WILEY SERIES IN PROBABILITY AND STATISTICS

Statistical Control by Monitoring and Adjustment

SECOND EDITION

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Statistical Control by Monitoring and Adjustment

Second Edition

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Preface

In 1962, in discussing a paper that had been presented to the Royal Statistical Society, Professor J. H. Westcott said, "Speaking as a control engineer, I welcome this flirtation between control engineering and statistics. I doubt however they can yet be said to be 'going steady.'" The reference is to the first of the series of articles by Box and Jenkins (1962, 1963, 1966, 1968, 1970), by Box and MacGregor (1974) and by MacGregor (1972, 1976). These addressed statisticians and quality professionals about some elementary ideas from engineering process control (EPC) which could supplement and improve statistical process control (SPC). Although at the time these initiatives did not excite much interest, there is now considerable activity in this area. The purpose of this book is to bring together these two kinds of process control and explain the less familiar ideas to a wider audience.

Shewhart charts are monitoring procedures for debugging the process and have two aspects:

1. Plotting and displaying developing process data
2. Drawing of limit lines to indicate when deviations from the norm are sufficiently large to justify the search for special causes

The first of these is very powerful and can account for many successes. However, the second assumes a fixed mean and sequential independence of process data. These approximations are frequently misleading.

This leads to the conclusion that process variation must be represented by *nonstationary* models that have no fixed mean. Analysis of industrial data confirms this. Such analysis frequently points to a particular nonstationary model called the *integrated moving average* (IMA). This model does not suffer from the deficiencies mentioned above. In particular, it requires that observations are measured *not* from a fixed mean but from a local adaptive average: the exponentially weighted moving average (EWMA).

The IMA model produces *two* component series. The first is a sequence of EWMAs which can estimate the current deviation from target. It shows when a serious deviation has occurred and calls for appropriate process adjustment. The second series is a sequence of residuals that can be used for process monitoring

and are plotted on a Shewhart chart that can suggest, find, and eliminate assignable causes.

So that the reader can quickly appreciate these important concepts, an example is given early in the book (Section 3.5.2) in which 200 observations from a nonstationary system are analyzed. The adjustment chart shows that only two adjustments are needed to remove major nonstationarity. Also the accompanying monitoring chart reveals a special cause midway through the series. (To fully understand such procedures and apply them to other examples require an elementary knowledge of a number of topics that do not appear in most discussions of SPC.) These include forecasting and process dynamics (Chapter 4), nonstationary time series (Chapter 5), discrete feedback control (Chapter 6), control by periodic adjustment (Chapter 7), control of a process with inertia (Chapter 8), minimizing cost of control (Chapter 9), efficient search for signals in noise using cuscore statistics (Chapter 10), monitoring an operating feedback system (Chapter 11), and review of time series analysis (Chapter 12). There are two preliminary chapters useful for revision or for those with no previous knowledge of SPC. Chapter 1 describes some necessary statistical tools and Chapter 2 standard SPC methods and how they would work if the assumptions were true. If you are familiar with the basic ideas of SPC, you can omit these two chapters.

Earlier drafts of the first edition of this book (under the title *Statistical Control by Monitoring and Feedback Adjustment*) were begun by one of the authors while a visiting fellow at the Institute of Advanced Study in the Behavioral Sciences at Stanford, a visit partially supported by a grant from the Guggenheim Foundation. The authors are also grateful for support from the National Science Foundation (Grant DMI–9414765), the Dirección General de Investigación Científica y Técnica of Spain (Grant PB95-0583), the Consejo Nacional de Ciencia y Tecnologia of México (CONACYT, Grant 135617), and the University of Cantabria, Santander, Spain.

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We especially wish to thank Claire Box for many years of inspiration and support in the realization of this book.

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CHAPTER 1

Introduction and Revision of Some Statistical Ideas

Now here, you see it takes all the running you can do, to keep in the same place.

Through the Looking Glass, LEWIS CARROLL

This chapter provides a quick revision of some basic ideas of statistics necessary for process control. These include dot diagrams, probability distributions, mean, variance, standard deviation, properties of averages, the central limit theorem, and the normal, Poisson, and binomial distributions.

1.1 NECESSITY FOR PROCESS CONTROL

If you have a house, you know that you must work hard to keep it habitable—the tiles on the roof, the paint on the walls, the washing machine, the refrigerator, the television, all need attention from time to time. A car, a friendship, and our own bodies must similarly be continually nurtured or they will not remain in shape very long. The same is true for industrial processes. If left to themselves, machines do not stay adjusted, components wear out, and managers and operators forget, miscommunicate, and change jobs. Thus a stable stationary state is an unnatural one and its approximate achievement requires a hard and continuous fight. Both process *monitoring* and process *adjustment* can help achieve this. Both are likely to be needed.

1.2 SPC AND EPC

Some 80 years ago Walter Shewhart introduced statistical process control (SPC) using charts. These quality control charts have been widely applied, especially in the parts industries, such as automobile manufacture, and have resulted in dramatic savings and important improvements in quality of products. Control charts are devices used to *monitor* quality characteristics and so keep them as close as possible

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