Multi-objective Evolutionary Optimisation for Product Design and Manufacturing

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Editors

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Preface

Product design and manufacturing are tightly connected to innovation. They have thus been the key areas that support and influence a nation's economy since the eighteenth century. As the primary driving force behind economic growth, design and manufacturing serve as the foundation of and contribute to other industries, with products ranging from heavy-duty machinery to hi-tech home electronics. In the past centuries, they have contributed significantly to modern civilisation and created the momentum that drives today's economy. Despite various achievements, we are still facing challenges due to the growing complexity in design and manufacturing.

The complexity in product design and manufacturing becomes obvious when solving problems simultaneously against multiple objectives that conflict to each other. In solving such problems, with or without the presence of constraints, it gives rise to a set of trade-off optimal solutions, popularly known as Pareto-optimal solutions. Due to the multiplicity in solutions, these problems were proposed to be solved suitably using evolutionary algorithms that use a population approach in its search procedure. Nevertheless, multi-objective evolutionary optimisation problems remain highly challenging in product design and manufacturing with increasing complexity. Designers and engineers across organisations often find themselves in situations that demand advanced optimisation capability when dealing with their daily activities related to product design and manufacturing.

Targeting the challenge in solving complex problems, over the past decades, researchers have focused their efforts on multi-objective evolutionary approaches to improving the optimality of solutions. While these efforts have resulted in a large volume of publications and impacted both present and future practices in design and manufacturing, there still exists a gap in the literature for a focused collection of works dedicated to multi-objective evolutionary optimisation. To bridge this gap and present the state-of-the-art to a much broad readership, from academic researchers to practicing engineers, is the primary motivation behind this book.

The first three chapters form Part-1 of the book on literature survey and trends. Chapter 1 begins with a clear definition of multi-objective optimisation. Based on a comparative analysis of the existing literature, this chapter provides an introduction to the operating principles of evolutionary optimisation and outlines the current research and application studies in both single- and multi-objective decision making. The chapter also highlights some research trends, particularly the issues of handling uncertainties, dynamic problems, many objectives, decision making, and knowledge discovery through the recently proposed *innovization* approach. The discussion on multi-objective optimisation is extended in Chap. 2 to supply chains. Supply chains are in general complex networks composed of autonomous entities whereby multiple performance measures in different levels have to be taken into account. Particularly, it reviews the research and practices of the existing multi-objective optimisation applications, both analysis- and simulation-based, in supply chain management. This chapter also identifies the needs of an integration of multi-objective optimisation and system dynamics models and presents a case study on its application to the investigation of bullwhip effects in a supply chain. Chapter 3 then introduces a unique perspective of state-of-the-art in multi-objective optimisation based on thermo-mechanical simulations. This perspective is reinforced through two case studies of friction stir welding and metal casting. Future challenges are also identified at the end of the chapter.

Part-2 of the book focuses on product design and optimisation, and is constituted from four chapters. Recognising the importance of optimisation in product family design, Chap. 4 presents a novel approach based on multi-objective evolutionary optimisation and visual analytics to resolve trade-offs between commonality and performance objectives when designing a family of products. A design example of a family of aircraft with a 10-objective trade-off is provided to validate this approach. Based on the functional behaviour in product family design, Chap. 5 introduces a product family hierarchy, where designs can be classified into phenomenological design family, functional part family and embodiment part family. Product portfolio selection is then possible after identifying and clustering non-dominated solutions. Chapter 6 applies the product family design concept to a family of industrial robots. The design problem is treated as a multi-objective optimisation problem where a Pareto optimal front is used to visualise the trade-off between commonality and performance of individual family members. In the area of rapid prototyping using the fused deposition method (FDM), Chap. 7 depicts a unique approach to simultaneously minimising two conflicting goals—average surface roughness and build time. Within the context, a comparative study between genetic algorithm and particle swarm optimisation is also conducted.

Optimisation issues in process planning and scheduling are covered in Chaps. 8 through 12, and organised into Part-3 of the book. Chapter 8 utilises ant colony optimisation for automatic machining setup planning of cast parts. It simultaneously considers the selection of available machines, tolerance analysis and cost modelling for achieving an optimal setup planning result. A tolerance cost factor is introduced when machining error stack-up occurs. The ant colony optimisation is extended in Chap. 9 to include a preference vector when searching for a set of

Pareto-optimal scheduling solutions using meta-heuristics. The scheduling problem is to minimise make-span and energy consumption, whereas the preference vector allows the search to focus on specific areas of interest to decision makers instead of searching for the entire Pareto frontier. However, in order to greatly improve the performance of a manufacturing system, the scheduling problem is better integrated with process planning. This issue is dealt with in Chap. 10 using a multi-agent approach that optimises the two functions simultaneously based on particle swarm optimisation. The feasibility and performance of this approach is verified through a comparative analysis against simulated annealing and genetic algorithm, with positive outcomes. The agent-based approach is also adopted in Chap. 11 for real-time scheduling, whereas reinforcement learning is implemented to job agents and resource agents in order to improve their coordination processes. Two case studies are performed to verify the effectiveness of the proposed method in dynamic shop environment. However, operation disruptions often occur on dynamic shop floors, which increase manufacturing complexity and trigger frequent rescheduling. Targeting the problem, Chap. 12 introduces a multiple ant colony optimisation approach to minimise changes during rescheduling while searching for trade-offs between time and cost.

In Part-4 of the book, the aspect of systems design and analysis is shared by Chaps. 13–17. Dynamic operations not only demand for rescheduling but also affect shop floor layout. The latter is the focal point of Chap. 13, looking into a hybrid approach for dynamic assembly shop layout. In this case, genetic algorithm is used to search for an optimal new layout if the change can justify a significant relocation cost. Otherwise, a function block-based approach is utilised to find the best routing of assembly jobs under a new condition but the existing layout. The multi-objective facility layout issue is further examined in Chap. 14 using a simulation-based optimisation approach where a genetic algorithm helps generate new design parameters for optimisation. Chapter 15 addresses a production system design problem by integrating the concept of innovization with discrete-event simulation and data mining techniques. The uniqueness of the integrated approach lies on applying data mining to the data sets generated from simulation-based multi-objective optimisation, in order to automatically or semi-automatically discover and interpret the hidden relationships and patterns for optimal production system analysis. An industrial case study of an automotive assembly line improvement is also presented to validate the new method. In reality, a good system design requires a good system optimisation, particularly from a cost perspective. Chapter 16 thus proposes to expand simulation-based optimisation and post-optimality analysis to cover the cost aspects of a production system, such as investments and running cost. Industrial empirical results indicate that this approach has opened up the opportunity to identify a set of design solutions with great financial improvement, which are otherwise not feasible to be explored by using current industrial procedures. Another application domain of multi-objective optimisation is manufacturing supply chain. Chapter 17 addresses the design of supply chain networks including both network configuration and related operational decisions such as order splitting, transportation allocation and inventory control. The goal is to achieve the best compromise between cost and customer service level. To illustrate its effectiveness, the proposed methodology is applied to two real-life case studies from automotive industry and textile industry.

All together, the seventeen chapters provide an overview of some recent R&D achievements of multi-objective evolutionary optimisation applied to product design and manufacturing. We believe that this research field will continue to be active for years to come.

Finally, the co-editors would like to take this opportunity express their deep appreciation to all the authors for their significant contributions to this book. Their commitment, enthusiasm, and technical expertise are what made this book possible. We are also grateful to Springer for supporting this project, and would especially like to thank Anthony Doyle, Senior Editor for Engineering, and Claire Protherough, Senior Editorial Assistant, for their constructive assistance and earnest cooperation, both with the publishing venture in general and the editorial details. We hope that readers find this book informative and useful.

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