# Chapter 24
# Applied Simulation Modelling and Evolutionary Computation Methods in Industry 4.0 CPS Architecture

**Robert Ojsteršek**
https://orcid.org/0000-0001-6244-3737
*Faculty of Mechanical Engineering, University of Maribor, Slovenia*

**Iztok Palčič**
*Faculty of Mechanical Engineering, University of Maribor, Slovenia*

**Borut Buchmeister**
*Faculty of Mechanical Engineering, University of Maribor, Slovenia*

## ABSTRACT

*Industry 4.0 has recently opened a number of new research questions relating to the production scheduling of flexible production systems. The high complexity of flexible production systems` scheduling is reflected in the multi-objective nature of optimisation problems, which cannot be solved satisfactorily with conventional techniques. Researchers are developing various optimisation techniques based on the use of advanced evolutionary computation methods and simulation modelling, but it is difficult to transmit the proposed solutions to the real world of Industry 4.0. The chapter present new method of evolutionary computation and simulation modelling for the purpose of comprehensive multi-objective optimisation of flexible production systems. In the research part, the chapter presents an applied example of the advanced optimisation methods used in order to provide timely and economically sustainable production systems in Industry 4.0. The research results prove the importance and justification of using the proposed CPS architecture ensuring economic and time optimised production systems.*

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## INTRODUCTION

In the time of Industry 4.0, the use of Simulation Modelling methods is becoming more and more necessary to ensure optimised flexible production systems. A wide range of Simulation Modelling applications relates to the production systems` planning and scheduling (Ojstersek, Palcic, & Buchmeister, in press). In the introduction of Simulation Modelling methods, one major limitation arises. The manufacturing systems of Industry 4.0 relate to the high degree of complexity and flexibility related to optimisation approaches, which are so complex that traditional Mathematical Modelling is no longer sustainable for determination of the optimal optimisation results. Recently, Evolutionary Computation methods have been introduced with great advantages, which solve multi-objective optimisation problems satisfactorily (Fu & Liu, 2019). However, the integration of Simulation Modelling and Evolutionary Computation methods proved to be very suitable for solving complex optimisation problems. The research work presented in the manuscript describes the introduction of a five-stage architectural model, which connects the individual components of the Industry 4.0 Cyber Physical System (CPS) into a complete unit suitable for detailed production system optimisation. Flexible production system planning and scheduling has been the subject of research for decades. Researchers thus put a lot of effort into developing new methods, approaches and algorithms for the purpose of production system optimisation. Order scheduling, shorter makespan, increased machine utilisation in subsequent production cost reductions are key to multi-objective optimisation of flexible production systems. In the time of Industry 4.0, which changes production types from mass production to batch production, the research area of flexible job shop production scheduling is, again, increasingly relevant (Ma, He, Wang, Han, & Shi, 2018). Due to the increasing complexity of batch production, some limitations appear in the use of conventional optimisation methods. For the purpose of multi-objective optimisation, the research proposes an introduced method of Evolutionary Computation that addresses optimisation problems satisfactorily. With the introduction of new Evolutionary Computation methods, one problem appeared, which is related to the limitations of the quality of the obtained optimisation solutions. In most cases, the transfer of obtained optimisation solutions is not possible into a real-world production system. On the other hand, verification must be made of the optimisation numerical and simulation results. Up to now, there were no comprehensive optimisation approaches to solve the problems of flexible production scheduling in Industry 4.0. The complexity of the optimisation parameters was conditioned by their interconnectedness, which, in some cases, may even be counterintuitive (improvement of the solution after one optimisation parameter means its deterioration after another). To this end, researchers use different approaches of Evolutionary Computation that offer satisfactory optimisation results. The proposed algorithms are limited by integrated decision logic, which, in most cases, is impossible to adapt or use in other software environments. In the presented research work, we want to show an example of the Evolutionary Computation and Simulation Modelling methods` connectivity in the advanced manufacturing systems of Industry 4.0, based on a five-stage CPS architectural model.

The research work presented consists of three main parts. The first part defines the research areas of multi-objective optimisation, Evolutionary Computation methods, Simulation Modelling and the five-level CPS architectural model within Industry 4.0. Here, we present the main research problem of flexible job shop production optimisation, we list the existing solutions, their advantages and limitations, and our own proposed methods of how to solve individual parts of the entire research problem. The second part is an example of the self-developed methods and approaches used in multi-objective flexible job shop production optimisation, based on the use of Evolutionary Computation and Simulation Modelling