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Computational Intelligence in Remanufacturing

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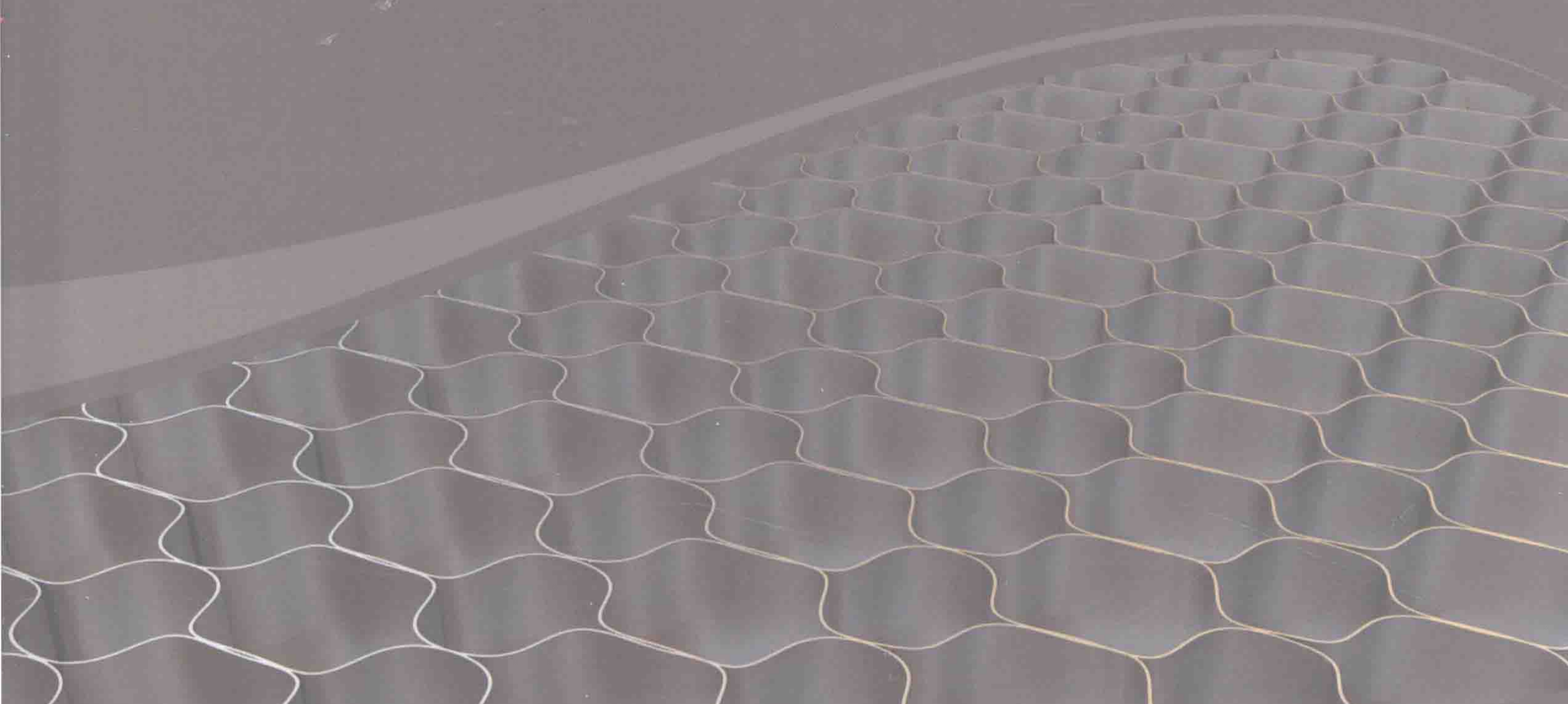

Bo Xing and Wen-Jing Gao

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Computational Intelligence in Remanufacturing

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Mei Yuan Mould Design and Manufacturing Co., Ltd, China

A volume in the Advances in Environmental Engineering and Green Technologies (AEEGT) Book Series

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Cover Design:	Jason Mull

Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Xing, Bo, 1979-
Computational intelligence in remanufacturing / by Bo Xing and Wen-Jing Gao.
pages cm
Includes bibliographical references and index.
ISBN 978-1-4666-4908-8 (hardcover) -- ISBN 978-1-4666-4910-1 (print & perpetual access) -- ISBN (invalid) 978-1-4666-4909-5 (ebook) 1. Remanufacturing--Data processing. 2. Computational intelligence. I. Gao, Wen-Jing, 1979- II. Title.
TS183.8.X56 2014
006.3--dc23

2013032972

This book is published in the IGI Global book series Advances in Environmental Engineering and Green Technologies (AEEGT) (ISSN: 2326-9162; eISSN: 2326-9170)

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

All work contributed to this book is new, previously-unpublished material. The views expressed in this book are those of the authors, but not necessarily of the publisher.

For electronic access to this publication, please contact: eresources@igi-global.com.

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ISSN: 2326-9162
EISSN: 2326-9170

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This book is dedicated to both authors' families, Mr. Tan Xing, Mrs. Qiu-Lan Ma, Mr. Ming-Sheng Gao, and Mrs. Fan Wang, for their unconditional love and support in making this book a reality.

Foreword

Remanufacturing is often regarded as one of the most environmentally friendly and profitable end-of-life product recovery options for its prominent advantages against other recovery treatments such as repairing, refurbishing, or recycling. With the push towards sustainable development and the quest to build a circular economy, remanufacturing has been gaining attention in industry and academia during the past decade. In industry this trend is witnessed by a rapidly growing number of remanufacturing companies in both established and emerging countries such as US, UK, Germany, The Netherlands, Singapore, Japan, Australia, Brazil, China, India, and South Africa. Meanwhile, a large number of international-level publications dedicated to remanufacturing including journal papers, books, conference proceedings, and magazine articles indicate that academicians have started to address various issues encountered in remanufacturing due to their significance and urgency.

In this book, *Computational Intelligence in Remanufacturing*, Bo and Wen-Jing offer a new perspective in the field of remanufacturing research. One of the key features of this book is that it provides a holistic view of remanufacturing by dividing it into three stages, namely, retrieval, reproduction, and redistribution. Various problems that arise within these three independent as well as interdependent stages are addressed in this book. In addition, as the title implies, the book intensively uses various Computational Intelligence (CI) techniques such as genetic algorithm, ant colony optimization, multi-agent system, fuzzy logic, teaching-learning-based optimization, and firefly algorithm. In addition, the book provides a comprehensive literature review of remanufacturing. Furthermore, the organization of the book is such that each of the main chapters in the book concludes with unresolved issues and key recommendations that would, no doubt, lead to further development of the use of advanced and innovative applications of CI methodologies in remanufacturing research.

This book will be beneficial to students in mechanical, industrial, and electrical engineering, particularly those pursuing postgraduate studies in advanced manufacturing. Moreover, the issues addressed in this book can serve as foundations for researchers to build bodies of knowledge in the growing area of remanufacturing. Finally, practitioners can also use the models presented in this book to solve and analyse specific remanufacturing problems. Overall, this book makes an interesting read and is a welcome addition to the remanufacturing literature.

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Surendra M. Gupta, *Ph.D., P.E., is a Professor of Mechanical and Industrial Engineering and the Director of the Laboratory for Responsible Manufacturing, Northeastern University, Boston, USA. He received his BE in Electronics Engineering from Birla Institute of Technology and Science, MBA from Bryant University, and MSIE and Ph.D. in Industrial Engineering from Purdue University. He is a registered professional engineer in the State of Massachusetts. Dr. Gupta's research interests are in the areas of Production/Manufacturing Systems and Operations Research. He is mostly interested in Environmentally Conscious Manufacturing, Reverse and Closed-Loop Supply Chains, Disassembly Modeling, and Remanufacturing. He has authored or coauthored well over 450 technical papers published in books, journals, and international conference proceedings. His publications have been cited by thousands of researchers all over the world in journals, proceedings, books, and dissertations. He has traveled to all seven continents and presented his work at international conferences on six continents. Dr. Gupta has taught over 100 courses in such areas as operations research, inventory theory, queuing theory, engineering economy, supply chain management, and production planning and control. Among the many recognitions received, he is the recipient of outstanding research award and outstanding industrial engineering professor award (in recognition of teaching excellence) from Northeastern University as well as a national outstanding doctoral dissertation advisor award.*

Preface

INITIATION

In 2011, governments from 194 countries, business representatives, and non-government organizations attended the United Nations (UN) Climate Change Conference, which was held in Durban, South Africa, from 28 November to 6 December. Since the international treaty of United Nations Framework Convention on Climate Change (UNFCCC) came into force in 1995, 2011 marks its 17^{th} year. As part of the UNFCCC, the Kyoto Protocol, which was adopted in Kyoto, Japan, in December 1997, created binding targets for the richer nations of the world to reduce Greenhouse Gas (GHG) emissions such as CO_2 by 5.2% from the levels measured in 1990. Among various sources of GHG emissions, the manufacturing sector has been identified by the UN's Intergovernmental Panel on Climate Change as one of the main sectors that contributes a significant portion of GHG emitted globally (Zhang et al., 2012). In general, manufacturing produces GHG emissions directly through onsite use of fossil fuels, as well as indirectly through resource and energy consumption to support product operations (Sutherland, Adler, Haapala, & Kumar, 2008). Therefore, in order to reduce the GHG emissions, the sustainable manufacturing alternatives should be introduced and encouraged on a worldwide scale.

Recently, Ijomah (2008) claimed that remanufacturing can reduce the production of GHG due to it limits raw materials production and the subsequent activities such as machining and shipping that for most products produce the highest CO_2 emissions. In the realm of sustainable manufacturing, remanufacturing is often interpreted as a premier eco-efficiency portfolio, since it can, through a broad set of reprocessing activities, reclaim economic and ecological value of a used or end-of-life product which was added in during its original manufacturing stage (Güngör & Gupta, 1999; Ilgin & Gupta, 2010; Thierry, Salomon, Nunen, & Wassenhove, 1995). According to one of the famous reviews conducted by Lund (1996), the remanufacturing industry in the U.S. includes more than 70,000 firms, directly employing nearly a half million and generating over $53 billion in sales annually. Moreover, researchers (Giuntini & Gaudette, 2003; Toffel, 2004) also remarked that "remanufacturing offers tremendous untapped opportunities for American businesses," such as reducing production cost, meeting customer demand, enhancing brand image, and protecting after market. Some examples of remanufacturing apply to tires (Ferrer, 1997b; Lebreton & Tuma, 2006; Sasikumar, Kannan, & Haq, 2010), gasoline engines (Östlin & Svensson, 2005; Sahni, Boustani, Gutowski, & Graves, 2010; Seitz, 2007; Seitz & Wells, 2006; Subramanian, 2010; Tang, Grubbström, & Zanoni, 2007), toner cartridges (Östlin & Ekholm, 2007; Taylor, 2002), single use cameras (Grant & Banomyong, 2010), home appliances (Kim, Ciupek, Buchholz, & Seliger, 2006; Sundin, 2001; Sundin & Bras, 2005), machinery (Cao, Du, & Chen, 2011; Ferguson, Guide, Koca, & Souza, 2006; King, Miemczyk, & Bufton, 2006; Klausner, 1998; Maslennnikova & Foley, 2000; Tan

& Kumar, 2006), cellular phones (Franke, Basdere, Ciupek, & Seliger, 2006; Geyer & Blass, 2010; Guide, Neeraj, Newmann, & Wassenhove, 2005; Guide, Teunter, & Wassenhove, 2003; Seliger, Skerlos, Basdere, & Zettl, 2003), and electrical equipments (Ferrer, 1997a; Quariguasi-Frota-Neto & Bloemhof, 2012; Spengler & Schröter, 2003).

THE CHALLENGES IN IMPLEMENTING REMANUFACTURING

The reasons for adopting remanufacturing are manifold:

- **On enterprises side:** Green image can help remanufacturing companies to distinguish themselves from their competitors, valuable data can be gathered through remanufacturing so as the original products' design and functionality can be improved, new business opportunities are created for the after sales service market by offering customers new low-cost solutions with remanufactured products.
- **On customer side:** A lower price, typically 40 to 60 percent less than similar new products, is a great reason for customers to embrace remanufacturing (Sahni, et al., 2010).
- **On community side:** Due to the labour intensive nature, remanufacturing can create more job positions for employment market; meanwhile, it also serves as a forum for workers' problem solving skills, more rewarding than traditional production line jobs.
- **On policymaker side:** Several recently passed Extended Producer Responsibility (EPR) directives such as Waste Electrical and Electronic Equipment (WEEE) and End-of-Life Vehicle (ELV) have heralded the start of a new era of waste management policy for durable goods worldwide. For example, a report recently published by the UK government stated that "In terms of landfill avoided, the WEEE Directive could lead to around 133,000-339,000 tonnes of landfill being avoided per annum in the UK" (Parlikad & McFarlane, 2007). In this context, remanufacturing, as a means of meeting these legislations' requirements, may help governments to gain insights of the early impacts of EPR directives.
- **On environment side:** Across all life cycle stages (e.g., beginning-of-life, middle-of-life, and end-of-life), design decisions influence the resulting cost and environmental impact of a product. The reason that used product remanufacturing is a meaningful subject is that this strategy removes some burden from the life cycle cost and environmental impact by eliminating the need for new materials and components for future products.

Lund (1998) identified 75 separate product types that are routinely remanufactured and the criteria for remanufacturing a product can be summarized as follows (Lund, 1998):

- The product is a durable good;
- The product fails functionally;
- The product is standardized and the parts are interchangeable;
- The remaining value-added is high;
- The cost to obtain the failed product is low compared to the remaining value-added;
- The product technology is stable; and
- The consumer is aware that remanufactured products are available.

Although there are good reasons to get involved in remanufacturing practice, at the same time there are many obstacles to the development of remanufacturing, which limit their implementation. Guide (2000) provided further support by presenting seven complicating characteristics in remanufacturing:

- The uncertain timing and quantity of returns;
- The need to balance returns with demands;
- The disassembly of returned products;
- The uncertainty in materials recovered from returned items;
- The requirement for a reverse logistics network;
- The complication of material matching restrictions; and
- The problems of stochastic routings for materials for remanufacturing operations and highly variable processing times.

In summary, these characteristics add different kinds of complexity and uncertainty in the remanufacturing process. Therefore many organizations consider those barriers confronted when developing remanufacturing practices to be greater than the advantages that they would obtain as a consequence of their implementation (Gupta, 2013; Tibben-Lembke, 2002). Examples can be seen from Allen (2010) for wind turbines and Besch (2005) for office furniture. Even though the automotive industry has been practicing environmentally friendly activities since its inception, it has been reluctant to adopt remanufacturing to some extent (Acaccia, Michelini, & Qualich, 2007). This was highlighted in González-Torre, Álvarez, Sarkis, and Adenso-Díaz (2010), Ilgin and Gupta (2012), and Seitz and Wells (2006).

SEARCHING FOR A SOLUTION

The field of remanufacturing has become a fully recognized sub-field of operational research. Remanufacturing research specifically deals with some central questions of manufacturing (e.g., production planning and control, supply network, and marketing), which have been of concern to researchers over the years. However, this environmentally friendly manufacturing option is still in its infancy (Ferguson & Toktay, 2006). Currently the concept of remanufacturing is not well understood by many countries and only a very small number of firms are taking full advantage of remanufacturing (González-Torre, et al., 2010; Kapetanopoulou & Tagaras, 2011). The reasons for this concerning situation are manifold, and this book is mainly concerned with several issues caused by some inherent uncertainties associated with remanufacturing. In Ferrer and Whybark (2001), Guide (2000), Guide, Jayaraman, and Srivastava (1999), and Güngör and Gupta (1999), the authors pointed out that the activities in remanufacturing can be more complicated than those in traditional manufacturing. For example, uncertain timing and quantity of returns, disassembly of returned products, and the need to balance returns with demands. Due to the multi-objective optimization nature of our focal problem, Computational Intelligence (CI) is chosen as a vehicle for fulfilling our research.

A major impetus in algorithmic development is to resolve increasingly complicated problems by designing various algorithmic models. Tremendous successes have been achieved through the modelling of biological and natural intelligence, resulting in so-called Computational Intelligence (CI). In fact, the term Computational Intelligence (CI) was introduced for the emulation of "intelligent" functions of animals by digital electronic computers. It is a fairly new research field, which is still in a process of evolution. At a more general level, CI comprises a set of computing systems with the ability to learn and deal with new events/situations, such that the systems are perceived to have one or more attributes of reason and intelligence (Marwala & Lagazio, 2011).

In recent years, CI has attracted more and more attention over traditional Artificial Intelligence (AI) due to its tolerant of imprecise information, partial truth, and uncertainty (Thammano & Moolwong, 2010). Compared with the well-known AI research area, CI has several unique characteristics: First, AI addresses the representation of symbolic knowledge, while CI deals with the information's numeric representation; second, AI focuses on high-level cognitive functions, while the low-level cognitive functions is the major concern of CI; third, through the analysis of the structure of a given problem, AI intends to construct an intelligent system based upon this structure, and thus the operating manner of AI is top-down, while CI analyzes the structure that is anticipated to emerge from an unordered beginning, thus operating in a bottom-up manner (Wu & Banzhaf, 2010). Another factor contributing to the use of CI is that it encompasses a huge variety of subfields, from general-purpose areas, such as perception and logical reasoning, to specific tasks, such as proving mathematical theorems and diagnosing diseases. Therefore, it is especially useful for solving those problems in which valid and formalized models cannot be established with ease. It is also effective to deal with the combinational problem in designing complicated systems.

Unlike exhaustive research, CI has the ability to deal with imprecise information, partial truth, and uncertainty (Andina & Pham, 2007). In addition, CI can guarantee finding optimal solutions in polynomial time, which is efficiently in practice. It is believed that the marriage of these two areas, CI in remanufacturing, represents an opportunity to increase the efficiencies of the whole remanufacturing process and results in a potentially far reaching economic, environmental, and societal influence.

ORGANIZATION OF THE BOOK

The book consists of 14 chapters that are organized into five sections. A brief description of each of the chapters follows:

Section 1: Introduction

Chapter 1 introduces the background knowledge of the main targeted problem considered in this book (i.e., remanufacturing and its associated reverse logistics). The chapter starts with an introduction about the role of remanufacturing in environment protection. Then, the related studies dealing with the remanufacturing are outlined in the background section, which is followed by a discussion about the work dedicated to the reverse logistics. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 2 presents an overview of computational intelligence. The chapter starts with an introduction about the issue of computational intelligence. Then, the related methodologies used in the book are discussed in the next section. Right after this, the use of computational intelligence methodologies to deal with various remanufacturing/reverse logistics problems are conducted. Finally, the conclusion drawn in the last section closes this chapter.

Section 2: Retrieval

Chapter 3 examines the used products return service quality perceived by the end users and their corresponding willingness-to-return with respect to the used products in their possession. The chapter starts with an introduction about the issue of return quantity encountered at the used product collection stage. Then, related studies dealing with returns quantity are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approach (i.e., agent-based modelling and simulation) can be found in the proposed methodology section. Right after this, three simulations, with each one linked to a specific used products return scenario, are conducted in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 4 addresses the collected used products transportation issue (i.e., used products are first transported from a set of collection points to a sorting centre and then returned to a facility for remanufacturing). The chapter starts with an introduction about the importance of transporting these collected returns in used products remanufacturing. Then, the related studies dealing with this issue are discussed in the background section. Next, the focal problem of this chapter (by considering timing and fuel consumption constraints) is stated in the problem statement section. A detailed description about the authors' approach (i.e., first, formulating the targeted problem as a multiple travelling salesmen problem and then employing genetic algorithms to solve it) can be found in the proposed methodology section. Right after this, an illustrative example is explained in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 5 focuses on the multi-objective methodology to establish an evaluation model for returned components and products. The chapter starts with an introduction about the issue of remanufacturability and the importance of the product information technology. Then, the related studies dealing with similar problems in the literature are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approaches (i.e., fuzzy logic and Bayesian approaches) can be found in the proposed methodology section. Right after this, an illustrative example is explained in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

In order to improve the overall output of remanufacturable end-of-life products, used products usually have to go through a pre-sorting system for identifying the sources of returns and rating them according to their characteristics (i.e., remanufacturable and non-remanufacturable). Under these circumstances, the radio frequency identification is normally used to ensure the efficiency and effectiveness of the pre-sorting process. In the last chapter, the authors focus on the multi-objective methodology to establish an evaluation model for the returned components and products; while in chapter 6, the authors deal with the radio frequency identifications' reliability in this evaluation model during the used products' pre-sorting procedure. The chapter starts with an introduction about the issue of used product pre-sorting process and the importance of radio frequency identification tags' reliability. Then, related studies dealing with similar problems in the literature are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approach (i.e., teaching-learning-based optimization algorithm) can be found in the proposed methodology section.

Right after this, an illustrative example is explained in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 7 aims at enhancing the scientific knowledge in reverse transportation by focusing on how returns in reverse systems can be effectively transported to offshore destinations. The authors argue that transportation action requires the seaport terminal actors to implement a set of coordination mechanisms. These mechanisms should coordinate both the physical flows (the movements of returns) and the commercial interests (control, services, etc.) because it has a direct impact on the performance of the reverse system. The chapter starts with an introduction about the issue of transhipping the remanufacturable used products to their offshore destination. Then, the related studies dealing with the similar problems are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approach (i.e., agent-based modelling and simulation) can be found in the proposed methodology section. Right after this, an illustrative example is explained in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Section 3: Reproduction

After transhipment, the remanufacturable parts/components are usually released to the reprocessing facility where the necessary operations (such as disassembly) are performed. At times, formation of parts/components for reprocessing operations is a complex problem with broad implications to an organization, both on system structure and system operations. Chapter 8 starts with an introduction about the issue of the classification of disassembled and reusable components. Then the related studies dealing with similar problems in the literature are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. The authors formulate the problem as a part-machine clustering problem in which, according to similarities of reprocessing requirement, disassembled parts/components are grouped into families, and machines are organized as cells. A detailed description about the approach (i.e., adaptive resonance theory neural network and ant colony system) can be found in the proposed methodology section. Right after this, two illustrative examples are explained in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 9 discusses the scheduling of the reusable components' reprocessing operations after the used products are disassembled and classified. The chapter starts with an introduction about the issue of scheduling disassembly operations and the scheduling in remanufacturing cells encountered at the used products post-disassembly stage. Then, related studies dealing with similar problems are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approaches (i.e., the fuzzy logic and the fuzzy MAX-MIN ant systems) can be found in the proposed methodology section. Right after this, an illustrative example is explained in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 10 describes the role of reprocessing cell layout design in reducing the material handling cost at the used product post-disassembly stage. The chapter begins with the discussion of material handling cost issues encountered at the reusable parts reprocessing phase. Then, related studies in the literature are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approach (i.e., the hybrid ant system) can be found in the proposed methodology section. Right after this, an illustrative numerical example and the corresponding comparison study are detailed in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 11 presents a novel approach for identification of the re-machining parameters. The chapter starts with an introduction about the significant role of re-machining at the reprocessing stage. Then, the related studies dealing with the selection of optimum machining parameters are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approach (i.e., firefly algorithm) can be found in the proposed methodology section. Right after this, an illustrative example is detailed in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Section 4: Redistribution

Chapter 12 concentrates on the batch order picking for remanufactured product distribution. The chapter starts with an introduction about the issue of secondary sales channels that arise in the remanufactured product redistribution phase and the delivery-oriented service strategy in remarketing. Then, the related studies in the literature are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approach (i.e., ant system and MAX-MIN ant system) can be found in the proposed methodology section. Right after this, an illustrative numerical example is discussed in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusion drawn in the last section closes this chapter.

Chapter 13 examines how to control the extreme events happening when a complex adaptive logistics system is implemented in used product remanufacturing, particularly in the used products transhipment stage. The chapter starts with an introduction about the necessity of introducing the complex adaptive logistics system. Then, the related studies dealing with similar issues are discussed in the background section. Next, the focal problem of this chapter is stated in the problem statement section. A detailed description about the approach (i.e., the agent-based modelling and simulation) can be found in the proposed methodology section. Right after this, an illustrative simulation example is discussed in the experimental study section. The potential research directions regarding the main problem considered in this chapter are highlighted in the future trends section. Finally, the conclusions drawn in the last section close this chapter.

Section 5: Epilogue

Chapter 14 closes the book, and it consists of three sections. The chapter starts with an introduction about the main issues in this book and the corresponding methodologies employed to address these problems. Then an overview of the work done in each previous chapter is summarized in the next section. Right after this, the emerging topics in CI and remanufacturing are outlined.

TARGET AUDIENCE OF THIS BOOK

This book will be beneficial to students in mechanical, industrial, and electrical engineering, particularly those pursuing postgraduate studies in advanced manufacturing. Moreover, the issues addressed in this book can serve as foundations for researchers to build bodies of knowledge in the fast growing area of remanufacturing. Finally, practitioners can also use the models presented in this book to solve and analyse specific remanufacturing problems. The book is carefully written to give a good balance between theory and the applications of various CI techniques.

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