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Discrete Optimization

# Detailed layout planning for irregularly-shaped machines with transportation path design

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**Abstract**

In order to obtain a competitive level of productivity in a manufacturing system, efficient machine or department arrangements and appropriate transportation path structures are of considerable importance. By defining a production system's basic structure and material flows, the layout determines its operational performance over the long term. However, most approaches proposed in the literature provide only a block layout, which neglects important operational details. By contrast, in this paper, we introduce approaches to planning layouts at a more detailed level. Hence, this present paper introduces an integrated approach which allows a more detailed layout planning by simultaneously determining machine arrangement and transportation paths. Facilities to be arranged as well as the entire layout may have irregular shapes and sizes. By assigning specific attributes to certain layout subareas, application-dependent barriers within the layout, like existing walls or columns, can be incorporated. We introduce a new mathematical layout model and develop several improvement procedures. An analysis of the computational experiments shows that more elaborate heuristics using variable neighborhoods can generate promising layout configurations.


*Keywords:* Facilities planning and design; Combinatorial optimization; Layout planning; Heuristics; Shortest path

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## 1. Introduction

After a dormant period, due to increased global competition and improved information technology, developing decision support systems has again become a vital research area. In particular, layout planning has recently gained renewed interest (e.g., [17,22] or [39]). The renewed awareness of the importance of productivity improvements in companies implies new challenges for layout planning approaches. Because the facility layout determines the basic structure of the production system, it has a considerable impact on the attainable efficiency. However, most approaches for layout planning only determine a block layout. This rough planning neglects many important operational details responsible for the overall productivity of the entire production system. Important details, e.g., aisle structure or transportation flow handling, are strongly dependent on the machine arrangement. Consequently, a separate determination of these details neglects many existing interdependencies and frequently results in inefficient layouts. Hence, this present paper introduces an integrated approach which allows a more detailed layout planning by simultaneously determining machine arrangement and transportation paths. By using a grid-based layout structure, the approach supports a detailed mapping of irregular, but fixed machine shapes. In addition, application-dependent requirements and attributes can be defined for specific subareas of the underlying layout, which may also have an irregular shape. Furthermore, machines can be allocated within four different orientations.

The paper is organized as follows. In Section 2, we provide a brief overview of the relevant literature for layout planning. In Section 3, we introduce the model formulation used throughout the paper. We first describe the main attributes of the model before presenting its full mathematical definition. In Section 4, we introduce several heuristics since a successful application of the proposed approach requires efficient solution procedures. To validate and compare the performance and practical applicability of these heuristics, we present numerical results for randomly generated problems. In Section 5, we conclude with a summary of findings and suggestions for future research.

## 2. Literature review

Layout planning has been a vital research area for many decades [26,22], because the facility layout significantly determines the attainable performance of a manufacturing system [3,16]. Therefore, the literature on facility layout is voluminous [23, p. 100]. Most of the concepts proposed are either algorithmic or procedural [41, p. 128]. While procedural approaches are used to incorporate quantitative as well as qualitative attributes and objectives, algorithmic approaches simplify applied constraints and objective functions in order to define the whole planning process as a combinatorial optimization model.

A procedural approach is typically designed as a component approach generating a variety of possible layout alternatives. Its practical application demands substantial experience from the designer, as it incorporates several subjective decisions. Among the procedural approaches, the methods of Apple [3], Reed [32] and Muther [30] in particular, can be highlighted [36, pp. 301–309]. The applicability of Muther's systematic layout planning procedure to generating a layout in the semiconductor industry was recently shown [42]. An important aspect of procedural approaches addresses the construction of alternative layouts [36, p. 368]. Consequently, evaluation procedures have been formulated to provide an appropriate comparison. For instance, Lin and Sharp propose a generic approach for developing quantitative indices [23]. Besides this, Yang and Kuo [41] propose a hierarchical analysis determining the relative importance of different decision criteria completed by a DEA-based multiple objective decision process. Graph-theory methods are frequently used in procedural approaches to generate alternative layouts. Therefore, the creation process is divided into the adjacency and the block layout problem [37, p. 449]. The adjacency prob-