



**Politecnico
di Torino**

ScuDo

Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

Doctoral Dissertation
Doctoral Program in Management, Production and Design (37th Cycle)

Advancing complexity models for human-robot collaboration in assembly processes

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Summary

This Doctoral Dissertation explores the concept of assembly complexity in collaborative processes, i.e., assembly processes where humans and robots work simultaneously sharing work-spaces and goals. In manufacturing, assembly complexity is a theoretical concept associated with the cognitive effort required by the operator to perform assembly tasks. This concept has been extensively studied due to its significant impact on process quality and overall performance. Greater manufacturing complexity typically requires more cognitive effort from operators, which increases the likelihood of errors and subsequently leads to inefficiencies. For this reason, assembly complexity has long been a subject of research, with various attempts to identify the various factors that contribute to it. The emergence of Industry 5.0, with its emphasis on human-centred manufacturing, requires a re-evaluation of traditional paradigms of assembly complexity. This paradigm shift emphasises the integration of technology like collaborative robots (“cobots”) not only to increase productivity, but mainly to support humans, also from a physical and psychological point of view. However, while cobots are designed to improve productivity and safety, they introduce new layers of complexity due to the need for interaction and collaboration between humans and robots. These novel layers of complexity are not adequately captured by existing models, which focus primarily on product and process metrics. Therefore, this gap highlights the importance of developing new assembly complexity assessment methodologies that are able to capture the full range of challenges presented by Human-Robot collaboration. Specifically, this thesis tries to answer the following research questions:

- Are traditional methods for the assessment of manual assembly complexity suitable also for collaborative processes?
- Do collaborative robotics support human operators in terms of process quality and effort required?
- Is it possible to define quantitative methodologies to assess collaborative assembly complexity?

This dissertation is composed of 5 main chapters. Chapter 1 lays the groundwork by providing a comprehensive review of existing approaches to assess assembly complexity in manufacturing,

classifying them into product-centred, information-centred and system-centred approaches. It critically evaluates these methodologies through real-world case studies, highlighting their strengths and weaknesses. Chapter 2 is a bridge chapter between the concept of assembly complexity and human-robot collaboration. It empirically investigates the impact of cobots on human operators, focusing on performance, usability and well-being. Through an experimental case-study that simulates prolonged assembly tasks, the chapter provides insights into the practical challenges and benefits of HRC, which will contribute to the development of the complexity model in collaborative assembly. Chapter 3 develops a novel quantitative approach to assess perceived assembly complexity using Thurstone's Law of Comparative Judgments. This method, named Thurstone-Inspired Complexity Scale (TICS), provides a way to measure perceived complexity and correlates it with traditional complexity performance metrics, providing a deeper understanding of the impact of cobots in assembly. Chapter 4 introduces the C-HRC model, a proposal for a novel complexity assessment method for collaborative assembly processes. It combines traditional complexity metrics with additional indicators specifically designed to assess interaction and collaboration complexity. This model provides a quantitative practical tool for assessing the multidimensional nature of complexity in collaborative assembly processes. In conclusion, this dissertation makes a contribution to the field by proposing methodologies that address the complexity of collaborative assembly processes where humans and robots work in close contact. In this way, process designer can rely on practical tools to improve the design and implementation of cobot-integrated assembly lines.