Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management
Istanbul, Turkey, July 3 – 6, 2012

An Improved Approach to Exchange Non-Rectangular Departments in CRAFT Algorithm

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Abstract

In this Paper, an algorithm which improves CRAFT algorithm's efficacy is developed. CRAFT is an algorithm widely used to solve facility layout problems. Our proposed method, named Plasma, can be used to improve CRAFT results. In this note, Plasma algorithm is tested in several sample problems. The comparison between PALSMA and classic CRAFT and also Micro-CRAFT indicates that Plasma is successful in cost reduction in comparison with CRAFT and Micro-CRAFT.

Keywords
Facility Layout Problem, Quadratic Assignment Problem, Craft Algorithm, Micro-Craft Algorithm.

1. Introduction

A fundamental integration phase in the design of a productive system is identifying the optimal layout of production facilities. A working definition of layout may be given as the arrangement of machinery and flow of materials from one facility to another which minimizes material handling costs while considering any physical restrictions on such arrangement.

The Facility Layout Problem (FLP) has attracted extensive attention from industry and academia. A number of survey papers, including Kusiak and Heragu [1] and Meller and Gau [2], summarize different modeling and solution approaches to the FLP. Due to the difficulty of the problem, however, the majority of work on the FLP has focused on heuristic approaches to find good solutions [3]. Exact solution methods, based on Mixed Integer Programming (MIP), cannot solve large problems and/or they make assumptions, such as equal sized departments and departments with fixed shapes and orientations, which are difficult to justify in practical cases [4, 5]. Some of meta-heuristics approaches have shown good solving results, but based on some of their assumptions, they aren't so applicable. For example by checking samples of Haktanirlar Ulutas and Kulturel-Konak [5] it's easy to grasp that the numbers of departments increasing the marginal unused space growing. Therefore, deeming rectangular facilities or sections makes the model easy to solve but dull to implement.

A main objective function which is frequently taken into account is to minimize material handling costs. Therefore, the departments that incur the most interdepartmental movement should be located close to one another. In general, the total material handling cost is expressed as relation (1) [4].

$$TC = \sum_{i=1}^{N} \sum_{j=1+1}^{N} \left(c_{ij} f_{ij} d_{ij}\right) \tag{1}$$

where d_{ij} is the distance between departments i and j for a specified distance metric, f_{ij} is the amount of material flow, and c_{ij} is the material handling cost per unit flow per unit distance traveled between departments i and j.

Computerized Relative Allocation of Facilities Technique (CRAFT) [6] is a heuristic algorithm that takes load matrix of interdepartmental flow and transaction costs with a representation of a block layout as inputs. The block layout could either be an existing layout or, for a new facility, any arbitrary initial layout. CRAFT algorithm is the most widely known algorithm which is developed for situations in which materials handling costs is a major consideration.

The CRAFT algorithm computes the departmental locations and returns an estimation of the total interaction costs for the initial layout. The governing algorithm is designed to compute the impact on a cost measure for two-way or three-way swapping in the location of the facilities. For each swap, the various interaction costs are computed afresh and the load matrix and the change in cost (increase or decrease) is stored. The algorithm proceeds this way through all possible combinations of swaps accommodated. The basic procedure is repeated a number of times resulting in a more efficient block layout every time till such no further cost reduction is possible. The final block layout is reported as output layout.

Micro-CRAFT (MCRAFT) is the extended version of CRAFT. It is presented by Hosni et al. [7]. MCRAFT divides the plant area into bands and assign the bands to one or more facilities. In addition, MCRAFT eliminates the pairwise exchange limitations - the adjacency and the area equality- that CRAFT faces. By using MCRAFT, all the pairs can be tried with the pairwise exchange algorithm. This situation makes a very important contribution to find the optimum solution. Some features of CRAFT, MCRAFT and our proposed algorithm, named Plasma, are presented at Table 1.

Table 1. The comparison between CRAFT, MCRAFT, and Plasma

features	CRAFT	MCRAFT	Plasma
Define transportation matrix	√	√	√
Exchanges are not limited to adjacent or equal-size departments	×	√	×
Allows nonrectangular departments.	√	×	√
It isn’t Limited to facility dimensions	×	×	√
Unlimited number of departments	×	×	√
Ability to jump from local Optimums	×	×	√

In this paper, we focus on the CRAFT as well-known heuristic which is still used in some real world facility layout problems and improve it. We named our proposed algorithm and its related software package Plasma. Plasma, like CRAFT and MCRAFT, also can be used as a building block in more complicated algorithms and software packages.

The rest of paper is organized as follows. First, the Plasma algorithm is introduced in details in section 2. In section3, the numerical examples are presented and a comparison between Plasma and two other algorithms is presented. Finally, section 4 presents the conclusion.

2. Plasma Introduction

Plasma is an algorithm developed to improve CRAFT. Similar to CRAFT, Plasma has no limitation on shape of departments, but Plasma tries to synchronize center of selected departments. One advantageous of Plasma is that its input data is similar to CRAFT which is a widely known layout software package. In addition, it will be shown that the results of Plasma outperform those of CRAFT and MCRAFT.

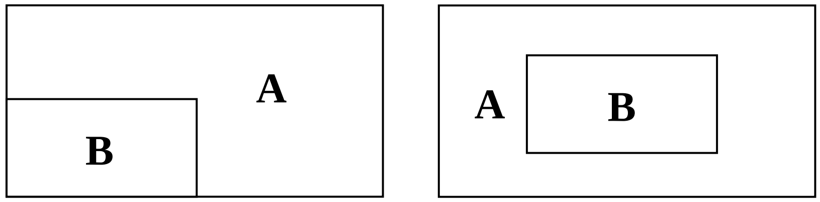
Steps of Plasma procedure are as follows:

1. Specifying the input data
   - 1.1. Determining departments’ name and number
   - 1.2. Specifying work flows between departments
   - 1.3. Creating cost matrix
   - 1.4. Specifying initial layout and determining departments color.

2. The procedure of algorithm
   - 2.1. Determine departments’ centroids.
   - 2.2. Calculate distances between centroids.
   - 2.3. Calculate current transportation cost for the layout.
   - 2.4. Considering department exchanges of either equal area departments or departments sharing a common border.
   - 2.5. Determining the estimated change in transportation cost of each possible exchange.
   - 2.6. Selecting and implementing the departmental exchange that offers the greatest reduction in transportation cost.

2.7. Repeating the procedure for the new layout until no interchange is able to reduce the transportation cost.

The only difference between CRAFT and Plasma lies on step 2.6. The difference between Plasma with CRAFT and MCRAFT is in the way that it uses to perform pairwise exchanges. Plasma selects among all possible pairwise exchanges in a way that results in a reduction in centroid distance (see Figure1).



(a) (b)

Figure 1: CRAFT's exchange (a); Plasma's exchange (b)

In Fig.1, two approaches are presented. In Fig.1(b) minimum cost will occurred because of minimum distance of its centroids. Distances between 2 departments are zero, but in real cases the zero value for the distance between two departments is unlikely. So, we should provide some reasonable proof to show minimum centroids distance method results in minimum real distance in non-convex departments, such as department *A* in fig.1. The following proposition is engaged with this issue.

Proposition 1. Minimum centroid distance results in minimum real distance in non-convex departments.

Proof. In the first step, to evaluate the distance in non-convex departments, we define the real distance function as in Eq. (2).

$$\overline{d_{IJ}} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{m}\sum_{j=1}^{m}(x_i - x_j)^2 + (y_i - y_j)^2\right) \tag{2}$$

In Eq. (2), *n* is the number of building blocks, or pixels, in the department *i* (bigger department) and *m* is the number of building blocks, or pixels, in the department *j* (smaller department). Based on pairwise exchange method, for the smaller department no change takes place in its shape. Without lose of generality, we can rewrite Eq. (2) as Eq. (3).

$$\overline{d_{IJ}} = \frac{1}{n}\sum_{i=1}^{n}(x_i - x_c)^2 + (y_i - y_c)^2 \tag{3}$$

Because only movement of smaller department in bigger department is considered, the distance between x_i with all x_j is equal to its distance with department *j* centroid (x_c). Therefore, we should find an optimal x_c to minimize $\overline{d_{IJ}}$.

$$\frac{\partial \overline{d_{IJ}}}{\partial x_c} = \frac{2}{n}\sum_{i=1}^{n}(x_i - x_c) = 0 \Longrightarrow x_c^* = \frac{\sum_{i=1}^{n} x_i}{n} \tag{4}$$

In a similar way, the y_c^* is obtained. The x_c^* and y_c^* are the coordinates of the center of the smaller department. In addition, Eq. (4) right side is center of bigger department. Therefore, minimum centroid distance will also result in minimum real distance (Eq. 2) in non-convex departments. □

For above proposition, the upper bound of complexity for calculating real distance (Eq. 2) is $O((N\text{-}1)^2)$, where *N* is total number of building blocks in the layout.

When Plasma wants to exchange two departments, first, these two departments are combined and make a big unnamed department (see white-space in Fig 2). The procedure continues with selecting the farthest point from centers of both departments. This selection is made using Eq. (5) as an objective function. Afterwards, the procedure continues with selecting another best available pixel from the vicinity of last selected pixel. In each iteration, Plasma finds the best point, using Eq. (5), and attaches it to the prior region. This procedure will end whenever successfully place all pixels of smaller department. The remained pixels of combined region will belong to the bigger department (see Figure 2).

$$Max_i \left\{ \frac{\left(\sqrt{(x_i - x_{c1})^2 + (y_i - y_{c1})^2}\right) + \left(\sqrt{(x_i - x_{c2})^2 + (y_i - y_{c2})^2}\right)}{2} \right\} \quad (5)$$

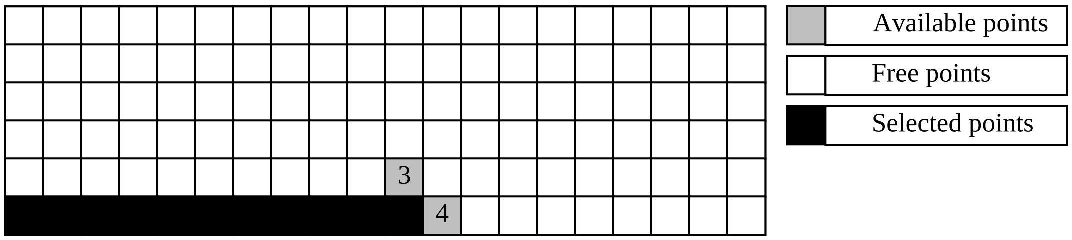
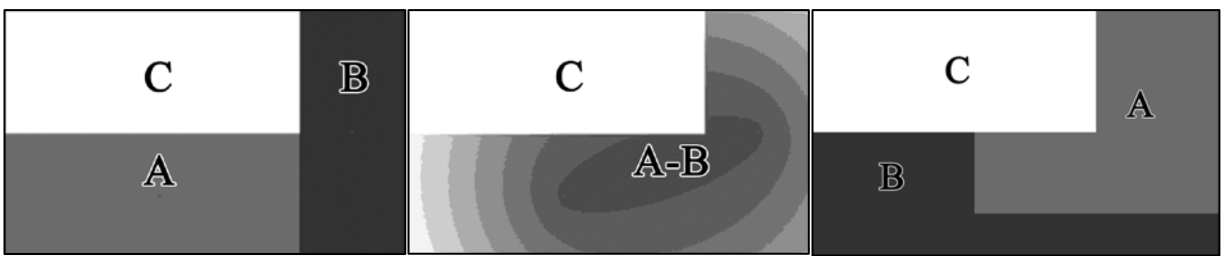


Figure 2: Method of pixel selection in Plasma

If the Plasma couldn’t find any available pixel in vicinity, then it starts to search available pixels to find the best available pixel and continues with this pixel.



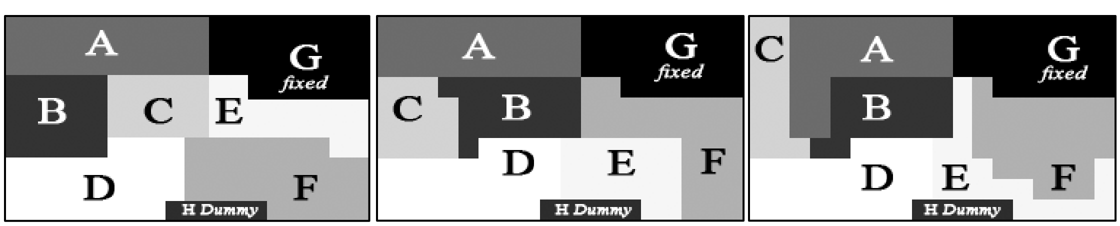
(a) (b) (c)

Figure 3: (a) Initial layout, (b) Pixel ranking values, (c) Final layout after exchanging departments *A* and *B*

The Fig 3 depicts the way by which Eq. (5) guides Plasma to select pixels. When Plasma aims to exchange departments *A* and B in Fig. 3, it starts to locate pixels in *A-B* part of layout with lighter color. The result of pairwise exchange between *A* and *B* is shown in Fig 3.c. The Objective function of pixel selection, which is according to Eq. 5, results in the unique method of exchanging between two departments in Plasma.

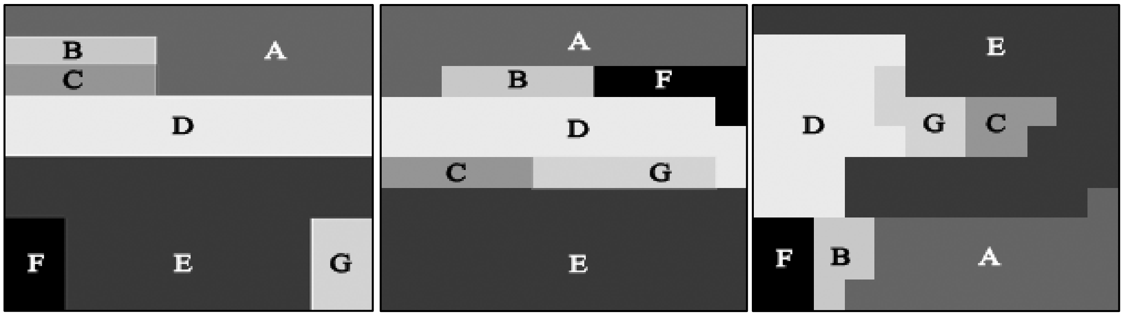
3. Numerical Examples

To shed light on how Plasma’s results are different from CRAFT and MCRAFT, some examples are presented. The Fig (4) and Fig (5) are two sample problems in which Plasma outperform CRAFT and MCRAFT respectively. The initial layout and optimal layouts are presented for each Fig.



(a) (b) (c)

Figure 4: (a) Initial layout (sample #2 with TC = 2980), (b) CRAFT optimal layout with TC = 2800, (c) Plasma optimal layout with TC = 2708.



(a) (b) (c)

Figure 5: (a) Initial layout (sample #13 with TC = 505.28), (b) MCRAFT optimal layout with TC = 300.21, and (c) Plasma optimal layout with TC = 293.05.

In this section, several problems from both the literature and real cases are studied to illustrate the capabilities and performance of Plasma. A brief description of the problems' size and initial costs are given in Table 2. To compare the cost function of Plasma in comparison with that of CRAFT and MCRAFT, two *%deviation* factors are defined as follows:

$$\%\ dev_{CRAFT} = \frac{C_{CRAFT} - C_{Plasma}}{C_{Plasma}} \times 100 \tag{6}$$

$$\%\ dev_{MCRAFT} = \frac{C_{MCRAFT} - C_{Plasma}}{C_{Plasma}} \times 100 \tag{7}$$

Table 2. The comparison between CRAFT, MCRFT and PLASMA

Sample #	Nu. Of Deps	Initial	C_{CRAFT}	C_{MCRAFT}	C_{Plasma}	$\%\ dev_{CRAFT}$	$\%\ dev_{MCRAFT}$
1	4	1020	927	445.28	660.6	40.33	-32.59
2	8	2980	2800	*N/A*	2708	3.40	*N/A*
3	3	44.5	37.5	26.5	37.5	0.00	-29.33
4	4	43.3	42	36	38	10.53	-5.26
5	9	1478.682	1237.339	991.26	1143	8.25	-13.28
6	4	150	123.65	129.7	119.75	3.26	8.31
7	4	125.25	110.25	75.33	104.16	5.85	-27.68
8	5	201.07	120.78	129.59	127.23	-5.07	1.85
9	4	144	101.2	101.2	101.2	0.00	0.00
10	3	257	257	82.5	243.09	5.72	-66.06
11	4	102	102	102	85.33	19.54	19.54
12	4	108.75	108.75	108.75	88.75	22.54	22.54
13	7	505.28	319.50	300.21	293.05	9.03	2.44
14	5	932.61	1650	1650	513.32	221.44	221.44
15	4	1235548	1235548	665714	879745	40.44	-24.32
16	5	1178.88	918.88	675	530.60	20.68	27.21

N/A = MCRAFT package couldn't solve solution because of limitation in determining fix and dummy departments.

Form Table (2) one can infer that Plasma outperforms CRAFT in most cases. Just in sample problem 8 CRAFT finds better solution than Plasma. It worth mentioning that, in this sample problem, CRAFT's solution is better than both Plasma and MCRAFT. In sample problems 3 and 9 both CRAFT and Plasma reach same cost function. In other sample problems Plasma is successful to find better solution with $\%dev_{CRAFT}$ ranged between %3.26 and %221.44. Even, in some sample problems, such as 1, 4, 11, 12, 14, 15, and 16, the $\%dev_{CRAFT}$ is greater than 10% which is a considerable amount.

The other interesting result is related to sample problem 14. In this sample problem both CRAFT and MCRAFT failed to improve the initial layout, but Plasma improves it from initial cost function of 932.61 to 513.32 (%45 improvement) which is a considerable improvement. Generally, it can be expected that in most cases, but not in any case, Plasma will performs more efficiently in reducing cost function of initial layout than CRAFT.

Comparing the Plasma with MCRAFT, one cannot easily allude that one algorithm is defiantly better than the other one. For example, in sample problem 1, plasma show weaker improvement rather than MCRAFT and in some sample problems plasma could not make better initial layout, but still in some cases Plasma's final layouts are more realistic than those of MCRAFT.(see Fig. 6)

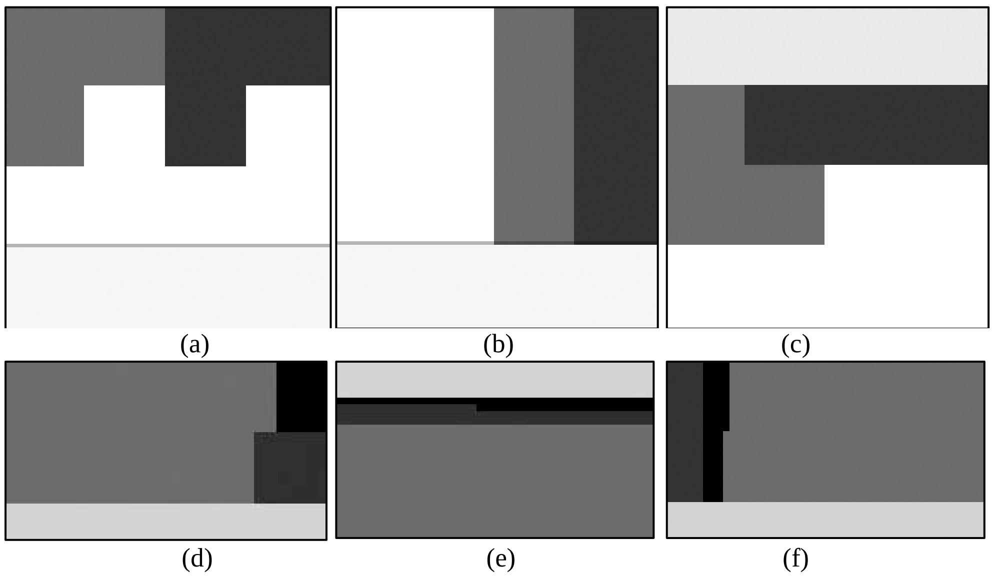


Figure 6: (a) Initial layout of sample problem #4 (b) Plasma result for sample problem #4 (c) MCRAFT result for sample problem #4 (d) Initial layout of sample problem #15 (Iran Poya Factory) (e) MCRAFT result for sample problem #15 and (f) Plasma result for sample problem #15

4. Conclusion

As one can perceive, Plasma algorithm in some cases has improved the initial layout better than CRAFT and MCRAFT, but still one of the most important positive characteristic of Plasma lies on its application that enable specialists to ignore local minimum plan without a restriction on number and size of departments. Plasma package is successfully applied in some industrial companies and offices. It worth mentioning that, the Plasma's final layout, similar to CRAFT and MCRAFT final layouts, needs a revision by an expert. The other important factor is that the Plasma algorithm can be used as a building block in more complicated layout packages. Future research may include developing fuzzy boarder in department based on convolution theory.

Acknowledgement

The authors tank Gohar Arya Company for its financial support and sponsorship during the process of developing *Plasma* software package which is available for free at http://www.GoharArya.ir/download/Plasma.zip.

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