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A concept of a flexible approach to the facilities layout problems in logistics systems

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Abstract. This paper describes a concept of computer software devoted to flexible modeling and solving facilities layout (FL) problems in logistics systems. In the beginning, a brief review of available approaches in this regard is provided. Next, diverse aspects of flexibility in designing FL are identified in the literature and discussed. These considerations constitute a background for the presentation of the system modules.

Keywords: facilities layout · logistics · flexible approach · ergonomics

1 Introduction

The main goal concerned with finding optimal arrangements of related objects is to minimize costs of their mutual functioning. In the area of industrial engineering one usually searches for such a layout of machines and tools in the production space that ensures minimal costs of material flows between analyzed objects.

From the mathematical modeling point of view this optimization is a combinatorial task belonging, at least, to the NP-Complete class of problems (Sahni and Gonzalez, 1976). This means that there is no efficient method of finding an optimal solution for big problems including more than twenty objects. Hence, a major trend in this area involves developing heuristic procedures for finding decent suboptimal solutions relatively quickly. In the literature one can find dozens of such proposals. Extensive reviews and classifications of optimization algorithms and systems are provided, for instance, in the works of Kusiak and Heragu (1987), Meller and Gau (1996), Singh and Sharma (2006), Drira et al. (2007).

All methods of searching FLP solutions may be generally divided into two groups i.e. classical and artificial intelligence based approaches. Among the first group methods one can distinguish optimal and suboptimal algorithms called also heuristics. Artificial intelligence based tools usually include: metaheuristics, expert systems, artificial neural networks, genetic and fuzzy logic algorithms.

The fundamental advantage of optimal algorithms is their ability to produce best possible solution every time they are applied. The most popular in this group are methods based on a branch and bound approach which was originally proposed by

Gilmore (1962) and then Lawler (1963). Despite being able to find the best solution they also have a generic drawback resulting from the NP-Complete nature of the problem under consideration. Since they would not provide optimal solutions in a reasonable time for problems with larger than twenty objects, therefore approximate algorithms of the heuristic character are more practical. They include construction, improvement (neighborhood search) and hybrid algorithms (Silver, 2004).

Creating a solution from scratch by specifying step by step the consecutive locations of objects according to the given rule is a characteristic feature of construction methods. The procedure is finished when all items are assigned to appropriate places. As construction algorithms may lead to weak solutions (Zanakis et al., 1989), they are especially useful for generating initial solutions for more efficient algorithms. Among the most known construction algorithms there are ALDEP (Seehof and Evans, 1967), CORELAP (Lee and Moore, 1967), HC66 (Hillier and Connors, 1966), PLANET (Deisenroth and Apple, 1972), MAT (Edwards et al., 1970), FATE (Block, 1977), FLAT (Heragu and Kusiak 1986). CORELAP has become very popular and it has been implemented many times in other computer programs such as those proposed by Parsaei and Galbiati (1987), Ziai and Sule (1988), or Chen and Kengskool (1990).

Improvement algorithms called also neighborhood search algorithms constitute the next group of heuristics. The specificity of these methods is a generation of an initial solution and then making improvements of such a layout by making beneficial locations changes of adjoining objects. The elaborated by Buffa et al. (1964) CRAFT method was one of the first improvement algorithms for solving FL problems. To this day, it is among the most respected optimization algorithms. It was repeatedly modified and the following methods were based on its original idea: COFAD (Tompkins and Reed, 1976), CRAHT-3D (Jacobs, 1984), or SPACECRAFT (Johnson 1982).

Classical algorithms are usually based on assumptions that make it possible to model the reality in a digital computer world. Unfortunately, they introduce significant constrains that simplify the real problems. The vast majority of algorithmic approaches take advantage of regular grids that model the space for the layout design. For instance, methods based on pairwise changes of objects' locations require strict specifications of available spaces in such grids (e.g. CRAFT or COFAD).

2 Various aspects of a flexible approaches to facilities layouts

Early, classical approaches to the facilities layout problem proposed regular algorithms with specified constraints imposed on input data and searching for deterministic, repetitive solutions for a specific data types. Very soon, however, works began on weakening the restrictions and making the FL models more flexible. Particular importance was gained by allowing the mathematical models to analyze different objects' dimensions and shapes as well as applying various goal functions and input data. Developments in these aspects are described in the subsections that follow.

2.1 Diverse objects' dimensions and shapes

Despite restrictions caused by using regular grids for modeling FA problems, already Armour and Buffa (1963) proposed to include objects having various sizes into their algorithm. The authors assumed that objects may be constructed by a different number of uniform bricks that were defined as regular grid cells of 1x1 dimensions. In this way it was possible to analyze more flexibly the objects sizes and even search for optimal objects shapes. The latter idea was implemented by Kim and Kim (1995) in the construction heuristic named SHAPE (Hassan et al., 1986).

The need for treating the FL problems in a more flexible way and allowing for representing objects of diverse dimensions embodied also in multiple approaches based on genetic algorithms. For example, the concept of flexible bays (Tong, 1991; Tate and Smith, 1995) provides solutions in a form of rectangular objects arranged in bays of various widths. In turn, the slicing tree approach (Tam, 1992; Liu and Sun, 2012) allows for optimizing objects as rectangles having individually different dimensions.

2.2 Flexible approach to defining goal functions and input data

Classical FL approaches mainly use objective criteria based on physical units like costs in monetary units, objects transport distances, man-meters etc. An interesting trend of research was initiated in the 70s of the last century, inter alia, by Scriabin and Vergin (1975). They drew attention to the human expert capabilities of solving facilities layout problems. Generally, investigations conducted in this direction demonstrated that intuition and experience help experts in achieving good layout designs in numerous situations.

These outcomes probably acted as an impulse to seek methods based on soft approaches to modeling and solving FL problems. An artificial intelligence manifesting itself, among other things, by applying fuzzy logic allowed for taking advantage of experts' knowledge in a form close to the natural language. As a starting point of modeling in such a perspective one may consider linguistic patterns proposals, put forward in the works of Grobelny (1987a, 1987b, 1988a, 1988b, 1995). Along with the Łukasiewicz formula used for obtaining a gradual truth of an implication they enable to express goal functions and output data in a versatile and very flexible way. Such an approach gives a possibility of taking advantage of experts' knowledge, experience, and intuition.

Beside treating the FL criteria softly, a significant reduction of FL modeling constrains was achieved in a breaking through method developed by Drezner (1987) concerned with arranging a large number of objects on a plane without the necessity of defining a grid of available locations. This heuristic way of computing objects coordinates is based on eigen values and eigen vectors and produces very good solutions for objects represented by points on a plane. Another method that follows this idea was proposed by Grobelny (1999). In contrast to the Drezner's algorithm, Grobelny's model can dynamically generate various solutions for the same FL problem as some of its parameters are specified at random.

2.3 Hybrid approaches

Another demonstration of a flexible approach to FL modeling is an attempt of applying several methods or phases within the confines of a single computer system implemented to solve FL problems. One of the first such ideas was presented by Scriabin and Vergin (1975). They first used a multidimensional scaling method for seeking initial objects' arrangements in a form a graphical sketch and then applied the classical CRAFT procedure for improving the initial solution projected on a regular grid.

Combining different algorithms into a single approach was also the subject to analyses in proposals based on genetic algorithms (e.g. Kazerooni et al., 1995; Sadrzadeh, 2012). Significant improvements in effectiveness of applying the CRAFT algorithm with initial solutions generated by scatter plot methods were reported also in the works of Grobelny et al. (2013) and Michalski and Grobelny (2014).

3 Proposed concept of the flexible system supporting facilities layout optimization

The various aspects of a flexible approaches to FL optimizations depicted in a previous section constituted a basis for determining assumptions and implementing the initial version of our Alinks software. The general idea of our approach is demonstrated in Figure 1 and described in next subsections.

3.1 Data input

The flexibility concerned with defining objects' sizes and shapes is realized in the first module of the system named data input. A user may specify objects' dimensions by drawing objects' rectangular outlines manually or by assigning an appropriate number of unitary regular grid cells to a given object. Relationships between objects and objects' components may be introduced either on a graphical scene by providing appropriate sequences that correspond to the material transport paths between objects (like in the spaghetti diagram) or by putting link values directly into the relationships matrix.

Associations between objects may be defined by: (i) binary values (1 - objects should be located next to each other, 0 – direct neighborhood of this pair of objects is not required), (ii) precise quantitative values, but also as (iii) linguistic variables. The latter case refers to the flexibility described in section 2.2. The concept of linguistic patterns developed by Grobelny (1987a, 1987b, 1988a, 1988b, 1995) is used here for determining the fuzzy goal function values. The linguistic patterns, define the understanding of terms strong relationship and small distance in trapezoidal or/and triangular fuzzy numbers.

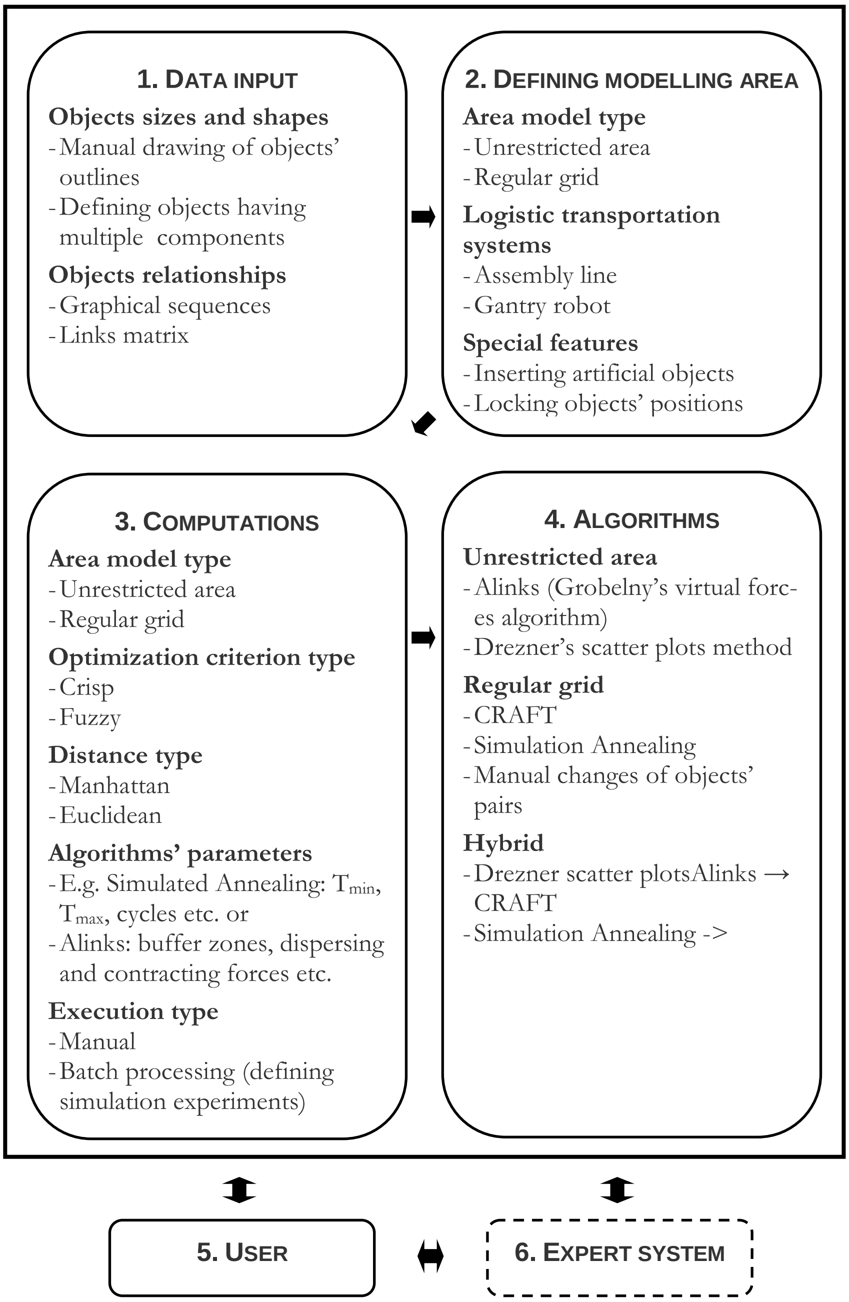

Fig. 1. The general idea of the software allowing for a flexible approach to model and solve various types of facilities layout problems.

3.2 Defining modeling area

Decisions realized in the second module called Defining modeling area allow for taking advantage of the scatter plot concepts developed by Drezner (1987) and Grobelny (1987a, 1987b, 1988a, 1988b, 1995). In this mode, there are no predefined locations for objects. The user defines only the available space for objects by specifying rectangle dimensions in natural measurement units.

In the regular grid mode, one defines sizes and shapes of objects and their locations by means of unitary grid cells. It is possible for specify a simplified grid shape for typical logistic transport systems such as an assembly line or gantry robot. Both approaches are illustrated in Figure 2.

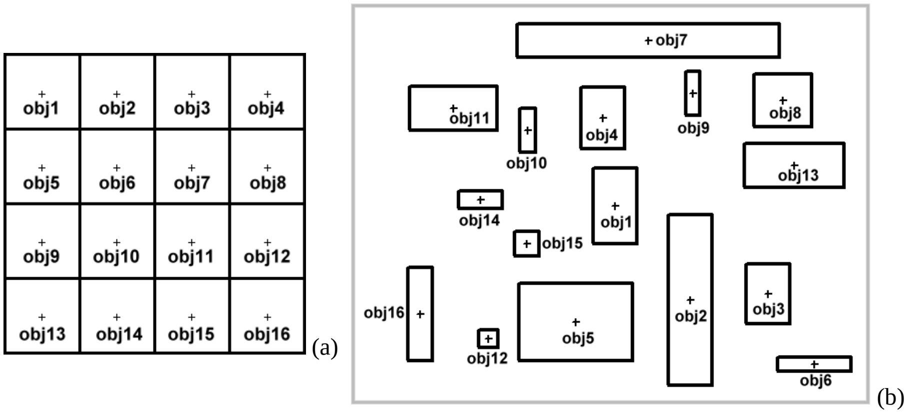

Fig. 2. The illustrations of regular grid (a) and unrestricted (b) modeling areas for FL.

Apart from that it is possible to lock the location of a specific object and insert artificial objects. These features are especially useful for designing layouts of already existing spaces where it is necessary to include various constrains, e.g. aisles or transport routes that need to be excluded from the possible target places for objects being arranged.

3.3 Computations

The third module regards computations directed at searching for optimal layouts either on an unrestricted plane or on a regular grid. The performance and behavior of selected algorithms from the fourth module depend to a significant extent on the attributes selected in this part of the system. The flexibility of our approach allows for selecting the goal function type (crisp or fuzzy) and the way the distance between objects should be calculated (Manhattan or Euclidean). Parameters necessary for the implemented algorithms to operate properly are also set in this section of the software. Additionally, the system has been prepared in such a way that it is possible to perform not only a single simulation but also a series of predefined simulations.

3.4 Algorithms

Algorithms that are available in the proposed system can be generally divided into those that operate on an unrestricted area and those where a regular grid is necessary for optimization procedure. The greatest degree of flexibility is characteristic for methods using unrestricted plane, that is: the Drezner's scatter plots method and Grobelny's virtual force algorithm. Although both approaches are similar in their general idea, there is a fundamental philosophical difference between them. While the former is deterministic in nature, the latter involves stochastic components. Therefore, Drezner's procedure provides only one solution for the given FL problem whereas Grobelny's virtual forces heuristic may generate numerous different solutions thanks to incorporated random mechanisms. Both approaches in their original implementations analyzed only dimensionless objects. In the presented system we developed a procedure that allows for taking objects' rectangular outlines into account by preventing them from overlapping.

3.5 User

The implemented capabilities available in the presented modules of the supporting system provide users with a great variety of possibilities for solving facilities layout problems. It is worth noting that apart from using the software in an interactive mode, one can also prepare and conduct automatically a series of simulations. This feature may be particularly useful for carrying out scientific experiments. The ideas of a flexible approach to modeling and solving various types of FL problems may be realized by applying qualitatively different algorithms, their combinations, supported by additional features developed within the framework of the current system. For instance, in the works of Grobelny et al. (2013) and Michalski and Grobelny (2014) it was shown that it was possible to decidedly improve the FL designs provided by CRAFT by involving the scatter plots concepts into generating initial solutions. Such a hybrid approach that combines in a sequential way the algorithms for regular grids like CRAFT or Simulated Annealing and unrestricted plane methods (Grobelny's virtual forces or Drezner's approach) is supported by the software. It is feasible to transform modular grid solutions to the natural measurement units' space and vice versa.

3.6 Expert system

The expert system module which is currently being developed is meant as a kind of a user supporting guide that prompts how to use the software in a specific design situation. Based on the FL problem parameters entered by a user, the module would produce appropriate suggestions. The system's proposals would be particularly concerned with modeling the solution space type and selecting appropriate optimization criteria definitions from among available options. The expert system section will also contain rules about combining implemented algorithms in sequences to achieve better designs. The latter feature would be mainly based on experimental studies outcomes.

4 Summary

In the presented concept of a computer system we managed to realize a number of postulates concerned with a flexible approach to modeling and solving FL problems. A practical verification of the described ideas requires, naturally, a series of empirical investigations. It seems to be especially interesting to conduct comparative studies demonstrating superiority of the proposed approach over the existing systems that usually take advantage of a single method without a possibility to mix different procedures. Such a research direction was undertaken in experiments reported by Grobelny et al. (2013) and Michalski and Grobelny (2014). Particularly promising finding presented in this paper is the behavior of the hybrid method combining classical CRAFT with the Grobelny's virtual forces algorithm. The first one seeks initial solutions on a plane of specific dimensions. The second one, based on objects' pair changes improves the initial solution provided by the previous procedure. Application of algorithms in such a sequence along with the batch processing produced significantly better solutions to test FL problems taken from the literature than those obtained by the CRAFT method alone. However, it was also demonstrated in the same study that Simulated Annealing was not sensitive to initial solutions generated by the virtual forces procedure. A wide area of possible experimental research is additionally related with the virtual forces approach involving fuzzy parameters. Results obtained in such studies would be used for elaborating rules included in the expert system module. The presented concept may be used in practice, for instance by managers or engineers that have in-depth knowledge about the given production process on one hand side, and basic information on how heuristic optimization algorithms work on the other.

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