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The Use of Scatter Plots for Finding Initial Solutions for the CRAFT Facility Layout Problem Algorithm

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Abstract

A simulation experiment was conducted to verify whether the Link scatter plot algorithm (Grobelny, 1999) used for searching solutions of the facility layout problems may be used as an input to the classical CRAFT algorithm (Buffa et al., 1964) which employs a regular grid for specifying possible locations of objects. Three independent variables were investigated in this study, namely (1) the size of the problem: 16 and 64 objects, (2) the type of links between objects: grid and line types, and (3) the shape of the possible places in which the objects can be situated: square and rectangle having two rows. The gathered data were statistically analysed and the obtained results shows substantial decrease in the goal function means for all of the examined experimental conditions. The experimental data investigation demonstrates the usefulness of the proposed approach and encourages further research in this direction.

Keywords: facility layout problem; initial solutions; scatter plots; simulation experiments
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Introduction

Facility Layout Problem

The facility layout problem in production engineering is usually defined as assigning specific objects (machines) to defined locations and situating those objects relative to each other. By finding an optimal solution to this problem one minimizes the number of transport operations, the production cycle length etc. Facility layout problems appear also at lower levels of production systems. For instance, within the confines of the ergonomic workplace design the facility layout models are used for minimizing the biological cost of a human being at work. The importance of the research in this field is amplified by empirical studies showing substantial decrease in production costs for optimized layouts well as the employees' efficiency increase at assembly line workplaces after improving the objects' arrangements.

Models and algorithms for facility layout optimization have a long history of research dating back to the 60's of the previous century. In 1976 Sahni and Gonzalez have shown that FLP as many other optimization problems belong at least to the class of NP-complete problems which means it cannot be resolve optimally in polynomial time. Therefore many heuristics have been developed to find a reasonable solution for a large size, layout problems.

During the last two decades the scientific explorations and practical applications are especially focused on such as meta-heuristics as genetic algorithms, simulated annealing or ant colony algorithms. Reviews of different approaches and classifications of the facility layout algorithms are presented in e.g. Kusiak and Hergau (1987), Meller and Gau (1996), Singh and Sharma (2006), Drira et al. (2007) or Moslemipour et al. (2012). The general tendency in consecutive approaches involves considering more and more real constrains and requirements on the one hand and searching for increasingly efficient methods on the other.

Scatter Plot Concepts

The scattered plots proposal was originally introduced in the works of Drezner (1980, 1987). The idea of this approach involves searching mutual relationships between objects located on the plane without the assumption of fixed and available places. The obtained scatter plots have usually irregular shape because the objects' locations are not limited in advance. However, the geometrical relationships (objects' adjacencies) in this type of solutions correspond to those objects' links. Therefore, the scatter plots can serve as a tool supporting designers by suggesting, for example, which pairs of real objects should be situated next to each other. Very effective deterministic algorithm for finding optimal scatter plots was developed by Drezner (1987). The final coordinates of the individual objects are determined in this algorithm by means of the appropriate eigen vectors of the specifically constructed matrix.

Different algorithm taking advantage of the idea of scatter plots put forward by Drezner was elaborated by Grobelny (1999). In this stochastic algorithm the scattered plot is produced by simulating virtual physical process, in which the stable state is a consequence of interacting two opposed forces. One acts on every object from the middle of the plane towards the direction which is chosen at random. The second force is proportional to the strength of links with other objects and works a resultant of forces pushing the given object to all the others. Every scatter plot is obtained by performing the objects behavior simulation step by step as they move on the plane until the stable state is achieved and objects do not change their position anymore. As the directions of the centripetal force are selected randomly, every scatter plot is different, but each one conserves mutual relationships between objects reflecting the links between them.

The computer implementation of the Links algorithm enables to get the solution in a regular grid by consecutively assigning the scatter plot objects located the closest to individual grid cells centers to those cells - one item to one cell. The dimension of every cell is identical and is equal to one. The best assignment of the given scatter plot to the regular grid is obtained by systematically rotating the grid in relation to the grid's center of gravity with the step of 5 degrees.

Objectives of the Study

The quality of developed algorithms is most often analyzed by comparing their outcomes. In many heuristic algorithms which by nature are looking for local optima, the optimization results are very sensitive to the input data structure and the initial solution adopted. In this study, a new approach to generating initial solutions for algorithms based on local neighbouring search paradigm is proposed. The suggested methodology takes advantage of a scatter plot idea introduced by Drezner (1980, 1987), later used by Grobelny (1999) and briefly described in the previous section.

The paper presents the simulation experiments which were designed to show how scatter plot starting solutions influence the quality of the outcomes produced by a selected classical algorithm. The experiments were conducted for tasks having diverse sizes and structures of the relationships matrix. The obtained results are statistically compared with the solutions obtained for randomly generated starting layouts. The last part of this paper includes the discussion of the obtained results and final conclusions.

Simulation Experiment

Independent Variables

Three factors were used as the independent variables, namely (1) the number of objects, (2) the type of relationship between objects, and (3) the objects' layout on the plane. The effects included the following levels:

- Number of items (NI): 16 and 64.

- Relationship type between objects (RO): grid - G (Figure 1 and 3) and line - L (Figure 2 and 4).
- Objects' layout on the plane (OL): square - S (Figure 5 and 6) and rectangular - R (Figure 7 and 8).

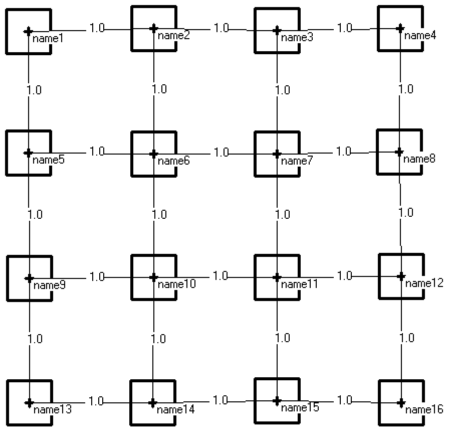

Figure 1. *Grid type links for 16 objects problem*

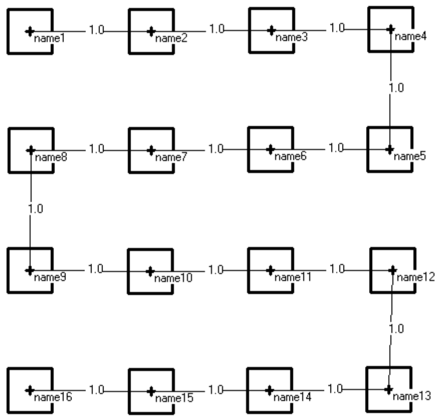

Figure 2. *Line type links for 16 objects problem*

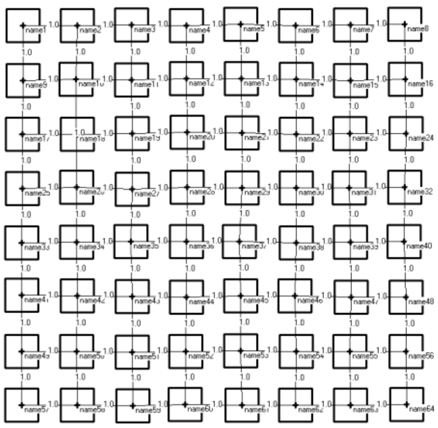

Figure 3. *Grid type links for 64 objects problem*

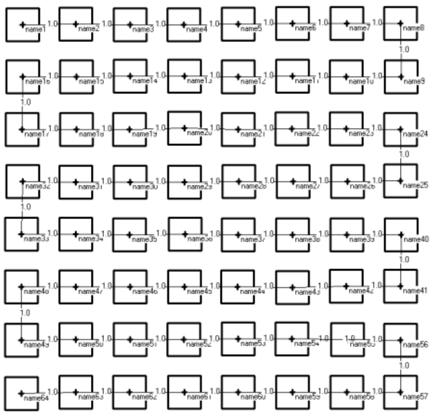

Figure 4. *Line type links for 64 objects problem*

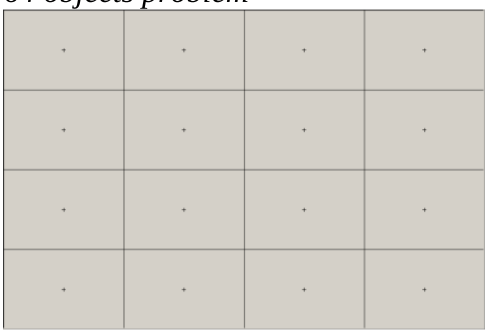

Figure 5. *Square layout for possible location of 16 objects*

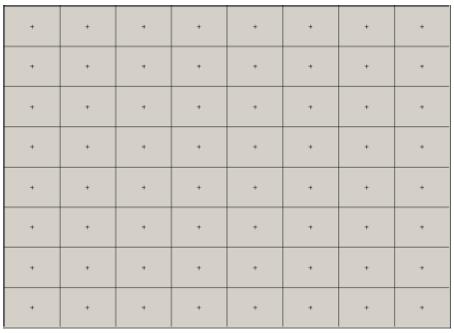

Figure 6. *Square layout for possible location of 64 objects*

Figure 7. *Rectangular (two rows) layout for possible location of 16 objects*

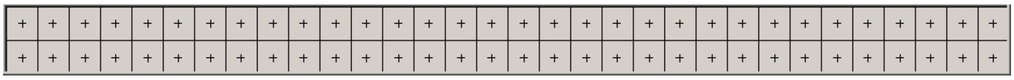

Figure 8. *Rectangular (two rows) layout for possible location of 64 objects*

Dependent Variables

As a dependent variable the following objective function was employed:

$$\textit{Goal function} = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left(D_{p(i)p(j)} \cdot L_{ij}\right),$$

where $D_{p(i)p(j)}$ is calculated as according to the Minikowsky metric:

$$D_{p(i)p(j)} = \left(\sum_{k=1}^{N}\left|x_{p(i)k} - x_{p(j)k}\right|^{r}\right)^{1/r},$$

where k is the dimension and r is the particular metric. In this study, for calculating the distance between location places of i and j objects rectilinear (city block or Manhattan) was employed. In this case the r parameter equals 1. The L_{ij} denotes the link strength between the pair of objects.

Experimental Design and Procedure

A full experimental design was applied and given the factors and their levels described above eight conditions were produced: NI (2) × RO (2) × OL (2) = 8.

A CRAFT algorithm (Buffa et al., 1964) was applied after random initial layout, after the layout obtained by applying Alinks algorithm, and finally after the initial solution provided by Alinks with a rotation procedure. The simulation was repeated 100 times for each of the eight experimental conditions.

Results

The results of the conducted simulations are presented individually for all of the examined experimental conditions. In each case the, a figure showing the mean values of the goal function for all three sequences used in the experiment were prepared. To formally verify whether the differences are statistically significant, standard one way analysis of variance was used. The Anova results are included in the figures' captions. Additionally, the individual differences between these sequences were analysed and the outcomes were presented in tables next to the figures. Vertical bars in all figures denote 0.95 confidence intervals while in all tables the *t*-Student's statistics were provided along with *p* values which were given in brackets.

LAYOUTS CONTAINING 16 OBJECTS

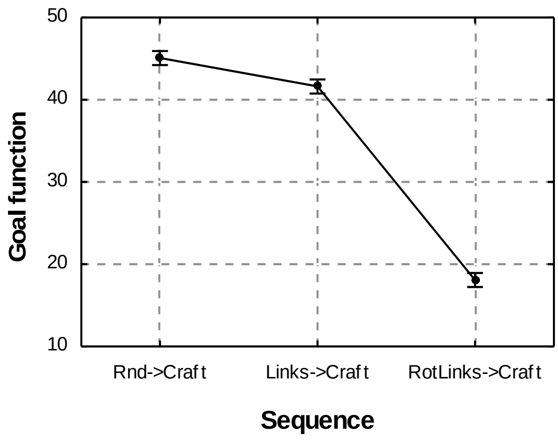

Figure 9. *The influence of the applied sequences of algorithms on the goal function for 16_G_R. F(2, 297)=1145, p<0.00001*

Table 1. *Differences between sequences of algorithms for 16_G_R*

	Links> Craft	**RotLinks> Craft**
Rnd> Craft	5.6 (*0.00001)	44 (*< 0.00001)
Links > Craft	×	38 (*< 0.00001)

* p < 0.00001

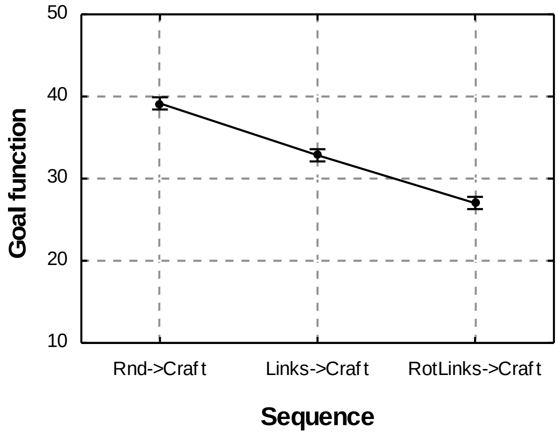

Figure 10. *The influence of the applied sequences of algorithms on the goal function for 16_G_S. F(2, 297)=259, p<0.00001*

Table 2. *Differences between sequences of algorithms for 16_G_S*

	Links> Craft	**RotLinks> Craft**
Rnd> Craft	12 (*0.00001)	23 (*< 0.00001)
Links > Craft	×	11 (*< 0.00001)

** p < 0.00001

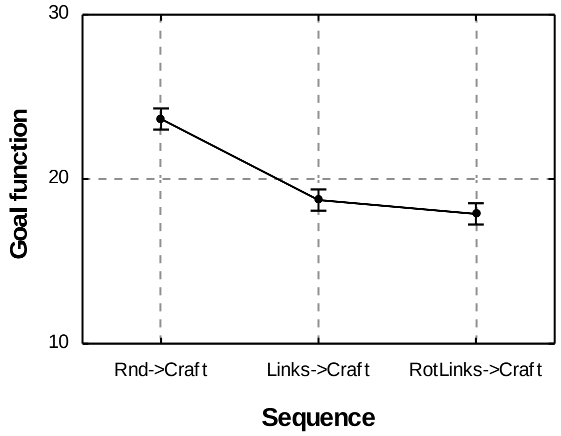

Figure 11. *The influence of the applied sequences of algorithms on the goal function for 16_L_R. F(2, 297)=91, p<0.00001*

Table 3. *Differences between sequences of algorithms for 16_L_R*

	Links> Craft	**RotLinks> Craft**
Rnd> Craft	11 (*0.00001)	12 (**< 0.00001)
Links > Craft	×	1.8 (< 0.067)

* $p < 0.00001$

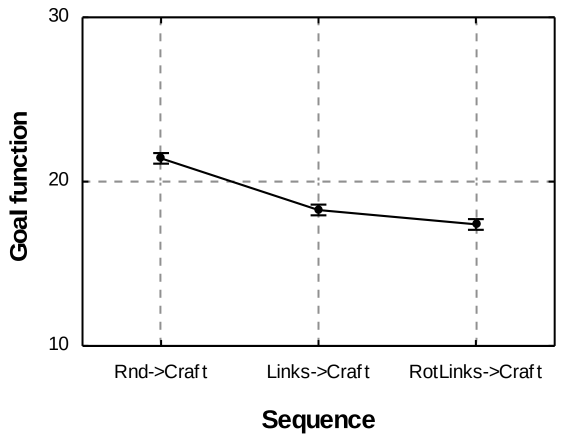

Figure 12. *The influence of the applied sequences of algorithms on the goal function for 16_L_S. F(2, 297)=165, p<0.00001*

Table 4. *Differences between sequences of algorithms for 16_L_S*

	Links> Craft	**RotLinks > Craft**
Rnd> Craft	13 (*0.00001)	17 (**< 0.00001)
Links > Craft	×	3.8 (**< 0.00019)

* $p < 0.00001$
** $p < 0.001$

LAYOUTS CONTAINING 64 OBJECTS

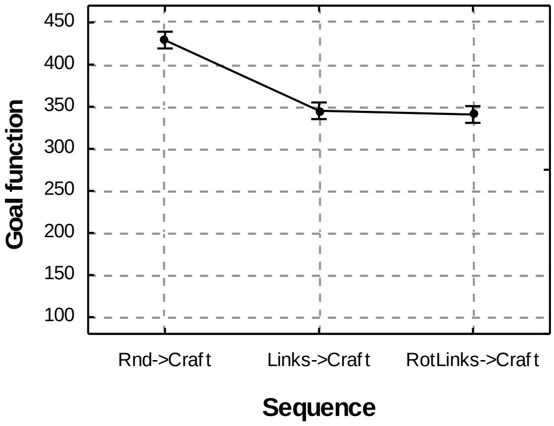

Figure 13. *The influence of the applied sequences of algorithms on the goal function for 64_G_R. F(2, 297)=98, p<0.00001*

Table 5. *Differences between sequences of algorithms for 64_G_R*

	Links> Craft	**RotLinks > Craft**
Rnd> Craft	12 (*0.000 01)	12 (**< 0.000 01)
Links > Craft	×	0.62 (< 0.54)

* p < 0.00001

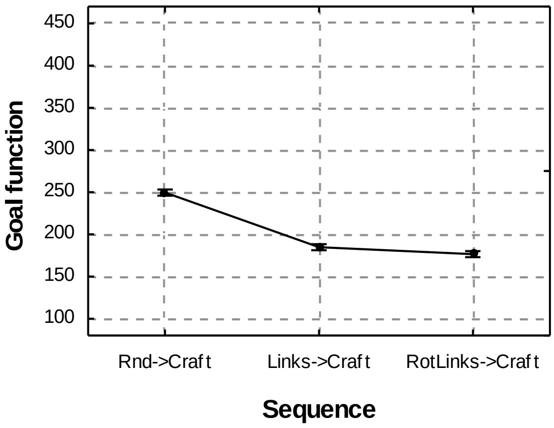

Figure 14. *The influence of the applied sequences of algorithms on the goal function for 64_G_S. F(2, 297)=474, p<0.00001*

Table 6. *Differences between sequences of algorithms for 64_G_S*

	Links> Craft	**RotLinks> Craft**
Rnd> Craft	25 (*0.000 01)	28 (*< 0.000 01)
Links > Craft	×	3.2 (**< 0.00 16)

* p < 0.00001
** p < 0.001

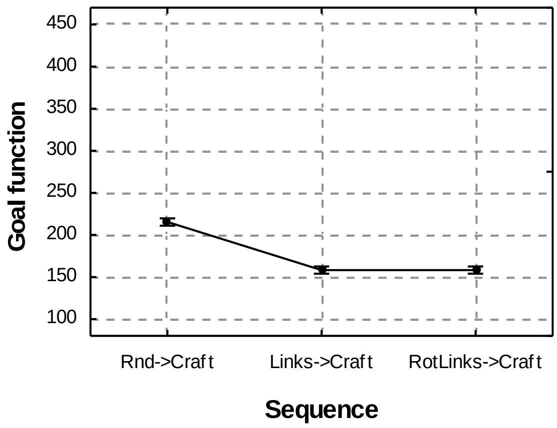

Figure 15. *The influence of the applied sequences of algorithms on the goal function for 64_L_R. F(2, 297)=226, p<0.00001*

Table 7. *Differences between sequences of algorithms for 64_L_R*

	Links> Craft	**RotLinks> Craft**
Rnd> Craft	18 (*0.00001)	18 (*< 0.00001)
Links > Craft	×	0 (1)

* p < 0.00001

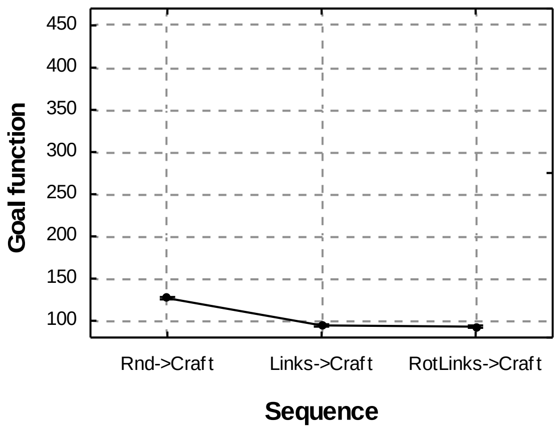

Figure 16. *The influence of the applied sequences of algorithms on the goal function for 64_L_S. F(2, 297)=696, p<0.00001*

Table 8. *Differences between sequences of algorithms for 64_L_S*

	Links> Craft	**RotLinks> Craft**
Rnd> Craft	32 (*0.00001)	33 (*< 0.00001)
Links > Craft	×	1.5 (< 0.14)

* p < 0.00001

Discussion of the Results and Conclusions

The results presented in figures unambiguously indicate the usefulness of applying the proposed way of finding the initial solution for the Craft method. In all of the analysed cases the obtained outcomes of the Craft algorithms are better once the links or links with rotation algorithms are used than when the initial solution is randomly generated.

For the layouts containing small number of objects, namely 16, the application of the regular grid rotation after the scatter plots were produced occurred to have a significant importance (Figs. 9-12). The contrast analysis conducted for problems with 64 objects with grid-type links and square layout (Figure 14) showed that in this case also the regular grid rotation significantly better improves the final Craft solutions than the standard assignment of objects locations to the regular grid. In all other examined in this paper experimental conditions related to the 64 items layouts the application of the simple method of placing the Links results in the regular grid seems to be sufficiently good.

The obtained results are promising and encourage continuing research regarding the application of scatter plot based solutions as a starting point for other facility layout searching methods. The examination should naturally be extended and include some different matrices of between objects relationships and additional types of possible target layouts. Additionally, it seems that especially interesting could be the investigation of how those conditions influence various types facility layout methods.

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