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# Optimierung der Rekonfigurationsplanung Cyber-Physischer Produktionssysteme

## Optimization of the Reconfiguration Planning of Cyber-Physical Production Systems

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### Kurzfassung

Companies strive for improved productivity and economically friendly green manufacturing. In this context, key technology targets for future production systems are, among others, efficient (re-)configurability, adaptability, and energy efficiency [1]. Accordingly, the design goals of mechanical systems tend to shift from tailored to highly flexible. Thus, measures tackling the dichotomy between efficiency and flexibility have grown in scope and importance over the last years. Against this background, a sophisticated tool to (automatically) identify suitable (re-)configuration patterns was presented in [2].

Efficient robotic systems are usually tailored to specific requirements of known production processes or handling tasks. The number of systems however is restricted due to limited factory areas and fixed costs. Imagine an assembly line with handling objects of great diversity (e.g., variable size or weight) resulting from highly fluctuating known order streams. These objects may impose different requirements (e.g., payload, workspace, or dof requirements) on the limited number of  $p$  handling systems. Then using  $p$  identical handling systems (or  $p$  handling systems with identical configurations) each covering all tasks may be less efficient than using the same number of systems with optimized configurations. The set of  $p$  handling systems with known information about the forthcoming product stream and its requirements is referred to as (reconfigurable) cyber-physical production system.

Delta-like robots were originally designed for high-speed pick-and-place-handling of lightweight objects. Modern variants of the Delta robots are well-suited for investigations in the field of reconfiguration planning for two reasons. First, as already noted by the inventor Clavel [3], the Delta robot is distinguished by its modularity and the fact that some components are found in several identical copies in one robot. Second, there is a current trend of equipping the original Delta robot with additional serial chains in order to extend its original field of application to handling tasks with up to six dof (e.g., assorting, tooling, or measuring tasks) and/or with heavy-weight objects (e.g., stacking or packing tasks). As a result, a great variety of dimensional and functional reconfiguration possibilities can be identified.

Previous work in [2] presented a novel and rigorous approach that effectively uses operations research techniques to reduce the energy consumption of such reconfigurable production systems. In this approach, a fixed number of configurations is optimally selected from the entire configuration space and simultaneously allocated to a set of handling tasks in a most energy efficient way (Fig. 1). However, even though efficient dynamic modeling techniques were introduced, using the total energy consumption as target value for optimization leads to expensive computational effort. The reason for this is that each potential allocation needs to be evaluated. Analyses of larger data sets thus require more elaborate modeling and solution techniques, from which two are presented in this contribution. Analyses are based on functionally extended Delta parallel robots with rotational actuation, whereas the approach is applicable to any production line with potentially adaptable systems or workstations.

First, it is tried to reduce the configuration space by preceding analyses of mandatory requirements as resulting from parametric relations of the design parameters based on practical implementation, kinematic characteristics, and performance criteria. Solving the resulting constraint satisfaction problem, the initial intervals for the design parameters are drastically reduced by preliminary considerations and analyses only before starting the actual optimization procedure. At the same time, the solution space is reduced without discarding viable candidates based on poor user experience.

Second, it is tried to enhance the performance of the initial formulation as so-called  $p$ -median problem (which was originally implemented in its standard formulation using Python™ and then solved with Gurobi Optimizer) by applying a column generation approach [4]. In this approach, the original binary integer programming problem is transformed to a relaxed problem and restricted to configuration subsets. Then, by iteratively adding variables of the model, computational efficiency may be improved while still solving optimally. The general approach is illustrated in Fig. 1.

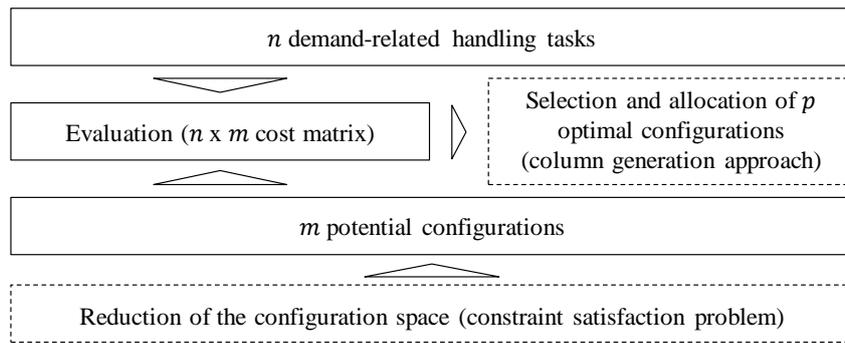


Fig. 1: Modeling and optimization approach

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## Literature

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