Chapter 16. Layout Methodology

16.1. Layout Methodology Definitions

Activity Centers or Departments

An ***activity center***, also commonly called a ***department***, is a compact area that has a homogeneous material flow with the rest of the facility so that it can be treated as a single unit (with respect to material flow).

Its area should not be too small, since otherwise it is not important enough to be considered separately. A rule of thumb is an area larger than 3 % of the total facility area. This means that the number of departments should be limited to 35. Its area should also not be too large, since the material flow might no longer be homogeneous over the area of this department.

Activity Relationships

The pairwise ***relationship*** between two departments expresses the affinity between these two departments, based on material flow and environmental considerations. Relationships can be numerical (quantitative) if accurate information is available, or symbolic (qualitative). The closer together one would like these departments to be, the more positive their relationship. A negative relationship means that it is desirable to keep the two departments separate, e.g. for noise or vibration pollution. The table of relationships is called a relationship chart or relationship matrix. An example of a qualitative relationship chart is shown in Figure 16.1. Possible representations of qualitative relationships are given in Table 16.2.

Table 16.1. Qualitative Relationship Chart

	A	B	C	D	E	F	G
A		E	O	I	O	U	U
B			U	E	I	I	U
C				U	U	O	U
D					I	U	U
E						A	I
F							E
G							

Table 16.2. Qualitative Relationships Representation

Closeness	Letter	Lines	Color
Absolute Necessary	A	4	Red
Especially Important	E	3	Orange
Important	I	2	Blue
Ordinary Closeness	O	1	Green
Unimportant	U	No	None
Undesirable	X	Wave	Brown

Layout Stages

Conceptual Block Layout

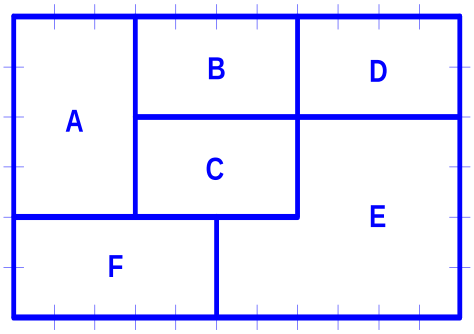


Figure 16.1. Conceptual Block Layout Example

Material Handling Layout

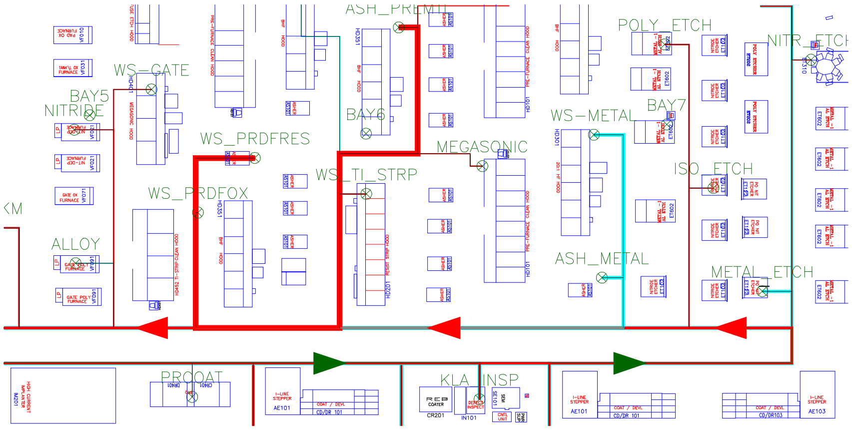


Figure 16.2. Material Handling Layout Example

Layout Algorithms

Construction versus Improvement Algorithms

There exist two major classes of algorithms. ***Construction*** algorithms design a layout from scratch, i.e. from raw numerical data such as the flow chart and area requirements. ***Improvement*** algorithms design a layout by modifying and improving an existing layout and hence require an initial feasible layout.

Area Based versus Graph Based Algorithms

There exist two major types of algorithms. Some algorithms are based on locating the areas of departments in a layout, these algorithms usually try to *minimize* the *distance score* of the layout. A second group of algorithms is based on determining the relative position of departments in a layout ignoring the area requirements of the departments. These algorithms try to *maximize* the *adjacency score* of a layout.

Discrete versus Continuous Layout Algorithms

Discrete layout algorithms divide the building and each department in a number of equal sized unit squares. The design decision is then to locate the unit squares of each department in the unit locations of the building. The coordinates of the vertices of the departments are integer multiples of the size of the unit square. Continuous layout algorithms allow the vertices of the departments to be located anywhere in the building area and thus the vertex coordinates can be fractional numbers.

Algorithm Components

Data Requirements

There are two major categories of required data.

The first category contains the *relationship data* between the departments (and the outside or building). These relationships can be given in qualitative form or in a quantitative form. The prime examples are the (qualitative) letter relationship chart and the (quantitative) flow chart.

The second category contains the *spatial requirements*. The departments areas are always required for area based algorithms. Sometimes the building area is required. Some of the programs also require the shape of each department and/or the building.

Department Selection Rule

A layout algorithm must specify at least two sets of rules or procedures for layout generation. The first set is called the *selection* procedure and it specifies in what order the departments will enter the layout (for a construction procedure) or will be considered for exchange (for an improvement procedure).

Department Location Rule

The second set is the *location* procedure and it specifies where the next department, as determined by the selection procedure, will located in the layout or where it will be located in the exchange. The department selection and department location rules can be combined into a single procedure.

Layout Evaluation Rule

The program must also specify a set of rules or evaluation procedure, which will assign a score to the obtained layout. For the *distance score* this usually is the product of the distance and the relationship matrices; for the *adjacency score* this usually is the product of the adjacency and relationship matrices. Further details on layout evaluation will discussed in the section on Layout Evaluation.

Special Functions

Facilities design algorithms can have several special characteristics such as

- the ability to fix departments in the building
- the ability to fix the building shape
- the ability to incorporate relationships with the outside
- the ability to handle multiple floors
- its user friendliness rating

Most facilities design algorithms are incorporated in computer programs. Three major categories of *user friendliness* of these programs can be distinguished. First generation programs require formatted batch input on punch cards and generate printed reports consisting of alphanumeric symbols. Their user friendliness is considered to be low. Second generation programs have interactive keyboard and CRT input and generate alphanumeric CRT output. Their user friendliness is considered to be medium. Third generation programs have interactive CRT and pointing devices (such as a mouse, a light pen and/or tablet) and generate color graphics CRT output. Their user friendliness is considered to be high.

16.2. Systematic Layout Planning or SLP

Steps in the SLP

Muther (1973) has developed a systematic way of constructing a layout. The steps are best illustrated by Figure 16.3. The SLP method attempts to create a good layout by introducing systematically more complicating factors in the design process.

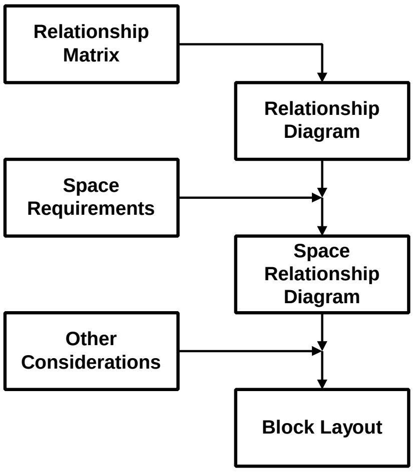
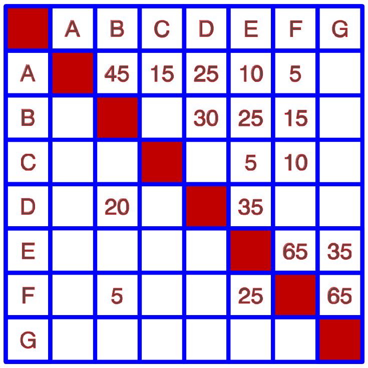


Figure 16.3. Systematic Layout Planning (SLP) Diagram



	A	B	C	D	E	F	G
A		45	15	25	10	5	
B				30	25	15	
C					5	10	
D		20			35		
E						65	35
F		5			25		65
G							

Figure 16.4. Relationship From-To Matrix

A relationship diagram positions departments in their relative position, while ignoring the space requirements of each department. A neutral symbol of the same size is used to represent departments. Relationships are shown with line coding or color coding. An illustration of a relationship diagram is given in Figure 16.5.

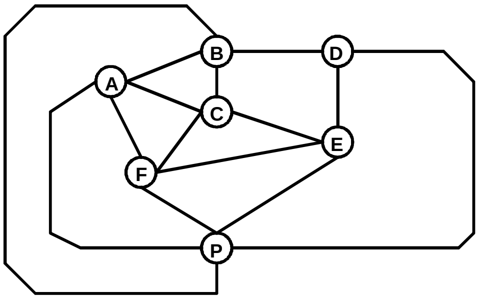


Figure 16.5. Relationship Diagram

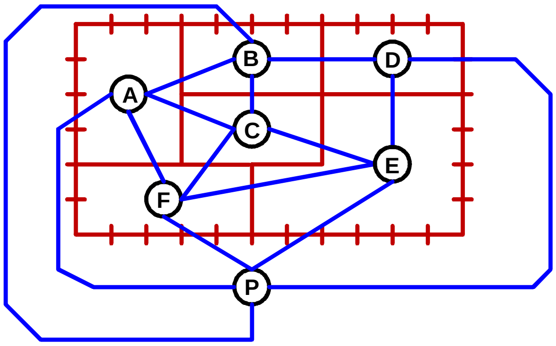


Figure 16.6. Relationship Diagram and Block Layout as Dual Graphs

A simple manual technique to generate a relationship diagram is the Spiral technique. The spiral algorithm can be executed on numerical or symbolic information. The Spiral algorithm is discussed in further detail in the Chapter on Computer Aided Layout.

Space Requirements

Space requirements are based on industry norms and health and safety rules.

The combination of the spatial relationship diagram and the space requirements is called the space relationship diagram. It is not yet a layout because it does not incorporate other considerations such as building shape.

Other Considerations

Other considerations include factors such as the building shape, department shapes, building supports, etc. After these considerations are incorporated, several alternative layouts can be generated.

16.3. Discrete Layout

Spacefilling Curves

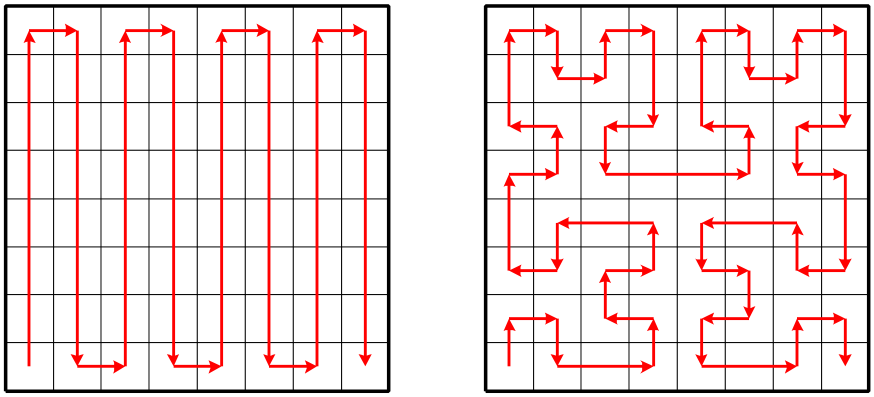


Figure 16.7. Spacefilling Curve Examples (Serpentine and Hilbert-19)

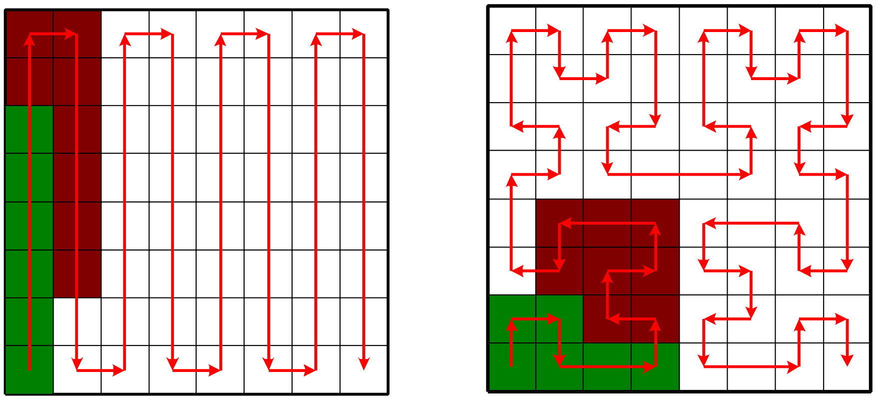


Figure 16.8. Department Locations Based on Spacefilling Curves (Serpentine and Hilbert-19)

16.4. Layout Evaluation

Adjacency Score

The adjacency score requires the information if corner adjacency is sufficient or if (regular) side to side adjacency is required. Corner adjacency requires only that the departments touch each other in one point, side to side adjacency requires that the departments have a common boundary of non zero length.

The adjacency score is the sum of the pairwise products of the relationship matrix with the adjacency matrix. The adjacency matrix has a one on the intersection of row and column if the two corresponding departments are adjacent, a zero otherwise. This measure is based on the notion that it is very cheap to pass products to an adjacent machine (requiring no external material handling), but that it is expensive to transport products between non-adjacent machines. The adjacency score is to be maximized by a good layout.

To score the graph, the sum of all **P**ositive relationships between **A**djacent departments will be denoted by PA. The sum of all **N**egative relationships between non-adjacent or **S**eparated departments will be denoted by NS. The sum of all **P**ositive relationships between non-adjacent or **S**eparated departments will be denote by PS, and the sum of all **N**egative relationships between **A**djacent department will be denoted by NA. The adjacency (A) and efficiency (e) are then computed as

$$A = PA + NA$$

$$e = \frac{PA - NS}{PA + PS - NS - NA} \cdot 100\ \% \tag{16.1}$$

The efficiency has in its numerator all relationships that are desirable, namely positive adjacent and negative separated ones. It has in the denominator the sum of all relationships. The efficiency is thus a measure of the quality of the adjacency graph with values between 0 and 1 and invariant with respect to the magnitude of the relationships. An efficiency of 100 % indicates a perfect diagram. Ranking alternatives based on their adjacency score is equivalent to ranking them based on their efficiency. In other words, a diagram which maximizes the adjacency will also maximize the efficiency since the numerator of the efficiency is equal to adjacency minus the constant (NS + NA) and the denominator is constant.

Sometimes the inefficiency rating, denoted by i, is used to evaluate the relationships diagram. The inefficiency rating is equal to

$$i = 100\% - e \tag{16.2}$$

Distance Score

Distances can be measured in many different ways, i.e. with many different norms. The most familiar is the straight-line distance or **E**uclidean norm, which is denoted by d_E. This norm is use in facilities location decisions, but not much facilities design decisions. In manufacturing facilities the **r**ectilinear distance is most predominantly used. It is denoted by d_R. This distance norm is based on the notion of material movement through a system of perpendicular aisle and cross aisles. The third commonly used distance measure is the **C**hebyshev norm, which is denoted by d_C. This norm is applicable when there is simultaneous travel in the x and y direction, such as travel of AS/RS cranes in the aisle and the travel of bridge cranes.

Given two points with coordinates (x_1, y_1) and (x_2, y_2), the respective distances are computed with the following formulas:

$$d_{ij}^{E} = L_2 = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{16.3}$$

$$d_{ij}^{R} = L_1 = \left|x_i - x_j\right| + \left|y_i - y_j\right| \tag{16.4}$$

$$d_{ij}^{C} = L_\infty = \max\{\left|x_i - x_j\right|, \left|y_i - y_j\right|\} \tag{16.5}$$

The distance computations require additional information such as which norm or distance measure should be used and where the start and end points of the material flows are located, i.e. are the distances centroid to centroid or boundary to boundary. The pairwise distances between departments are stored in the distance matrix. The distance score D is the sum of the pairwise products of the relationship matrix with the distance matrix. The most common measure is the centroid to centroid rectilinear distance, based on the notion of aisles and cross aisles. The centroid assumption is valid if no additional information is available, because the departments are defined as areas of homogeneous material flow. The distance score is to be minimized by a good layout. The distance score is composed of two elements: the internal distance score between each pair of departments and the external distance score between each department and the outside. The distance to the outside is the shortest distance of the centroid of the department to any of the four sides of the building.

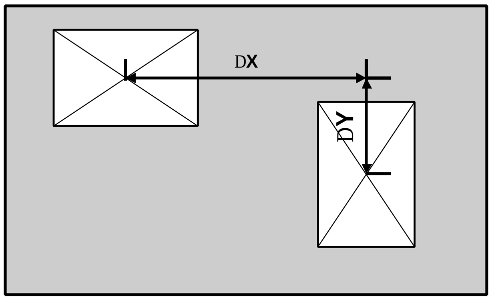


Figure 16.9. Internal Pairwise Department Distance Illustration

$$\begin{aligned} D_{int} &= \sum_i \sum_j rel_{ij} dist_{ij} \\ dist_{ij} &= \Delta x_{ij} + \Delta y_{ij} = \left| xc_i - xc_j \right| + \left| yc_i - yc_j \right| \end{aligned} \tag{16.6}$$

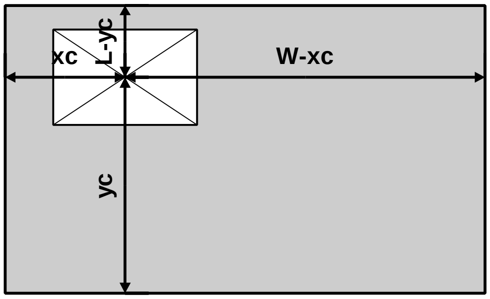


Figure 16.10. External Distance to the Outside Illustration

$$\begin{aligned} D_{ext} &= \sum_i rel_{io} dist_{io} \\ dist_{io} &= \min\left\{ xc_i, W - xc_i, yc_i, H - yc_i \right\} \end{aligned} \tag{16.7}$$

$$D = D_{int} + D_{ext} \tag{16.8}$$

The average distance d provides a measure of the distance traveled by a single load on a single trip, i.e., the expected length of a single trip. It yields a measure of layout quality irrespective of the magnitude of the material flows. The average distance is computed by dividing the distance score by the sum of the absolute values of all relationships.

$$d = \frac{D}{PA + PS - NS - NA} \cdot 100\ \% \tag{16.9}$$

Scoring Example

An example of the computation of the distance and adjacency score is given is next. Assume the layout is given in Figure 16.11, the associated adjacency matrix is given in Table 16.3 and the relationship values are given in Table 16.4. Assume further that all departments have either dimensions of 10 by 10 or 20 by 10 (as indicated in the layout) and that the distance score uses the rectilinear centroid to centroid distances. The interdepartmental distances are then given in Table 16.5.

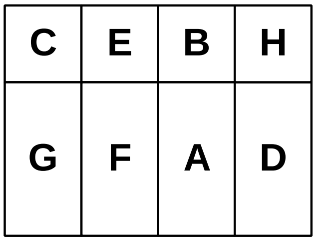


Figure 16.11. Small Layout Example

Table 16.3. Adjacency Matrix for Layout Example

	A	B	C	D	E	F	G	H
A		1	0	1	0	1	0	0
B			0	0	1	0	0	1
C				0	1	0	1	0
D					0	0	0	1
E						1	0	0
F							1	0
G								0
H								

Table 16.4. Relationship Values for Layout Example

	A	B	C	D	E	F	G	H
A		45	15	25	10	5		
B				50	25	20		
C					5	10		
D					35			
E						90	35	
F							65	
G								
H								

The adjacency score is then equal to 45 + 25 + 5 + 25 + 5 + 90 + 65 = 260. The efficiency of this layout is 260 / 435 = 60 %.

Table 16.5. Distance Matrix for Layout Example

	A	B	C	D	E	F	G	H
A		15	35	10	25	10	20	25
B			20	25	10	25	35	10
C				55	10	25	15	30
D					35	20	30	15
E						15	25	20
F							10	35
G								45
H								

The rectilinear distance score is then equal to 45 · 15 + 15 · 35 + 25 · 10 + 10 · 25 + 5 · 10 + 50 · 25 + 25 · 10 + 20 · 25 + 5 · 10 + 10 · 25 + 35 · 35 + 90 · 15 + 35 · 25 + 65 · 10 = 8,150. The average distance traveled is then 8,150 / 435 = 18.74.

16.5. Material Handling Layout Algorithms

The SLP methodology developed by Muther can be extended to include the design of the material handling system in the facility. The material handling equipment and system design is based on the block layout and yields a material handling layout. The steps are illustrated by Figure 16.12.

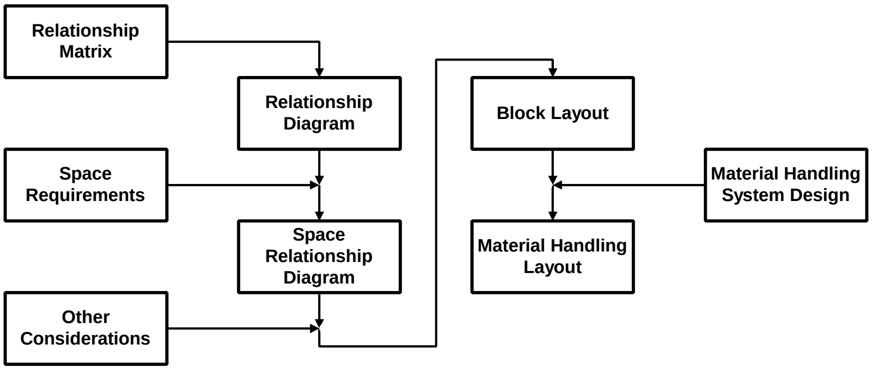


Figure 16.12. SLP Extension for Material Handling Layouts

16.6. Layout Selection

Ranking Method

Rank all evaluation methods or criteria by decreasing importance, i.e. the most important gets rank 1, and assign a column to each criteria in this order.

Construct a row for each layout alternative. In this row a one in a column indicates that this alternative layout satisfies the corresponding criteria.

Traverse columns from left to right and eliminate all criteria which have not a one in the current column, until only a single layout alternative is left.

Observe that the ranking method is not additive, i.e. any criterion is more important the sum of all following criteria.

Factoring Method

Assign a weight to each criterion. Usually the weights are normalized so that their sum adds up to 100 %. The criteria must be worded such that the alternatives that maximize the criteria are desirable.

For each alternative, fill in how much the alternative satisfies each criteria. Usually this value is normalized between zero and one.

Compute a score for each alternative by multiplying the criterion weight with the corresponding alternative value. The alternative with the highest score is selected.

Example

The criteria and their ranking for a layout evaluation are given in following Table 16.6.

Table 16.6. Selection Criteria with Their Ranking and Weight Factors

criterion	ranking	weight
D	4	8
C	2	25
A	1	60
E	5	10
B	2	30

Table 16.7 shows which alternative satisfies which criterion, which is indicated by a one in the satisfaction matrix.

Table 16.7. Satisfaction Matrix

Criterion	D	C	A	E	B
1	1	1	0	1	1
2	1	1	1	1	0
3	1	1	1	0	1
4	1	0	1	1	1
5	0	1	1	1	1

The results of the ranking method and factoring method are shown in Table 16.8 and Table 16.9, respectively.

Table 16.8. Ranking Method Example

Criterion	A	B	C	D	E	Selected
1	0	1	1	1	1	
2	1	0	1	1	1	
4	1	1	0	1	1	
5	1	1	1	0	1	
3	1	1	1	1	0	(*)

Table 16.9. Factoring Method Example

Criterion	D	C	A	E	B	Sum	Selected
1	1	1	0	1	1	73	
2	1	1	1	1	0	103	
3	1	1	1	0	1	123	
4	1	0	1	1	1	108	
5	0	1	1	1	1	125	(*)
weight	8	25	60	10	30		

Dominance Method

The weights in the factoring method are usually not known with great precision, so it is of interest to determine the range of weight values for which a particular layout is selected as the preferred one. The factoring method does not allow for such sensitivity analysis on the criteria weights. The dominance method allows this sensitivity analysis for a limited number of criteria. A graphical illustration of the sensitivity analysis of the weight of two criteria is given in Figure 16.13. Both criteria must either be minimized or maximized. In the example, the criteria are to be maximized. Six layout alternatives are considered. Their scores for criterion 1 are marked on the (left) vertical axis of criterion 1, their scores for criterion 2 are marked on the (right) vertical axis of criterion 2. For each layout alternative, those two points are then connected, corresponding to the continuous change of the weight of criterion 2. The weight of criterion 2 ranges from 0 at the criterion 1 axis to 100 at the criterion 2 axis. The weight of criterion 1 is equal to 100 minus the weight of criterion 2. The efficiency frontier or dominant alternative is then found by starting from the optimal side of the axes and moving in the direction for which the criteria values deteriorate until a line is encountered. The collection of these points for all possible weights is called the *efficiency frontier*. This efficiency frontier is marked in bold in the Figure 16.13. Observe that for a weight of criterion 2 less than 58, layout alternative five is preferred, and for a weight more than 58 the preference shifts to layout alternative one. When the weight of criterion 2 is exactly 58, then there exists a three-way tie between layout alternatives 5, 6, and 1. This range allows for sensitivity analysis. Layout alternative 2, 3, and 4 are never preferred and are said to be inefficient.

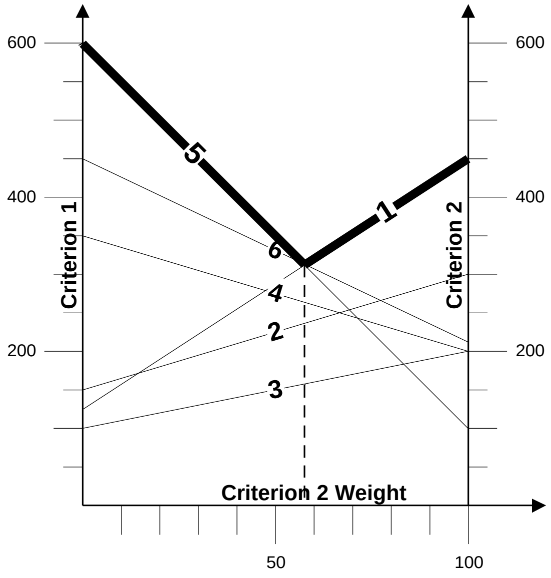


Figure 16.13. Sensitivity Analysis with Dominance Method

This analysis can be extended to a small number of criteria, but the graphics become very quickly hard to interpret.

16.7. Summary and Conclusions

Layout Algorithm Classification and Hierarchy

An overview of the algorithm hierarchy is provided in Figure 16.14.

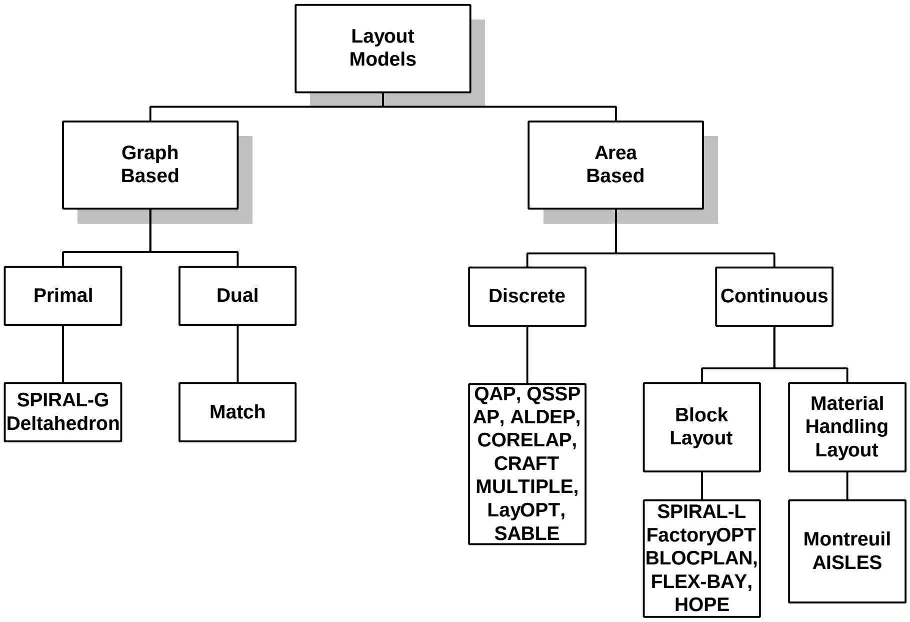


Figure 16.14. Layout Models, Algorithms, and Software Classification

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