



Smart and Sustainable Manufacturing Systems

Contents:

Special Issue on Education and Curriculum for Smart and Sustainable Manufacturing

Guest Editors: Jeremy L. Rickli and Yinlun Huang

- 1 Editorial: Special Issue on Education and Curriculum for Smart and Sustainable Manufacturing—Jeremy L. Rickli and Yinlun Huang**
- 4 Developing the Workforce for Next-Generation Smart Manufacturing Systems: A Multidisciplinary Research Team Approach—**
Ilya Kovalenko, Efe C. Balta, Yassine Qamsane, Patricia D. Koman, Xiao Zhu, Yikai Lin, Dawn M. Tilbury, Z. Morley Mao, and Kira Barton
- 25 Team-Based Learning of Sustainability: Incorporation of Sustainability Concept and Assessment into Chemical Engineering Senior Design Course—Aida Amini-Rankouhi and Yinlun Huang**
- 36 Problem-Based Learning on Incorporation of Data Analysis Skills into Chemical Engineering Senior Advanced Analysis Course—Helen H. Lou, Yifan Chen, and Ravinder Singh**

REVIEW PAPER

- 45 Game-Based Mechanical Engineering Teaching and Learning - A Review—**
Fernando César Meira Menandro and Sylvester Annab
- 60 Development and Implementation of a Framework for Adaptive Undergraduate Curricula in Manufacturing Engineering—**
Kamyar Raoufi, Brian K. Paul, and Karl R. Haapala
- 80 An Innovation Framework to Integrate Engineering Standards into Industrial Engineering Graduate Curriculum—Hua Li and Kai Jin**

TECHNICAL NOTE

- 88 Recycling or Rubbish? Understanding Decision-Making in Household Recycling Programs—C. A. Browne and B. Moloney**



ASTM INTERNATIONAL
Helping our world work better

ISSN: 2520-6478
Stock #: SSMS2102

www.astm.org

CO-EDITORS

Dr. Yinlun Huang
Department of Chemical
Engineering and Materials
Science
Wayne State University
Detroit, MI, USA

Dr. Sudarsan Rachuri
Advanced Manufacturing
Office
Office of Energy Efficiency
and Renewable Energy
Department of Energy
Washington, DC, USA

EDITORIAL SERVICES

Sara Welliver
Supervisor, Peer Review
Services
J&J Editorial Services
201 Shannon Oaks Cir #124
Cary, NC 27511, USA
tel +1.919.650.1459, ext. 210
astm@jjeditorial.com

EDITORIAL OBJECTIVES

*Smart and Sustainable
Manufacturing Systems* (SSMS)
is published online by ASTM
International, a nonprofit
technical organization that
develops and publishes
voluntary consensus standards
and related information for
materials, products,
systems, and services.

Contributions are peer
reviewed prior to publication.

PURPOSE AND SCOPE

This journal fosters
transdisciplinary research that
crosses the boundaries
of information science, systems
engineering and engineering
design, manufacturing, and
product life cycle with a
focus on how to make
manufacturing systems
smarter and sustainable.

ASSOCIATE EDITORS

Dr. Darek Ceglarek
University of Warwick
Coventry, UK

Prof. Matthew Doolan
University of New South Wales
Canberra, Australia

Dr. Karl R. Haapala
Oregon State University
Corvallis, OR, USA

Dr. Sagar V. Kamarthi
Northeastern University
Boston, MA, USA

Dr. Soundar Kumara
Pennsylvania State University
University Park, PA, USA

Dr. Minna Lanz
Tampere University
of Technology
Tampere, Finland

Dr. Sankaran Mahadevan
Vanderbilt University
Nashville, TN, USA

Dr. Raju Mattikalli
The Boeing Company
Seattle, WA, USA

Prof. Lihong Qiao
BeiHang University
Beijing, China

Prof. K. Senthilkumaran
Indian Institute of Information
Technology
Chennai, India

Prof. Roberto Teti
University of Naples Federico II
Napoli, Italy

Dr. Manoj Kumar Tiwari
National Institute of Industrial
Engineering,
Mumbai, India

Prof. Thorsten Wuest
West Virginia University
Morgantown, WV, USA

Dr. Li Zheng
Tsinghua University
Beijing, China

EDITORIAL BOARD

Dr. Fazleena Badurdeen
University of Kentucky
Lexington, KY, USA

Dr. Yashwanth Kumar Bandari
Oak Ridge National Lab
Knoxville, TN, USA

Dr. Abdelaziz Bouras
Qatar University
Doha, Qatar

Dr. Bryony DuPont
Oregon State University
Corvallis, OR, USA

Prof. Sebti Fofou
University of Burgundy Franche-Comté
Dijon, France

Prof. Pasquale Franciosa
University of Warwick
Coventry, UK

Dr. Robert Gao
The University of Connecticut
Storrs, CT, USA

Dr. Oleg Gusikhin
Ford Motor Company
Dearborn, MI, USA

Prof. Sanjay Jain
George Washington University
Washington, DC, USA

Prof. I. S. Jawahir
University of Kentucky
Lexington, KY, USA

Dr. Kincho H. Law
Stanford University
Stanford, CA, USA

Dr. Mahesh Mani
Allegheny Science and Technology
Washington, DC, USA

Dr. Shreyes N. Melkote
Georgia Institute of Technology
Atlanta, GA, USA

Dr. Sachin U. Nimbalkar
Oak Ridge National Laboratory
Oak Ridge, TN, USA

Dr. Rahul Patil
BASF/WorleyParsons
Houston, TX, USA

Prof. P. V. M. Rao
Indian Institute of Technology Delhi
New Delhi, India

Dr. Utpal Roy
Syracuse University
Syracuse, NY, USA

Dr. Christopher J. Saldana
Georgia Institute of Technology
Atlanta, GA, USA

Prof. Eswaran Subrahmanian
Carnegie Mellon University
Pittsburgh, PA, USA

Dr. Dawn Tilbury
University of Michigan
Ann Arbor, MI, USA

Dr. Conrad S. Tucker
Carnegie Mellon University
Pittsburgh, PA, USA

Dr. Anahita Williamson
NJ, USA

Dr. Paul William Witherell
NIST
Gaithersburg, MD, USA

Dr. Lang Yuan
University of South Carolina
Columbia, SC, USA

Dr. Jing Zhang
Indiana University–Purdue
University Indianapolis
Indianapolis, IN, USA

Dr. Bicheng Zhu
H.A. Automotive Systems Inc.
Troy, MI, USA

POSTMASTER send address change to:

ASTM International—SSMS, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959

EXECUTIVE COMMITTEE

John R. Logar, **Chair**
Cesar A. Constantino, **Vice Chair**
William A. Ells, **Vice Chair**
Bill Griesse, **Finance and Audit Committee Chair**
Taco van der Maten, **Past Chair**
Andrew G. Kireta, Jr., **Past Chair**
Katharine E. Morgan, **President**

DIRECTORS

Amer Bin Ahmed
Klas M. Boivie
Francine Bovard
Gregory J. Bowles
Michael J. Brisson
Scott Fenwick
Linda Freeman
Bonnie McWade-Furtado
Timothy J. Morris
Elise Owen
David W. Parsonage
Carol Pollack-Nelson
Christopher R. Reid
Casandra W. Robinson
Julia C. Schimmelpenninck
Rina Singh
Brian P. Shiels
Dalia Yarom

COMMITTEE ON PUBLICATIONS

William J. Likos, **Chair**
K. Russell DePriest, **Vice Chair**
John R. Logar, **ex officio**
Jay Bhatt
John E. Haddock
Yinlun Huang
Jason H. Ideker
Ibironke Lawal
M. R. Mitchell
Richard W. Neu
Majdi A. Othman
Sudarsan Rachuri
Donya Stubbs
Theresa A. Weston
Nazli Yesiller

INFORMATION FOR AUTHORS

For details regarding paper submission go to <http://mc04.manuscriptcentral.com>.

The subject matter must not be of a speculative nature and the contents must not include materials of an advertising nature. The paper must not be seriously defective as to literary form and structure, continuity of thought, and clarity of expression. The substance of the paper should not have been published previously in the open literature. Authors preparing papers for submittal should observe the conventions of style explained in the ASTM Style Manual. Since the journal does not request page charges, the author is expected to conform to these standard conventions for style. SI units are to be used throughout; if data were not measured in SI units, a note should appear to that effect and the original units should be included in parentheses after the SI units.

IN APPRECIATION OF THE REVIEWERS

The high quality of the papers that appear in this publication is a tribute not only to the obvious efforts of the authors represented but to the unheralded, though essential, efforts of their reviewers. It is to the reviewers' dedication to upholding the high standards of their profession that this note pays tribute. On behalf of ASTM International and the authors as well, we acknowledge with appreciation their important contribution to the success of this journal.

ADVISORY BOARD MEMBERS

Dr. Rakesh Agrawal
Purdue University
West Lafayette, IN, USA

Dr. Dean Bartles
National Center for Defense
Manufacturing and Machining
Blairsville, PA, USA

Dr. Gahl Berkooz
Ford Motor Company
Dearborn, MI, USA

Prof. Jian Cao
Northwestern University
Evanston, IL, USA

Dr. S. K Gupta
University of Maryland
College Park, MD, USA

Dr. Rob Ivester
U.S. Department of Energy
Washington, DC, USA

Prof. Mark Johnson
Clemson University
Clemson, SC, USA

Dr. Pramod Khargonekar
University of California, Irvine
Irvine, CA, USA

Prof. Thomas Kurfess
Oak Ridge National Laboratory
Oak Ridge, TN, USA

Dr. Peter B. Luh
University of Connecticut
Mansfield, CT, USA

Dr. Efstratios Pistikopoulos
Texas A&M University
College Station, TX, USA

Dr. Bahram Ravani
University of California
Davis, CA, USA

Dr. William C. Regli
University of Maryland
College Park, MD, USA

Dr. S. Sadagopan
International Institute of
Information Technology
Bangalore, India

Dr. Vijay Srinivasan
NIST
Gaithersburg, MD, USA

Dr. Ram D. Sriram
NIST
Gaithersburg, MD, USA

Mr. Albert J. Wavering
NIST
Gaithersburg, MD, USA

Smart and Sustainable Manufacturing Systems (Print ISSN 2520-6478; E-ISSN 2572-3928) is published online by ASTM International. The views expressed in this journal are not those of ASTM International. The data and opinions appearing in the published material were prepared by and are the responsibility of the contributors, not of ASTM International.

Copyright © 2021 ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. All rights reserved. This material may not be reproduced or copied, in whole or in part, in any printed, mechanical, electronic, film, or other distribution and storage media without the written consent of the publisher.

Subscriptions

Contact sales for individual and institutional subscriptions

Single copies \$55.00

Multi-site subscription and pricing
sales@astm.org
tel +1.877.909.ASTM

To subscribe
please send prepaid order to ASTM International, Customer Service, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 or visit www.astm.org.

Photocopy Rights

Authorization to photocopy items for internal, personal, or educational classroom use, or the internal, personal, or educational classroom use of specific clients, is granted by ASTM International provided that the appropriate fee is paid to:

Copyright Clearance Center
222 Rosewood Drive
Danvers, MA 01923

tel +1.978.646.2600
www.copyright.com