



PROCEEDINGS OF SPIE
SPIE—The International Society for Optical Engineering

Environmentally Conscious Manufacturing

Surendra M. Gupta
Chair/Editor

6–8 November 2000
Boston, USA

Sponsored and Published by
SPIE—The International Society for Optical Engineering



Volume 4193

SPIE is an international technical society dedicated to advancing engineering and scientific applications of optical, photonic, imaging, electronic, and optoelectronic technologies.



The papers appearing in this book compose the proceedings of the technical conference cited on the cover and title page of this volume. They reflect the authors' opinions and are published as presented, in the interests of timely dissemination. Their inclusion in this publication does not necessarily constitute endorsement by the editors or by SPIE. Papers were selected by the conference program committee to be presented in oral or poster format, and were subject to review by volume editors or program committees.

Please use the following format to cite material from this book:

Author(s), "Title of paper," in *Environmentally Conscious Manufacturing*, Surendra M. Gupta, Editor, Proceedings of SPIE Vol. 4193, page numbers (2001).

ISSN 0277-786X
ISBN 0-8194-3858-8

Published by
SPIE—The International Society for Optical Engineering
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone 1 360/676-3290 (Pacific Time) • Fax 1 360/647-1445
<http://www.spie.org/>

Copyright© 2001, The Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$15.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923 USA. Payment may also be made electronically through CCC Online at <http://www.directory.net/copyright/>. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/01/\$15.00.

Printed in the United States of America.

Contents

vii *Conference Committee*
ix *Introduction*

SESSION 1 REMANUFACTURING AND INVENTORY ISSUES

- 1 **Substitution policies for a hybrid system** [4193-01]
A. Korugan, S. M. Gupta, Northeastern Univ. (USA)
- 7 **Life-cycle management for style goods inventory** [4193-02]
T. Nose, K. Nakashima, Osaka Institute of Technology (Japan); H. Ishii, Osaka Univ. (Japan)
- 13 **Effect of reusable rate variation on the performance of remanufacturing systems** [4193-03]
H. K. Aksoy, S. M. Gupta, Northeastern Univ. (USA)

SESSION 2 END-OF-LIFE MANAGEMENT

- 21 **Disassembly and material recovery models for end-of-life electronics products** [4193-05]
B. Reimer, M. Sodhi, Univ. of Rhode Island (USA)
- 29 **Economics of PC recycling** [4193-07]
J. E. Boon, J. A. Isaacs, S. M. Gupta, Northeastern Univ. (USA)
- 36 **Economic analysis of end-of-life computer systems in educational institutions** [4193-08]
M. Dincer, E. A. Kizilkaya, S. M. Gupta, Northeastern Univ. (USA)
- 44 **Reuse of assembly systems: a great ecological and economical potential for facility suppliers** [4193-09]
H. Weule, C. Buchholz, Univ. Karlsruhe Technische Hochschule (Germany)

SESSION 3 DISASSEMBLY

- 56 **Optimum disassembly sequence generation** [4193-10]
A. J. D. Lambert, Technische Univ. Eindhoven (Netherlands)
- 68 **Genetic algorithm for disassembly strategy definition** [4193-14]
C. Caccia, A. Pozzetti, Politecnico di Milano (Italy)

SESSION 4 LIFE-CYCLE ASSESSMENT

- 78 **Integrated design strategy for product life-cycle management** [4193-15]
G. P. Johnson, National Science Foundation (USA)
- 85 **Streamlining environmental product declarations: a stage model** [4193-16]
É. Lefebvre, L. A. Lefebvre, S. Talbot, G. Le Hen, École Polytechnique de Montréal (Canada)

- 96 **Application of LCA method to an emergency lamp 626 Autotest Beghelli** [4193-17]
P. Neri, P. Buttol, Ente per le Nuove tecnologie l'Energia e l'Ambiente (Italy); G. Danielli, Univ. of Bologna (Italy); R. M. Pareschi, Beghelli SpA (Italy); G. Tani, Univ. of Florence (Italy)
- 106 **Life-cycle assessment of an axial air compressor manufactured by the firm Fini Compressori** [4193-18]
P. Neri, P. Buttol, Ente per le Nuove tecnologie l'Energia e l'Ambiente (Italy); M. Cremonini, Fini Compressori SpA (Italy); A. Ronchi, Univ. of Bologna (Italy); G. Tani, Univ. of Florence (Italy)
- 116 **Allocation of environmental loads in recycling: a model based in the qualitative value of recycled material** [4193-19]
J. V. R. Ferreira, I. Domingos, Instituto Superior Politécnico de Viseu (Portugal); P. Antunes, Univ. Nova de Lisboa (Portugal)
- 124 **Tool to incorporate environmental costs into life-cycle assessment** [4193-20]
S. K. Durairaj, S. K. Ong, R. B. H. Tan, A. Y.-C. Nee, National Univ. of Singapore

SESSION 5 MANAGEMENT ISSUES

- 135 **Proactive environmental management of manufacturing companies** [4193-24]
K.-W. Hansmann, C. Kroeger, Univ. of Hamburg (Germany)
- 145 **Comparison between the environmental damages of two axial air compressors manufactured by the firm Fini Compressori** [4193-62]
P. Neri, Ente per le Nuove tecnologie l'Energia e l'Ambiente (Italy); G. Bernardi, Univ. of Bologna (Italy); P. Buttol, Ente per le Nuove tecnologie l'Energia e l'Ambiente (Italy); G. Naldi, Univ. of Bologna (Italy); M. Saric, Fini Compressori SpA (Italy); G. Tani, Univ. of Florence (Italy)

SESSION 6 SUPPLY-CHAIN MANAGEMENT AND INFORMATION SYSTEM

- 157 **Optimizing the supply chain in reverse logistics** [4193-26]
P. Veerakamolmal, IBM Corp. (USA); S. M. Gupta, Northeastern Univ. (USA)
- 167 **Goal programming approach to the remanufacturing supply-chain model** [4193-27]
E. Kongar, S. M. Gupta, Northeastern Univ. (USA)
- 179 **Disassembly knowledge representation via XML** [4193-28]
I. Zeid, S. M. Gupta, Northeastern Univ. (USA)
- 186 **Case-based reasoning disassembly system** [4193-29]
I. Zeid, S. M. Gupta, L. Pan, Northeastern Univ. (USA)

SESSION 7 ENVIRONMENT IMPACT ASSESSMENT

- 194 **Ecoefficiency: how data envelopment analysis can be used by managers and researchers** [4193-31]
J. Sarkis, Clark Univ. (USA)
- 204 **Methodology to assess the environmental impact of a product and its processes** [4193-32]
K. R. Kumar, D. Lee, Univ. of Southern California (USA); A. Malhotra, Univ. of North Carolina/Chapel Hill (USA)

- 215 **Measuring business performance using indicators of ecologically sustainable organizations** [4193-34]
C. G. Snow, Jr., Rhode Island College (USA); C. C. Snow, Manna, Inc. (USA)
- 223 **Environmental impact assessment model for manufacturing processes** [4193-35]
C. P. Li, I. K. Hui, City Univ. of Hong Kong

SESSION 8 SUSTAINABLE PRODUCT

- 231 **Surface cleaning substitutability in manufacturing organizations: an exploratory study** [4193-36]
S. P. Shah, J. Sarkis, Clark Univ. (USA)
- 243 **Artifact System (AS) framework: a study of the coevolution of technological artifacts** [4193-37]
R. Raj, V. Allada, Univ. of Missouri/Rolla (USA)
- 252 **VerdEE: a new tool for the adoption of life-cycle assessment in small- and medium-sized enterprises** [4193-39]
P. Masoni, E. Scimìa, B. Sàra, Ente per le Nuove tecnologie l'Energia e l'Ambiente (Italy)
- 261 **Environmental aspects in product development: an investigation among small- and medium-sized enterprises** [4193-41]
S. H. Byggeth, G. Broman, Univ. of Karlskrona/Ronneby (Sweden)

SESSION 9 ECM DESIGN OF PRODUCT AND PROCESSES

- 272 **Environmentally conscious redesign of turbine blade fixtures** [4193-42]
J. J. Bausch III, Rochester Institute of Technology (USA)
- 281 **Evaluation of product design in environmentally conscious manufacturing** [4193-43]
A. Rivera-Becerra, L. Lin, SUNY/Buffalo (USA)
- 289 **Complications in disassembly line balancing** [4193-44]
A. Güngör, Pamukkale Univ. (Turkey); S. M. Gupta, K. Pochampally, S. V. Kamarthi, Northeastern Univ. (USA)
- 299 **Planning end-of-life management within the product design process** [4193-45]
E. Cagno, A. Di Giulio, P. Trucco, Politecnico di Milano (Italy)

SESSION 10 FABRIC AND PAPER

- 309 **Reduction of colorants in nylon flock dyeing effluent** [4193-47]
Q. Fan, S. Hoskote, Y. Hou, Univ. of Massachusetts/Dartmouth (USA)
- 321 **Improved crosslinking systems for high-quality fiber/fabric performance** [4193-48]
S. C. Ugbolue, S. B. Warner, Q. Fan, J. Boisvert, M. DiPietro, R. Stacey, S. Hoskote, Univ. of Massachusetts/Dartmouth (USA)
- 332 **Effects of technological developments in paper manufacturing and recycling: a case study of the Finnish pulp and paper industry** [4193-49]
S. Poikkimäki, Univ. of Jyväskylä (Finland)

- 340 **Tradeoff between environmental impacts and economic benefits?: A case study of the Finnish and British pulp and paper industries** [4193-50]
M. Valtonen, Univ. of Jyväskylä (Finland)

SESSION 11 RECYCLING OF CONSTRUCTION MATERIALS

- 352 **Recycling of manufactured waste shingles in asphalt paving mixes** [4193-53]
R. B. Mallick, Worcester Polytechnic Institute (USA); W. S. Mogawer, Univ. of Massachusetts/Dartmouth (USA); M. R. Teto, Worcester Polytechnic Institute (USA); J. Siegel, Chelsea Ctr. for Recycling and Economic Development (USA)
- 364 **Reuse and recycling of construction and demolition material** [4193-54]
J. P. Curro, Camp Dresser & McKee Inc. (USA)
- 372 **Sustainable development in the building industry: an analysis and assessment tool for design of disassembly** [4193-55]
C.-A. Graubner, K. Reiche, Technische Univ. Darmstadt (Germany)
- 382 **Application of life-cycle assessment (LCA) methodology for valorization of building demolition materials and products** [4193-56]
B. Sára, LCA Consultant (Italy); E. Antonini, Qualification and Development of Constructing (Italy); M. Tarantini, Ente per le Nuove tecnologie l'Energia e l'Ambiente (Italy)

SESSION 12 POTPOURRI

- 391 **Disassembly problem and the blood-cracking decision process** [4193-57]
B. Adenso-Díaz, F. Moure, M. Rendueles, M. Díaz, Univ. de Oviedo (Spain)
- 403 **Use of shell chitin extracted from seafood processing waste in recycling of industrial wastewater** [4193-58]
Y. Zuo, J. Zhan, N. Costa, Univ. of Massachusetts/Dartmouth (USA)
- 413 *Addendum*
- 415 *Author Index*

Conference Committee

Conference Chair

Surendra M. Gupta, Northeastern University (USA)

Program Committee

Venkat Allada, University of Missouri/Rolla (USA)
Ad J. de Ron, Technische Universiteit Eindhoven (Netherlands)
Aşkiner Güngör, Pamukkale University (Turkey)
Jacqueline A. Isaacs, Northeastern University (USA)
G. Patrick Johnson, National Science Foundation (USA)
Sagar V. Kamarthi, Northeastern University (USA)
A. J. D. Lambert, Technische Universiteit Eindhoven (Netherlands)
Kenichi Nakashima, Osaka Institute of Technology (Japan)
Joseph Sarkis, Clark University (USA)
Manbir Sodhi, University of Rhode Island (USA)
Pitipong Veerakamolmal, IBM Corporation (USA)
Ibrahim Zeid, Northeastern University (USA)

Session Chairs

- 1 Remanufacturing and Inventory Issues
Surendra M. Gupta, Northeastern University (USA)
- 2 End-of-Life Management
Manbir Sodhi, University of Rhode Island (USA)
- 3 Disassembly
A. J. D. Lambert, Technische Universiteit Eindhoven (Netherlands)
- 4 Life-Cycle Assessment
G. Patrick Johnson, National Science Foundation (USA)
- 5 Management Issues
Pitipong Veerakamolmal, IBM Corporation (USA)
- 6 Supply-Chain Management and Information System
Ibrahim Zeid, Northeastern University (USA)
- 7 Environment Impact Assessment
Joseph Sarkis, Clark University (USA)
- 8 Sustainable Product
Venkat Allada, University of Missouri/Rolla (USA)

- 9 ECM Design of Product and Processes
Surendra M. Gupta, Northeastern University (USA)
- 10 Fabric and Paper
Aybek Korugan, Northeastern University (USA)
- 11 Recycling of Construction Materials
Rajib B. Mallick, Worcester Polytechnic Institute (USA)
- 12 Potpourri
Belarmino Adenso-Díaz, Universidad de Oviedo (Spain)

Introduction

Environmentally Conscious Manufacturing (ECM) is concerned with developing methods for manufacturing new products from conceptual design to final delivery, and ultimately to the end-of-life disposal, such that all environmental standards and requirements are satisfied. In recent years, environmental awareness and recycling regulations have put pressure on manufacturers and consumers to produce and dispose of products in an environmentally responsible manner. This has created a need to design products that are friendly toward the environment, to develop models for disassembly process planning, to develop algorithms, heuristics, and software to support disassembly planning, and to address related issues, such as the logistic and economic viability of disassembly, recycling, and remanufacturing.

The first international conference on Environmentally Conscious Manufacturing, which took place in Boston, 6–8 November 2000, was a result of such needs. Both academia and the industrial community in the United States and abroad participated in this timely conference. The conference provided a forum for the latest developments in the field of ECM. For three days, conference participants immersed themselves in the engaging world of environment, remanufacturing, end-of-life management, disassembly, life-cycle and environmental impact assessment, sustainability, recycling, and product design. The goal for this conference was to bring together a broad, interdisciplinary group of experts, practitioners, and researchers to discuss the state of the art in ECM, and to determine appropriate future plans to guide scholarship and awareness of these crucial areas that concern the very existence of human life as we know it.

This volume is a compilation of the papers presented at the conference. The papers represent the wide variety of research areas in ECM. Based on the quality and variety of papers included in this volume, it is clear that the conference was a resounding success! I hope that this volume will inspire further research in ECM, and will attract new researchers to this enormously important field of study.

The conference and its resulting proceedings volume would not have been possible without the devotion and commitment of the authors. They have been very patient in preparing their manuscripts. I would also like to express my appreciation for having been given the opportunity to chair this conference. Finally, I want to thank the SPIE staff for providing seamless support in unraveling all of the obstacles that arose in putting the conference and this proceedings volume together.

Surendra M. Gupta

