjective judgment of design engineers during the design stage, and data collected during the

⁴ See Warranty Week (<http://www.warrantyweek.com>) for detailed lists of warranty costs for companies in different industry sectors in the USA.