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Simulation-based Flexible Layout Planning Considering Stochastic Effects

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Abstract

Layout planning is an important practical problem for manufacturing companies. In today's market conditions —characterized with continuously changing product portfolio and shortening product lifecycles— frequent reconfiguration is requested if the primary goal for the company is to remain competitive. The key to win customers is to widen the product portfolio and customize the products, however, this leads to the problem that the manufacturing system has to be re-organized several times during its life cycle that requires solving design problems frequently. In the paper, a novel layout planning method is introduced that can be applied efficiently to solve real industrial problems. The method applies automated simulation model building to create the different layouts. It focuses on minimizing the objective function that is specified according to the pre-defined key performance indicators (KPI). The solution is a hybrid optimization method, in which evaluation of the layout alternatives is done by simulation and the improvement of the solution is performed by a near-to-optimal search algorithm. The optimization is separated from the simulation model in order to boost the computations. Important advantage of the solution is the efficiency consideration of stochastic parameters that improve the applicability of the results.

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1. Introduction

1.1. Background and motivation

Practical layout planning problem is often faced by companies when extending the production capacities (e.g. new plant or facility is built), introducing new products in their portfolio or modifying available manufacturing resources. The latter two cases are more frequent, as competitive markets and changing customer requirements ask for continuous innovation, new technologies, processes and products. Although flexible and reconfigurable production systems offer efficient solutions to manage both internal (new products) and external changes (change in the volumes), they need to be applied in the right way to exploit their advantages. Besides the management of these systems, the design of the entire facility is also needed to efficiently utilize the flexible approaches.

The above requirements lead to the practical problem of layout planning, which stands for the physical allocation of production facilities and equipment (e.g. machines, workplaces) on the shop-floor. The complexity of the layout planning problem is generally inherited from several factors that need to be considered to take the right decisions. Logistics related objectives include the minimization of the transportation routes, besides, the layout needs to match the production-related requirements like the availability of the material, maximal utilization of the machine resources and lowest possible work-in-progress (WIP). While respecting all the above mentioned aspects of the layout planning problem, the production system evaluation calculations cannot be performed by considering ideal parameters —like deterministic processing times and order arrivals— but a robust solution is needed that is able to perform well even in a dynamic environment with random events and stochastic parameters.

Therefore, the proposed, novel layout planning method is aimed at calculating the near-to-optimal layout while considering stochastic factors that are relevant in the industrial practice. The method relies on the discrete-event simulation (DES) model of the considered production system, and the layout is planned applying search heuristics, by iteratively evaluating layout alternatives. The structure of the paper is as follows. First, the review of the relevant literature and the state-of-the-art layout planning methodologies are listed and evaluated, then the general layout planning problem is specified by the consid-

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ered parameters and the related boundaries. Next, the proposed simulation optimization workflow is introduced by the description of the coupled simulation model as well as the search heuristics. The efficiency of the proposed method is justified by experimental results, then outlook and future steps are detailed.

1.2. State-of-the-art in layout planning

Layout planning and optimization has an extensive literature: based on the different objectives and constraints various different approaches exist to solve the assignment problem. An extensive review in the topic was introduced by Singh, highlighting that facility layout planning is a well-studied combinatorial optimization problem, which can be defined as finding the most efficient arrangement of n indivisible facilities in n locations [1]. As for the classification of the different layout planning problem alternatives, Drira et. al presents a comprehensive study, in which the emerging problems are characterized according to different criteria [2]. The authors highlight that workshop characteristics regarding the facility shapes and dimensions, as well as the product volume and variety leads to different problem formulations and thus various solutions.

Considering the product portfolio of the company, both variety and volume affects the characteristics of the problem, as the applied production system type basically relies on these factors. Thus, one can distinguish among cellular, process- and product-oriented systems that ask for different modeling approaches. Besides, characteristic of the problem is the configuration of the layout, which stands for the general arrangement scheme of the resources. In this classification, single-, multi-row, open-field and loop layout categories exist, and different constraints and formulations are required to represent these arrangements in the planning models. Next to the characteristics of the considered production environment, the layout model and the solver algorithm are also important elements of the planning problem. In general, layout planning is modeled in four different formulations: quadratic assignment [3], graph theoretic model [4], mixed-integer programming model [5] and stochastic optimization problem [6], which models induces directly the set of applicable solver algorithms. In the paper, the latter formulation is preferred to represent the practical layout planning problem, and to capture the actual, stochastic nature of the important parameters. Most formulations (quadratic assignment, mixed-integer) of the layout planning problem are $\mathcal{NP}$-complete by nature, therefore optimal solution cannot be obtained by polynomial-time algorithms [7]. Moreover, if stochastic parameters are considered, the problem becomes even more complex thus it can be solved only by heuristics, search metaheuristics and stochastic optimization methods.

As for the search metaheuristics, simulated annealing (SA), and evolution methods like genetic algorithm (GA) are applied in most of the cases. In case of well-tuned parameters and good evaluation functions, these methods able to provide good solutions in reasonable running time, even in case of complex problems. These metaheuristics often serve as a basis to implement more efficient but problem type specific heuristics. In layout planning, well-known successful heuristics are *CLASS* (SA-based, [8]), *SABLE* (SA-based, [9]), *LOGIC* (GA-based, [10]) or *FACOPT* (SA and GA, [11]). Besides the above described approaches, fuzzy and graph theory approaches are also applied successfully to solve the layout planning problem. Different perspective in the layout planning problem is the time-representation, which introduces novel constraints and objectives, as well as complexity in the problem. Nowadays, production systems must be react quickly on the changes in the product portfolio and/or customer order stream, therefore the time factor is important, in case the evolution of the facility is also considered in the layout planning problem. Dynamic layout planning problems are aimed at optimizing the arrangement of the shop-floor equipment over multiple-periods, considering the above mentioned changes, whereas static problems apply a single planning period. Another aspect of layout planning is the design level, in this case one can distinguish between plant and cell levels of which the latter is considered in the paper.

2. Problem statement

2.1. General characteristics of the layout planning problem

Having the classification factors and model formulation alternatives defined in the previous section, the general characteristics of the layout planning problem considered in the paper is summarized as it follows. The layout planner of a company has to arrange a given set of machines in a two-dimensional (z dimension is disregarded here) space in order to minimize the costs that incur when producing a given set of products. Accordingly, the layout planning can be classified as a single period problem, or it can be considered as a problem whose time period is continuous. It means that the planner respect the fluctuation of the individual orders in time, and does not arrange the machines considering only cumulated volumes and order stream data.

The task is to arrange a set of machines (with different sizes and functions) on the shop-floor by harmonizing the layout with the production of the quasi-random order arrivals. There are different product types with specific routings and processing time, and individual customer orders, each of which corresponds to a single product. The boundaries of the shop floor are given, as well as the inbound and outbound logistics positions that specify the arrival (input) and exit (output) points of the material flow on the layout. Besides the walls of the factory hall, further physical constraints of the layout planning problem are the columns that are arranged in raster-like pattern on the shop-floor (representing e.g. pillars of the production hall or any other restricted areas). The machines can be arbitrarily arranged on the floor respecting the physical constraints, however, pattern-like arrangement is preferred for easier realization considering production management and logistics processes. Not only the positions but also the orientations of the machines are respected and optimized in the proposed approach. As introduced in the previous section, important aspect of the layout planning is the representation of the stochastic parameters and random events in the formulated model, therefore, a detailed specification of the problem is provided in Section 2.2.

2.2. Boundaries and specification of the problem in question

In the considered benchmark layout planning problem, machines need to be placed and arranged on an L-shaped shop-