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Discrete Optimization

Exact and heuristic procedures for the material handling circular flow path design problem

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Abstract

In this study we develop optimization, decomposition, and heuristic procedures to design a unidirectional loop flow pattern along with the pickup and delivery station locations for unit load automated material handling vehicles. The layout of the facility is fixed, the edges on the boundary of the manufacturing cells are candidates to form the unidirectional loop flow path, and a set of nodes located at an intermediate point on each edge are candidates for pickup and delivery stations of the cell formed by those edges. The objective is to minimize the total loaded and empty vehicle trip distances. The empty vehicle dispatching policy underlying the model is the shortest trip distance first. A binary integer programming model describes the problem of determining the flow path and locations of the pickup and delivery stations in which we then provide a decomposition procedure based on a loop enumeration strategy coupled with a streamlined integer linear programming model. It is shown that only a small proportion of all loops have to be enumerated to reach an optimum. Therefore a truncated version of this algorithm should yield a good heuristic. Finally we propose a neighbourhood search heuristic method and report on its performance.

Keywords: Facility planning; Material handling; Automated guided vehicle systems; Generalized traveling salesman problem

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1. Introduction

Tompkins et al. (1996) estimate that between 20% and 50% of operating expenses in manufacturing can be attributed to facility planning and material handling. Thus any cost saving in this area can contribute to the overall efficiency of the production system. In this article we model and solve the problem of optimally designing a material handling system in a factory. In a basic layout design, each cell is represented by a rectilinear, but not necessarily convex polygon. The set of fully packed adjacent polygons is known as a *block layout*. Each polygon in a block layout is a department, a cell, a station, etc. We refer to all these elements as *cells*. There exists several algorithms for the design of block layouts. A common one is BLOCPLAN (1990).

The three principal and interdependent design decisions in the facility layout design problem are: (1) the conceptual design of the block layout including the shapes and locations of cells, (2) the determination of the locations of the pickup (P) and delivery (D) stations on the boundary of each cell, and (3) the design of the flow paths or aisles connecting the station points. Although these three problems are closely related, they have traditionally been solved separately in a sequential manner because of the computational intractability of the integrated design problem (Kim and Goetschalckx, 2003). In this paper we approach the integrated design of the latter two components.

We design a unidirectional loop flow path and the station locations on a given block layout for unit load automated material handling vehicles. The loop layout is one of the four well-known general types of design used in production systems (Apple, 1977). It lends itself to both product and production simplicity (Afentakis, 1989). Compared to a conventional configuration (a unidirectional network formed by all the edges on all cells in the block layout) a circular flow path (a unidirectional loop covering at least one edge of each cell) occupies a smaller portion of shop floor. Furthermore, it has no intersection, and therefore, traffic management, vehicle routing, and dispatching decisions are simple.

In our problem, the layout of the facility is fixed, and the edges on the boundary of the manufacturing cells are candidates to form the unidirectional loop flow path. A set of nodes located at the midpoint of each edge are candidates for pickup and delivery stations of the cell formed by those edges. We develop optimal and heuristic procedures for the simultaneous design of a unidirectional loop flow along with the location of the pickup and delivery stations. The empty vehicle dispatching rule of the shortest trip distance first is implemented in the design of the loop and station locations. The objective function is to minimize the total loaded and empty vehicle trip distances.

The remainder of this paper is organized as follows. A literature review followed by a statement of our contributions are provided in the next section. After defining the problem and the required notations, a global model is developed and solved in Section 3. An alternative heuristic decomposition procedure is developed in Section 4, and its efficiency is compared with that of the global solution procedure. A partial enumeration procedure based on properties of optimal solutions is described in Section 5, followed by a neighbourhood search heuristic in Section 6. Conclusions follow in Section 7.

2. Literature review and scientific contribution

Literature reviews on four topics related to our problem have been produced in recent years: the facility layout problem (Meller and Gau, 1996); the integration of two components of the facility layout: the material handling network and the location of stations (Kim and Goetschalckx, 2003); the design and operational issues in AGV-served manufacturing systems (Ganesharajah et al., 1998); and the loop based facility planning and material handling (Asef-Vaziri and Laporte, 2005). Because of the availability of these reviews, we limit our discussion to the contributions that have a direct impact on our work.