Frontiers in Statistical Quality Control 7

Hans-Joachim Lenz
Peter-Theodor Wilrich
Editors

Frontiers in Statistical Quality Control 7

With 70 Figures
and 64 Tables

Springer-Verlag Berlin Heidelberg GmbH
A Springer-Verlag Company

Professor Dr. Hans-Joachim Lenz
lenz@wiwiss.fu-berlin.de

Professor Dr. Peter-Theodor Wilrich
wilrich@wiwiss.fu-berlin.de

Freie Universität Berlin
Institut für Statistik und Ökonometrie
Garystraße 21
14195 Berlin, Germany

ISBN 978-3-7908-0145-3 ISBN 978-3-7908-2674-6 (eBook)
DOI 10.1007/978-3-7908-2674-6

Cataloging-in-Publication Data applied for

A catalog record for this book is available from the Library of Congress.

Bibliographic information published by Die Deutsche Bibliothek

Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie;
detailed bibliographic data available in the internet at <http://dnb.ddb.de>

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Physica-Verlag. Violations are liable for prosecution under the German Copyright Law.

springeronline.com

© Springer-Verlag Berlin Heidelberg 2004

Originally published by Physica-Verlag Heidelberg in 2004

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover design: Erich Kirchner, Heidelberg

SPIN 10972977 88/3130 – 5 4 3 2 1 0 – Printed on acid-free paper

Editorial

The VIIth International Workshop on "Intelligent Statistical Quality Control" took place in Waterloo, Canada, and was hosted by Professor St. H. Steiner, Institute for Improvement in Quality and Productivity, University of Waterloo.

The papers collected in this volume fall into four main categories: General SQC Methodology, On-line Control including Sampling Inspection and Statistical Process Control, Off-line Control with Data Analysis and Experimental Design, and, finally, fields related to Reliability.

In the first group there are three papers on "**General Aspects of Statistical Quality Control**".

v. **Collani** in "A Note on the Quality of Statistical Quality Control Procedures" proposes substituting classical designs of statistical procedures by a unified approach called the "Neyman procedure". The problem is to minimise the weighted volume of the measurement procedure and the prediction procedure constrained by the confidence level and the sample size. **Hryniewicz** in "Statistical Decisions in Quality Audits - a Possibilistic Interpretation of Single Statistical Tests" uses possibilistic and necessity measures defined on the null hypothesis space H and the alternative hypothesis space K . This approach enables the user, for example in quality audits, to substitute p-value based decisions by degrees of indication that a specific alternative hypothesis is true. **Takeuchi, Suenaga, Yadohisa, Yamaguchi, Watanabe and Asano** in "Dynamic Link Library and Electronic Book for Statistical Quality Control" present a statistical software library system called DLLQC that is particularly useful for SQC problems, and an e-book system on the Web named EBQC.

In the second group there are twelve papers on "**On-line Control**".

Wilrich in "Sampling Plans for Inspection by Variables under a Variance Component Situation" extends single sampling plans for inspection by variables to applications where the variance of the quality characteristic X consists of two components. One component describes the variation of X due to repeated use of a specific item, the other one the variation between mean values of X of different items. **Lam and Rahim** in "Joint Determination of Economic Design of $\bar{X}$ -Control Charts, Economic Production Quantity, and Production Run Length for a Deteriorating Production System" simultaneously determine the economic production rate and the economic production run length. **Stoumbos and Reynolds** in "The Robustness and Performance of CUSUM Control Charts Based on the Double-Exponential and Normal Distributions" investigate the effects of non-normality on the statistical performance of CUSUM control charts for monitoring the process mean μ . They consider the standard CUSUM chart, which is based on the normal distribution, and a second CUSUM chart, which is based on the heavy-tailed double-exponential distribution. **Ohta and Kusakawa** in "An Application of Confirmation Sample Control Chart in the High-Yield Processes and Its Economic Design" deal with control chart design for detecting small and moderate changes of the fraction defective. The four chart parameters are the reaction point, the sampling interval and the lower and upper control limits LCL and UCL. The parameters are determined from a cost model due to Collani and Dräger (1995). **Saniga, Davis and Lucas** in "Statistical Design of Attribute Charts for Monitoring and Continuous Improvement When Count Levels are Low" present a procedure to find a

design of a control chart for count data when the lower Shewhart control limit is zero. The approach is based on a proposal of Lucas, Davis and Saniga (2001). **Nishina and Matsubara** in "A Markov Approach to the Average Run Length of CUSUM Charts for an AR(1) Process" derive analytically the item-dependent distribution of the CUSUM statistic and the Average Run Length (ARL). Thus, one obtains the conditional out-of-control ARL for any change point, and, of course, the steady-state ARL. **Steiner and MacKay** in "Effective Monitoring of Processes with Parts Per Million Defective. A Hard Problem!" analyse the monitoring of the defective rate where a process produces defectives measured in parts per million. As sample sizes tend to be huge in such cases, the authors propose the use of related (auxiliary) variables that are identified in a pre-processing step. **Thyregod, Melgaard and Iwersen** in "On Monitoring Processes and Assessing Process Capability under a Hierarchical Model" discuss sub-grouping in control charting and suggest charting on a hierarchical model that reflects variation between subgroups. In the second part of their paper, the authors develop a simple hierarchical model of "between subgroup" variation based on historical data, in order to specify the long-term distribution of subgroup averages. **Alexopoulos, Goldsman and Tsui** in "SPC Monitoring and Variance Estimation" review common monitoring methods for SPC in the case of auto-correlated data. The underlying characteristics and relationships are investigated. **Knoth and Schmid** in "Control Charts for Time Series: A Review" classify charts into the two classes 'residual charts' and 'modified control charts'. For each type, charts with memory like EWMA or CUSUM exist. By using the ARL as the performance measure, the authors show that there is no clear preference when there is no auto-correlation. They recommend a modified EWMA chart for positive auto-correlation, and the classical EWMA or CUSUM chart applied to residuals for negative auto-correlation. **Morais and Pacheco** in "A Note on Stochastic Ordering Criteria in SPC for the Case of Correlated Output" establish stochastic ordering results concerning the in-control and out-of-control run length of residual schemes for the mean of stationary auto-regressive processes of first and second order.

In the third group entitled "Off-line Control" there are five contributions.

Yamaguchi, Kono and Asano in "A New Statistical Tool for Finding Causal Conditions for Small Data Sets and Its Software" propose a sub-grouping method for small data sets based on algorithms due to Quine (1952) and Miller (1965), and illustrate the user interface of the corresponding software. **Sparks** in "What has Data Mining got to do with Statistical Process Monitoring? A Case Study" gives best-practise recommendations to monitor complex multivariate systems. He advocates simple charting in combination with a stepwise refinement involving the study of corresponding reports by the management. For example, slicing and dicing of SPC data cubes helps them to focus on important issues and avoids looking at too many low level charts. **Hirotsu and Ohta** in "Profile Analysis Based on Repeated Measurements – A New Approach to the Analysis of Interaction" give their own view on the analysis of interactions within multiple comparison techniques when there exists a natural ordering of the categories in two-way contingency tables. **Lenz** in "Trouble-Shooting by Graphical Models" applies cause-and-effect modelling based on Bayesian Network models to problems of troubleshooting. As call-backs, accidents etc. are isolated events, no-data driven procedures can be applied. Instead of estimation, marginal and conditional probabilities have to be settled by experts. Risk assessment and a sensitivity study within a case study show the potential of the approach, which dominates the classic FMEA set-up. **Ojima, Suzuki and Yasui** in "An Alternative Expression of the Fractional Factorial Designs for Two-level and Three-level Factors" present an alternative approach to two- and three-level factor designs by using the Hadamard product from group theory based on the columns of the corresponding design matrix. As is well established in the

theory of experimental design, this operator helps to solve many related design problems like fold-over designs in an elegant way.

In the final group "**Studies in Areas Related to Reliability**" there are three papers.

Prendergast and Murphy in "Building in Reliability. Is Statistical Process Control Statistical Reliability Control?" demonstrate that, although many nodes (units) are controlled in an integrated circuit manufacturing process, only few have an impact on reliability. If these nodes are identified and controlled carefully in a real environment, reliability can be controlled and predicted. **Ladany and Shore** in "Optimal Warranty Period when Sale-Price Increases with the Lower Specification Limit" address the optimal warranty period. It is assumed that the increase of the warranty period causes proportionality of sale price and the cost of non-conforming items. The problem is solved analytically in the case of an exponentially distributed quality characteristic, other distributional assumptions requiring numerical solution. **Solojentsev and v. Collani** in "Evaluation of Quality and Market Risk of Complex Industrial Products" study risk assessment of complex products with several quality characteristics, where each of them may fail or be in one of several operating states, and initiating events leading to object failure define logical connections between the characteristics.

The impact of such a workshop is mainly shaped by the quality of papers, which are read at the meeting, revised later and finally submitted. We would like to express our deep gratitude to the following members of the scientific programme committee, who did an excellent job with respect to the recruiting of invited speakers as well as refereeing all the submitted papers:

Prof. Choichiro Asano, Japan
 Mr David Baillie, United Kingdom
 Prof. Elart von Collani, Germany
 Prof. Hans-J. Lenz, Germany
 Prof. Hiroshi Ohta, Japan
 Prof. Poul Thyregod, Denmark
 Prof. Peter.-Th. Wilrich, Germany
 Prof. William H. Woodall, United States of America.

We would like to close with our cordial thanks to *Mrs. M. Eckardt*, who managed to clean up and to integrate WINWORD and LATEX papers. A financial grant of the Institute of Statistics and Econometrics, Free University of Berlin, which finally made it possible to get this volume to press, is gratefully acknowledged. Moreover, we kindly acknowledge the smooth collaboration with Physica-Verlag, Heidelberg.

On behalf of all participants, the editors would like to thank Professor Steiner and his staff for their superb hospitality, the perfect organisation, and the stimulating atmosphere. We are happy and proud to announce that the International Workshop on Intelligent Statistical Quality Control will be continued in Warszawa, Poland, in the near future.

Berlin, August 2003

Hans - J. Lenz
 Peter - Th. Wilrich

Contents

PART 1: GENERAL ASPECTS OF STATISTICAL QUALITY CONTROL

A Note on the Quality of Statistical Quality Control Procedures E. v. Collani	3
Statistical Decisions in Quality Audits – a Possibilistic Interpretation of Single Statistical Tests O. Hryniewicz	15
Dynamic Link Library and Electronic Book for Statistical Quality Control A. Takeuchi, K. Suenaga, H. Yadohisa, K. Yamaguchi, M. Watanabe, Ch. Asano	28

PART 2: ON-LINE CONTROL

Single Sampling Plans for Inspection by Variables under a Variance Component Situation P.-Th. Wilrich	43
Joint Determination of Economic Design of $\bar{X}$ - Control Charts, Economic Production Quantity, and Production Run Length for a Deteriorating Production System K.K. Lam, M.A. Rahim	58
The Robustness and Performance of CUSUM Control Charts Based on the Double-Exponential and Normal Distributions Z.G. Stoumbos, M.R. Reynolds, Jr.	79
An Application of Confirmation Sample Control Chart in the High-Yield Processes and Its Economic Design H. Ohta, E. Kusakawa	101
Statistical Design of Attribute Charts for Monitoring and Continuous Improvement When Count Levels Are Low E.M. Saniga, D.J. Davis, J.M. Lucas	119
A Markov Approach to the Average Run Length of CUSUM Charts for an AR(1) Process K. Nishina, Sh. Matsubara	130
Effective Monitoring of Processes with Parts Per Million Defective. A Hard Problem! St.H. Steiner, R.J. MacKay	140
On Monitoring Processes and Assessing Process Capability under a Hierarchical Model, Part 1 P. Thyregod, H. Melgaard, J. Iwersen	150

On Monitoring Processes and Assessing Process Capability under a Hierarchical Model, Part 2 P. Thyregod, J. Iwersen, H. Melgaard	168
SPC Monitoring and Variance Estimation C. Alexopoulos, D. Goldsman, K.-L. Tsui, W. Jiang	194
Control Charts for Time Series: A Review S. Knoth, W. Schmid	210
A Note on Stochastic Ordering Criteria in SPC for the Case of Correlated Output M.C. Morais, A. Pacheco	237

PART 3: OFF-LINE CONTROL

A New Statistical Tool for Finding Causal Conditions for Small Data Sets and Its Software K. Yamaguchi, Y. Kono, Ch. Asano	263
What Has Data Mining Got to Do with Statistical Process Monitoring? A Case Study R. Sparks	270
Profile Analysis Based on Repeated Measurements – A New Approach to the Analysis of Interaction Ch. Hirotsu, E. Ohta	282
Trouble-Shooting by Graphical Models H.-J. Lenz	296
An Alternative Expression of the Fractional Factorial Designs for Two-level and Three-level Factors Y. Ojima, T. Suzuki, S. Yasui	309

PART 4: STUDIES IN AREAS RELATED TO RELIABILITY

Building In Reliability. Is Statistical Process Control Statistical Reliability Control ? J. Prendergast, E. Murphy	319
Optimal Warranty Period when Sale-Price Increases with the Lower Specification Limit S.P. Ladany, H. Shore	335
Evaluation of Quality and Market Risk of Complex Industrial Products E. Solojentsev, E. v. Collani	346

Author Index

Alexopoulos, Christos., Ph.D., Prof., Georgia Institute of Technology, School of Industrial and Systems Engineering, Atlanta, GA 30332-0205, U.S.A
e-mail: christos.alexopoulos@isyse.gatech.edu

Asano, Chooichiro, Prof. Dr., Soka University, Faculty of Engineering, Tokyo, Japan
e-mail: QYG04340@niftyserve.ne.jp

Collani, Elart von, Prof. Dr., Universität Würzburg, Volkswirtschaftliches Institut, Sanderring 2, D-97070 Würzburg, Germany
e-mail: collani@mathematik.uni-wuerzburg.de

Davis, Darwin J., Ph.D., Prof., Department of Business Administration, College of Business and Economics, University of Delaware, 204 MBNA America Building, Newark, DE 19716, U.S.A
e-mail: davisd@lerner.udel.edu

Goldsman, David, Ph.D., Georgia Institute of Technology, School of Industrial and Systems Engineering, Atlanta, GA 30332-0205, U.S.A
dave.goldsman@isyse.gatech.edu

Hirotsu, Chihiro, Prof. Dr., Meisei University, Faculty of Science and Technology, 2-1-1- Hodokubo, Hino City, Tokyo 191-8506, Japan
e-mail: hirotsu@ge.mesei-u.ac.jp

Hryniewicz, Olgierd, Prof. Dr., Polish Academy of Sciences and University of Applied Informatics and Management, Systems Research Institute, Newelska 6, 01-447 Warsaw, Poland
e-mail: hryniewi@ibspan.waw.pl

Iwersen, Jørgen, Dr., Novo Nordisk A/S, Novo Alle, DK 2880 Bagsvaerd, Denmark
e-mail: jiw@novo.dk

Jiang, W., INSIGHT, AT&T Labs, Short Hills, NJ 07078, U.S.A

Knoth, Sven, Dr., Europe University Viadrina, Department of Statistics, Postfach 1786, D-15207 Frankfurt(Oder), Germany
e-mail: knoth@euv-frankfurt-o.de

Kono, Yasunari, Rikkyo University, Graduate School of Social Relations, Tokyo, Japan

Kusukawa, Etsuko, Dr., Osaka Prefecture University, Department of Industrial Engineering,
Sakai, Osaka 599-8531, Japan
e-mail: kusukawa@ie.osakafu-u.ac.jp

Ladany, Shaul P., Prof. Dr., Ben-Gurion University of the Negev, Department of Industrial
Engineering and Management, P.O. Box 653, Beer Sheva 84105, Israel
e-mail: ladany@bgumail.bgu.ac.il

Lam, Kian Keon, University of Brunswick, Faculty of Administration, P.O. Box 4400,
Fredericton, New Brunswick, E3B 5A3, Canada
e-mail: a89kh@unb.ca

Lenz, Hans-J., Prof. Dr., Freie Universität Berlin, Institut für Statistik und Ökonometrie,
Garystr. 21, 14915 Berlin, Germany
e-mail: hjlenz@wiwiss.fu-berlin.de

Lucas, James M., Dr., J. M. Lucas and Associates
e-mail: jamesm.lucas@worldnet.att.net

MacKay, R. Jock, University of Waterloo, Department of Statistics and Actuarial Science,
Waterloo, Ontario, N2L 3G1, Canada
e-mail: rjmackay@uwaterloo.ca

Matsubara, Shin'ichiro, Nagoya Institute of Technology, Department of Systems
Engineering, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan

Melgaard, Henrik, Dr., Novo Nordisk A/S, Novo Alle, DK 2880 Bagsvaerd, Denmark
e-mail: hmel@novo.dk

Morais, Manuel C., Technical University of Lisbon, Department of Mathematics and
Centre for Mathematics and its Applications, Instituto Superior Técnico,
Av. Rovisco Pais, 1049-001 Lisboa, Portugal
e-mail: maj@math.inst.utl.pt

Murphy, Eamonn, Prof., University of Limerick, Plassey Technology Park, Limerick,
Ireland
e-mail: eamonn.murphy@ul.ie

Nishina, Ken, Prof. Dr., Nagoya Institute of Technology, Department of Systems
Engineering, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan
e-mail: nishina@system.nitech.ac.jp

Ohta, Eri, Prof. Dr., Meisei University, Faculty of Science and Technology,
2-1-1-Hodokubo, Hino City, Tokyo 191-8506, Japan
e-mail: otha@ge.meisei-u.ac.jp

Ohta, Hiroshi, Prof. Dr., Osaka Prefecture University, Department of Industrial Engineering,
Sakai, Osaka 599-8531, Japan
e-mail: ohta@ie.osakafu-u.ac.jp

Ojima, Yoshikazu, Prof. Dr., Science University of Tokyo, Department of Industrial
Administration, 2641, Yamazaki, Noda, Chiba, 278-8510, Japan
e-mail: ojima@ia.noda.tus.ac.jp

Pacheco, António, Technical University of Lisbon, Department of Mathematics and Centre
for Mathematics and its Applications, Instituto Superior Técnico, Av. Rovisco Pais,
1049-001 Lisboa, Portugal
e-mail: apacheco@math.inst.utl.pt

Prendergast, James, Dr., Institute of Technology, Clash, Tralee, Co. Kerry, Ireland
email: james.prendergats@ittralee.ie

Rahim, M.A., Prof. Dr., University of New Brunswick, Faculty of Administration,
P.O. Box 4400, Fredericton, New Brunswick, E3B 5A3, Canada
e-mail: rahim@unb.ca

Reynolds Jr., Marion, Prof. Dr., Virginia Polytechnic Institute and State University,
Department of Statistics, Blacksburg, VA 24061-0439, U.S.A.
e-mail: mrr@vt.edu

Saniga, Erwin M., Prof. Dr., University of Delaware, Department of Business
Administration, Newark, DE 19716, U.S.A.
e-mail: sanigae@be.udel.edu

Schmid, Wolfgang, Prof. Dr., Europe University Viadrina, Department of Statistics,
Postfach 1786, D-15207 Frankfurt(Oder), Germany
e-mail: schmid@euv-frankfurt-o.de

Shore, Haim, Prof. Dr., Ben Gurion University of the Negev, Department of Industrial
Engineering and Management, P.O. Box 653, Beer-Sheva 84105, Israel
e-mail: shor@bgumail.bgu.ac.il

Solojentsev, Evgueni, Prof. Dr., Russian Academy of Science, Institute of Mechanical
Engineering Problems, Intelligent Integrated Systems Laboratory, St. Petersburg,
Russia
e-mail: sol@sapr.ipme.ru

Sparks, D. Ross, Dr., CSIRO Mathematical and Information Sciences,
Locked Bag 17, North Ryde, NSW 2113, Australia
e-mail: ross.sparks@cmis.csiro.au

Steiner, Stefan, Prof. Dr., University of Waterloo, Department of Statistics and Actuarial Science, Waterloo, Ontario, N2L 3G1, Canada
e-mail: shsteine@uwaterloo.ca

Stoumbos, Zachary, Prof. Dr., Rutgers, University of New Jersey, Piscataway, NJ 08854-8054, U.S.A
e-mail: stoumbos@andromeda.rutgers.edu

Suenaga, Katsuyuki, Prof. Dr., Kagoshima Immaculate Heart College, Japan,
e-mail: sue@k-junshin.ac.jp

Suzuki, Tomomichi, Tokyo University of Science, 278-8510, Japan
e-mail: suzuki@tqm.t.u-tokyo.ac.jp

Takeuchi, Akinobu, Ph.D., Rikkyo University, College of Social Relations,
Nishi-Ikebukuro 3-34-1, Tokyo 171-8501, Japan
e-mail: akitake@rikkyo.ac.jp

Thyregod, Poul, Prof. Dr., The Technical University of Denmark, Informatics and Mathematical Modelling (IMM), Richard Petersen Plads 321, DK-2800 Lyngby, Denmark
e-mail: pt@imm.dtu.dk

Tsui, Kwok-Leung, Prof. Dr., Georgia Institute of Technology, School of Industrial and Systems Engineering, Atlanta, GA 30332-0205, U.S.A.
e-mail: ktsui@isye.gatech.edu

Watanabe, Michiko, Prof. Dr., Toyo University, Faculty of Economics, Japan
e-mail: watanabe_michiko@nifty.com

Wilrich, Peter-Th., Prof. Dr., Freie Universität Berlin, Institut für Statistik und Ökonometrie, Garystr. 21, 14195 Berlin, Germany
e-mail: wilrich@wiwiss.fu-berlin.de

Yadohisa, Hiroshi, Prof. Dr., Kagoshima University, Faculty of Science, Department of Mathematics and Computer Science, Japan
e-mail: yado@sci.kagoshima-u.ac.jp

Yamaguchi, Kazunori, Prof. Dr., Rikkyo University, Department of Industrial Relations, Nishi-Ikebukuro 3-34-1 Tokyo 171-8501, Japan
e-mail: kyamagu@rikkyo.ac.jp

Yasui, Seiichi, Tokyo University of Science, 278-8510, Japan