Evolutionary Computation in Scheduling
Evolutionary Computation in Scheduling

Edited by

Amir H. Gandomi, Ali Emrouznejad,
Mo M. Jamshidi, Kalyanmoy Deb, and Iman Rahimi
Contents

List of Contributors vii
Editors’ Biographies xi
Preface xv
Acknowledgments xvii

1 Evolutionary Computation in Scheduling: A Scientometric Analysis 1
   Amir H. Gandomi, Ali Emrouznejad, and Iman Rahimi

2 Role and Impacts of Ant Colony Optimization in Job Shop Scheduling
   Problems: A Detailed Analysis 11
   P. Deepalakshmi and K. Shankar

3 Advanced Ant Colony Optimization in Healthcare Scheduling 37
   Reza Behmanesh, Iman Rahimi, Mostafa Zandieh, and Amir H. Gandomi

4 Task Scheduling in Heterogeneous Computing Systems Using
   Swarm Intelligence 73
   S. Sarathambekai and K. Umamaheswari

5 Computationally Efficient Scheduling Schemes for Multiple Antenna
   Systems Using Evolutionary Algorithms and Swarm Optimization 105
   Prabina Pattanayak and Preetam Kumar

6 An Efficient Modified Red Deer Algorithm to Solve a Truck Scheduling
   Problem Considering Time Windows and Deadline for Trucks’ Departure 137
   Amir Mohammad Fathollahi-Fard, Abbas Ahmadi, and Mohsen S. Sajadieh
7 Application of Sub-Population Scheduling Algorithm in Multi-Population Evolutionary Dynamic Optimization 169
Javidan Kazemi Kordestani and Mohammad Reza Meybodi

8 Task Scheduling in Cloud Environments: A Survey of Population-Based Evolutionary Algorithms 213
Fahimeh Ramezani, Mohsen Naderpour, Javid Taheri, Jack Romanous, and Albert Y. Zomaya

9 Scheduling of Robotic Disassembly in Remanufacturing Using Bees Algorithms 257
Jiayi Liu, Wenjun Xu, Zude Zhou, and Duc Truong Pham

10 A Modified Fireworks Algorithm to Solve the Heat and Power Generation Scheduling Problem in Power System Studies 299
Mohammad Sadegh Javadi, Ali Esmaeel Nezhad, Seyed-Ehsan Razavi, Abdollah Ahmadi, and João P.S. Catalão

Index 327
List of Contributors

Abbas Ahmadi
Department of Industrial Engineering and Management Systems, Amirkabir University of Technology, Tehran, Iran

Abdollah Ahmadi
School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney, NSW, Australia

Reza Behmanesh
Young Researchers and Elite Club, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

João P.S. Catalão
INESC TEC and Faculty of Engineering of the University of Porto, Porto, Portugal

P. Deepalakshmi
Department of Computer Science and Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Tamilnadu, India

Ali Emrouznejad
Aston Business School, Aston University, Birmingham, UK

Ali Esmaeel Nezhad
Department of Electrical, Electronic, and Information Engineering, University of Bologna, Bologna, Italy

Amir Mohammad Fathollahi-Fard
Department of Industrial Engineering and Management Systems, Amirkabir University of Technology, Tehran, Iran

Amir H. Gandomi
Faculty of Engineering and IT, University of Technology Sydney, Ultimo, Australia
List of Contributors

Mohammad Sadegh Javadi
Department of Electrical Engineering, Shiraz Branch, Islamic Azad University, Shiraz, Iran

Javidan Kazemi Kordestani
Department of Computer Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

Preetam Kumar
Department of Electrical Engineering, Indian Institute of Technology Patna, Bihar, Patna, India

Jiayi Liu
School of Information Engineering, Wuhan University of Technology, Wuhan, China

Mohammad Reza Meybodi
Soft Computing Laboratory, Computer Engineering and Information Technology Department, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

Mohsen Naderpour
Centre for Artificial Intelligence, Faculty of Engineering and Information Technology, University of Technology Sydney (UTS), Sydney, NSW, Australia

Prabina Pattanayak
Department of Electronics and Communication Engineering, National Institute of Technology Silchar, Assam, Silchar, India

Duc Truong Pham
Department of Mechanical Engineering, University of Birmingham, Birmingham, UK

Iman Rahimi
Young Researchers and Elite Club, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

Fahimeh Ramezani
Centre for Artificial Intelligence, Faculty of Engineering and Information Technology, University of Technology Sydney (UTS), Sydney, NSW, Australia

Seyed-Ehsan Razavi
School of engineering and IT, Murdoch University, Perth, Australia

Jack Romanous
Centre for Artificial Intelligence, Faculty of Engineering and Information Technology, University of Technology Sydney (UTS), Sydney, NSW, Australia
Mohsen S. Sajadieh  
Department of Industrial Engineering and Management Systems, Amirkabir University of Technology, Tehran, Iran

S. Sarathambekai  
Department of Information Technology, PSG College of Technology, Coimbatore, Tamilnadu, India

K. Shankar  
Department of Computer Applications, Alagappa University, Karaikudi, Tamilnadu, India

Javid Taheri  
Department of Computer Science, Karlstad University, Karlstad, Sweden

K. Umamaheswari  
Department of Information Technology, PSG College of Technology, Coimbatore, Tamilnadu, India

Wenjun Xu  
School of Information Engineering, Wuhan University of Technology, Wuhan, China

Mostafa Zandieh  
Department of Industrial Management, Management and Accounting Faculty, Shahid Beheshti University, G.C., Tehran, Iran

Zude Zhou  
School of Information Engineering, Wuhan University of Technology, Wuhan, China

Albert Y. Zomaya  
Centre for Distributed and High Performance Computing, School of Computer Science, University of Sydney, Sydney, NSW, Australia
Editors’ Biographies

**Amir H. Gandomi** is a Professor of Data Science at the Faculty of Engineering & Information Technology, University of Technology Sydney. Prior to joining UTS, Prof. Gandomi was an Assistant Professor at the School of Business, Stevens Institute of Technology, USA and a distinguished research fellow in BEACON center, Michigan State University, USA. Prof. Gandomi has published over 160 journal papers and five books. He has been named as one of the most influential scientific minds (top 1%) and a Highly Cited Researcher (H-index = 56) for three consecutive years, 2017 to 2019. He also ranked 19th in GP bibliography among more than 12000 researchers. He has served as associate editor, editor, and guest editor in several prestigious journals, such as AE of SWEVO and IEEE TBD. Prof. Gandomi is active in delivering keynote and invited talks. His research interests are global optimization and (big) data mining using machine learning and evolutionary computations in particular.

**Ali Emrouznejad** is a Professor and Chair in Business Analytics at Aston Business School, UK. His areas of research interest include performance measurement and management, efficiency and productivity analysis, as well as data mining and big data. He holds an MSc in applied mathematics and received his PhD in operational research and systems from Warwick Business School, UK. Prof Emrouznejad is editor, associate editor, and guest editor to several respected journals including: *Annals of Operations Research, European Journal of Operational Research, Socio-Economic Planning Sciences, and Journal of Operational Research Society*. He has published over 150 articles in top-ranked journals and authored/edited several books including *Applied Operational Research with SAS* (CRC Taylor & Francis), *Big Data Optimization* (Springer), *Performance Measurement with Fuzzy Data Envelopment Analysis* (Springer), *Big Data for Greater Good* (Springer), *Managing Service Productivity* (Springer), *Fuzzy Analytics Hierarchy Process* (CRC Taylor & Francis), and *Handbook of Research on Strategic Performance Management and Measurement* (IGI Global). See www.emrouznejad.com.
Mo M. Jamshidi is a F-IEEE, F-ASME, AF-AIAA, F-AAAS, F-TWAS, F-NYAS. He received BSEE (Cum Laud) at Oregon State University in 1967, and MS and PhD in EE from the University of Illinois at Urbana-Champaign in June 1969 and February 1971, respectively. He holds honorary doctorate degrees from the University of Waterloo, Canada, 2004, Technical University of Crete, Greece, 2004, and Odlar Yourdu University, Baku, Azerbaijan in 1999. Currently, he is the Lutcher Brown Endowed Distinguished Chair Professor at the University of Texas, San Antonio, TX, USA.

He was an advisor to NASA for 10 years (including with 1st MARS Mission and 7 years with NASA HQR), spent 9 years with US AFRL, 8 years with USDOE, and 1 year with the EC/EU. Currently he is a consultant on the Army Science Board. He has close to 800 technical publications, including 75 books (11 textbooks), research volumes, and edited volumes in English and five foreign languages. He is the Founding Editor or co-founding editor or Editor-in-Chief of five journals, including IEEE Control Systems Magazine and the IEEE Systems Journal. He has graduated or advised 65 PhD and 85 MS students. Moreover, he has advised over 120 US ethnic minority students at MS and PhD and over 850 undergraduate students. Among them are 4 Native American PhDs, 10 Hispanic PhDs and 8 African American PhDs. His former students are successful professionals in 22 nations around the world. Six of his edited and authored books are on System of Systems Engineering in English and Mandarin.

He is the recipient of IEEE Centennial Medal 1984 and WAC Medal of Honor 2014, among many other awards and honors. He is a member of the UTX System Chancellor’s Council. He is currently involved in research on system of systems engineering with an emphasis on robotics, drones, biological and sustainable energy systems. He has over 10 940 citations on Google Scholar.

Kalyanmoy Deb is Koenig Endowed Chair Professor at the Department of Electrical and Computer Engineering in Michigan State University, USA. Prof. Deb's research interests are in evolutionary optimization and their application in multi-criterion optimization, modeling, and machine learning. He has been a visiting professor at various universities across the world including IITs in India, Aalto University in Finland, University of Skovde in Sweden, and Nanyang Technological University in Singapore. He has been awarded the IEEE Evolutionary Computation Pioneer Award, Infosys Prize, TWAS Prize in Engineering Sciences, CajAstur Mamdani Prize, Distinguished Alumni Award from IIT Kharagpur, Edgeworth-Pareto award, Bhatnagar Prize in Engineering Sciences, and Bessel Research award from Germany. He is fellow of IEEE, ASME, and three Indian science and engineering academies. He has published over 520 research papers with over 132 000 Google Scholar citations with an h-index of 114.
He is on the editorial board of 18 major international journals. More information about his research contribution can be found at http://www.coin-lab.org.

**Iman Rahimi**, BSc. (Applied Mathematics), MSc (Applied Mathematics – Operations Research) received his PhD in the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia in 2017. His research interests include supply chain management, data mining, and optimization.
Preface

Scheduling problems are devoted to allocating tasks to resources. When the number of tasks is increased, the scheduling and planning problems become complex, large-scale, and involve numerous constraints. To catch a real solution, most real-world problems must be formulated as discrete or mixed variable optimization problems. Moreover, finding efficient and lower-cost procedures for the common use of the structure is critically important. Although several solutions are suggested to solve the issues mentioned above, there is still an urgent need for more efficient methods. By cause of their complexity, real-world scheduling problems are challenging to solve using derivative-based and local optimization algorithms. Evolutionary Computation (EC) approaches are known as the more effective approaches to cope with this limitation. Evolution can be viewed as a method for searching through enormous numbers of possibilities in parallel, in order to find better solutions to computational problems. It is a way to find solutions that, if not necessarily optimal, are still good.

This book intends to show a variety of single- and multi-objective problems which have been solved using ECs including evolutionary algorithms and swarm intelligence. Because of clear space constraints, the set of presentations included in the book is relatively small. However, we trust that such a set is illustrative of the existing trends among both scholars and practitioners across several disciplines.

This book aims to display a representative sampling of real-world problems as well as to offer some visions into the diverse features related to the use of ECs in real-world applications. The reader might find the material mainly useful in studying the realistic opinion of each contributor concerning how to choose a specific EC and how to validate the results which have been found using metrics and statistics.

This edited book provides an indication of several of the state-of-the-art developments in the field of evolutionary scheduling and reveals the applicability of evolutionary computational approaches to tackle real-world scheduling problems.

This edited book will emphasize the audiences of engineers in industries, research scholars, students (advanced undergraduates and graduate students), and faculty teaching and conducting research in operations research and industrial
engineering from academia, who work mainly on evolutionary computations in scheduling problems (ECSP). Many scientists from operations research labs will also benefit from this book. There is a scarcity of quality books on ECSP which deal with the practicability of this technology. We hope that this book is a great source of research material for enthusiastic people who deal with ECSP.

To facilitate this goal, Chapter 1 presents scientometric analysis to analyze scientific literature in EC in Scheduling. Chapter 2 presents the implementation of Ant Colony Optimization (ACO) in the Job Shop Scheduling Problem with makespan. This is followed by Chapter 3, which describes the application of ACO algorithm in healthcare scheduling.

The focus of the next two chapters is on swarm optimization. Chapter 4 introduces the significance of neighborhood structure in discrete particle swarm optimization algorithm for meta-tasks scheduling problem in heterogeneous computing systems while Chapter 5 addresses genetic algorithm and particle swarm optimization for multi-antenna systems with various carries.

Chapter 6 presents a new variant of the truck scheduling problem in the cross-docking system. This application has been explained along with introducing a new modified version of the Red Deer Algorithm. Chapter 7 presents the management function evaluations (FEs) for intelligent distribution of FEs among sub-populations.

A comprehensive review of the recent literature on models that use evolutionary algorithms to optimize task scheduling in cloud environments is given in Chapter 8. Chapter 9 addresses scheduling of robotic disassembly using the Bees algorithm. Finally, Chapter 10 investigates the state of the art of power generation scheduling problem using a modified Fireworks algorithm.

This book is suitable for research students at all levels, and we hope it will be used as a supplemental textbook for several type of courses, including operations research, computer science, statistics, and many fields of science and engineering related to scheduling problems/ECs.

Amir H. Gandomi
Faculty of Engineering and IT, University of Technology Sydney, Australia

Ali Emrouznejad
Aston Business School, Aston University, Birmingham, UK

Mo M. Jamshidi
Department of Electrical and Computer Engr., University of Texas San Antonio, USA

Kalyanmoy Deb
Department of Electrical and Computer Engineering, Michigan State University, USA

Iman Rahimi
Young Researchers and Elite Club, Islamic Azad University, Iran
Acknowledgments

This book would not have been possible without help of a number of people. First of all, we would like to thank all the authors who contributed in this book. We would also like to extend our appreciation to all the reviewers for their critical review of the chapters and their insightful comments and suggestions provided in several rounds.

The editors also would like to thank the project team in Wiley, for supporting us to finish this project. Special thanks to Kathleen Santoloci, Mindy Okura-Marszycki, and Linda Christina E, project editors in Wiley, for their continuous support to complete this book. The editors hope the readers will find this book to be a valuable contribution to the body of knowledge in Evolutionary Computation in Scheduling.

Amir H. Gandomi
Ali Emrouznejad
Mo M. Jamshidi
Kalyanmoy Deb
Iman Rahimi
1

Evolutionary Computation in Scheduling

A Scientometric Analysis

Amir H. Gandomi1, Ali Emrouznejad2, and Iman Rahimi3

1 Faculty of Engineering and IT, University of Technology Sydney, Ultimo, Australia
2 Aston Business School, Aston University, Birmingham, UK
3 Young Researchers and Elite Club, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

1.1 Introduction

Evolutionary computation (EC) is known as a powerful tool for global optimization-inspired nature. Technically, EC is also known as a family of population-based algorithms which could be addressed as metaheuristic or stochastic optimization approaches. The term “stochastic” is used because of the nature of these algorithms, such that a primary set of potential solutions (initial population) is produced and updated, iteratively. Another generation is made by eliminating the less desired solutions stochastically. Increasing the fitness function of the algorithm resulted from evolving the population. A metaheuristic term refers to the fact that these algorithms are defined as higher-level procedures or heuristics considered to discover, produce, or choose a heuristic which is an adequately good solution for an optimization problem [1, 2]. Applications of metaheuristics can be found in the literature, largely [3–9]. Swarm intelligence algorithms are also a family of EC, based on a population of simple agents which are interacting with each other in an environment. The inspiration for these algorithms often comes from nature, while these algorithms behave stochastically and the agents possess a high level of intelligence as a colony. The most common used algorithms reported in literature are: particle swarm optimization, ant colony optimization, the Bees algorithm, and the artificial fish swarm algorithm [10–15].

Scheduling and planning problems are generally complex, large-scale, challenging issues, and involve several constraints [16–19]. To find a real solution,
most real-world problems must be formulated as discrete or mixed-variable optimization problems [16, 20]. Moreover, finding efficient and lower-cost procedures for frequent use of the system is crucially important. Although several solutions are suggested to solve the problems mentioned above, there is still a severe need for more cost-effective methods. As a result of their complexity, real-world scheduling problems are challenging to solve using derivative-based and local optimization algorithms. A possible solution to cope with this limitation is to use global optimization algorithms, such as EC techniques [21]. Lately, EC and its branches have been used to solve large, complex real-world problems which cannot be solved using classical methods [22–24]. Another critical problem is that several aspects can be considered to optimize systems simultaneously, such as time, cost, quality, risk, and efficiency. Therefore, several objectives should usually be considered for optimizing a real-world scheduling problem.

This is while there are usually conflicts between the considered objectives, such as cost-quality, cost-efficiency, and quality-cost-time. In this case, the multi-objective optimization concept offers key advantages over the traditional mathematical algorithms. In particular, evolutionary multi-objective computations (EMC) is known as a reliable way to handle these problems in the industrial domain [22, 25–27].

With the advent of computation intelligence, there is renewed interest in solving scheduling problems using evolutionary computational techniques. The spectrum of real-world optimization problems dealt with the application of EC in industry and service organizations, such as healthcare scheduling, aircraft industry, school timetabling, manufacturing systems, and transportation scheduling in the supply chain. This chapter gives a general analysis of many of the current developments in the growing field of evolutionary scheduling using scientometrics and charts.

1.2 Analysis

1.2.1 Data Collection

For this scientific literature review, we use a scientometric mapping technique to find the most common keywords used among research articles. First, we searched for the topics “evolutionary scheduling,” “metaheuristic scheduling,” and “swarm intelligence scheduling” in the SCOPUS database between 2000 and the present. We identified 1107 scientific articles. Figure 1.1 presents the distribution of papers from 2000 (articles in the area of the multi-objective vs. total number of documents).
Most of the analysis in this part has been carried out by VOSviewer, which is known as a powerful tool for scientometric analysis [28–30].

### 1.3 Scientometric Analysis

#### 1.3.1 Keywords Analysis

Figure 1.2 shows a cognitive map where the node size is comparable with a number of documents in the specified scientific discipline. Links among disciplines are presented by a line whose thickness is proportional to the extent to which two subjects are employed in one paper.

Top keywords and the number of occurrences found in the analysis are presented in Table 1.1.

#### 1.3.2 An Analysis on Countries/Organizations

Figure 1.3 presents an organization ranking indicating the top 10 organizations which have the most contribution in the field. As is observed from Figure 1.3, the Huazhong University of Science and Technology is the most active organization in this area with 107 published documents, the Ministry of Education China and Tsinghua University are in second and third places, respectively.

Figure 1.4 illustrates the ranking of countries by number of documents. As shown, China, with almost 1100 published articles, possesses the first rank, followed by India, United States, Iran, respectively.
1.3.3 Co-Author Analysis

In Figure 1.5, the analysis of co-authors and networks shows the robust and fruitful connections among collaborating scholars. The links across the networks show channels of knowledge, and networks which highlight the scientific communities engaged in research on the EC in scheduling.

Figure 1.2  Cognitive map (keyword analysis considering co-occurrences).

Table 1.1  Top 10 keywords.

<table>
<thead>
<tr>
<th>No.</th>
<th>Keyword</th>
<th>Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scheduling</td>
<td>1185</td>
</tr>
<tr>
<td>2</td>
<td>Optimization</td>
<td>840</td>
</tr>
<tr>
<td>3</td>
<td>Evolutionary algorithms</td>
<td>698</td>
</tr>
<tr>
<td>4</td>
<td>Scheduling algorithms</td>
<td>345</td>
</tr>
<tr>
<td>5</td>
<td>Genetic algorithms</td>
<td>335</td>
</tr>
<tr>
<td>6</td>
<td>Algorithms</td>
<td>321</td>
</tr>
<tr>
<td>7</td>
<td>Particle swarm optimization</td>
<td>256</td>
</tr>
<tr>
<td>8</td>
<td>Problem solving</td>
<td>248</td>
</tr>
<tr>
<td>9</td>
<td>Heuristic algorithms</td>
<td>224</td>
</tr>
<tr>
<td>10</td>
<td>Job shop scheduling</td>
<td>208</td>
</tr>
</tbody>
</table>

1.3.3 Co-Author Analysis

In Figure 1.5, the analysis of co-authors and networks shows the robust and fruitful connections among collaborating scholars. The links across the networks show channels of knowledge, and networks which highlight the scientific communities engaged in research on the EC in scheduling.
Figure 1.3  Top 10 organizations ranking by number of documents.

Figure 1.4  Ranking of countries by number of documents.

Figure 1.5  The scientific community (co-author) working on EC in scheduling.
1.3.4 Journal Network Analysis

Figures 1.6 and 1.7 show bibliographic coupling and a density map of the active sources (journals) of EC in scheduling, respectively. Figure 1.6 shows the journals aggregated by network visualization. For Figure 1.6, a bibliographic coupling analysis for sources has been used. Considering a minimum number of one document of a source, a total of 585 sources have been found. The most frequent active journals are *Applied Soft Computing*, *Computers and Industrial Engineering*, *International Journal of Advanced Manufacturing Technology*, *European Journal of Operational Research*, and *International Journal of Production Research*. The colors/shadings in Figure 1.6 represent clusters, indicating five clusters for all the items.

In Figure 1.7, the color/shading of each node in the map is related to the density of the nodes at the point. The shading ranges from high density of journals (*Applied Soft Computing*) to low density (e.g. *Neurocomputing*).

1.3.5 Co-Citation Analysis

Figure 1.8 displays the co-citation analysis of cited authors (first author only) who have a minimum of one citation for each author, resulting in 28,203 authors with strength co-citation links. In Figure 1.8, the full strength of co-citation links to other authors has been considered. The top-cited authors in the field are Kalyanmoy Deb, Eckart Zitzler, David E. Goldberg, and Edmund Kieran Burke.

1.4 Conclusion and Direction for Future Research

In this chapter, scientometric analysis of “Evolutionary Computation in Scheduling” for a time zone between 2000 and 2019 has been investigated. Keywords analysis and citation analysis fractional counting with VOSviewer software was used,
and commonly used keywords were identified. The analysis includes different parts such as keyword, organization, country, bibliographic coupling, co-author, and co-citation. Keyword analysis shows that genetic algorithms and particle swarm optimization have been used frequently among other metaheuristic approaches, and job shop scheduling is the most challenging problem in the field of scheduling. China, India, United States, and Iran have the most active organizations in the research area. Moreover, co-authorship and co-citation analysis have been addressed. From a source analysis point of view, *Applied Soft Computing*,

![Density map](image1)

**Figure 1.7** Density map.

![Co-citation analysis](image2)

**Figure 1.8** Co-citation analysis (cited authors).
Evolutionary Computation in Scheduling

Expert System with Application, European Journal of Operational Research, and Annals of Operations Research have been found as well-known active journals in the field.

As a future study, it is recommended to do other analyses with more detail, such as co-citation analysis on cited references and cited sources and/or bibliographic coupling analysis on authors. The analysis also shows how interdisciplinary works have been focused recently; more research in this area is recommended. There are also some other gaps which need to be focused on: robustness is one of these urgent needs, where practitioners should focus more on solving real problems. Scalability is another issue in the field; applicability of EC algorithms in the case of big data is an important matter for practical problems. Comparative works which try to compare evolutionary algorithms and other methods could be also a promising area for more research in the future, especially when tackling these problems in different sources of benchmark data.

References

9 Zarei, M., Davvari, M., Kolahan, F., and Wong, K. (2016). Simultaneous selection and scheduling with sequence-dependent setup times, lateness penalties, and


1 Evolutionary Computation in Scheduling


