6.4.4 Craft

Introduced in 1963 by Armour, Buffa, and Vollman (see [3], [9]), the *Computerized Relative Allocation of Facilities Technique* (CRAFT) is one of the earliest layout algorithms presented in the literature. It uses a from-to chart as input data for the flow. Layout "cost" is measured by the distance-based objective function shown in Equation 6.1. Departments are not restricted to rectangular shapes, and the layout is represented in a discrete fashion.

Since CRAFT is an improvement-type layout algorithm, it starts with an initial layout, which typically represents the actual layout of an existing facility but may also represent a prospective layout developed by another algorithm. CRAFT begins by determining the centroids of the departments in the initial layout. It then calculates the rectilinear distance between pairs of department centroids and stores the values in a distance matrix. The initial layout cost is determined by multiplying each entry in the from-to chart with the corresponding entries in the unit cost matrix (i.e., the c_{ij} values) and the distance matrix.

CRAFT next considers all possible two-way (pairwise) or three-way department exchanges and identifies the best exchange, that is, the one that yields the largest reduction in the layout cost. (No department can be split as a result of a two-way or three-way exchange.) Once the best exchange is identified, CRAFT updates the layout according to the best exchange and computes the new department centroids as well as the new layout cost to complete the first iteration. The next iteration starts with CRAFT once again identifying the best exchange by considering all possible two-way or three-way exchanges in the (updated) layout. The process continues until no further reduction in layout cost can be obtained. The final layout obtained in such a manner is also known as a two-opt (three-opt) layout since no two-way (three-way) exchanges can further reduce the layout cost.

Since computers were relatively "slow" in the 1960s, the original implementation of CRAFT deviated slightly from the above description. When the program considered exchanging the locations of departments i and j, instead of actually exchanging the department locations to compute their new centroids and the actual layout cost, it computed an *estimated* layout cost simply by temporaily treating the centroid of department i in the current layout as the centroid of department j and vice versa; that is, it simply swapped the *centroids* of departments i and j.

The error incurred in estimating the layout cost as described above depends on the relative size of the two departments being exchanged. If the departments differ in size, then the estimated centroids may deviate significantly from their correct locations. (Of course, if the departments are equal in area, no error will be incurred.) As a result, the actual reduction in the layout cost may be overestimated or underestimated. Although it does not fully address the above error, once the best exchange *based on the estimated layout cost* is identified, CRAFT exchanges the locations of the departments and computes their new centroids (and the actual layout cost) before continuing to the next iteration.

A more important refinement we need to make in the above description of CRAFT is concerned with the exchange procedure. Although at first it may seem "too detailed," this refinement is important from a conceptual point of view since it demonstrates an intricate aspect of using computers for layout purposes. When CRAFT considers exchanging two departments, instead of examining all possible exchanges as we stated above, it actually considers exchanging only those departments that are either adjacent (i.e., that share a border) or that are equal in area. Such a restriction is not arbitrary. Given that departments cannot be split, it would be impossible to exchange two departments without "shifting" the location of the other departments in the layout, *unless the two departments are either adjacent or equal in area.* (Why?) Since CRAFT is not capable of "automatically" shifting departments in such a manner, it considers exchanging only those that are adjacent or equal in area.

Obviously, two departments with equal areas, whether they are adjacent or not, can always be exchanged without shifting the other departments in the layout. However, if two departments are not equal in area, then adjacency is a *necessary but not sufficient* condition for being able to exchange them without shifting the other departments. That is, in certain cases, even if two (unequal-area) departments are adjacent, it may not be possible to exchange them without shifting the other departments. We will later present an example for such a case.

We also need to stress that, while searching for a better solution, CRAFT picks only the best (estimated) exchange at each iteration, which makes it a "steepest descent" procedure. It also does not "look back" or "look forward" during the above search. Therefore, CRAFT will terminate at the first two-opt or three-opt solution that it encounters during the search. Such a solution is very likely to be only locally optimal. Furthermore, with such a search procedure, the termination point (or the final layout) will be strongly influenced by the starting point (or the initial layout). Consequently, CRAFT is a highly "path-dependent" heuristic and to use it effectively, we generally recommend trying different initial solutions (if possible) or trying different exchange options (two-way vs. three-way) at each iteration.

CRAFT is generally flexible with respect to department shapes. As long as the department is not split, it can accommodate virtually any department shape. Theoretically, due to the centroid-to-centroid distance measure, the optimum layout (which has an objective function value of zero) consists of concentric rectangles! Of course, the above problem stems from the fact that the centroids of some O-shaped, U-shaped, and L-shaped departments may lie outside the department itself. Unless the initial layout contains concentric departments, CRAFT will not construct such a layout. However, some department shapes may be irregular, and the objective function value may be underestimated due to the centroid-to-centroid measure.

CRAFT is normally restricted to rectangular buildings. However, through "dummy" departments, it can be used with nonrectangular buildings as well. Dummy departments have no flows or interaction with other departments but require a certain area specified by the layout planner. In general, dummy departments may be used to

1. Fill building irregularities.
2. Represent obstacles or unusable areas in the facility (such as stairways, elevators, plant services, and so on).
3. Represent extra space in the facility.
4. Aid in evaluating aisle locations in the final layout.

Note that, when a dummy department is used to represent an obstacle, its location must be fixed. Fortunately, CRAFT allows the user to fix the location of any department (dummy or otherwise). Such a feature is especially helpful in modeling obstacles, as well as in modeling departments such as receiving and shipping in an existing facility.

One of CRAFT's strengths is that it can capture the initial layout with reasonable accuracy. This strength stems primarily from CRAFT's ability to accommodate nonrectangular departments or obstacles located anywhere in a possibly nonrectangular building. However, in addition to being highly path dependent, one of CRAFT's weaknesses is that it will rarely generate department shapes that result in straight, uninterrupted aisles as is desired in the final layout. Fixing some departments to specific locations, and in some cases placing dummy departments in the layout to represent main aisles, may lead to more reasonable department shapes. Nevertheless, as is the case with virtually all computerized layout algorithms, the final layout generated by the computer should not be presented to the decision maker before the layout planner "molds" or "massages" it into a practical layout.

As we demonstrate in the following example, molding or massaging a layout involves relatively minor adjustments being made to the department shapes and/or department areas in the final layout. The fact that such adjustments are almost always necessary does not imply that computerized layout algorithms are of limited use. To the contrary, by considering a large number of alternatives in a very short time, a computerized layout algorithm narrows down the solution space for the layout planner, who can then concentrate on further evaluating and massaging a few "promising" solutions identified by the computer.