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Innovative Applications of O.R.

Block layout for attraction-based enterprises

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ABSTRACT

This paper proposes an approach for block layout for attraction based enterprises such as theme parks, museums, casinos and exhibitions. The approach takes into account the attraction of individual entities within the enterprise and any adjacency requirements among entities while enforcing reasonable shapes. Using Moran's *I* of spatial statistics and a newly devised shape control method, an optimization mathematical model is established. To solve the model, a space filling curve mechanism works with a tabu search heuristic. The effectiveness and practicality of the approach are demonstrated using three layout cases including the SeaWorld San Diego Park. The approach is easy to use, effective and can readily accommodate varying degrees of preference regarding adjacencies and fixed entities.

1. Introduction

In many museums, exhibitions and theme parks, visitor crowding occurs when there are a large number of visitors or a highly uneven distribution of visitors among the enterprise's entities. Visitor crowding negatively affects visitor satisfaction (Rathnayake, 2015). Because individual entities of a site can differentially attract volumes of visitors, strategic layout of entities is critical. Researchers have studied how to guide visitors to reduce crowding and improve satisfaction (Jaén, Mocholí, Catalá, & Navarro, 2011; Kawamura, Kataoka, Kurumatani, & Ohuchi, 2004; Yu, Lin, & Chou, 2010), but no previous research has explicitly considered the actual layout of the attractors.

The design of such an enterprise can be classified as a block layout problem. Layout problems are generally NP-hard (Garey & Johnson, 1979) and have been extensively studied (e.g., Ahmadi & Jokar, 2016; Drira, Pierreval, & Hajri-Gabouj, 2007; Saraswat, Venkatadr, & Castillo, 2015). Problems can be formulated as discrete or continuous. The slicing tree (Komarudin & Wong, 2010; Ripon, Glette, Khan, Hovin, & Torresen, 2013; Shayan & Chittilappilly, 2004) and the flexible bay structure (Kulturel-Konak, 2012; Kulturel-Konak & Konak, 2011; Tate & Smith, 1995) are popularly used to model layouts in continuous space. For a discrete representation, the planar site is divided into square blocks of the same size and each block is assigned to a department or entity. Space filling curves (abbr. SFC) are generally used to model these layouts (Bozer, Meller, & Erlebacher, 1994; Islier, 1998; Wang, Hu, & Ku, 2005). SFC can ensure the blocks assigned to a department are contiguous, but cannot ensure reasonable shapes on their own. While a slicing tree or flexible bay construct can model attraction based enterprises, they are not as flexible as the SFC in the shapes allowed. The SFC allows rectangles but also L's and other complex shapes. This greater freedom in attraction shape may be an advantage for some applications.

Various methods and procedures have been proposed to solve layout problems. Because exact approaches are only applicable to small size problems, approximated approaches such as heuristics and meta-heuristics have been extensively used (Drira et al., 2007; Gonçalves & Resende, 2015). The meta-heuristics mainly includes genetic algorithms, ant colony algorithms, simulated annealing algorithms and tabu search algorithms (Bashiri & Karimi, 2012; Drira et al., 2007). These approaches can be applicable to both discrete and continuous layout problems.

Traditionally, the main objective of layout problems is to minimize a material flow cost function, perhaps while considering adjacencies (Aiello, Scalia, & Enea, 2012; Lee, Roh, & Jeong, 2005). In a few cases, maximizing an area utilization factor and minimizing shape irregularities have been considered (e.g., Wang et al., 2005). However, the layout of attraction based entities has largely been ignored in the literature. Although some studies have simulated crowd evacuation in emergency situations of large-scale events, these have not considered block layout design.

The contributions of this paper include: (1) the first analytic formulation of an attraction-based block layout design problem; (2) a new department shape control method using a discrete layout representation; (3) the adaptation of Moran's *I* to measure the

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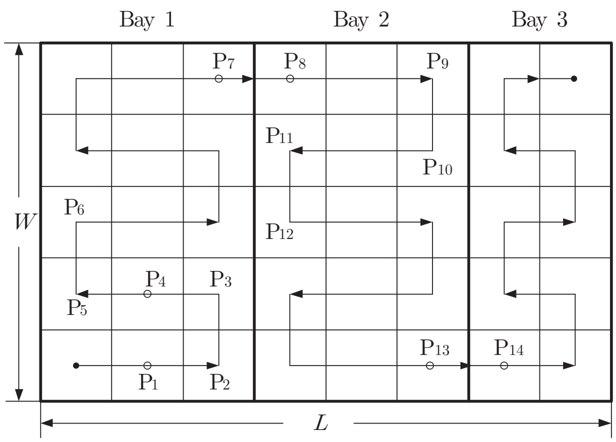

Fig. 1. Site size 8 by 5 with 3 bays.

attraction distribution of the layout to reduce visitor crowding; and (4) improvements on the classical SFC with a set of rules and procedures to ensure reasonable department shapes including rectangles and L's.

2. Problem formulation

This section provides the formulation of the model for block layout design of attraction-based enterprises. We use terminology in this section, without loss of generalization, appropriate to exhibits within an exhibition.

2.1. Problem description

N entities denote N exhibits in an exhibition. These entities are to be placed in a rectangular planar site which is divided into a grid of square blocks of L by W. Each block has the same unit size, such as one meter square. Every entity has a required area (e.g., A_k denotes area required by entity k), and needs to occupy contiguous blocks whose total area is equal to the required entity area.

Each entity has a certain attraction to visitors, which is determined by its popularity and the value of its exhibits. This is termed the attraction value and is normalized to [0, 1]. Attraction values of entities vary considerably. In addition, each entity has a predefined correlation or affinity with each other entity, termed adjacency.

In brief, this problem can be represented as an unequal-area facility block layout problem. The objective function takes into account an attraction distribution requirement and an adjacency requirement, i.e., maximize the uniformity of attraction and maximize specified adjacency. Other objectives might be included. The constraints include: (1) a block cannot be shared by more than one entity; (2) the area required by any entity must be satisfied; (3) the total area required by all entities must not exceed the available area; (4) the blocks that form the total area of a given entity are contiguous and of reasonable shape.

2.2. Space filling curve and shape control

Since the planar site is divided into a grid of square blocks, a discrete layout representation using a SFC is adopted. The SFC connects every block in the planar site, and ensures that the blocks allocated to an entity are contiguous. All entities are placed in the planar site along the SFC in a sequence.

The planar site is vertically divided into N_b bays as shown in Fig. 1. B_i is the width of the ith bay and $L = \sum_{i=1}^{N_b} B_i$. The SFC is generated based on certain rules. The detailed procedure of generating the SFC is described in Section 3.1.

When an entity becomes irregular in shape, it may be impractical. Bozer et al. (1994) proposed a method to control department shape as follows:

$$\varphi_i = \frac{P_i/A_i}{P_i^*/A_i} = \frac{1}{4} P_i A_i^{-0.5} \quad (1)$$

where P_i is the perimeter of department i, A_i is the area of department i, and P_i^* is the perimeter of department i when it is square. With this measure, φ increases as the shape becomes more irregular. Although this method is better than the other shape control methods when using a SFC, it still has limitations, e.g., it cannot enforce specific shapes. Furthermore, this method considers the square as the ideal shape when a rectangle or L shape may work perfectly well for attraction-based entities.

To address these shortcomings for our application, we devised a new shape control method termed the corner-control method. Generally, if an entity consists of equally sized blocks in a planar site, the entity shape is more regular when it has fewer corners. For example, a square or rectangular entity has four corners, and an L-shaped entity has six corners. There are four possible shapes when the number of corners of an entity is eight, as shown in Fig. 2. Shapes become more irregular when the number of corners increases. Therefore, entity shape can be controlled by constraining the number of corners. If set to four, the shape will be square or rectangular. If set to six, the shape will be square, rectangular or L-shaped. These three shapes are very reasonable and practical.

Calculating the number of corners of an entity in a layout is straightforward and computationally simple. It will be formulated and explained in Section 2.5.3. However, if this is a strict constraint, there will be fewer feasible layouts or possibly no feasible layouts when L and W are fixed to equal to the sum of the entity areas. Therefore, we can optionally relax the bounding facility area to allow for feasible layouts as explained later in the paper.

To further refine the shape of each entity, we consider the ratio of perimeter to area as defined in Eq. (1). Even if an entity is rectangular, it may be impractical by being too long and narrow. To achieve reasonable entity shapes, we add an objective function factor termed the shape ratio for each entity. This is defined later in Eq. (6).

2.3. Attraction distribution consideration

A uniform distribution of attraction is an important objective factor while designing an enterprise's layout. This depends on the spatial distribution of the entities. We use Moran's I from spatial statistical analysis to characterize the attraction distribution. Moran's I is a measure of spatial autocorrelation that measures the correlation of an attribute among nearby locations in space (Cliff & Ord, 1981; Moran, 1950). Moran's I is defined as

$$I = \frac{N}{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}} \cdot \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}(v_i - \bar{v})\left(v_j - \bar{v}\right)}{\sum_{i=1}^{N}(v_i - \bar{v})^2} \quad (2)$$

where N is the number of spatial objects indexed by i and j, v_i is the attribute (e.g., attraction value) for spatial object i, $\bar{v} = \frac{\sum_{i=1}^{N} v_i}{N}$ is the mean of v, and w_{ij} is an element of a matrix of spatial weights ($i \neq j$). Usually there are two methods to set the w_{ij} value. One is an adjacency criterion: when spatial object i and spatial object j are adjacent, w_{ij} is 1, otherwise 0. The other is a distance criterion: when spatial object i and spatial object j are within a given distance, w_{ij} is 1, otherwise 0. However, w_{ij} might also be a real number reflecting the distance between spatial objects i and j.

Values of Moran's I range from −1 to +1. A negative value denotes negative spatial autocorrelation and a positive value denotes positive spatial autocorrelation. A zero value denotes a random spatial pattern. The greater I is, the greater the correlation of spatial distribution is, that is, the spatial distribution is

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